Use case set up Report

STIB – VUB - Brussels

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Abstract	This report describes the two use-cases that will be performed in Brussels in the scope of the ELIPTIC European project. Both its electric bus feasibility study – identification of the best path to progressively electrify its bus network - and its tram feasibility study – optimization of braking energy recovery modules in light rail network – are presented.

	After presenting the context conditions of the use-cases, in which economic, geographical, urban and public transport service contexts are described, the reports splits into two sections. For each use-case, objectives, risks, detailed description, work plan and expected results are provided.
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Critical risks	

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1. Executive Summary

This report describes the two use-cases that will be performed in Brussels in the scope of the ELIPTIC European project.

Both its electric bus feasibility study – identification of the best path to progressively electrify its bus network - and its tram feasibility study – optimization of braking energy recovery modules in light rail network – are presented.

After presenting the context conditions of the use-cases, in which economic, geographical, urban and public transport service contexts are described, the reports splits into two sections. For each use-case, objectives, risks, detailed description, work plan and expected results are provided.

2. Partner Contribution

Company	Sections	Description of the partner contribution
STIB	3, 4 & 5	Sections 3 to 5 have been provided by STIB in collaboration with VUB
VUB	4	Sections 4 have been provided by VUB in collaboration with STIB
UITP	All document	Review of document

3. Context conditions

This section presents the context in which both use-cases will take place. First, the city of Brussels and its urban context is described. Then, our public transport company STIB is presented. Finally, information about the intended Use Case sites is provided.

3.1. Geographical, economic, and urban context

Geography

Brussels is a region of Belgium comprising 19 municipalities. It holds the role of capital in many ways: capital of Belgium, capital of the French and the Flemish communities of Belgium and is also the de facto capital of the European Union.

	French name	Dutch name	
	Anderlecht	Anderlecht	I
	Auderghem	Oudergem	II
	Berchem-Sainte-Agathe	Sint-Agatha-Berchem	III
	Bruxelles-Ville	Stad Brussel	IV
	Etterbeek	Etterbeek	V
	Evere	Evere	VI
	Forest	Vorst	VII
	Ganshoren	Ganshoren	VIII
	Ixelles	Elsene	IX
	Jette	Jette	X
	Koekelberg	Koekelberg	XI
	Molenbeek-Saint-Jean	Sint-Jans-Molenbeek	XII
	Saint-Gilles	Sint-Gillis	XIII
	Saint-Josse-ten-Noode	Sint-Joost-ten-Node	XIV
	Schaerbeek	Schaarbeek	XV
	Uccle	Ukkel	XVI
	Watermael-Boitsfort	Watermaal-Bosvoorde	XVII
	Woluwe-Saint-Lambert	Sint-Lambrechts-Woluwe	XVIII
	Woluwe-Saint-Pierre	Sint-Pieters-Woluwe	XIX

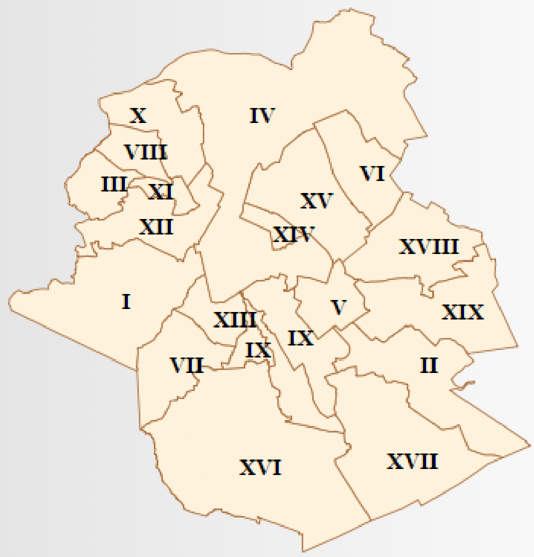


Figure A 1: The Region of Brussels comprises 19 municipalities[1]

[1] This figure, as well as an important parts of this section are inspired by Wikipedia - https://en.wikipedia.org/wiki/Brussels

The city has a population of 1.2 million and a metropolitan area with a population of over 1.8 million, both of them the largest in Belgium.

Since the end of the Second World War, Brussels has been a major centre for international politics. Hosting principal EU institutions, the secretariat of the Benelux and the headquarters of the North Atlantic Treaty Organization (NATO), the city has become the polyglot home of numerous international organizations, politicians, diplomats and civil servants.

Brussels is just a few kilometres north of the boundary between Belgium's language communities—French in the south, Dutch in the north. Today, although the majority language is French, the city is officially bilingual. All road signs, street names, and many advertisements and services are shown in both languages.
Brussels is increasingly becoming multilingual with increasing numbers of migrants, expatriates and minority groups speaking their own languages, and English sometimes serves as a lingua franca.

Economy

Brussels has a robust economy. Its GDP per capita is nearly double that of Belgium as a whole, and it has the highest GDP per capita of any region in the European Union at €62,000 in 2011. That being said, the GDP is boosted by a massive inflow of commuters from neighbouring regions; over half of those who work in Brussels live in Flanders or Wallonia, with 230,000 and 130,000 commuters per day respectively. Not all of the wealth generated in Brussels remains in Brussels itself, and in 2013 the unemployment among residents of Brussels is 19.3%.

Transport in Brussels

Transport in Brussels can be made by means of many private or public transportation means. Public transportation means include Brussels buses, trams, metro (all three operated by the STIB) as well as a set of railway lines (operated by Infrabel) and railway stations served by public trains (operated by the SNCB). Bicycle-sharing and car-sharing public systems are also available. Air transport is available via one of the two city's airports (the Brussels National Airport and the Brussels-South Charleroi Airport) or with the boat, via the Port of Brussels. The city is relatively car-dependent by northern European standards.

The complexity of the Belgian political landscape makes some transportation issues difficult to solve. The Brussels Capital Region is encircled by the Flemish and Walloon regions, which means that the airports, as well as many roads serving Brussels (most notably the Brussels Ring) are located in the other two Belgian regions.

STIB operates mainly in Brussels Region, but also has some lines active in the Walloon and Flemish regions

The following section provides further details on the means of transports in Brussels.

3.2. PT service context

Overview

Founded in 1954, the Société des Transports Intercommunaux de Bruxelles (STIB) is the main public transport operator in Brussels. It now operates a network of four metro lines (39.9 km), 17 tramlines (140.9 km) and 50 bus lines (356.7 km). Its network extends over 19 municipalities of the Brussels Capital Region (161 km2) and 11 municipalities of the Brussels periphery. In 2014, 346,6 million trips were performed on the network.

STIB defines every five years a management contract with the Brussels-Capital Region to secure its strategic objectives (mission, kilometric output, market share) and determine the value of the subsidy.

At the strategic level, the STIB is a consultant of the Region. At the tactical level (determine the network to be implemented to achieve the objectives) and operational (operations, marketing), STIB has a high degree of autonomy. Nevertheless, the Region must agree for the network modifications.

Mobility is a major attention point in the Brussels Region, both from an environmental point of view of congestion and regarding the quality of life. First Belgian urban public transport company, STIB is an essential mobility partner.

During the last 10 years, the number of STIB travellers has increased by almost 80%. In 2014, STIB has offered more than 345 million trips, up +10% compared to 2011.

This growth will continue to increase dramatically in the coming years, requiring anticipating and managing the future growth in population as well as the changing energy context.

STIB fundamentally contributes to the sustainable development of Brussels and its region in all dimensions that it entails: economic, social and environmental. STIB environmental activities allow the development of low emissions urban public transport and furthermore to initiate a series of improvements at the heart of the organization.

Modal Share

The following table presents the transport modal share in Brussels, based on the BELDAM 2010[2] study.

[2] BELDAM: BELgiumDAilyMobility - http://www.beldam.be/

	Mode used for transport		Principal mode	
	Incoming / Outgoing	Internal	Incoming / Outgoing	Internal
Car - driver	59,80%	24,10%	51,00%	23,90%
Car - passenger	15,30%	8,30%	12,70%	8,10%
Taxi	0,10%	0,30%	0,00%	0,30%
Walk	53,90%	75,10%	1,90%	37,00%
Motorcycle	1,20%	0,80%	0,70%	0,80%
Bike	3,70%	3,70%	0,40%	3,50%
Train	26,70%	1,00%	26,30%	0,90%
Tram	3,00%	11,00%	1,00%	8,30%
Metro	7,30%	12,50%	0,80%	10,00%
STIB bus	3,60%	8,70%	0,70%	6,00%
De Lijn bus	4,10%	0,80%	2,50%	0,50%
TEC bus	1,70%	0,20%	0,40%	0,10%
Other	2,30%	0,60%	1,60%	0,60%
Total	100%	100%	100%	100%
# trips	1.510	3.005	1.504	2.995

Table A 1: Brussels transport modal share

STIB bus, tram and metro map

This map presents an overall view of STIB’s network.

Figure A 2: STIB map

Metro (STIB)

The Brussels metro was first opened in 1976 and has been expanding since, to comprise as of 2009 a set of 4 metro lines serving a total of 60 metro stations, most of them being underground. Line 1 connects the Brussels-West station to the East of the city. Line 2 runs in a loop around the city centre. Line 5 runs between the West to the South-East of the city via the centre. Line 6 connects the King Baudouin Stadium at the north-west of Brussels, to the city centre, ending by a loop around the centre in the same way as line 2. Major trams operate lines 3 and 4 in Brussels.

