**POLITECNICO DI MILANO**

Electric systems for Mobility

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Project Work

# Implementation of an electric school-bus service in Heron Gate Neighborhood, Ottawa, Canada

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## EXECUTIVE SUMMARY

The following paper discusses the implementation of an electric school bus line in Ottawa, Canada. The project is motivated by sustainable development goals (SDGs) regarding environmental and social sustainability.

Briefly, this paper analyses the performances of the feet along the designed path, given a scheduled service constraint. Based on the results obtained, further analysis on the energy and infrastructural requirement and carbon emission are carried out, as well as a comparison with a traditional diesel fleet.

Finally, the last section hypothesizes the costs and revenues of the project.

# 1. INTRODUCTION

## 1.1 Project Description and Objectives

This project consists of an analysis that investigates the characteristics and overall technical, environmental, and economic feasibility of an electric school bus service in the city of Ottawa, Canada.

The project is driven by the following Sustainable Development Goals (SDGs), defined by the United Nations General Assembly:

- SDG 11.2: "[…] provide access to safe, affordable, accessible and sustainable transport systems for all, […], with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons"[1]
- SDG 11.6: "[…] reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality, […]"[2]


The main goal of the implementation of the service is to substitute existing diesel busses to provide a socially and environmentally sustainable transport solution for the communities involved.

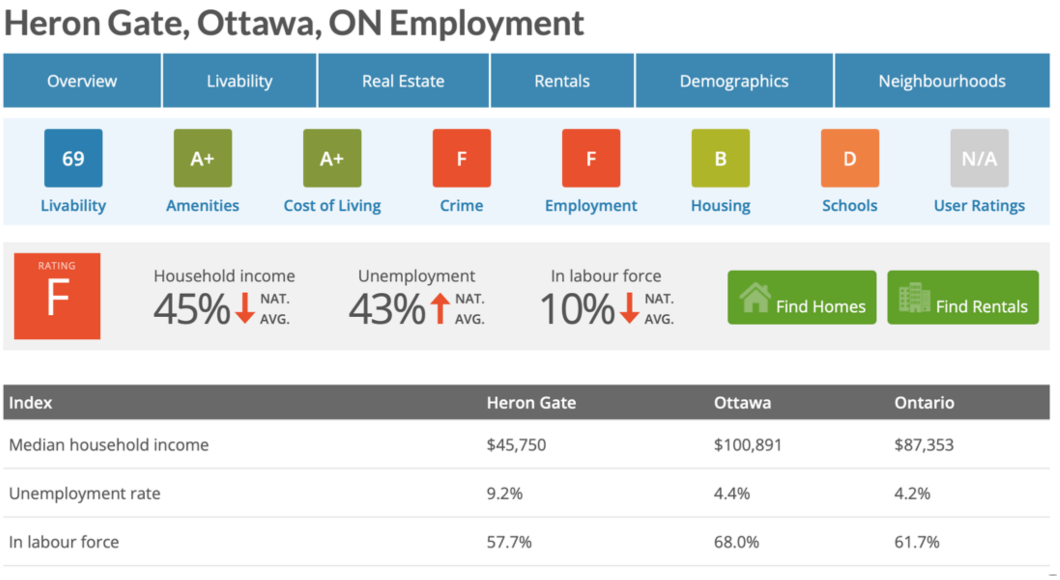
The relative targets are:

- The substitution of the existing diesel fleet operating with a full-electric school bus fleet, so to reduce carbon emission as much as possible and to make a more efficient use of the resources.
- The integration of the school service with a dedicated transit service to the elder and vulnerable individuals of the community. These strata of society often find it difficult to satisfy their transportation needs, mainly because of their higher difficulty in using reliable private modes of transportation, combined with the relatively poor quality of public transit infrastructure in north American suburbia. [3]
- Solving the high level of turnover among the bus drivers. Mainly caused by low salaries and few active working hours (drivers are on duty only during school time). [4] [5]

[1] United Nations (2017) Resolution adopted by the General Assembly on 6 July 2017, Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development
[2] United Nations (2017) Resolution adopted by the General Assembly on 6 July 2017, Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development
[3] "Why American public transit is so bad", Laura Bult, Vox, 2020 (article, video, and related sources)
[4] "Stubborn factors causing school bus driver shortage in Ottawa", Michelle Allan, CBC News, 2021
[5] "Nearly 200 school bus delays reported in York Region amid driver shortage", Chris Fox, CTV News, 2021

## 1.2 Study area overview: Heron Gate neighborhood

The study area of the project is set on the Heron Gate neighborhood, located south-east Ottawa, which among all the neighborhoods is the one characterized by the lowest family income, and overall living conditions below average.

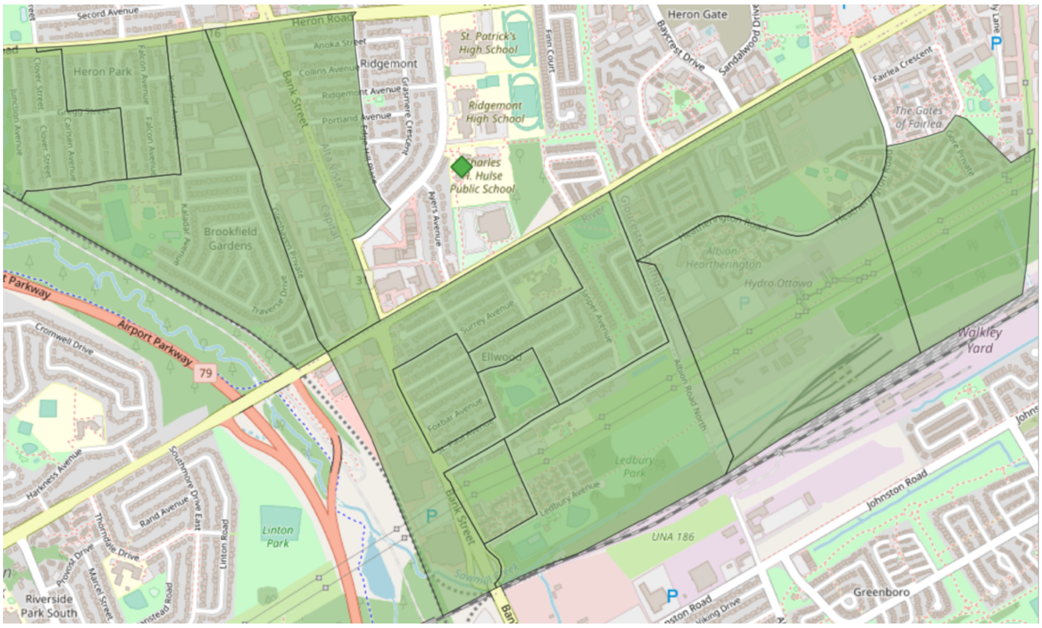



| Index | Heron Gate | Ottawa | Ontario |
|---|---|---|---|
| Median household income | $45,750 | $100,891 | $87,353 |
| Unemployment rate | 9.2% | 4.4% | 4.2% |
| In labour force | 57.7% | 68.0% | 61.7% |

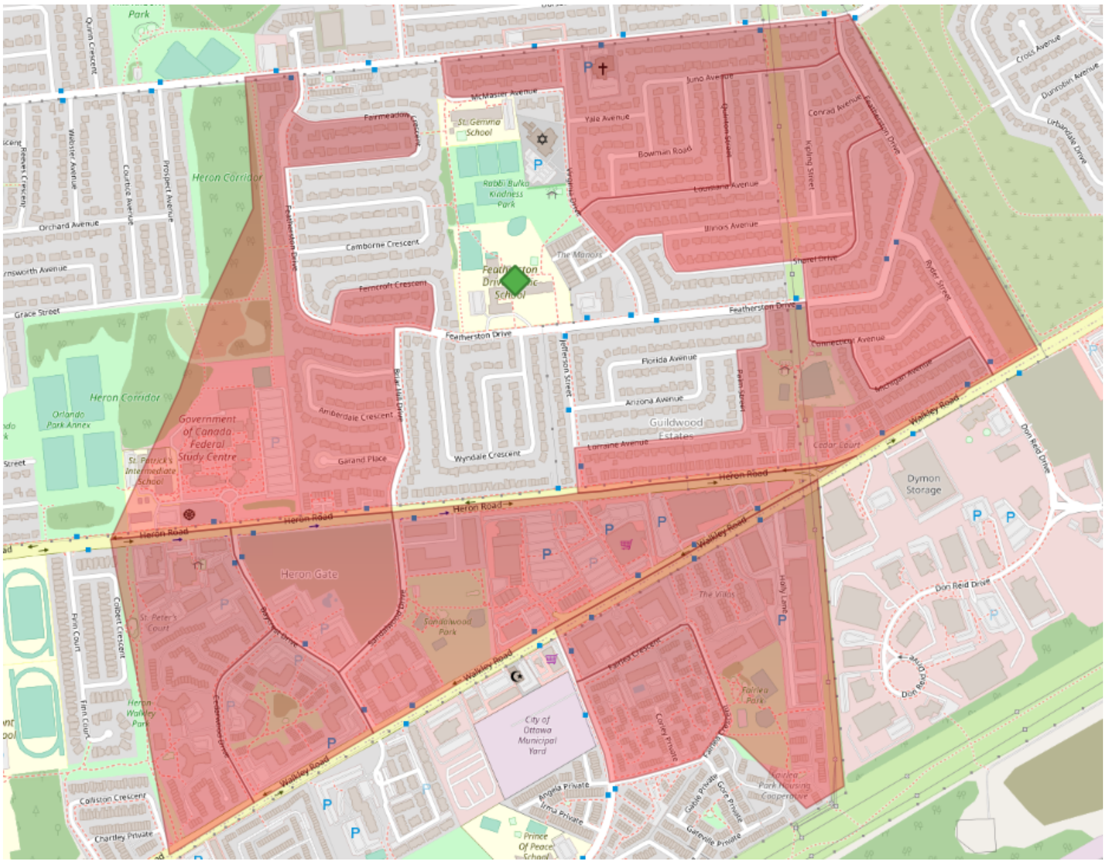
Using QGIS software, the whole neighborhood was subdivided into smaller census units of which the population and other census data is known.
Since the service is intended only for children from 5 to 11 years old, three elementary schools have been identified:
-Alta Vista public school
-Featherstone public school
-Charles st. Hulse public school

| | |
|---|---|
| *St. Hulse public School* | *8:30 a.m.- 15:00 p.m.* |
| *Featherstone Public School* | *9:00 a.m.- 15:30 p.m.* |
| *Alta Vista Public School* | *9:30 a.m.- 16:15 p.m.* |

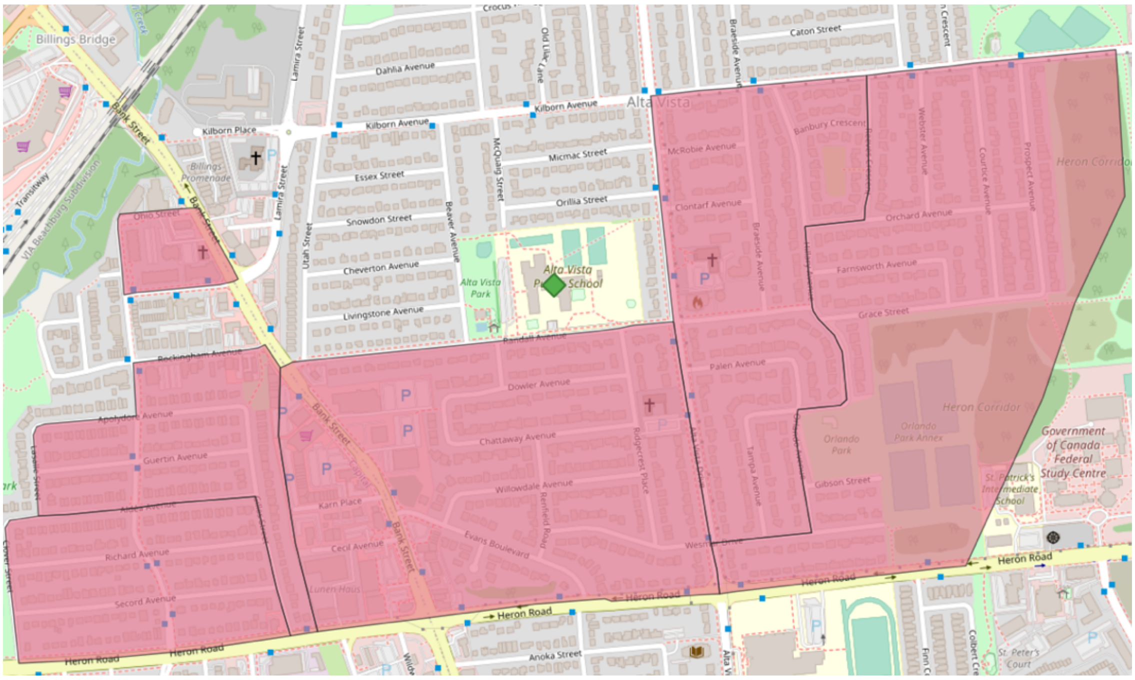
The study area has then been divided into 3 sub-areas, each one with a single school associated to it, and in which the school bus will operate the service. The sub-areas are called S1, S2 and S3.
This subdivision was done given the assumption that children who live in close proximity to the sub-area's schools will go on foot (alone or with their parents), and therefore will not take the bus.




**S1 sub-area –** associated to *St. Hulse public School*




**S2 sub-area –** associated to *Featherstone Public School*

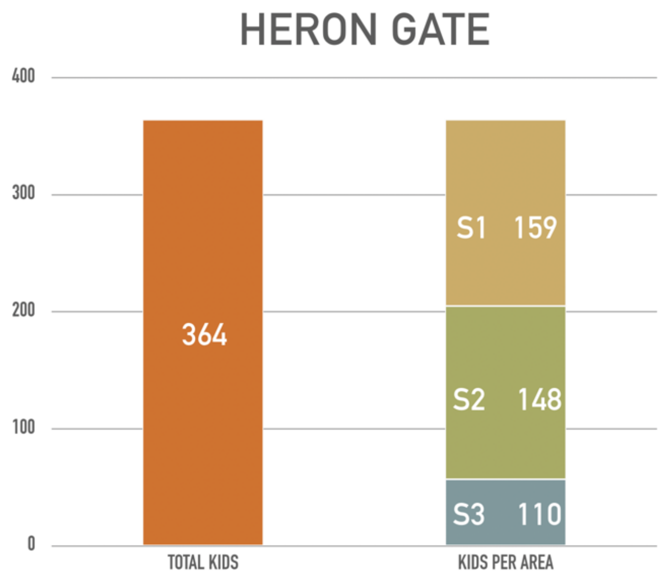



**S3 sub-area –** associated to *Alta Vista Public School*

The number of children to be transported by the service was calculated using the percentage of Canadian population between 5 and 11 years old and the percentage of school bus utilization[6]

| | |
|---|---|
| Percentage of children 5-11 y/o over Canadian population | 3,2%[7] |
| Percentage of school bus utilization | 55% |

Via QGIS, these two pieces of data were applied to the census units inside each sub-area.
The distribution of the children in Heron Gate is the following:



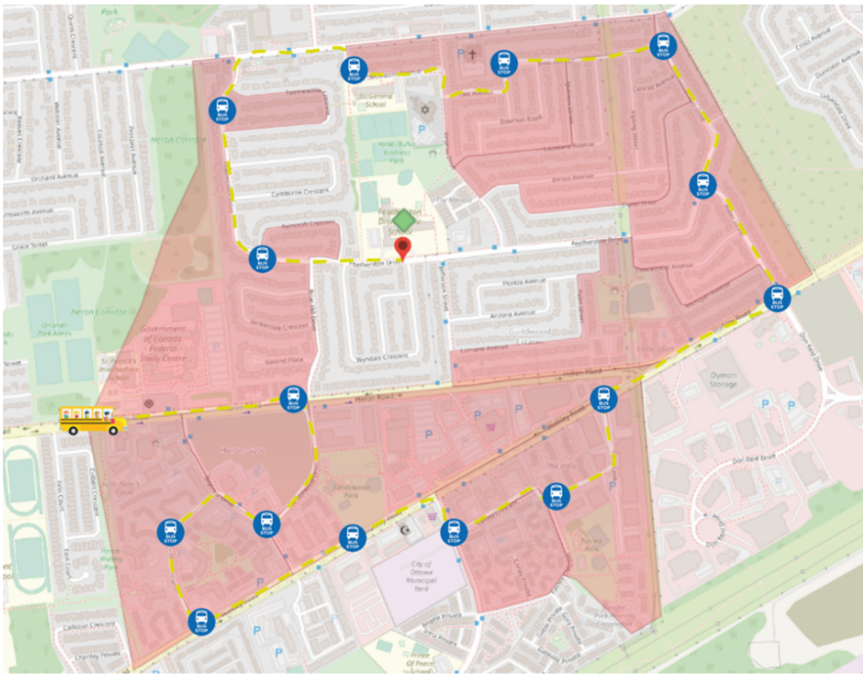

[6] "School bus", Amalgamated Transit Union (ATU), 2021
[7] Census of Population, Statistics Canada

The area characterized by the largest number of kids is S1 (159 kids); for this reason, our fleet will be composed of two buses with the capacity of 83 passengers each.

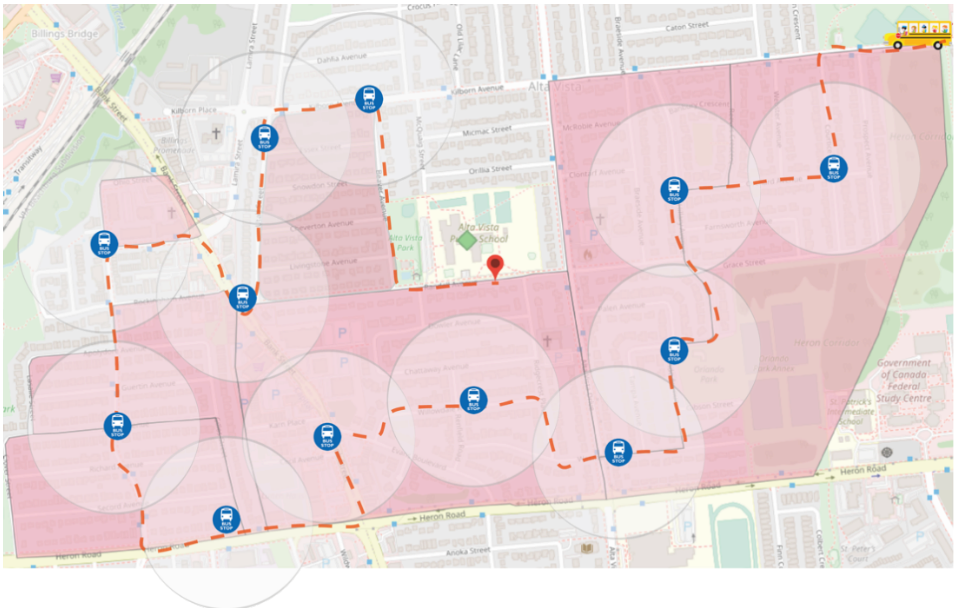
## 1.3 Route design

The order in which children are picked up and taken to school follows the schools' schedule, so the service will start from the S1 area, and will end in the S3 area.
The fleet depot is located next to the railway station.

**S1 route –** the **depot** is identified by the garage icon



**S2 route**



**S3 route**

The bus stops in each sub-area are identified by the blue icon. Their arrangement along the path was decided so that their area of competence, which corresponds to a 150m radius circle, would cover most of the sub-area, given the hypothesis that 150m is the max allowed walking distance for elementary school kids to get to the bus stop.

Moreover, an extra service will be included in the analysis. As a matter of fact, during morning break hours from school service, one bus of the fleet will be used to provide a public transportation duty for elders and vulnerable people in the district of Heron Gate.

Here is a summary table of the whole bus service:

| SCHOOL BUS SERVICE + MORNING PUBLIC SERVICE | | |
|---|---|---|
| **Morning** | Description | Distance (km) |
| S1 | | 3,8 |
| S2 | | 5,47 |
| S3 | | 4,157 |
| public service for elders and vulnerables | city center route - bus depot | 21 |
| **Afternoon** | Description | Distance (km) |
| connection 1 (no service) | bus depot- St. Hulse Public School | 1,8 |
| S1 | | 3,66 |
| connection 2 (no service) | last stop of S1 - Featherston Public school | 2,2 |
| S2 | | 5,008 |
| connection 3 (no service) | last stop of S2- Alta vista public School | 2 |
| S3 | | 4,157 |
| connection 4 (no service) | Last stop of S3- bus depot (albion road north) | 2,9 |
| Distance traveled daily (km) | 56,152 | |
| Distance traveled weekly (km) 5 days | 280,76 | |

* The public service route is simplified as being 7 kilometres long. It will be repeated 3 times in the morning.

# 2. DYNAMIC ANALYSIS

## 2.1 Vehicle technical data sheet

The vehicle chosen to operate this service is the LION D, a full-electric plug-in school bus produced by Lion Electric Co., a company specialized in designing zero-emission busses and trucks.
The vehicle, as shown in the datasheet below, is equipped with an electric motor that can provide a total of 250 kW of traction power and a battery pack of 210 kWh, which stores enough energy to sustain the vehicle's functioning for 248 km. This value of autonomy strongly varies depending on the environmental conditions during operations. This aspect will be further developed in chapter 3.
The Lion D school bus can transport up to 83 passengers, hence two busses will be required to operate the service.