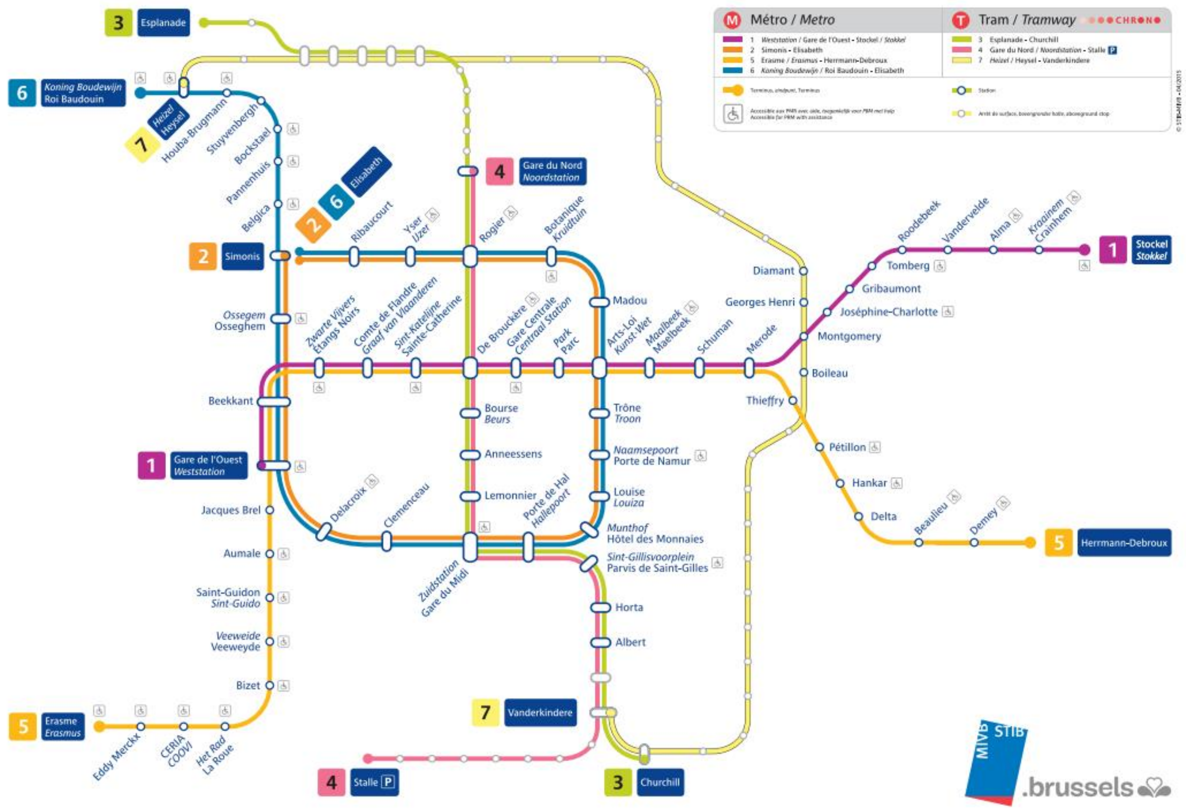


Figure A 3: Metro map & Tram lines 3, 4 & 7

Tram (STIB)

Brussels trams are an old transportation means in Brussels, operated by the STIB from 1954 on, but existing since 1869. The Brussels tram system evolved a lot over time, from a rise in the first half of the 20th century (246 km of tram rails were serviced in 1955) to a fall in the second half of the 20th century due to the popularization of transport by bus and by car. In 1988 only 134 km of tram rails remained in Brussels. Finally, the reduced tram network was extended in the late 2000s with the extension of existing lines from 131 km in 2007 to 140 km in 2014.

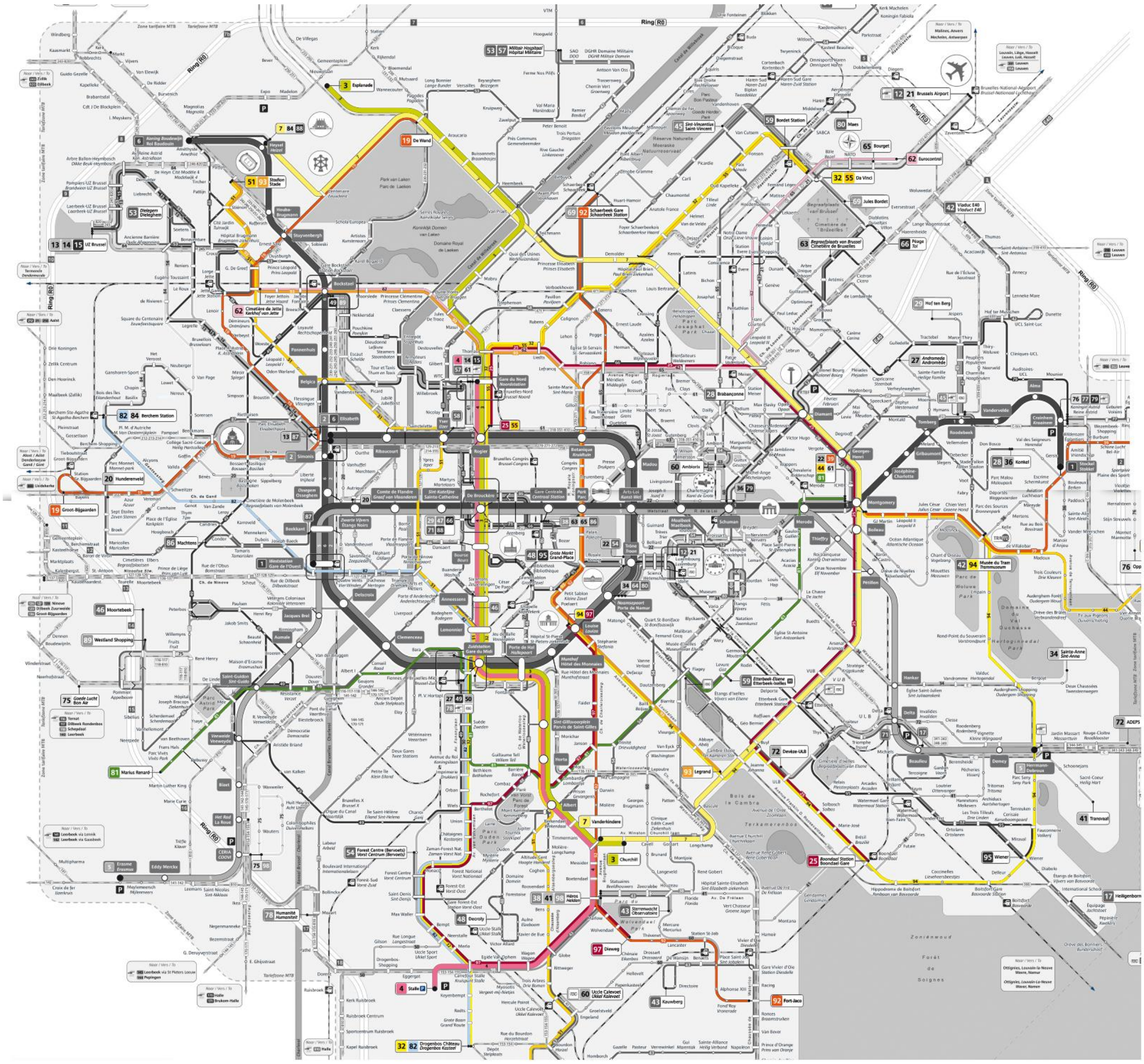


Figure A 4: Brussels Tram map

Buses *(Mainly STIB, with several lines from TEC and De Lijn)*

The first Brussels bus ran in 1907 from the Brussels Stock Exchange to the Ixelles city hall. The bus network in Brussels now comprise 360 km of bus line by day and 84 km by night as of 2014, and service the 19 municipalities of Brussels. Buses operated by the Walloon (TEC) and Flemish (De Lijn) public transport companies also run in Brussels in order to allow Walloon and Flemish people to go to the capital city.

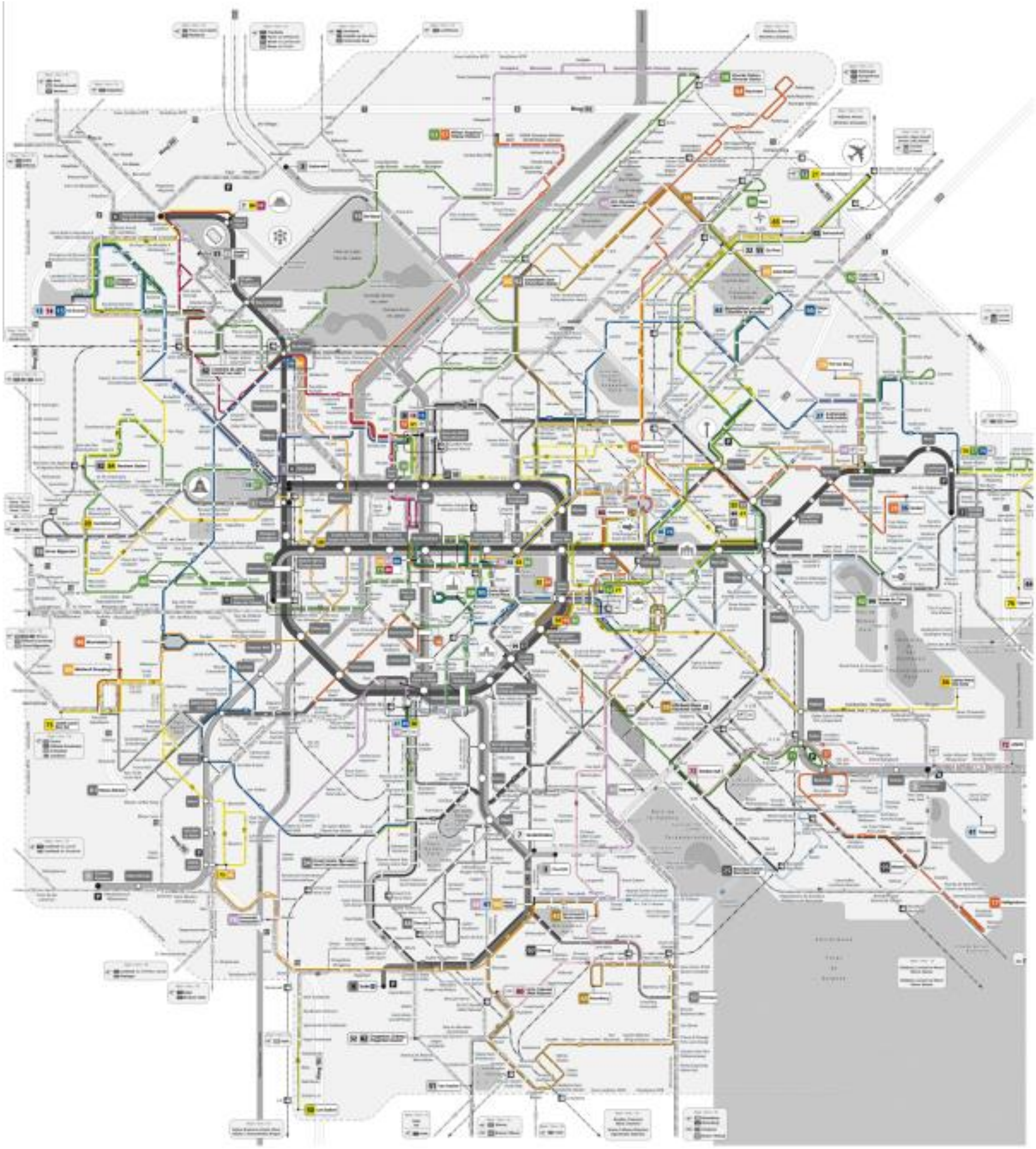


Figure A 5: Brussels Bus Map

Heavy Rail (SNCB)

The Infrabel railway network has 8 lines used by passenger trains, which lie partly of completely within the region of Brussels. Those 8 lines serve a total of 29 railway stations in Brussels, all of which offer a correspondence with one or more STIB bus, tram and/or metro lines. This system is planned to be upgraded to the Brussels RER. The Brussels-South railway station is a major station on the European High Speed train network, being served by TGV, Thalys, Eurostar and ICE high speed train services.

Roads

Roads in Brussels range from highways leading to neighbouring countries or cities to national roads, major roads down to local streets. Brussels is surrounded by the Brussels Ring, and is crossed by two smaller orbital roads: the Greater Ring and the Small Ring.

Brussels buses, trams, taxis, cars and bicycles share the road network in Brussels. A car-sharing system is operated by the public company STIB with Cambio.

Cycling

Brussels is characterized by a relatively low level of cycling compared to Flanders and many other north-western European cities, with a modal share of 3.7% for 2013. This rate has increased significantly in recent years. Since 2009 a bicycle-sharing system named Villo! has been made available to the public.

Airports

Brussels is served by two airports, the Brussels National Airport located in the neighbouring municipality of Zaventem can be accessed by highway, train and bus and the Brussels-South Charleroi Airport located between Brussels and Charleroi in Gosselies, which can be accessed by highway or a private bus.

Water transport

Brussels has its own port and is crossed by the Brussels-Charleroi Canal and the Brussels-Scheldt Maritime Canal.

3.3. Information about the Use Cases

FEASIBILITY STUDY A: *Progressive electrification of hybrid bus network, using existing tram and underground electric Infrastructure*

STIB is currently planning to introduce diesel-electric hybrid buses as a first step of progressive electrification of a significant portion of its bus network.

Within ELIPTIC, STIB, with the support of VUB, will study the options for the actual supply of electric energy from its own electric grid. The feasibility study will involve drafting the documentation (including itineraries, topography, service planning, load profiles, existing electric infrastructure) of several hypothetic, yet realistic, use cases in 3 categories:

- Neighbourhood bus: small vehicle, battery bus, single charging station;
- Feeder bus: standard vehicle, battery or plug-in opportunity charging;
- Trunk line: large vehicle, multiple strategies.

The Use-Case team will identify the most promising technical solutions based on state-of-the-art review (academic, desktop and ELIPTIC consortium documentation) and model the most promising solutions for each of the use cases, in order to determine robust configurations of infrastructure, equipment and operations, namely:

- Type and location of charging stations;
- Charging time and charging power levels;
- Type and capacity of on-board electric storage;
- Impact on service planning.

Moreover, it will assess the model results concerning:

- Energetic efficiency;
- Impact on the electric grid;
- Technical, operational and architectural impacts;
- Cost-Benefit (as input for WP3 and WP4 “business case”).

FEASIBILITY STUDY B: *Optimized braking energy recovery in light rail network*

STIB has modelled and evaluated strategies for optimal assimilation by the electric grid of braking energy recovered by metros. On this basis, 8 electric substations have been upgraded, resulting in energy savings that will pay back the investment in 5 years.

Within ELIPTIC, STIB will transpose this successful approach to its tram network, as to make optimal use of modern light rail vehicles' energy recovery ability. It will update the documentation of the light rail network and associated electric grid and identify the sections of the network with the greatest potential for braking energy recovery based on the amount of energy to be recovered (based on topography, vehicle speeds & loads) and network configuration.

Moreover, it will also model the most promising sections of the network, in order to determine robust configurations of infrastructure and equipment. The models will be assessed concerning:

- Energetic efficiency
- Technical, operational and architectural feasibility
- Cost-Benefit (as input for WP3 and WP4 "business case")

4. Use case A: Progressive electrification of hybrid bus network, using existing tram and underground electric Infrastructure

4.1. Use case A Objectives

4.1.1. Objectives of the Use Case

The Use Case “*Progressive electrification of hybrid bus network, using existing tram and underground electric Infrastructure”* consists of a **STUDY** achieved jointly by STIB and VUB to prepare for an upcoming electrification of STIB’s bus lines. This study is in line with the Brussels government clear strategy for the transition towards local zero-emission busses: a progressive electrification of its bus fleet.

The objectives of this Use-Case are twofold:

1. Grasp the **operational implications** of electrification
2. Evaluate the **financial impacts** of electrification

While this is not directly be included in the feasibility study, the two objectives described above will enable STIB to go forward with its **stakeholders** on the issue of electrification.

These objectives are declined in two perimeters:

1. Operational and financial implications for three representative bus lines analysed in details (short term)
2. Extrapolation of these implications on the global bus network (long-term)

4.1.2. Use Case KPIs

STIB and VUB have selected a rather wide variety of parameters and KPI for this Use Case for two reasons. The first reason is to evaluate consistently the expected impacts based on the computer modelling developed by VUB. The second reason is to gather a large number of parameters enabling STIB to perform a solid cost-benefits analysis for the Use Case.

Context parameters

The context parameters are divided in three families: Operations, sustainability and context

Operations

- Vehicles (Fleet composition, passenger capacity, range, distance driven, …)
- Charge (Time to recharge, state of the battery, etc.)
- Kinematics and dynamics (Speed, acceleration, braking space, …)

Sustainability

- Power and energy (Diesel engine power, battery capacity, traction diagrams, …)

Context

- Route description
- Environment

KPIs

The KPIs are divided in two families: Financial costs and “Energy and Environment” (consumption, supply and emissions).

Financial costs

- Staff (drivers, maintenance staff, …)
- Supply (line capacity, service coverage, peak vehicle requirements, …)
- Maintenance (vehicle failures, days in workshops, durability of vehicles, …)
- Service (bus frequency, dwell time, round trip time, …)
- Energy costs (electricity, fuel, …)

Energy and environment

- Consumption (vehicle fuel efficiency, fuel mix, electricity consumption, …)
- Supply (battery supply)
- Emissions (CO_2, CO, NOx, PM_{10}, …)

Some KPIs will be calculated once, based on existing figures, and other KPIs will be based on data collected during a two-month measurement campaign done on three bus lines of Brussels during November and December 2015.

4.2. Use case A Risks

Internal conditions

For the bus use-case, some internal risks could influence the progress and quality of the bus use-case. These risks are:

- Delay in the measurements due to the schedule time of the selected bus-lines;
- Low accuracy of the measurements due to the associated noise with the measured data;
- The data format due to using different time scale or sampling time.

External conditions

Some external conditions could affect the success of this Use-Case, but over which STIB and VUB do not have direct control.

These conditions are a shift in political vision, that could impact the decision to go towards an electrification of our bus fleet, and impact the studies. The probability of this change in policies is very low.

Staff members leaving the company, or staff delocalization on other priorities is also a risk. This is true for VUB and STIB.

Finally, technology evolution could make the considered technology obsolete.

4.3. Detailed description of the Use Case A

In this Use Case, three bus lines will be studied to provide insights on the impact of an electrification of those bus lines.

These lines are representative of the diversity of STIB's bus network. These lines are contrasted in terms of topology, urban density, but will also be powered with different techniques:

1. **Neighborhood line**: small vehicles, battery bus, single charging station;
2. **Feeder line**: standard vehicle, battery or plug-in opportunity charging;
3. **Trunk line**: large vehicle, multiple strategies.

The first step of the ELIPTIC project at STIB has been to select the lines to consider. At this stage, we selected the lines described hereafter. However, we could add/modify our current line selection later.

- **Line 17** as a Neighborhood bus-line operated by standard buses (12 m);
- **Line 86** as Feeder bus-line operated by standard buses (12 m);
- **Line 48** as a Trunk bus-line operate by articulated buses (18 m).