LIOND

Technical Specifications

| WEIGHT & DIMENSIONS | |
|---|---|
| Vehicle length | 473 in |
| Vehicle width | 102 in |
| Vehicle height | 122 in |
| Wheelbase | Up to 252 in |
| Gross Vehicle Weight Rating (G.V.W.R) | Up to 36,200 lb |
| Capacity | Up to 83 passengers |

| ELECTRIC POWERTRAIN | |
|---|---|
| Top Speed | 60 mph |
| Maximum Power | 250 kW • 335 HP |
| Maximum Torque | 2 500 NM • 1 800 ft-lb |
| Range | 100 – 125 – 155 miles |
| Battery Capacity | 126 – 168 – 210 kWh |
| Motor & Inverter | SUMO-MD • Dana/TM4 |
| Transmission | Direct Drive<br>No Transmission |
| Charging Type | Level II (AC) – J1772 &<br>Level III (DC) – CCS-Combo |
| Level II - Charging Time | |
| 19,2 kW | 6,5 – 11 hours |
| Level III - Charging Time | |
| 24 kW<br>50 kW | 5 - 9 hours<br>2,5 - 4,25 hours |

| CHASSIS | |
|---|---|
| Front axle | Up to 13,000 lb |
| Rear axle | Up to 23,200 lb |
| Suspension<br>Standard | Rear air ride |
| Braking<br>Standard | Air disc brakes |

All-electric Type D School Bus

LION ELECTRIC

thelionelectric.com

## 2.2 Dynamic simulation on a selected part of the route

This chapter analyses the simulated dynamic interaction between the designed route and the vehicle. Here is the set of equations that defines the dynamic model.

| | |
|---|---|
| Equivalent Mass | $m_e = m(1+\beta) = m(1+0{,}22)$ |
| Starting traction force | $F_{t,start} = m_e * a_{max}$ |
| Max allowed traction force | $F_{ad_{max}} = f_{ad,max} * m * g * \frac{N_{wheelset}}{N_{wheel\_tot}}$ |
| Transition velocity | $v_{trans} = \frac{P_{max}}{F_{t,start}}$ |
| Distance at time t | $d_t = \frac{v_{t-1} + v_t}{2} * \Delta t + d_{t-1}$ |
| Velocity at time t | $v_t = a_{t-1} * \Delta t + v_{t-1}$ |
| Acceleration at time t | $a_t = \frac{1000F_t - (R_0 + R_i)}{1000m_e}$ |
| Rolling and aerodynamic resistance | $R_0 = [0{,}5 * 1{,}25 * v_t^2 * (2{,}6 * 3{,}1) * 0{,}6] + (0{,}02m * 1000g)$ |
| Grade resistance | $R_i = mg\alpha$ |
| Traction force | $F_t = \begin{cases} BRAKE = NO \rightarrow \begin{cases} if\ v_t < v_{trans} \rightarrow F_{t,start} \\ if\ v_t \geq v_{trans} \rightarrow \begin{cases} if\ v_t > v_{max} \rightarrow \frac{(R_0 + R_i)}{1000} \\ if\ v_t \leq v_{max} \rightarrow \frac{P_{max}}{v_t} \end{cases} \end{cases} \\ BRAKE = YES \rightarrow F_{t,brake} \end{cases}$ |
| Braking distance | $d_{braking} = \frac{v_t^2}{a_{braking}}$ |
| braking | $BRAKE = \begin{cases} if\ (d - d_t - d_{braking}) > 0 \rightarrow NO \\ if\ (d - d_t - d_{braking}) \leq 0 \rightarrow YES \end{cases}$ |
| Adherence force | $F_{ad} = \left[\frac{f_{ad,max}}{1 + 0{,}011 * v_t}\right] * mg * \frac{N_{wheelset}}{N_{wheel\_tot}}$ |
| Slippage | $SLIPPAGE = \begin{cases} \lvert F_t \rvert \leq F_{ad} \rightarrow NO \\ \lvert F_t \rvert > F_{ad} \rightarrow YES \end{cases}$ |
| Electric power need | $P_{el} = \begin{cases} if\ F_t \geq 0 \rightarrow \frac{F_t * v_t}{\mu_t} + P_{aux} \\ if\ F_t < 0 \rightarrow \frac{F_t * v_t * \mu_{braking} * \beta_{reg}}{100} + P_{aux} \end{cases}$ |
| Current intensity | $I = \frac{1000P_{el}}{V}$ |
| Electric energy consumption | $E_{el,t} = \frac{P_{el} * \Delta t}{3600} + E_{el,t-1}$ |

The vehicle's technical data has been extracted and adapted to the dynamic model studied in the course, as the table below shows:

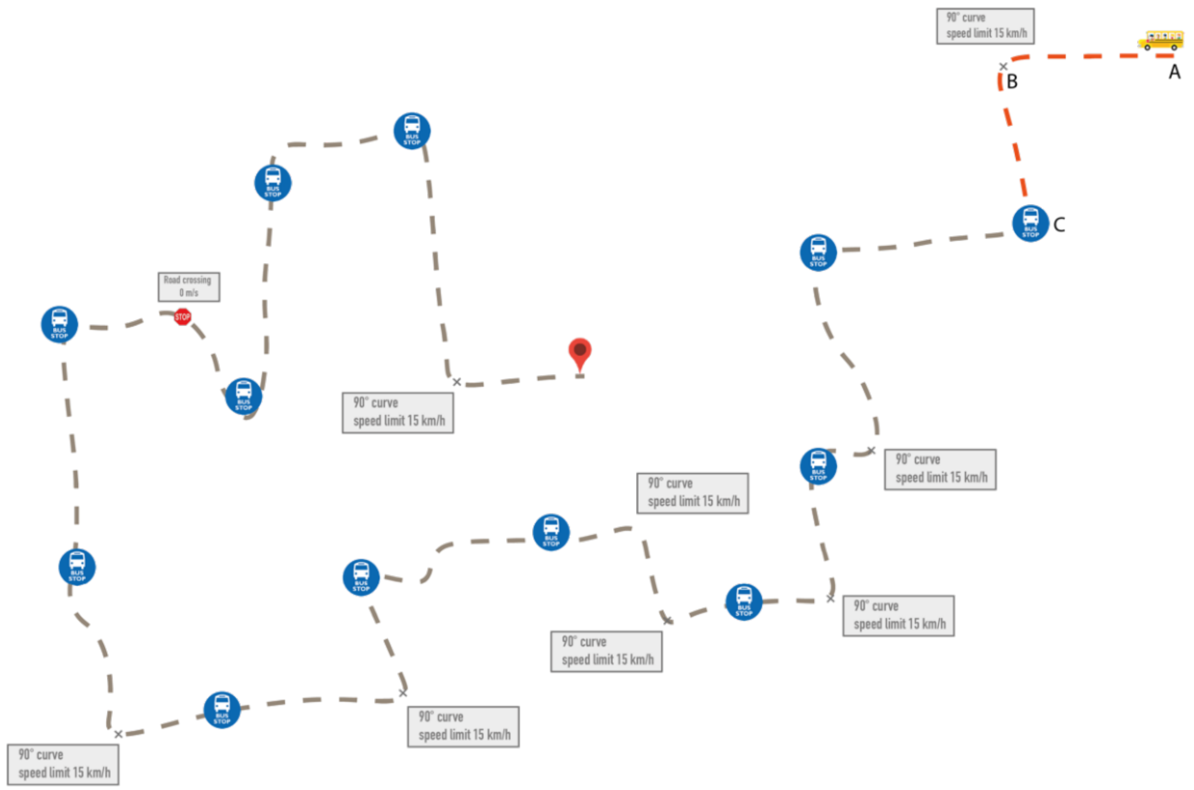
| ELECTRIC SCHOOL BUS | | |
|---|---|---|
| Pmax [kW] | **200** | maximum wheel power |
| v [km/h] | **50** | maximum allowed speed in the considered section |
| V[V] | **12** | Supply system voltage |
| Paux[kW] | **20** | Power absorbed by auiliaries |
| m [t] | **17,82** | gravitational mass |
| me [t] | **21,7404** | equivalent mass |
| a max [m/s2] | **1** | max acceleration for the comfort of passengers |
| fad max | **0,7** | (normal condition of roads) |
| Nwheelset | **4** | number of motorized wheelset |
| Nwtot | **6** | overall number of wheelsets |
| Ftstart [kN] | **21,7404** | maximum starting tractive effort |
| Fadmax [kN] | **81,57996** | maximum adhesion condition |
| vtrans (vb) [m/s] | **9,20** | base speed |
| abr [m/s2] | **1,2** | braking deceleration |
| ηt | **0,8** | traction efficiency |
| ηb | **0,8** | braking efficiency |
| β regenerative [%] | **80** | percentage of regenerative braking |
| Dtot [m] | **200,87** | lenght of the considerated path |

The auxiliary systems need 20 kW to operate. This is approximately the amount of power needed to operate the auxiliary systems during winter months, when the heating and electric systems are requiring the max amount of power.

This can be treated as the worst scenario possible, in terms of energy consumption. More info on this energy analysis can be found at chapter 3.

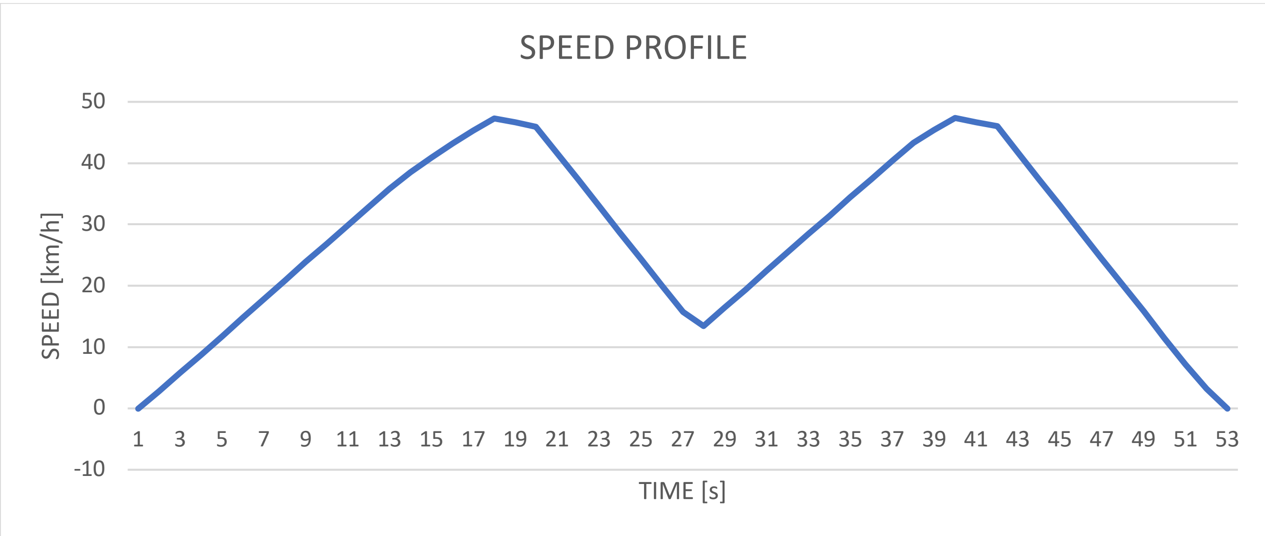
To simplify the simulation and to compute final energy and time requirements, only a small section of the path was analysed in the detail. The results of this analysis were then multiplied to extend the simulation to the whole track.

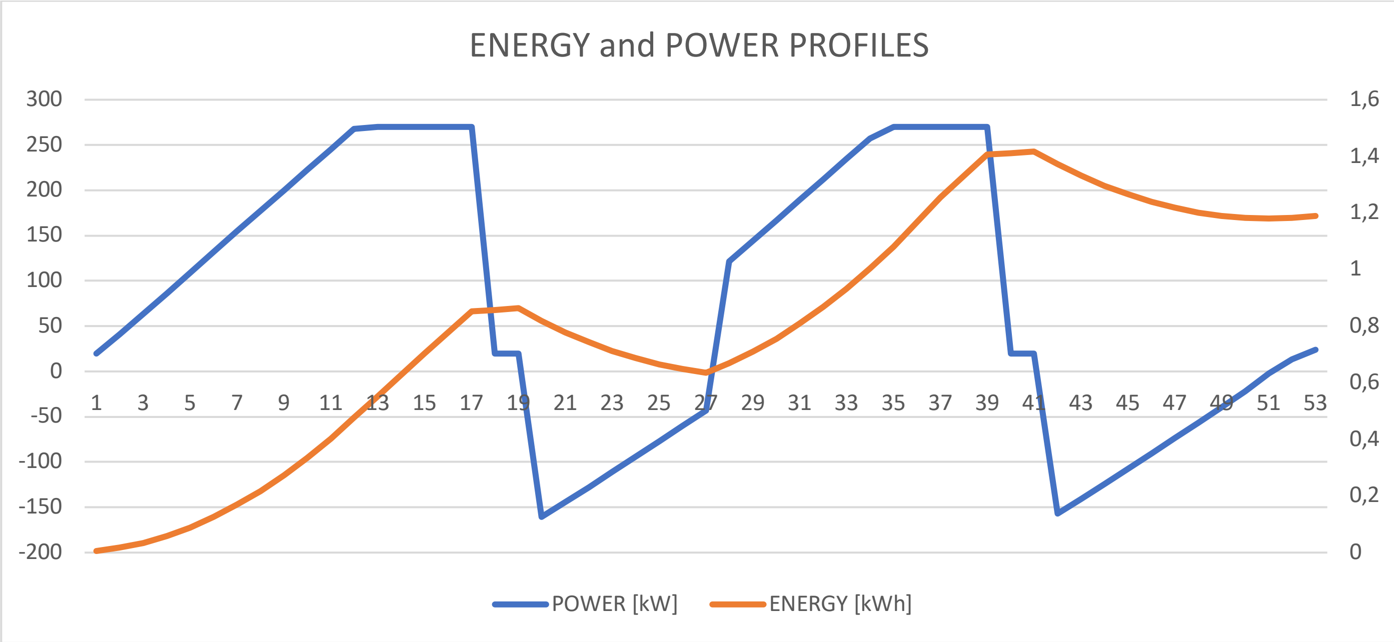
In detail, the considered section is the one composed by the two segments AB and BC (both in the S3 area). This also shows the reason for the applied simplification since the designed path is mostly made up of 90° degrees curves (that the bus has to catch at 15 km/h) and bus stops. Stop time at bus stops is 30 seconds.




Here are the results of the simulation of the AB+BC segment:

| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] | Specific Energy Consumption [kWh/km] |
|---|---|---|---|---|---|
| 53,00 | 0,88 | 406,04 | 1,19 | 99,43% | 2,92 |





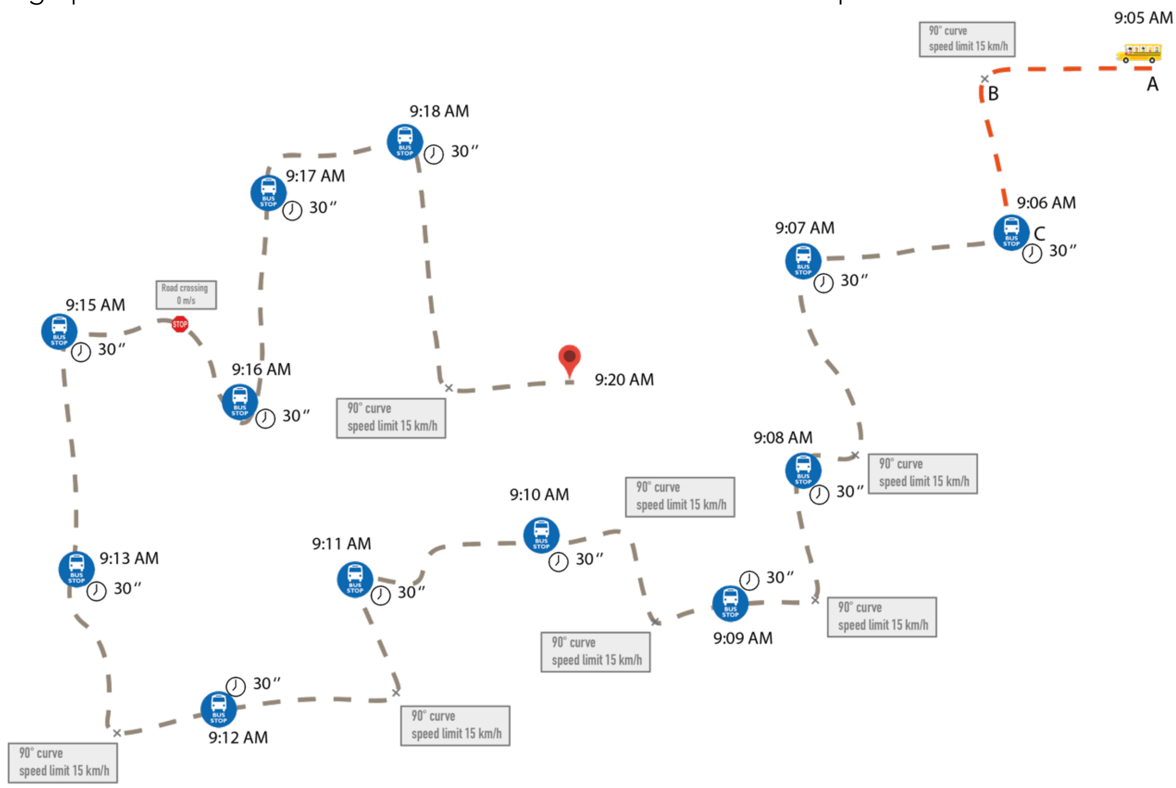

## 2.3 Service Schedule

The extraction of information on energy consumption, and consequent $CO_2$ emissions, of the bus line, starts from the definition of an hypothetical timetable of operations.
The table below shows the service schedule for a regular day of operations, which is made up of 3 tasks: the morning and afternoon school service and the city centre connection service for the elderly and vulnerable, that will be repeated three times throughout the first half of the day.

The main guideline for this timetable is that the bus has to arrive to each school at maximum 10 minutes before the start of the lectures.

| | SERVICE SCHEDULE | | | | | |
|---|---|---|---|---|---|---|
| | START LOCATION | START TIME | DESTINATION | ARRIVAL TIME | STARTING/ENDING OF LESSONS | |
| morning | Bus Depot | 08:06 | St. Hulse | 08:20 | 08:30 | am |
| | St. Hulse | 08:30 | Featherston | 08:50 | 09:00 | am |
| | Featherston | 09:05 | Alta Vista | 09:20 | 09:30 | am |
| | city center route | 10:00 | Bus depot | 12:00 | / | am |
| afternoon | Bus Depot | 14:56 | St. Hulse | 15:00 | 15:00 | pm |
| | St. Hulse | 15:10 | Featherston | 15:30 | 15:30 | pm |
| | Featherston | 15:40 | Alta Vista | 16:05 | 16:15 | pm |

Here is a graph that shows the estimated time of arrival for each bus stop of the S3 area.




These results are the starting point for calculating the state of charge (SOC) of the battery pack along the whole work shift.
There are a series of parameters that influence the capacity of the battery pack and the power consumption of the bus that need to be considered before calculating the actual recharging schedule of the fleet.
This topic will be developed in the following chapter.

# 3. ENERGETIC ANALYSIS

## 3.1 Factors affecting the performance

For the energetic consumption analysis, some considerations have been made on the autonomy of the battery pack during the year.

In fact, the performance of an electric vehicle is influenced by:
- the use of cooling and heating systems (more generally, the auxiliary systems)
- the atmospheric temperature
- the air density
- the poor functioning of the braking energy recovery system.

All these aspects combined can potentially reduce the efficiency of the battery by as much as 50%, thus halving the autonomy. Hence, a further deepening of these penalizing factors is necessary.

*The use of cooling and heating systems (Auxiliary power consumption)*

Three different values of maximum power for auxiliaries have been considered: 20 kW, 10 kW and 5 kW, for simulating the operations of the heating and cooling systems over the year, depending on the average temperature of the city of Ottawa.
Each month was then assigned a power value:

January, February, March and December - 20 kW of auxiliaries (Worst case)
April, October and November - 10 kW of auxiliaries (Average case)
May, June and September – 5 kW of auxiliaries (Optimal case)

*Atmospheric temperature*

In addition, the different behavior of the battery as a function of temperature was also considered. In fact, the standard range of an electric vehicle is calculated on a level track and in the best weather conditions, therefore with an external temperature of 15-20 ° C and clear sky.
When these conditions are not met, the range of the vehicle tends to decrease.
On average, in winter, the autonomy of an electric car drops up to 15% less than its capacity in optimal conditions, while in summer the loss is limited to 5-10%.
The percentages of loss in autonomy are shown in the table below.

*Air density*

The increased resistance due to air density has been neglected since the max speed reached rather low.

*The limited functioning of the braking energy recovery system*

The reduction in the regenerative braking system performance was also included in the analysis under the heading "loss of range". In fact, considering the maximum value of autonomy loss of the vehicle (equal to -

15% in January, February, March and December and -10% in April, October and November) per km, a lower percentage of regenerated energy is also taken into account.

## 3.2 Energetic results

In order to estimate the energy consumption of the service during the whole school year, the results of the previous analysis on a 400-metre-long route in the study area (S3) were used. As can be seen, depending on the power of the auxiliaries considered (5,10,20 kW), the specific energy consumption [kWh/km] is different.
These results were then applied to the whole route in order to know the energy consumption of the school buses per day and per week.

Finally, a table was constructed to visualize the organization of recharging during the week. It can be seen that the energy aspects and the recharging demand change when also considering the loss of range (-15% and -10%) mentioned above. In particular, in the colder months there is a daily recharge for both school buses.

## Paux=20 kW - WORST CASE (January, February, March and December)

| AB+BC (S3) | | | | |
|---|---|---|---|---|
| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] |
| 53 | 0,883333 | 401,55 | 1,17 | 99,44% |
| | | | | |
| STUDY AREA (S3) | | | | |
| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] |
| 542,61 | 9,04 | 4111,04 | 11,98 | 94,30% |
| | | | | |
| FULL ROUTE (Morning + Afternoon + public service) | | | | |
| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] |
| 7411,41 | 123,52 | 56152,00 | 163,6136725 | 22,09% |
| | | | SPECIFIC CONSUMPTION [kWh/km] | 2,914 |

| | distance [m] | time [s] | time [min] | Energy consumption [kWh] | Specific energy consumption [kWh/km] |
|---|---|---|---|---|---|
| AB+BC | 406,0 | 53 | 0,88 | 1,19 | 2,93 |
| S3 no stop considered | 4157,0 | 542,6 | 9,04 | 12,17 | 2,93 |
| **S3** complete (12 stop of 30'') | 4157,0 | 902,6 | 15,04 | 12,17 | 2,93 |
| city center route (3 times) | 21000,0 | 2741,1 | 45,68 | 61,48 | 2,93 |
| **S2** complete (15 stops) | 5470,0 | 1164,0 | 19,40 | 16,01 | 2,93 |
| **S1** complete (12 stops) | 3800,0 | 856,0 | 14,27 | 11,12 | 2,93 |
| | | | | | |
| connection 1 | 1800,0 | 234,9512125 | 3,92 | 5,27 | 2,93 |
| connection 2 | 2200,0 | 287,1625931 | 4,79 | 6,45 | 2,93 |
| connection 3 | 2000,0 | 261,0569028 | 4,35 | 5,86 | 2,93 |
| connection 4 | 2900,0 | 378,5325091 | 6,31 | 8,50 | 2,93 |

| | | | |
|---|---|---|---|
| (A)consumption for the 1° bus | CONSUMPTION PER DAY [kWh/day] | 166,17 | full service: school + public |
| | CONSUMPTION PER WEEK [kWh/week] | 830,84 | |
| (B)consumption for the 2° bus | CONSUMPTION PER DAY [kWh/day] | 104,69 | half service: school |
| | CONSUMPTION PER WEEK [kWh/week] | 523,45 | |
| TOTAL FLEET CONSUMPTION | CONSUMPTION PER DAY [kWh/day] | 270,86 | |
| | CONSUMPTION PER WEEK [kWh/week] | 1.354,29 | |