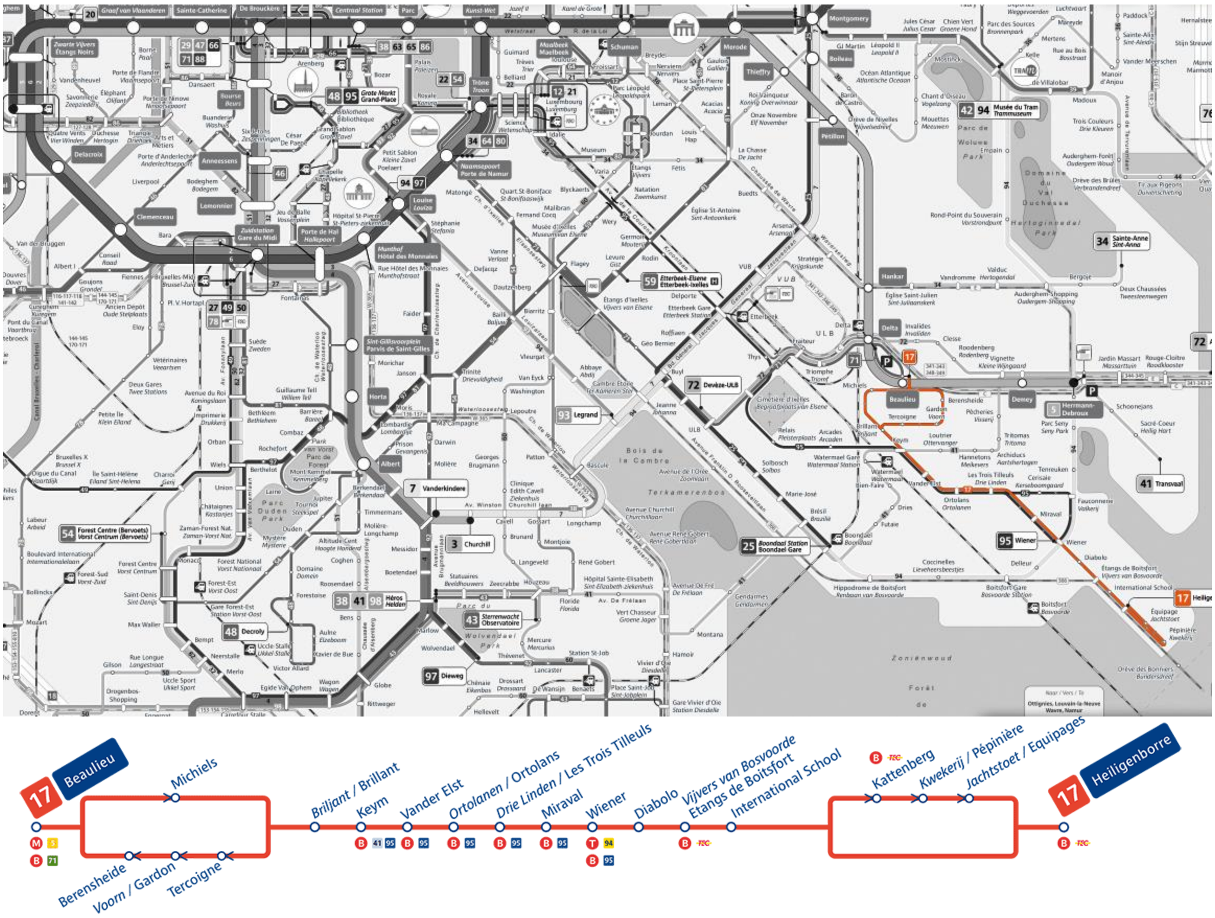


Figure A 6: Overview of line 17: Neighborhood line

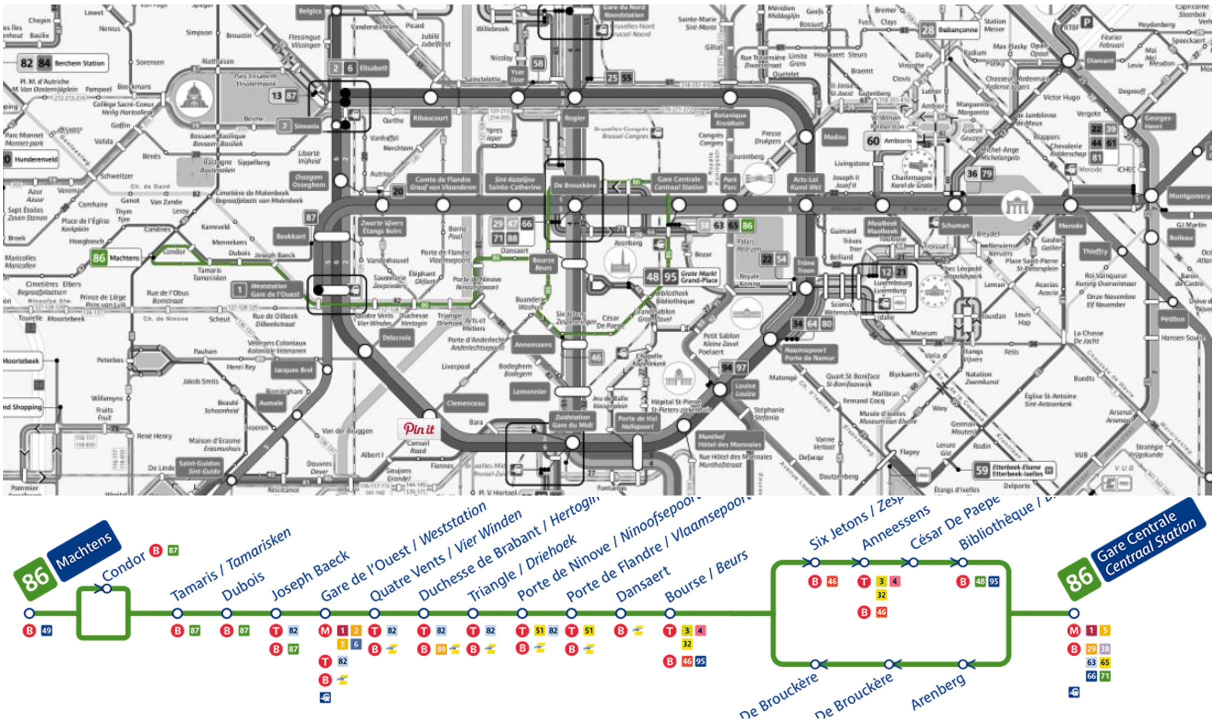


Figure A 7: Overview of Line 86: Feeder line

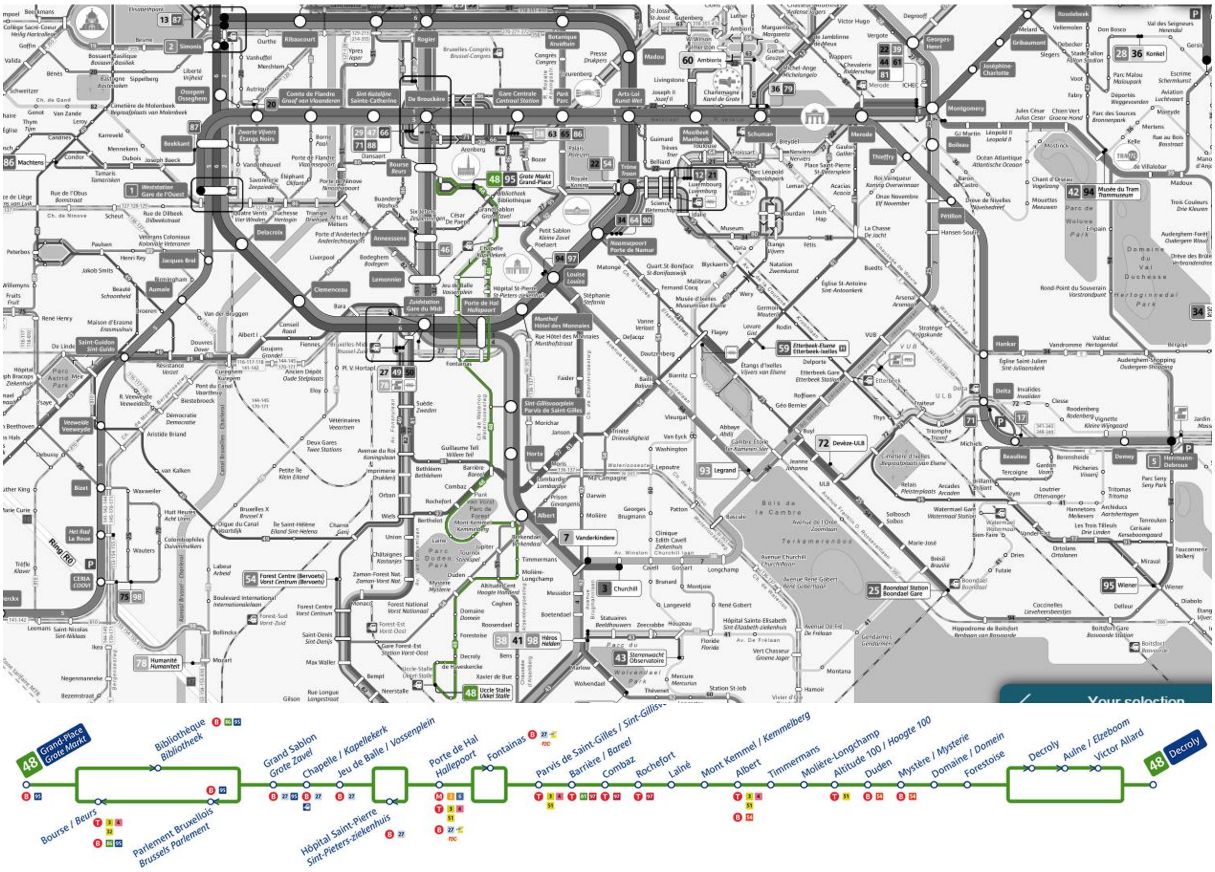


Figure A 8: Overview of Line 48: Trunk bus-line

4.3.1. Description of expected use case features, establishing the link among use case conditions, objectives and background

This section describes in details the use case features, in particular the measurements, modelling and simulation steps.

Measurements

In order to achieve the objectives of increased understating of the operational implications and financial impacts, the feasibility study will be fuelled by real measurements done on the three lines analysed with 3 buses (2 standard buses 12m and 1 articulated bus 18m).

The following measurements will be performed:

- Measurements of energy (fuel) consumption vs time:
    - ICE energy (fuel) consumption;
    - Auxiliary energy consumption or equivalent consumption.

- Measurements of vehicle time schedules:
    - Stop Time intervals at intermediate stops;
    - Max & min time at the end of the line.

This fuel consumption will be measured at three different load conditions:
- Empty,
- Middle Load,
- Full Load.

The consumption will be measured for three different time slots:
- 06h00-14h00,
- 10h00-18h00,
- 14h00-22h00.

This consumption will also be measured during three days of the week:
- Monday,
- Tuesday,
- Wednesday.

The other days of the week are reserved for the preparation of the test equipment.

The measurements will begin, for each line, a terminal to another, without respect The energy consumption of auxiliary will not be measured. An order of magnitude of the average consumption of these will be given.

The energy measurement will be based on the acquisition of the following parameters:
- Speed (Odometry)
- Fuel consumption (depending on accuracy of data available on FMS)
- Hours, Date

Semaine	Bus	Lundi	Mardi	Mercredi	Jeudi	Vendredi
		Préparation Véhicule				
semaine 45	semaine de la toussain du lundi 02 novembre au vendredi 06 novembre 2015	Lundi	Mardi	Mercredi	Jeudi	Vendredi
		Mise à disposition std 1	Preparation Véhicule (lestage & équipement) validation programmation (taille fichier, data, etc.) parammetrage véhicule et essais in situ en exploitation			
		Test en exploitation			Préparation Véhicule	
semaine 46	S1	Lundi	Mardi	Mercredi	Jeudi	Vendredi
	86 (pleine charge)	06h00-14h00	10h00-18h00	14h00-22h00	Préparation Véhicule std 1 pour essais S2 (lestage & équipement)	Préparation équipement et Test
		Mise à disposition bus std 2	Préparation Véhicule std 2 pour essais S2 (lestage & équipement)			Préparation équipement et Test
semaine 47	S2	Lundi	Mardi	Mercredi	Jeudi	Vendredi
	86 (mi- charge)	06h00-14h00	10h00-18h00	14h00-22h00	Préparation Véhicule std1 pour essais S3 (lestage & équipement)	Préparation équipement et Test
	17 (à vide)	06h00-14h00	10h00-18h00	14h00-22h00	Préparation Véhicule std2 pour essais S3 (lestage & équipement)	Préparation équipement et Test
semaine 48	S3	Lundi	Mardi	Mercredi	Jeudi	Vendredi
	86 (à vide)	06h00-14h00	10h00-18h00	14h00-22h00	Dépréparartion du véhicule std 1 & retour BUS std 1 à l'exploitation	Préparation équipement et Test
	17 (mi- charge)	06h00-14h00	10h00-18h00	14h00-22h00	Préparation Véhicule std 2 pour essais S4 (lestage & équipement)	Préparation équipement et Test
		Mise à disposition bus art 1	Préparation Véhicule std 2 pour essais S4 (lestage & équipement)			Préparation équipement et Test
semaine 49	S4	Lundi	Mardi	Mercredi	Jeudi	Vendredi
	17 (pleine charge)	06h00-14h00	10h00-18h00	14h00-22h00	Dépreparartion du véhicule std 2 & retour BUS std 2 à l'exploitation	Préparation équipement et Test
	48 (à vide)	06h00-14h00	10h00-18h00	14h00-22h00	Préparation Véhicule art 1 pour essais S5 (lestage & équipement)	Préparation équipement et Test
semaine 50	S5	Lundi	Mardi	Mercredi	Jeudi	Vendredi
	48 (mi- charge)	06h00-14h00	10h00-18h00	14h00-22h00	Préparation Véhicule art 1 pour essais S6 (lestage & équipement)	Préparation équipement et Test
semaine 51	S6	Lundi	Mardi	Mercredi	Jeudi	Vendredi
	48 (pleine charge)	06h00-14h00	10h00-18h00	14h00-22h00	Dépreparartion du véhicule art 1 & retour BUS art 1 à l'exploitation	

Figure A 9: Illustration of planning for the bus measurements

Modelling and Simulations

VUB, with support from STIB, will develop accurate models for electric buses that will enable the study of the proper electrification of the selected bus-lines (aforementioned lines: 17, 48 and 86). These models will be used to optimise the selection of the on-board energy storage systems.

These models will be developed in a Matlab/Simulink environment and are mainly based on the 'backwards-looking' or 'effect-cause' method, which calculates the energy consumed by a vehicle following a predefined driving cycle by going upstream the vehicle components and accounting for their losses depending on the working point.

In addition, the developed models will enable to investigate different charging scenarios and to study their impact on the size of the on-board energy storage system, charging time, charging location, interaction with tram network and charging power level. These models will be validated using the obtained measurements that will be performed on the selected bus-lines.

Based on the developed models, VUB will provide a realistic feasibility study that will support STIB to achieve its target towards zero-local emissions buses. This study will also evaluate the costs, benefits and operating efficiency of these use case scenarios.

4.3.2. Use Case A constraints

The main constraints for this Use-Case are related to the precision of the measurements, and their interpretation and inclusion in the modelling tool.

With the simulations results, the extrapolation of the results of the three lines to the whole network is another important challenge.

4.3.3. Use Case A monitoring criteria

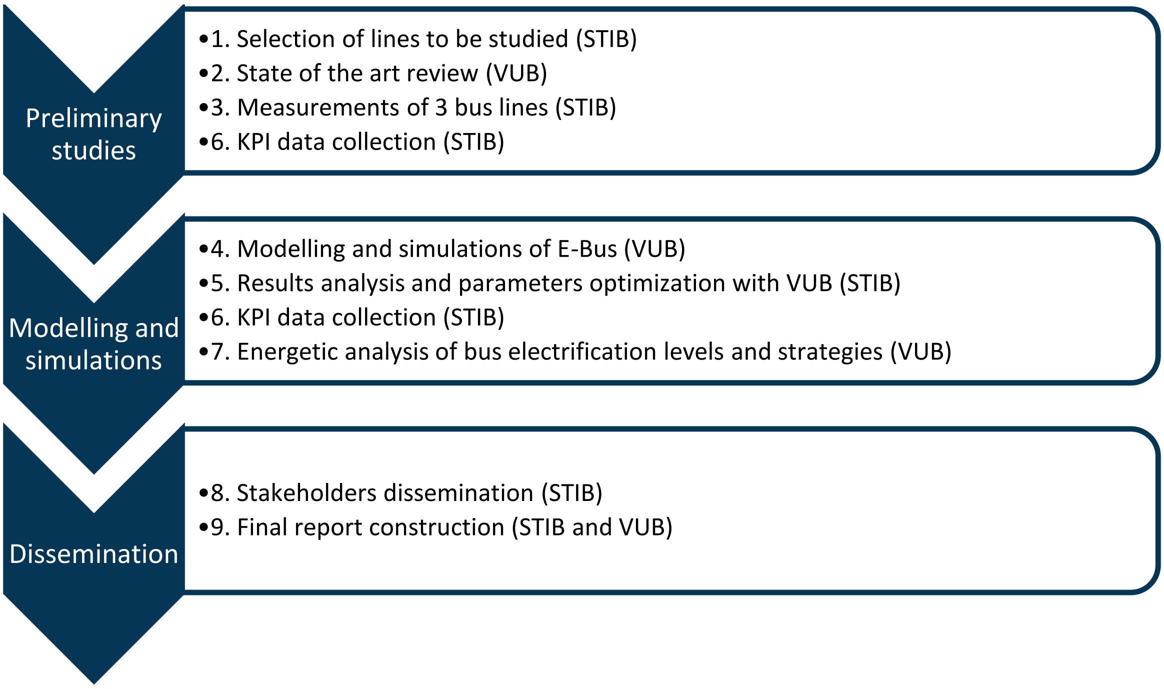
The Use Cases will be monitored using the Planning and Execution Checklist provided by the ELIPTIC coordinators, as well as the usual Project Management tools used at STIB.
The monitoring criteria are all related to the timing of the actions.
Section 4.4.2 below details the actions and respective timings.

4.4. Use case A work plan

This chapter provides a complete overview of the use case work plan.

4.4.1. Use Case A development logic

This section presents the expected Use Case development logic.



As detailed in the figure above, the development logic for this study is rather straightforward. After preliminary studies, the core of the work will be achieved in the "Modelling and simulations" phase, during which VUB and STIB will iterate to optimize the parameters considered for each scenario (number of charging points, bus characteristics …) based on the outputs of the various simulations done by VUB.
The final phase will consist in disseminating the project results through the various stakeholders impacted by the study results, and through the final publication.