| WORST CASE CONSUMPTION (Paux 20 kW) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **battery charge (morning) [kWh]** | **SERVICE TYPE** | **battery charge (evening) [kWh]** | **state of charge** | **Recharging** |
| week | Monday | BUS A | 210,00 | full | 43,83 | 21% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 105,31 | 50% | RECHARGING NOT NEEDED |
| | Tuesday | BUS A | 210,00 | full | 43,83 | 21% | RECHARGING NEEDED |
| | | BUS B | 105,31 | half service | 0,62 | 1% | RECHARGING NEEDED |
| | Wednesday | BUS A | 210,00 | full | 43,83 | 21% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 105,31 | 50% | RECHARGING NOT NEEDED |
| | Thursday | BUS A | 210,00 | full | 43,83 | 21% | RECHARGING NEEDED |
| | | BUS B | 105,31 | half service | 0,62 | 1% | RECHARGING NEEDED |
| | Friday | BUS A | 210,00 | full | 43,83 | 21% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 105,31 | 50% | RECHARGING NOT NEEDED |

| WORST CASE CONSUMPTION (Paux 20 kW and 15% autonomy loss) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **battery charge (morning) [kWh]** | **SERVICE TYPE** | **battery charge (evening) [kWh]** | **state of charge** | **Recharging** |
| week | Monday | BUS A | 210,00 | full | 18,91 | 9% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 89,61 | 43% | RECHARGING NEEDED |
| | Tuesday | BUS A | 210,00 | full | 18,91 | 9% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 89,61 | 43% | RECHARGING NEEDED |
| | Wednesday | BUS A | 210,00 | full | 18,91 | 9% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 89,61 | 43% | RECHARGING NEEDED |
| | Thursday | BUS A | 210,00 | full | 18,91 | 9% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 89,61 | 43% | RECHARGING NEEDED |
| | Friday | BUS A | 210,00 | full | 18,91 | 9% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 89,61 | 43% | RECHARGING NEEDED |

## Paux=10 kW- AVERAGE CASE (April, October and November)

| AB+BC (S3) | | | | |
|---|---|---|---|---|
| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] |
| 53 | 0,88333333 | 406,04 | 1,04 | 99,50% |
| STUDY AREA (S3) | | | | |
| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] |
| 542,61 | 9,04 | 4157,01 | 10,66 | 94,92% |
| FULL ROUTE (Morning + Afternoon + public service) | | | | |
| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] |
| 7329,43 | 122,16 | 56152,00 | 143,9611393 | 31,45% |
| | | | SPECIFIC CONSUMPTION [kWh/km] | 2,56 |

| | distance [m] | time [s] | time [min] | Energy consumption [kWh] | Specific energy consumption [kWh/km] |
|---|---|---|---|---|---|
| AB+BC | 406,04 | 53,00 | 0,88 | 1,04 | 2,56 |
| S3 no stop considered | 4157,01 | 542,61 | 9,04 | 10,66 | 2,56 |
| **S3** complete (12 stop of 30'') | 4157,01 | 902,61 | 15,04 | 10,66 | 2,56 |
| city center route (3 times) | 21000,00 | 2741,10 | 45,68 | 53,84 | 2,56 |
| **S2** complete (15 stops) | 5470,00 | 1163,99 | 19,40 | 14,02 | 2,56 |
| **S1** complete (12 stops) | 3800,00 | 856,01 | 14,27 | 9,74 | 2,56 |

| | | | | | |
|---|---|---|---|---|---|
| connection 1 | 1800,00 | 234,95 | 3,92 | 4,61 | 2,56 |
| connection 2 | 2200,00 | 287,16 | 4,79 | 5,63 | 2,56 |
| connection 3 | 2000,00 | 261,06 | 4,35 | 5,12 | 2,56 |
| connection 4 | 2900,00 | 378,53 | 6,31 | 7,42 | 2,56 |

| | | | |
|---|---|---|---|
| (A)consumption for the 1° bus | CONSUMPTION PER DAY [kWh/day] | 145,47 | full service: school + public |
| | CONSUMPTION PER WEEK [kWh/week] | 727,36 | |
| (B)consumption for the 2° bus | CONSUMPTION PER DAY [kWh/day] | 91,63 | half service: school |
| | CONSUMPTION PER WEEK [kWh/week] | 458,16 | |
| TOTAL FLEET CONSUMPTION | CONSUMPTION PER DAY [kWh/day] | 237,10 | |
| | CONSUMPTION PER WEEK [kWh/week] | 1.185,51 | |

MEDIUM CASE CONSUMPTION (Paux 10 kW)

| | | | battery charge (PREservice) [kWh] | SERVICE TYPE | battery charge (POST service) [kWh] | state of charge | Recharging |
|---|---|---|---|---|---|---|---|
| week | Monday | BUS A | 210,00 | full | 64,53 | 31% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 118,37 | 56% | RECHARGING NOT NEEDED |
| | Tuesday | BUS A | 210,00 | full | 64,53 | 31% | RECHARGING NEEDED |
| | | BUS B | 118,37 | half service | 26,74 | 13% | RECHARGING NEEDED |
| | Wednesday | BUS A | 210,00 | full | 64,53 | 31% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 118,37 | 56% | RECHARGING NOT NEEDED |
| | Thursday | BUS A | 210,00 | full | 64,53 | 31% | RECHARGING NEEDED |
| | | BUS B | 118,37 | half service | 26,74 | 13% | RECHARGING NEEDED |
| | Friday | BUS A | 210,00 | full | 64,53 | 31% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 118,37 | 56% | RECHARGING NOT NEEDED |

MEDIUM CASE CONSUMPTION (Paux 10 kW and 10% autonomy loss)

| | | | battery charge (PREservice) [kWh] | SERVICE TYPE | battery charge (POST service) [kWh] | state of charge | Recharging |
|---|---|---|---|---|---|---|---|
| week | Monday | BUS A | 210,00 | full | 49,98 | 24% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 109,21 | 52% | RECHARGING NOT NEEDED |
| | Tuesday | BUS A | 210,00 | full | 49,98 | 24% | RECHARGING NEEDED |
| | | BUS B | 109,21 | half service | 8,41 | 4% | RECHARGING NEEDED |
| | Wednesday | BUS A | 210,00 | full | 49,98 | 24% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 109,21 | 52% | RECHARGING NOT NEEDED |
| | Thursday | BUS A | 210,00 | full | 49,98 | 24% | RECHARGING NEEDED |
| | | BUS B | 109,21 | half service | 8,41 | 4% | RECHARGING NEEDED |
| | Friday | BUS A | 210,00 | full | 49,98 | 24% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half service | 109,21 | 52% | RECHARGING NOT NEEDED |

## Paux=5 kW- OPTIMAL CASE (May, June and September)

| AB+BC (S3) | | | | |
|---|---|---|---|---|
| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] |
| 53 | 0,883333 | 406,04 | 0,97 | 99,54% |
| | | | | |
| STUDY AREA | | | | |
| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] |
| 542,61 | 9,04 | 4157,01 | 9,87 | 95,30% |
| | | | | |
| FULL ROUTE (Morning + Afternoon + public service) | | | | |
| t [s] | t[min] | d [m] | Eel[kWh] | SOC [%] |
| 7329,43 | 122,16 | 56152,00 | 133,3703194 | 36,49% |
| | | | | |
| | | | SPECIFIC CONSUMPTION [kWh/km] | 2,38 |

| | distance [m] | time [s] | time [min] | Energy consumption [kWh] | Specific energy consumption [kWh/km] |
|---|---|---|---|---|---|
| AB+BC | 406,04 | 53,00 | 0,88 | 0,97 | 2,38 |
| S3 no stop considered | 4157,01 | 542,61 | 9,04 | 9,91 | 2,38 |
| **S3** complete (12 stop of 30'') | 4157,01 | 902,61 | 15,04 | 9,91 | 2,38 |
| city center route (3 times) | 21000,00 | 2741,10 | 45,68 | 50,06 | 2,38 |
| **S2** complete (15 stops) | 5470,00 | 1163,99 | 19,40 | 13,04 | 2,38 |
| **S1** complete (12 stops) | 3800,00 | 856,01 | 14,27 | 9,06 | 2,38 |
| | | | | | |
| connection 1 | 1800,00 | 234,95 | 3,92 | 4,28 | 2,38 |
| connection 2 | 2200,00 | 287,16 | 4,79 | 5,24 | 2,38 |
| connection 3 | 2000,00 | 261,06 | 4,35 | 4,76 | 2,38 |
| connection 4 | 2900,00 | 378,53 | 6,31 | 6,90 | 2,38 |

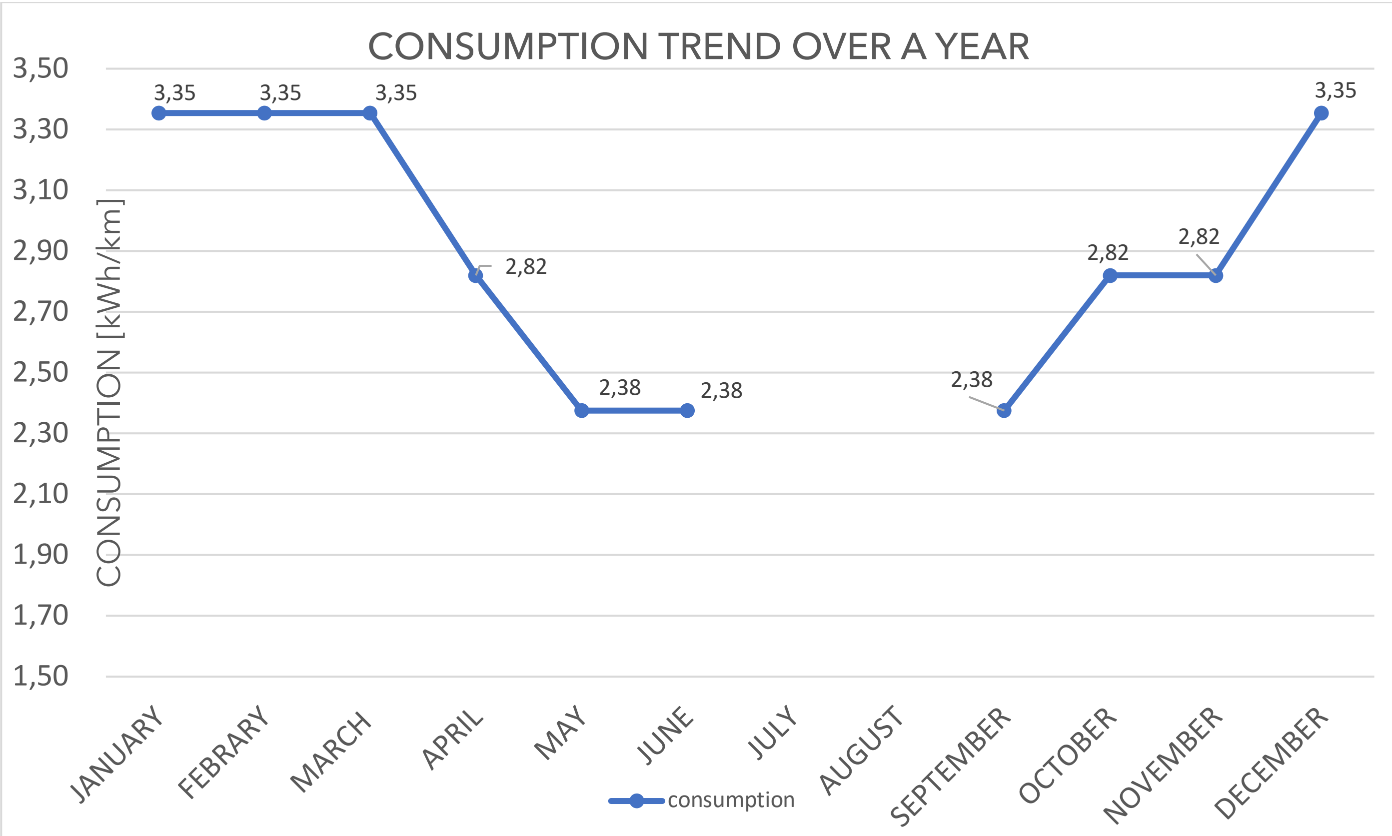
| | | | |
|---|---|---|---|
| (A)consumption for the 1° bus | CONSUMPTION PER DAY [kWh/day] | 135,27 | full service: school + public |
| | CONSUMPTION PER WEEK [kWh/week] | 676,33 | |
| (B)consumption for the 2° bus | CONSUMPTION PER DAY [kWh/day] | 85,20 | half service: school |
| | CONSUMPTION PER WEEK [kWh/week] | 426,01 | |
| TOTAL FLEET CONSUMPTION | CONSUMPTION PER DAY [kWh/day] | 220,47 | |
| | CONSUMPTION PER WEEK [kWh/week] | 1.102,34 | |

| BEST CASE CONSUMPTION (Paux 5 kW) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **battery charge (PREservice) [kWh]** | **SERVICE TYPE** | **battery charge (POST service) [kWh]** | **state of charge** | **Recharging** |
| **week** | Monday | BUS A | 210,00 | full | 74,73 | 36% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half | 124,80 | 59% | RECHARGING NOT NEEDED |
| | Tuesday | BUS A | 210,00 | full | 74,73 | 36% | RECHARGING NEEDED |
| | | BUS B | 124,80 | half | 39,60 | 19% | RECHARGING NEEDED |
| | Wednesday | BUS A | 210,00 | full | 74,73 | 36% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half | 124,80 | 59% | RECHARGING NOT NEEDED |
| | Thursday | BUS A | 210,00 | full | 74,73 | 36% | RECHARGING NEEDED |
| | | BUS B | 124,80 | half | 39,60 | 19% | RECHARGING NEEDED |
| | Friday | BUS A | 210,00 | full | 74,73 | 36% | RECHARGING NEEDED |
| | | BUS B | 210,00 | half | 124,80 | 59% | RECHARGING NOT NEEDED |

The following table and graph summarize the results of our analysis. As expected, it can be noticed that the consumption trend [kWh/km] variates throughout the year and also the total energy demand to perform the service. This means that the recharging schedule has to be rearranged during the year according to the vehicle performances.

| | YEAR | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | JANUARY | FEBRARY | MARCH | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER | OCTOBER | NOVEMBER | DECEMBER |
| AVERAGE TEMPERATURE [°C] | - 9,30 | - 7,80 | - 2,40 | 5,50 | 13,12 | 18,30 | | | 16,60 | 9,20 | 2,40 | - 4,60 |
| CLASS OF FUNCTIONING | WORST CASE | | | AVERAGE | OPTIMAL | | | | OPTIMAL | AVERAGE | | WORST CASE |
| AUXILIARIES POWER [kW] | 20,00 | 20,00 | 20,00 | 10,00 | 5,00 | 5,00 | | | 5,00 | 10,00 | 10,00 | 20,00 |
| LOSS IN AUTONOMY due to T (°C) and regenerative drops [%] | - 0,15 | - 0,15 | - 0,15 | - 0,10 | - | - | | | - | - 0,10 | - 0,10 | - 0,15 |
| STANDARD CONSUMPTION [KWh/km] | 2,91 | 2,91 | 2,91 | 2,59 | 2,40 | 2,40 | | | 2,40 | 2,59 | 2,59 | 2,91 |
| EFFECTIVE CONSUMPTION [KWh/km] | 3,35 | 3,35 | 3,35 | 2,85 | 2,40 | 2,40 | | | 2,40 | 2,85 | 2,85 | 3,35 |
| TOTAL CONSUMPTION FOR THE FLEET [kWh] | 6.822,55 | 6.822,55 | 6.822,55 | 5.806,27 | 4.890,11 | 4.890,11 | - | - | 4.890,11 | 5.806,27 | 5.806,27 | 6.822,55 |
| TOTAL CONSUMPTION FOR THE FLEET [kWh] | 59.379,37 | | | | | | | | | | | |
| BUS A | 4.195,87 | 4.195,87 | 4.195,87 | 3.570,86 | 3.007,42 | 3.007,42 | | | 3.007,42 | 3.570,86 | 3.570,86 | 4.195,87 |
| | 36.518,34 | | | | | | | | | | | |
| BUS B | 2.626,68 | 2.626,68 | 2.626,68 | 2.235,41 | 1.882,69 | 1.882,69 | | | 1.882,69 | 2.235,41 | 2.235,41 | 2.626,68 |
| | 22.861,03 | | | | | | | | | | | |

*For comparisons it is assumed that the service in July and August is not carried out as the schools are closed



# 4. RECHARGING INFRASTRUCTURE

## 4.1 Charging mode

In overnight charging systems, the buses are recharged only once they arrive at the depot and do not require the construction of infrastructure along the line. They therefore have the advantage of traveling without the need for intermediate stops for recharging, but once the energy runs out, they must return to the base.

The 210kWh battery can be recharged in the depot with the installation of Level III DC charging station. using Although the bus also supports two other charging modes (a J1772 plug at 19.2 kW AC, and a CCS-Combo at 50kW DC), a CCS-Combo plug with 24kW of output power allows to achieve a compromise between charging time and low battery maintenance[8].

The overnight charging is made possible using a fast DC charging station, with a CCS-Combo connector (cable length 4 m), that is able to recharge two buses at once.[9]

## 4.2 Smart grid implementation and infrastructure localization

In the area designated to be suitable for the construction of the depot, a 115kV 60 Hz high-voltage transmission power line passes by[10], as well as a low voltage distribution line and its relative substation transformer.

---

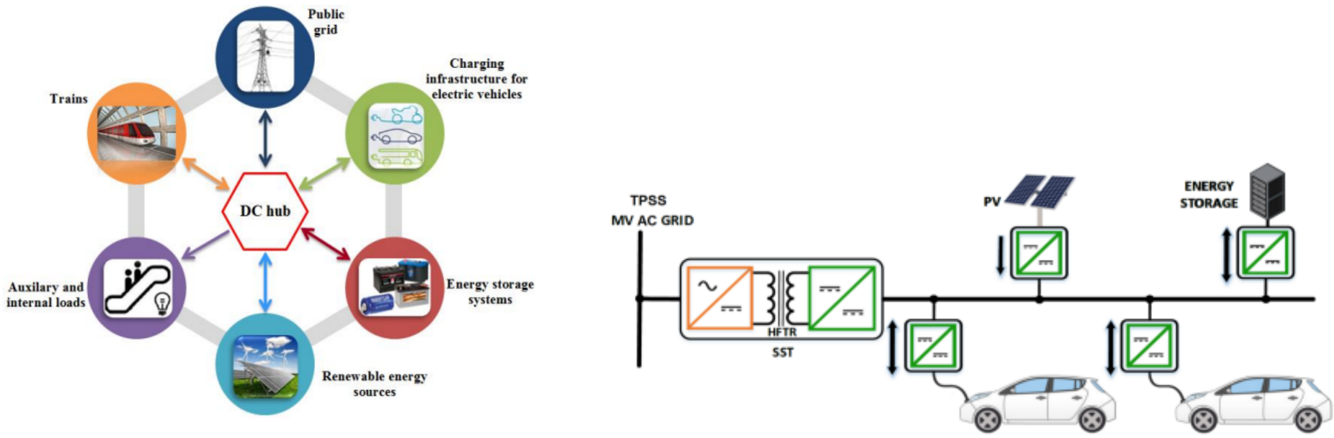
[8] The Lion Electric, Lion D

[9] E-station, Fast DC Colonna multi-standard 24kW

[10] Map of Ontario's Electricity System, Independent Electricity System Operator, 2021


This configuration of the power grid would be ideal for the construction of a microgrid that would allow for a more efficient use of the energy resources. In particular, a low voltage DC microgrid would be the best configuration for the situation, giving the possibility for:

- Constructing a Level 3 (up to 24kV) EV charging infrastructure to be used by the bus and other EVs.
- Connecting a low-power wind farm that would supply the hub with completely clean energy
- Storing energy for local demand peak shaving




Approximative schema of the AC grid/DC hub integration

## 4.3 Wind plant design

Two solutions were considered when choosing the type of wind farm.
First, a micro-turbine power plant was dimensioned, but it resulted to be too large (251 units) to be integrated into the city's infrastructure. Then a traditional wind power plant was chosen, which, by two turbines, is able to supply all the energy and power the system needs and also to generate a surplus that will then be sold to the grid.

| microWIND PLANT | | |
|---|---|---|
| 1 wind turbine | | |
| Area | 3,30 | m2 |
| density | 1,23 | kg/m3 |
| wind speed | 5,50 | m/s |
| wind power | 337,66 | W |
| rotor power coefficient | 0,40 | |
| max power extracted | 135,06 | W |

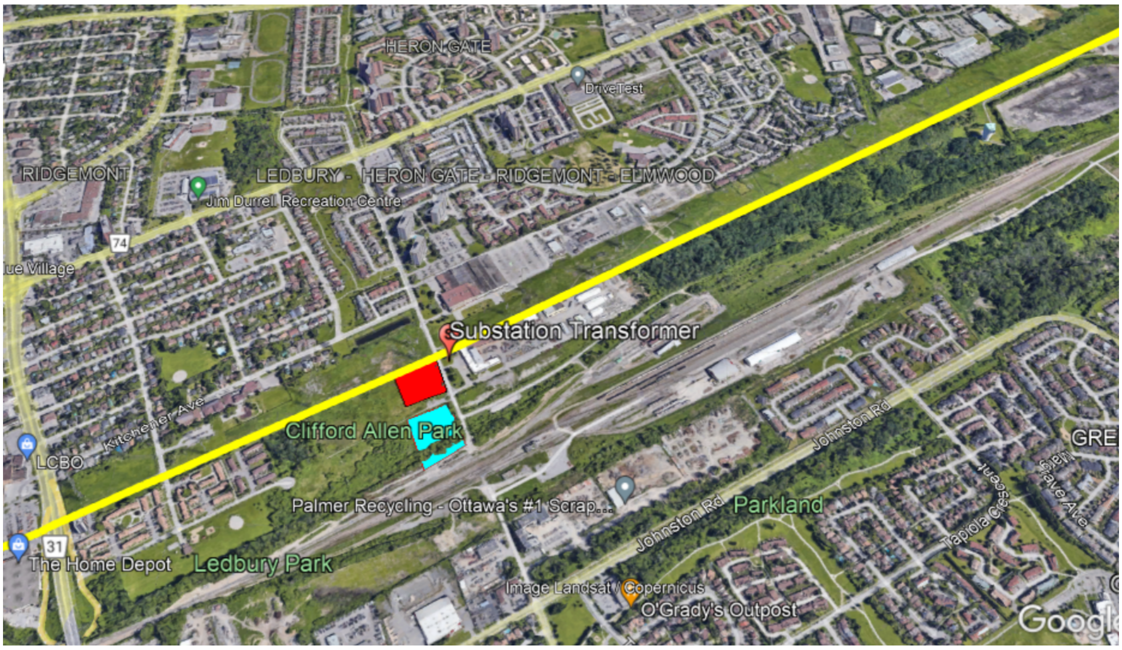
| | | |
|---|---|---|
| daily hour | 8,00 | h |
| daily energy extracted | 1,08 | kWh/day |
| daily energy demand | 270,86 | kWh/day |
| n° of turbines | 251,00 | units |