4.4.2. Work plan

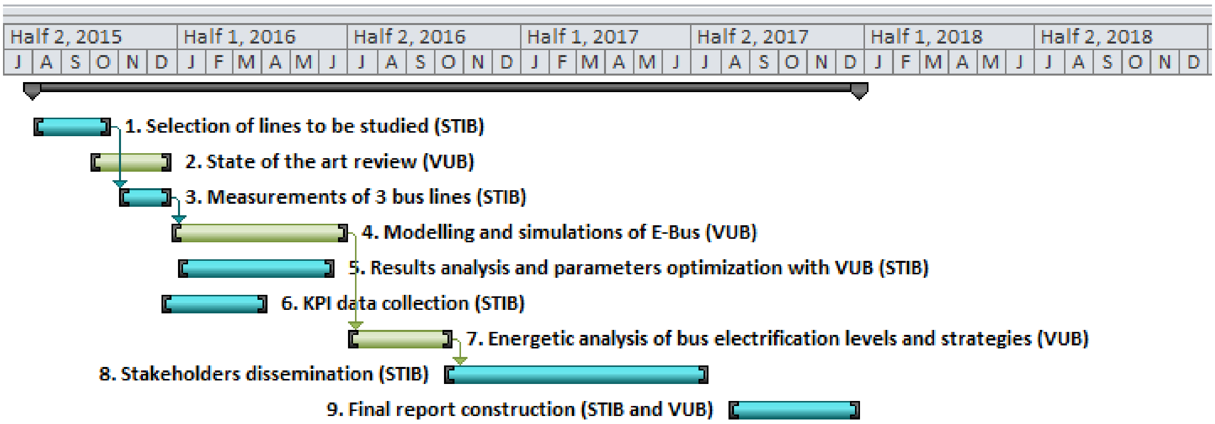
The following table presents the expected action plan with the involved partners efforts and timing:

#	Action	Person months	Staff	Start-month	End-month
1	Selection of lines to be studied	1	STIB	aug-15	oct-15
2	State of the art review	2	VUB	oct-15	dec-15
3	Measurements of 3 bus lines	3	STIB	nov-15	dec-15
4	Modelling and simulations of E-Bus	2	VUB	dec-15	june-16

5	Results analysis and parameters optimization with VUB	3	STIB VUB	jan-16	june-16
6	KPI data collection	2	STIB	dec-15	apr-16
7	Energetic analysis of bus electrification levels and strategies	1	VUB	june-16	oct-16
8	Stakeholders dissemination	3	STIB	oct-16	jul-17
9	Final report construction	2	STIB VUB	aug-17	dec-17

4.4.3. Detailed timeline

The following Gantt chart presents the work plan presented in the previous section.



4.5. Use Case A expected results

The results of this study can be classified in three categories:

- Global implications of E-Bus technologies;
- Concrete implications for three bus lines in Brussels;
- Recommendations for further steps with stakeholders.

1. Global implications of E-Bus technologies

This study will enable STIB to gauge the impact of its future E-Bus technologies on its:

- ***Network:*** To what extent should the existing bus lines be adapted to be compatible with the electric traction?
- ***Buses:*** Which are the main E-Buses characteristics that are essential for operations in Brussels
- ***Electrical grid:*** What is the impact on its own electrical grid of charging E-BUSES in the depots and on the routes themselves?

These results will be global and qualitative and will be disseminated through the company to facilitate the technical and cultural shift related to the transition to electrical bus traction.

2. Concrete implications for three bus lines in Brussels

The deep modelling of three representative bus lines will bring very concrete and quantitative results regarding various technical aspects:

- ***Bus operations*** (vehicles, charging locations, speed profile, impact on drivers, …)
- ***Bus power and energy requirements*** (precise dimensioning of traction chain and storage solutions)
- ***Impact on the electrical grid*** and sizing of charging stations
- ***Financial impact*** of the electrification of the bus lines

Unlike the first point, these results will be very specific and precise for the three lines studied.

3. Recommendations for further steps with stakeholders

Based on the global and specific results presented above, STIB will be able to provide concrete recommendations for a real-world deployment of E-Buses. These recommendations will target internal collaborators, but also the various stakeholders implicated or impacted by the electrification of a bus line.

5. Use Case B: Optimised braking energy recovery in light rail network

5.1. Objectives

5.1.1. Objectives of the Use Case

The Use Case "*Optimised braking energy recovery in light rail network"* consists of a **FEASIBILITY STUDY** aiming at studying the opportunity to install braking energy recovery systems for Brussels Tram Network.

The objectives of this Use Case are twofold:
1. Grasp the **operational implications** of braking energy recovery solutions;
2. Evaluate the **financial costs and benefits** of such technologies.

The operational implications will be analysed for both the vehicles themselves and the traction infrastructure (traction infrastructure, electrical network …)

5.1.2. Use Case KPIs

STIB has selected a rather wide variety of parameters and KPI for this Use Case for two reasons. The first reason is to evaluate consistently the expected impacts on the tram network based on computer-modelled results. The second reason is to gather a large number of parameters enabling STIB to perform a solid cost-benefits analysis for the Use Case.

Context parameters

The context parameters are divided in three families: Operations, sustainability and context

Operations
- Vehicles (Fleet composition, passenger capacity, range, distance driven, …)
- Kinematics and dynamics (Speed, acceleration, braking space, …)

Sustainability

- Power and energy (auxiliary power, battery capacity, traction diagrams, …)

Context

- Route description
- Environment

KPIs

The KPIs are divided in two families: “Financial costs” and “Energy and Environment” (consumption, supply and emissions).

Financial costs

- Staff (drivers, maintenance staff, …)
- Supply (line capacity, service coverage, peak vehicle requirements, …)
- Maintenance (vehicle failures, days in workshops, durability of vehicles, …)
- Service (Tram frequency, dwell time, round trip time, …)
- Energy costs (electricity, …)

Energy and environment

- Consumption (vehicle fuel efficiency, electricity consumption, …)
- Particle emissions related to electricity production

Some KPI will be calculated once, based on existing figures, and other KPI will be based on data collected during a two-month measurement campaign done on three tramlines of Brussels during December and January 2016.

5.2. Use Case B Risks

Internal conditions

For the bus use-case, some expected internal risks could influence the progress and quality of the tram use-case. These risks are:

- Delay in the measurements due to the schedule time of the selected tram lines;
- Low accuracy of the measurements due to the associated noise with the measured data;
- The data format due to using different time scale or sampling time.

External conditions

Some external conditions could affect the success of this Use-Case, but over which STIB does not have any direct control.

Staff members leaving the company, or staff delocalization on other priorities is a first risk. The second risk is related to technology evolution that could make the considered technology obsolete.

5.3. Detailed description of Use Case B

In this Use Case, three tram lines will be studied to provide insights on the potential of braking energy recovery technologies for our tram network.

These lines are representative of the diversity of STIB's tram network. These lines are contrasted in terms of topology, urban density, vehicle speed and load.

The first step of the ELIPTIC project at STIB has been to select the lines to consider:

- **Ligne 7** : Line with a good recovery potential due to its separate lane, a high speed and rather high load.
- **Ligne 19 :** Urban line with a high load – it also goes through several very urban zones.
- **Ligne 94** : Line with a variable profile, with an important load from Louis to ULB, followed by a lower load section.

However, we could add/modify our current line selection later.

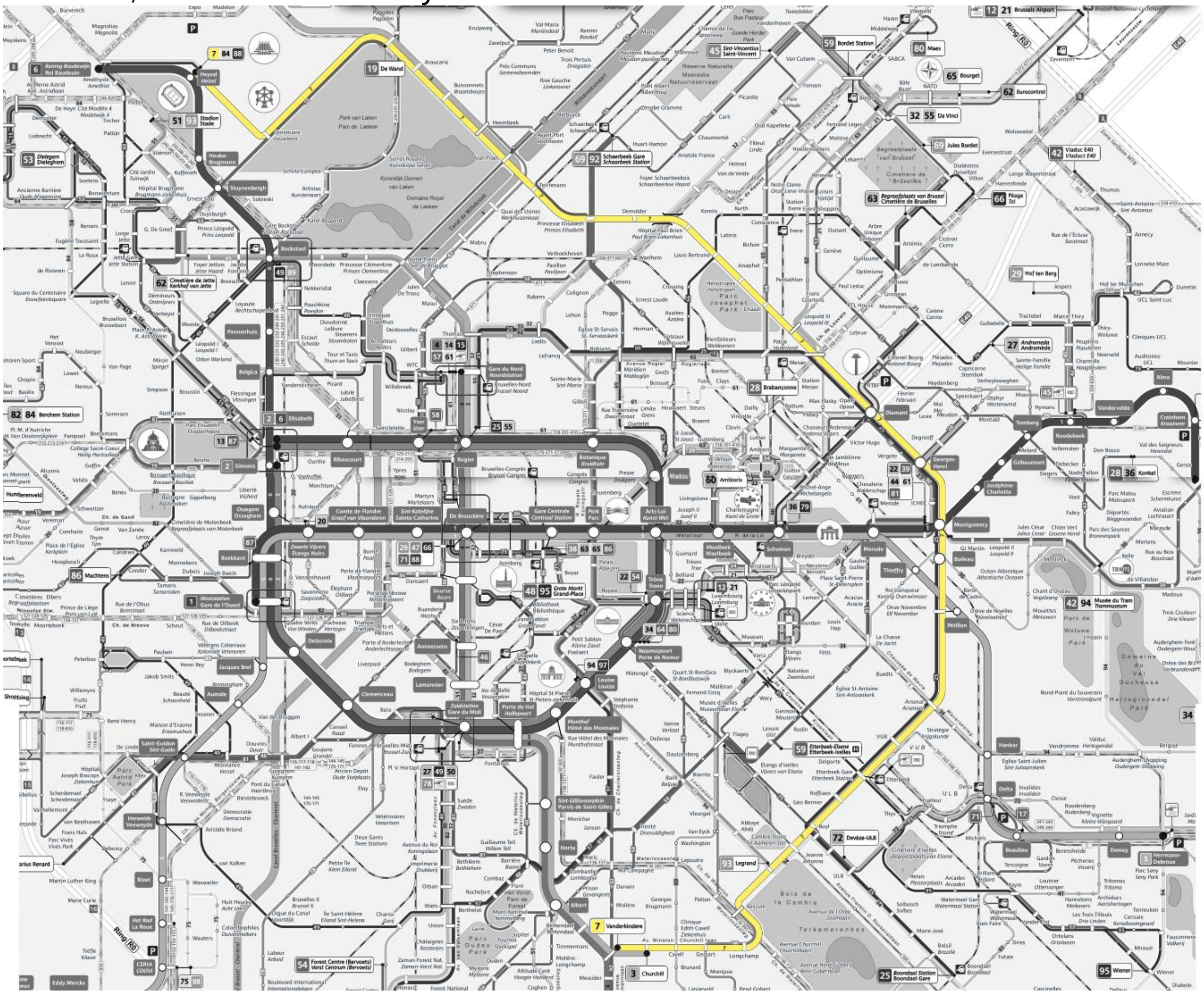


Figure B 10: Overview of tram Line 7

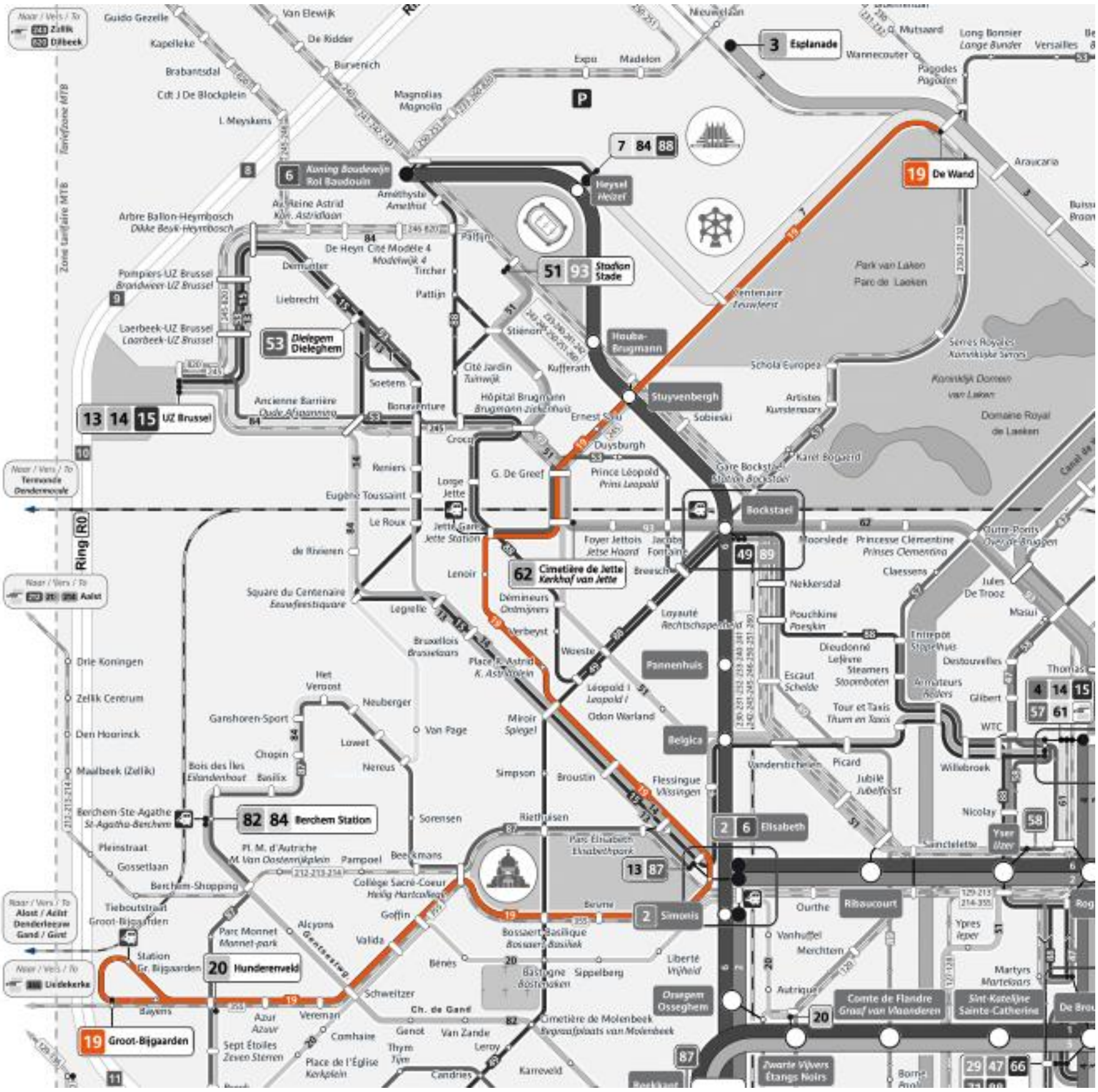


Figure B 11: Overview of tram Line 19

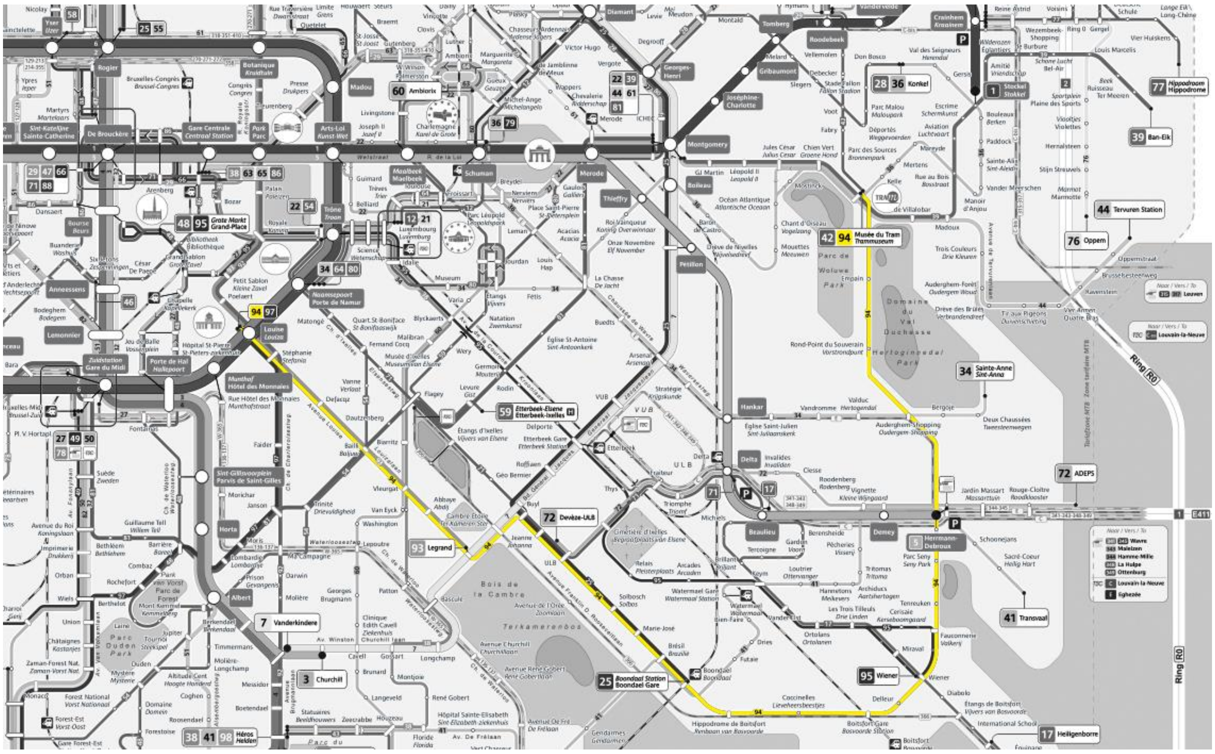


Figure B 12: Overview of Line 94

5.3.1. Description of expected use case features, establishing the link among use case conditions, objectives and background

This section describes in details the use case features, in particular the measurements, modelling and simulation steps.

Measurements

In order to achieve the objectives of increased understating of the operational implications and financial impacts, the feasibility study will be fuelled by real measurements done on the three lines analysed.

The following data will be gathered:

Technical data (based on datasheets)

- Type of vehicles on the line (T3000, T4000 or T2000)
- Diagram of the vehicle kinematic chain (inverter, motor, gearbox, wheels, etc.)
- Specifications of the vehicle:
  - Mass; equivalent mass of the rotating components
  - Efficiency of drivetrain
    - motor, inverter, gearbox
  - Wheel diameter
  - the gearbox reduction factor
- Maximum acceleration according to speed.
- Front surface of the tram
- Traction and braking curves, i.e., max tractive effort. vs. speed, max braking effort. vs. speed.
- Max. traction power vs. overhead line voltage
- Dynamic braking behaviour: Power dissipated in braking resistors vs. catenary voltage. (or returned to the catenary power vs. voltage).
- Operation of the pneumatic brake and electrical vs. speed.
- Rolling resistance: equation and parameters
- Auxiliary consumption (measured or estimated) [kW]

Measurements on three lines

Required data (frequency ≈ 500 ms)

- Speed
- Entry Traction current
- Input voltage

Other useful data

- Annual consumption in kWh / km by type of train
- Annual Regeneration rate (if available) as a percentage. (Energy returned to the catenary / Energy consumed in traction)
- Power to the braking resistors (frequency ≈ 500 ms)
- Power to the engine (frequency ≈ 500 ms)
- Consumption of auxiliary
- Snakes load a route in rush hour, off-peak and weekend.

Measurements of vehicle time schedules:

- Stop Time intervals at intermediate stops;
- Max & min time at the end of the line.