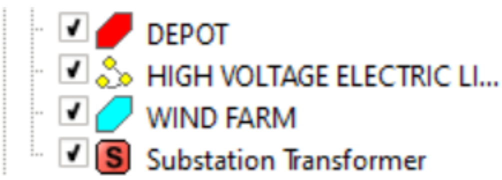
| WIND PLANT | | |
|---|---|---|
| 1 wind turbine | | |
| Area | 1.256,00 | m2 |
| density | 1,23 | kg/m3 |
| wind speed | 5,50 | m/s |
| wind power | 128.514,71 | W |
| rotor power coefficient | 0,40 | |
| max power extracted | 51,41 | kW |

| | | |
|---|---|---|
| daily hour | 8,00 | h |
| daily energy extracted | 411,25 | kWh/day |
| daily energy demand | 295,26 | kWh/day |
| n° of turbines | 2,00 | units |
| el energy sellable | 527,24 | kWh/day |

*daily energy demand value is the mean calculated over the whole service period

Overview of the Depot construction site:



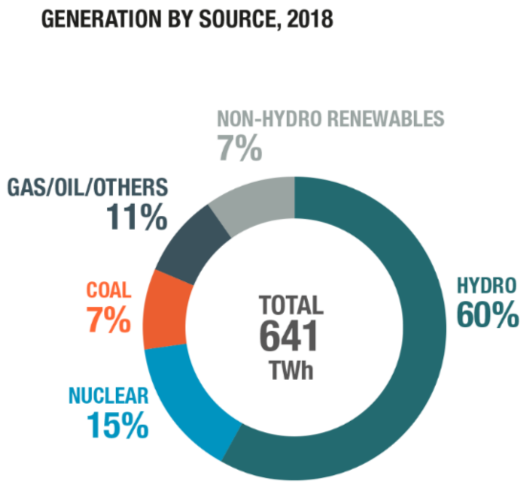

If the depot were to be set up in this location, the DC hub would be in proximity of a reasonable amount of industrial and commercial building, that would utilize the energy stored and produced. On the other hand, residential building are far enough to guarantee the minimum 550m distance to wind turbines. Provincial laws set this threshold to limit the amount of noise preceived by physical receptors to 40 dB. [11]

[11] "Technical Guide to Renewable Energy Approvals" (Chapter 3), Government of Ontario, Updated: April 30, 2019

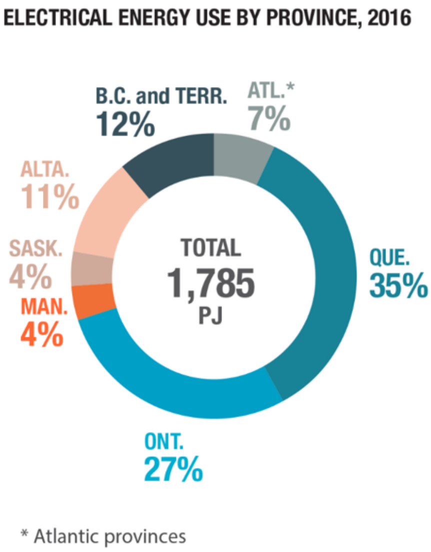
# 5. ENVIRONMENTAL EVALUATION: $CO_2$ EMISSIONS FROM POWER GENERATION

## 5.1 Ontario Energy Mix

After having calculated the energy required for running the service, the focus is moved to the environmental analysis related to the energy production methods.
Looking at Canada electricity production, it can be noticed that 67% of Canada's electricity comes from renewable sources and 82 % from negligible GHG emitting sources; moreover, Canada is the world's third largest producer of hydroelectricity.

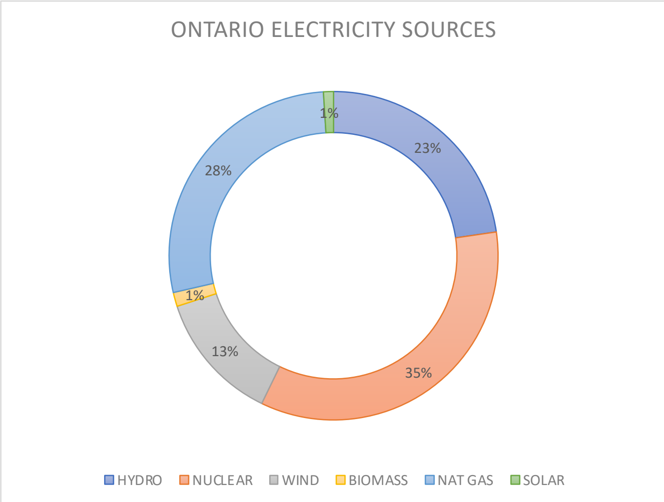



Electricity energy use varies greatly from province to province. Provinces with plentiful and cheap electricity from large scale electricity projects like British Columbia, Quebec and Ontario, tend to use more electricity per person than those provinces who rely on other energy means to do things like heat their homes and water.



Total electricity use in Canada in 2016 was 1,812 PJoule. Québec has the largest share of consumption at 35%, followed by Ontario at 27%, British Columbia and the Territories at 12%, the Atlantic provinces at 7%, Saskatchewan and Manitoba both at 4%.

Focusing on the State of Ontario, electricity production is divided in the following way:




## 5.2 Life Cycle Assessment on Ontario electricity sources[12]

For each of these energy production technologies, *GreenHouseGases* emissions rates have been calculated. These emissions are expressed by a parameter called Equivalent Carbon Dioxide, which is a unit of measurement that expresses the impact of each greenhouse gas, emitted by a certain activity, in terms of the amount of $CO_2$.
The carbon dioxide equivalent was then weighted on the electrical kilowatt-hours produced in the individual processes to obtain a homogeneous analysis ($gCO2_{eq}/kWh_{el}$).

This analysis is only focused on the Operations&Maintenance stages of each technology; therefore it does not include the full life cycle. This choice is explained by the fact that in the first scenario of the project the energy required for running the service would be bought from the grid and no novel plant would be built.
Only the wind production will be analyzed over the whole life cycle since the projects includes a wind farm proposal for generating the electricity needed to recharge the school buses.
The energy produced and not used for the service will be sold on the grid generating additional revenues that will be included in the cost analysis.
Since a plant from scratch would be built, the appropriate emissions analysis should include all stages.

- *NUCLEAR*

In Ontario, nuclear power is produced using Canada Deuterium Uranium (CANDU) Reactors which use unenriched uranium as fuel and deuterium oxide (or heavy water) as a coolant and moderator. There are currently 18 CANDU reactors operating in 3 facilities in Ontario.

[12] "Greenhouse Gas Emissions associated with various methods of power generation in Ontario", Ontario power generation INC., October 2016

The combined installed capacity for these reactors for 2016 is 11,295 MW, with a projected decrease in capacity to 9,852 MW by 2032.

**Nuclear power plants in Canada, location and capacity, 2016**

| Facility | Province | Total capacity (MW) | Units |
|---|---|---|---|
| Darlington | Ontario | 3,512 | 4 |
| Bruce A | Ontario | 3,220 | 4 |
| Bruce B | Ontario | 3,390 | 4 |
| Pickering A | Ontario | 1,084 | 2 |
| Pickering B | Ontario | 2,160 | 4 |
| Point Lepreau | New Brunswick | 705 | 1 |

While the generation of electricity from nuclear resources does not directly emit GHGs, emissions occur during various stages of the overall lifecycle. The nuclear power lifecycle generally consists of five stages:

| 5 STAGES FOR NUCLEAR POWER LIFE CYCLE |
|---|
| 1) The front-end consisting of the mining, milling, conversion and enrichment of uranium |
| 2) The construction of the facility including generators, turbines, and cooling towers |
| 3) The operation phase in which electricity is produced and energy is required for facility maintenance and fuels for backup generators |
| 4) The back-end consisting of fuel processing, interim storage and final disposal and management of nuclear waste |
| 5) The decommissioning and dismantling of the facility and the reclamation of the mine sites |

The current analysis focuses exclusively on the GHG emissions associated with the operations phase.

Three plants are considered: Pickering, Darlington and Bruce station.
GHG emissions associated with energy production at the Pickering and Darlington Stations are associated with the burning of diesel fuel for standby generator (SG) and emergency power generator (EPG) testing. Emissions are calculated based on annual fuel deliveries which vary annually.

Based on data from 2011 to 2015, the five-year average GHG emissions for the Pickering and Darlington Stations were 7,501 and 3,050 tons of $CO_2e$, respectively.

| Energy Generation and GHG Emission Rates associated with Operation and Maintenance of Nuclear Facilities in Ontario | | | |
|---|---|---|---|
| *Facility* | *GHG Emissions (tonnes $CO_2e$)* | *Electricity Generation (GWh)* | *Emissions per Energy Production (g $CO_2e$/kWh)* |
| **Pickering**[a] | | | |
| 2011 | 5,657 | 19,675 | 0.29 |
| 2012 | 9,300 | 20,735 | 0.45 |
| 2013 | 4,279 | 19,642 | 0.22 |
| 2014 | 4,351 | 20,045 | 0.22 |
| 2015 | 13,919 | 21,231 | 0.66 |
| Average | 7,501 | 20,266 | **0.37** |
| **Darlington**[a] | | | |
| 2011 | 4,007 | 28,951 | 0.14 |
| 2012 | 1,525 | 28,318 | 0.054 |
| 2013 | 1,224 | 25,051 | 0.049 |
| 2014 | 4,806 | 27,960 | 0.17 |
| 2015 | 3,688 | 23,293 | 0.16 |
| Average | 3,050 | 26,715 | **0.11** |
| **Bruce**[b] | | | |
| 2010 | 68,464 | - | - |
| 2011 | 46,489 | - | - |
| 2012 | 32,311 | - | - |
| 2013 | 16,215 | - | - |
| 2014 | 3,681 | 46,895[c] | **0.078** |

\- Emissions per unit of energy were not considered for these years since they are not considered to be representative of current or future conditions.

[a] Emission and energy generation data for the Pickering and Darlington Stations was provided by OPG.

[b] Emission data for the Bruce Station was taken from the Regulation 452/09 database

Due to the significant reductions in emissions reported for the Bruce Station following plant improvements, emission rates were based on data for 2014 as they are considered to be representative of current and future conditions.

For 2014, IESO reported that nuclear facilities provided 94,900 GWh to the Ontario grid. Using the production data for the Pickering (20,045 GWh) and Darlington (27,960 GWh) stations, the estimated production for the Bruce Station was 46,895 GWh.