The following figure illustrates the kind of data that will be collected

Ligne 7. Trajet : Vanderkindere -> Heizel. (Peak hour)						
Required data						
Time	t_0	t_1	t_2	t_3	…	t_n
Speed	v_0	v_1	v_2	v_3	…	v_n
Current	i_0	i_1	i_2	i_3	…	i_n
Voltage	V_0	V_1	V_2	V_3	…	V_n
Other useful data						
Snakes load	$Charge_1$			…	$Charge_k$	
Engine power	Pm_0	Pm_1	Pm_2	Pm_3	…	Pm_n
Braking resistors power	Pfr_0	Pfr_1	Pfr_2	Pfr_3	…	Pfr_n
Auxiliaries power	$Paux_0$	$Paux_1$	$Paux_2$	$Paux_3$	…	$Paux_n$

Figure B 13: Illustration of data collection for the tram measurements

Network Data (operational side)

- Average annual distance travelled by type of train and online
- Passenger load depending on the time of day
- Interval trains at various periods: peak hours, off-peak, night and weekend (winter and summer)
- Topographic profile selected tram lines
- Speed limits (if applicable)

Network data (infrastructure side)

Technical data

- Electric Map of the 700 VDC distribution network
    - Location of substations
    - Length and diameter of the cables connecting the substations with the catenary
    - Interconnections between catenary different directions
- Section of the catenary, rails and any cable for transmitting energy along the line.
- Type substation (rectifiers 6 or 12 pulses)

- Topographic profile selected tramlines and rails bending radius depending on the location.
- Speed limits (if applicable)

Measures

- Open circuit voltage of traction substations feeding the selected lines, and internal impedance of substations

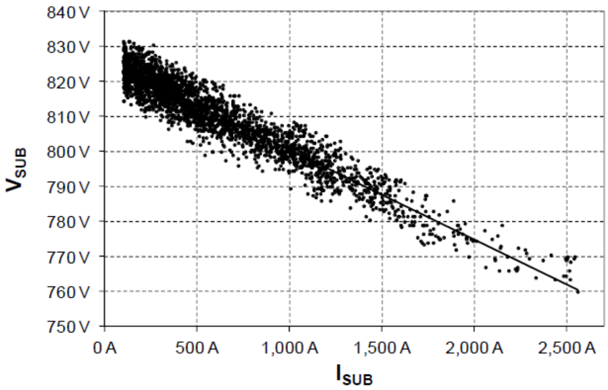


Figure B 14: Typical Open Circuit voltage of a traction substation

- Monthly consumption of traction substations supplying the line.
- For traction substations supplying several lines:
  - Power profile given to other lines outside the scope of the study (frequency ≈ 500 ms - 1s)
  - Energy consumed for monthly lined studied (This would involve taking measurements downstream consumption of the rectifier, only for the cables that feed the lined studied)

Development of a multi-train simulation tool adapted to the Brussels tram network topology

Based in the previous experience of a Brussels metro line model, a dedicated simulation tool for the Brussels tram network will be developed. Unlike the metro network, where each line is electrically isolated from the others and has dedicated sub-stations, the Brussels tram network is formed by a mesh with line junctions and substations that feed several lines at the same time. Thus, the system complexity is much higher than the one of the metro. To overcome this issue, a network model that accounts for the influence of several tram lines will be developed. This model will be able to realistically reproduce the behaviour of vehicles and substations of representative lines of the tram network that will be the subject of the study.

The objective of these models is to obtain realistic results in terms of power and energy flows. The vehicles' models can then be either quasi-static or dynamic, the latter being more precise but entailing higher simulation times. The input to the vehicle model will be the speed cycle reference, and the network voltage at the pantograph contact point.

Regarding the network model, a nodal approach can be utilised, although this research is opened to other methodologies (discovered during the state of the art research) showing advantages for highly complex networks. The network inputs will be the vehicles positions and their requested current; and the energy recovery systems positions and current. With these inputs, the network model will yield the voltages and currents in the line at the points of interest such as substations, vehicles pantographs, energy storage devices connection points, etc. Reversible substations will be modelled within this task and the control algorithm that manages the power flow will be defined. The systems will decide whether to withdraw energy from the tram network in function of the voltage.

Simulation of selected tram network zones, analysis and validation

This task consists in the simulation of the three selected lines of the tram network as they are in reality, without the influence of energy recovery technologies. The simulation will be carried out in different real traffic conditions (peak time, off-peak times and night & weekends periods) based on the measurements achieved on the network. The simulation will yield values such as the energy consumed by the traction substations, the energy exchange among vehicles, the energy dissipated in the braking resistors, as well as the vehicles power consumption and network current and voltages.

Modelling and simulation of braking energy recovery technologies

The influence of braking energy recovery technologies will be studied during this task. Simulations of the tram network including energy recovery technologies will be carried out considering the existing traffic conditions. The goal is to determine what would be the optimal solution for the tram network in terms of energy savings. Reversible substations, whose the technical characteristics will come from the current market will be compared in this regard.

Besides, the number of energy recovery systems (ERS) needed and their peak power capabilities can be assessed by developing a sensibility study, i.e., several simulations are run with an increasing (or decreasing) number of ERS so that we can see what is the added value of having an extra ERS in the network. Likewise, the same approach can be used for the peak power of the ERS.

The outcome of this task will be the potential energy savings achieved with a certain number of ERS with certain technical features such as peak power capabilities, etc.; and their ideal location on the selected tram lines.

This study will also evaluate the costs, benefits and operating efficiency of these use case scenarios.

5.3.2. Use Case B constraints

The main constraints for this Use-Case are related to the precision of the measurements, and their interpretation and inclusion in the modelling tool.

With the simulations results, the extrapolation of the results of the three lines to the whole network is another important challenge.

5.3.3. Use Case B monitoring criteria

The Use Cases will be monitored using the Planning and Execution Checklist provided by the ELIPTIC coordinators, as well as the usual Project Management tools used at STIB.
The monitoring criteria are all related to the timing of the actions. Section 5.4.2 below details the actions and respective timings.

5.4. Use case B work plan

This chapter provides a complete overview of the use case work plan.

5.4.1. Use Case B development logic

This section presents the expected Use Case development logic.

Preliminary studies

- 1. Selection of lines to be studied
- 2. Measurements & Data collection
- 3. State-of-the-art review of multi-train simulation techniques
- 4. Analysis and characterization of existing tram network

Modelling and simulations

- 5. Development of a multi-train simulation tool adapted to the Brussels tram network
- 6. Simulation of selected tram network zones, analysis and validation
- 7. Modelling and simulation of braking energy recovery technologies

Dissemination

- 8. Final report construction

As detailed in the figure above, the development logic for this study is rather straightforward.

The preliminary studies will enable STIB to select and gather data for tram lines, characterize the tram network and review state-of-the-art multi-train simulation techniques.

The core of the work will then be achieved in the “Modelling and simulations” phase, during which STIB will develop a simulation tool, simulation the selected tram lines, analyse and validate the results. Then, braking energy recovery technologies for tram will be modelled and simulated to evaluate the potential benefits of investing in such technologies.

The final phase will consist in disseminating the project results through the various stakeholders impacted by the study results, and through the final publication.

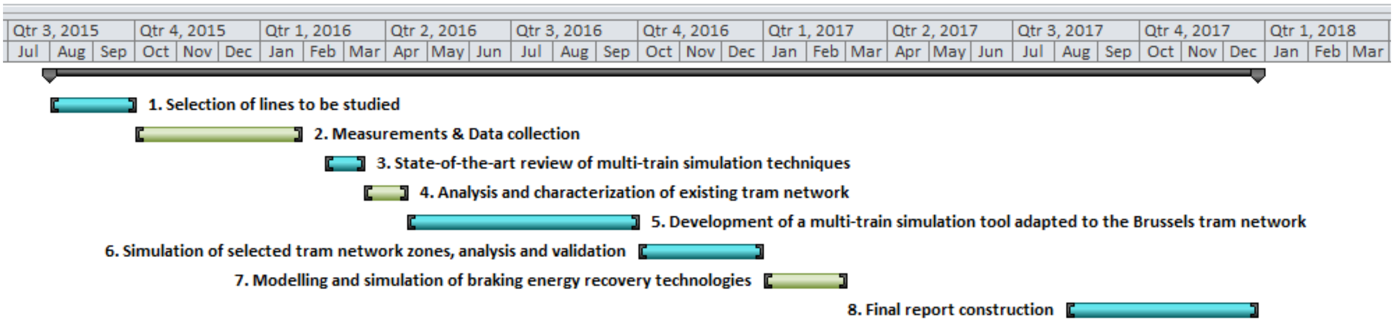
5.4.2. Work plan

The following table presents the expected action plan with related efforts and timing:

#	Action	Person months	Start-month	End-month
1	Selection of lines to be studied	1	aug-15	oct-15
2	Measurements & Data collection	2	oct-15	jan-16
3	State-of-the-art review of multi-train simulation techniques	1	feb-16	mar-16
4	Analysis and characterization of existing tram network	2	mar-16	apr-16
5	Development of a multi-train simulation tool adapted to the Brussels tram network	6	apr-16	oct-16
6	Simulation of selected tram network zones, analysis and validation	2	oct-16	dec-16
7	Modelling and simulation of braking energy recovery technologies	3	jan-17	mar - 17
8	Final report construction	3	aug-17	dec-17

5.4.3. Detailed timeline

The following Gantt chart presents the work plan presented in the previous section.


Qtr 3, 2015
Qtr 4, 2015
Qtr 1, 2016
Qtr 2, 2016
Qtr 3, 2016
Qtr 4, 2016
Qtr 1, 2017
Qtr 2, 2017
Qtr 3, 2017
Qtr 4, 2017
Qtr 1, 2018
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar
1. Selection of lines to be studied
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3. State-of-the-art review of multi-train simulation techniques
4. Analysis and characterization of existing tram network
5. Development of a multi-train simulation tool adapted to the Brussels tram network
6. Simulation of selected tram network zones, analysis and validation
7. Modelling and simulation of braking energy recovery technologies
8. Final report construction

5.5. Use Case B expected results

The results of this study can be classified in two categories

- Technical implications of tram braking energy recovery
- Financial and environmental potential of such investments

1. Technical implications of tram braking energy recovery

The study will bring direct results related to

- Impacts on tram traction substations
- Impacts on STIB electrical grid
- Impacts on tram vehicles and potential on-board storage solutions
- Evaluation of the energy recovery potential for the global tram network based on the simulations done on the representative lines

2. Financial and environmental potential of such investments

Based on the technical results listed in the previous section, STIB will be able to evaluate the financial benefits, based on a cost-benefits analysis of braking energy recovery technologies, as well as the environmental benefits of the technologies.