A single emission rate for nuclear energy production was derived by weighting emission rates for the individual Stations by their contribution to total nuclear energy production in 2014: 49.4% Bruce; 29.5% Darlington; and 21.1% Pickering.

$$\text{GHG emissions} = 0.494 \times 0.078 \text{ g } CO_2e/\text{kWh} + 0.295 \times 0.11 \text{ g } CO_2e/\text{kWh} + 0.211 \times 0.37 \text{ g } CO_2e/\text{kWh} = 0.15 \text{ g } CO_2e/\text{kWh}$$

Although the mining, milling and refining of uranium is included within the operation stage of some LCAs, the extraction and processing of fuels or materials for any of the power generating methods don't have been considered to allow for a consistent comparison across each resource.

Moreover, some LCAs have reported that the energy-intensive production of heavy water as a coolant and moderator would result in significant emissions for CANDU reactors.

The current study does not include emissions associated with the production of heavy water, but rather assumes that production is carbon neutral as it was generated utilizing nuclear-generated steam rather than relying on fossil fuels as a heat source and upgrading occurs at each station.

- *HYDROELECTRIC*

Hydroelectric facilities in Ontario include both reservoir systems as well as numerous run-of- river stations.

Due to the capacity of reservoirs to store water, these stations generally have a larger electricity generating capacity than
run-of-river stations.

Unlike wind and solar, hydro represents a non-intermittent source of renewable energy.

The contribution of hydro to the province's energy production was 22% in 2013 and is projected to remain about 25% through to 2032. Hydro has a nameplate capacity of approximately 9000 MW, contributing 40 TWh to Ontario's electricity grid.

GHG emissions over the life cycle of hydroelectric facilities are primarily associated with three stages:

| 3 | STAGES FOR HYDRO POWER LIFE CYCLE |
|---|---|
| 1) | The front-end consisting of the construction of the facility |
| 2) | the decomposition of organic material as lands are flooded for reservoirs |
| 3) | The decommissioning of the facility and the release of GHGs associated with the remaining biomass |

The facility construction phase includes the dam construction and related equipment.
The GHGs emissions derived by this step are expected to be between 1 to 10 g $CO_2$e/kWh.

However, one of the most significant sources of pollutants are the GHGs created by the decomposition organic materials diffuse through the water column within the reservoir and subsequently released to the atmosphere.
Emission rates are largely dependent on the type of habitat flooded, the size and depth of the reservoir, and the climate.
The flooding of Boreal forests in colder climates, such as those found in Ontario, is reported to result in lower emissions than found for tropical areas, with an average GHG emission rate of 15 g $CO_2$e/kWh. This is consistent with an estimated range of 0.35 to 30 g $CO_2$e/kWh reported for European hydroelectric facilities.
However, GHG emissions associated with the decomposition of biomass are not a concern for run-of-river facilities which do not require the flooding of large areas for reservoirs.

To be consistent with the derivation of GHG emission estimates for other resources, the flooding of reservoirs and the associated emissions associated with the decomposition of biomass was considered to be a component of the construction phase and was not included within the operational stage for the current study.
When GHG emissions related to biomass degradation are excluded, emissions during the operational phase of hydroelectricity generation are considered to be negligible.
Unlike other resources, hydro facilities do not necessarily rely on fossil fuels or outside sources of energy to resume energy production following an outage. Therefore, the estimated GHG emission rate for the operational component of hydroelectric facilities in Ontario was assumed to be negligible for our considerations.

The decommissioning of these facilities is estimated to result in an even greater source of emissions due to the release of methane from exposed sediments following the draining of the reservoir.

The alternative project scenario is the supply of electricity through a wind farm, which will be built next to the bus depot.

- *WIND*

Wind power development in Ontario has increased significantly over the past decade. This trend is expected to continue, with the contribution of wind power to the province's energy production anticipated to increase from 3% in 2013 to 13% in 2021 (4783MW) and more than 15% in 2032.
While the generation of electricity from wind turbines does not directly emit GHGs, emissions occur during various stages of the overall lifecycle.

The wind power life cycle generally consists of four stages:

| 4 STAGES FOR WIND POWER LIFE CYCLE |
|---|
| 1) Fabrication of the wind turbine consisting of mining, processing materials, and manufacturing |
| 2) Construction of the wind turbine consisting of transporting turbine components, constructing foundation and substations, and assembling support structure and wind turbine |
| 3) Operation and maintenance of the wind turbine |
| 4) Decommissioning activities consisting of deconstruction of the wind turbine, disposal, recycling of turbine components, and land reclamation, as required |

The Ontario GHG emissions were on the low end of the range reported in the literature, partly due to the exclusive use of onshore turbines rather than the energy-and material-intensive construction of offshore wind farms.
The current assessment focused exclusively on the GHG emissions associated with the operation and maintenance phase of onshore wind turbines.

The stages of O&M of on-shore wind turbines generally has the lowest GHG contribution to the overall lifecycle.
While there are no direct GHG emissions associated with wind power generation, there are periodic maintenance activities that are required to ensure continued operation which may indirectly contribute GHG emissions, including:
- regular maintenance and cleaning;
- component replacement over the service life of the wind turbine;
- change of oils and lubricants.

For wind power generation in Canada, an operational emission rate of 0.49 g $CO_2$e/kWh were calculated. However, this value was based on activities associated with the periodic maintenance of onshore wind farms in Canada including wind turbines with a capacity greater than 100 kW.
In order to take into account also plant with smaller capacity, the GHG emissions per energy production value of 0.74 g $CO_2$e/kWh was selected in the current assessment.

However, some sources of variability in estimating GHG emissions per energy production associated with O&M of wind facilities include wind speed and maintenance assumptions.

The average wind speed plays an important role in determining the GHG emissions per energy production. As a result, the same wind turbine placed in two different locations may produce differing amounts of electricity.
The assumptions regarding the maintenance requirements over the course of a wind turbine's lifetime can significantly alter the GHG emissions per energy production. Currently, there does not appear to be a consistent set of assumptions used in LCAs of wind power facilities; as a matter of fact, some LCAs do not consider the replacement of parts in their assessment, while others assume a certain proportion of components will need to be replaced.

Focusing on our project proposal to build a wind power plant next to the bus depot and the railway, the table below shows the shares in the contribution to GHGs over the whole life cycle of a wind plant.

| | Upstream processes | O&M | Downstream processes |
|---|---|---|---|
| WIND PLANT | Raw Materials extraction<br>Module manufacture<br>Parts Manufacture<br>Wind/turbine/Farm construction | Power generation<br>Plant operation and Maintenace | Wind turbine/farm decommissioning |
| | ~ 86% | ~ 9% | ~ 5% |

- *NATURAL GAS*

Natural gas power generation provides flexibility to address fluctuations in electricity supply and demand. It is often regarded as a practical source of energy to support the intermittency of energy generated by renewable resources such as wind and solar.
The contribution of natural gas to the Ontario province's energy production was 10% in 2013 and is projected to remain at 10% in 2032. Currently, there are 43 natural gas-fueled generating stations in Ontario that provide approximately 10 000 MW of total capacity.

Unlike resources such as nuclear, wind, solar and hydro where the majority of GHG emissions are related to the upstream and downstream stages of the life cycle, the combustion of natural gas during the operational stage of energy production represents the greatest source of GHGs.

The natural gas power lifecycle generally consists of four stages:

| 4 STAGES FOR NATURAL GAS LIFE CYCLE |
|---|
| 1) The front-end consisting of the extraction and production of natural gas, including both conventional and unconventional sources (*e.g.*, shale gas); |
| 2) construction of the facility including turbines and generators |
| 3) operation phase in which electricity is produced through the combustion of natural gas |
| 4) decommissioning, dismantling and disposal of all facility components |

For cogeneration and CHP facilities, the GHG emissions are associated with the generation of both electricity and thermal energy (*i.e.*, steam). However, a study derived an electricity allocation ratio of 87% based on energy output capacity data for two cogeneration facilities in Ontario which would result in a 13% reduction in the overall GHG emission rate per unit energy production.
To only consider GHG emissions associated with electricity generation, the allocation factor of 87% was applied to the total GHG emissions for cogeneration and CHP facilities in Ontario.

Based on available data from for Ontario, the average annual GHG emissions per energy production for natural gas was 525 g $CO_2$e/kWh.

Moreover, to be consistent with the estimation of GHG emission rates for nuclear and other power generation methods, GHGs associated with the mining, extraction and transportation of fuels and materials was not included in the current study.

- *SOLAR PHOTOVOLTAIC*

Solar PV currently plays a minor role in Ontario's power generation. The contribution of solar PV to the province's energy production is expected to double from 1% in 2013 to 2% in 2032. Currently, solar PV facilities in Ontario provide 478 MW in nameplate capacity.

While the generation of electricity from solar PV does not directly emit GHGs, emissions occur during various stages of the overall lifecycle.

The solar PV power cycle generally consists of four stages:

| | 5 STAGES FOR SOLAR POWER LIFE CYCLE |
|---|---|
| 1) | Fabrication of the solar PV modules consisting of mining, smelting, refining, and purification |
| 2) | Fabrication of the balance of systems including inverters, transformers, wiring, and structural support |
| 3) | Operation and maintenance of the solar PV |
| 4) | Decommissioning activities |

A review of GHG emissions from solar PV reported a range in lifetime emissions of 28 to 110 g $CO_2$e/kWh for crystalline silicon and 18 to 48 g $CO_2$e/kWh for cadmium telluride.
The fabrication and installation of the solar PV have the highest GHG contribution to the overall lifecycle, while the operation/maintenance phase of solar PV have a small contribution. There are no direct GHG emissions associated with solar PV power generation; however, operation and maintenance activities can indirectly result in GHG emissions (range of 0 to 12.3 g $CO_2$e/kWh). Given the lack of other literature-based values, the GHG emission rate of 6.15 g $CO_2$e/kWh was selected for use in the current study.

However, when estimating GHG emissions per unit energy production, the amount of energy generated by the solar PV units will significantly affect the calculated rates. There are two main factors that can impact energy production and the resulting GHG emission rate for solar PV: insolation and efficiency.

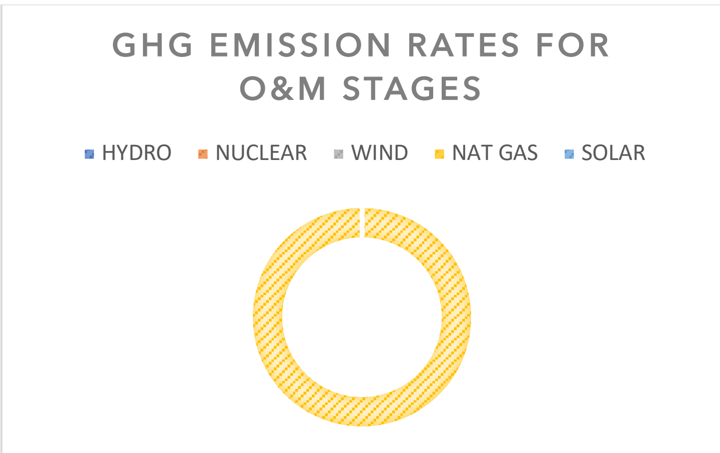
Insolation (or solar irradiance) represents the amount of solar radiation energy that reaches a given surface during a specific time. Insolation varies greatly around the world and even across Ontario and impacts the overall electricity generation capacity of solar PV, and in turn, the lifecycle GHG emissions rate for a solar facility. Another consideration is the efficiency of the solar PV technology. The efficiency of commercially available solar PV varies greatly from 7% to 18%. As a result, studies evaluating solar PV facilities in different parts of the world that utilize different types of solar PV technology may derive vastly different GHG emission rates.

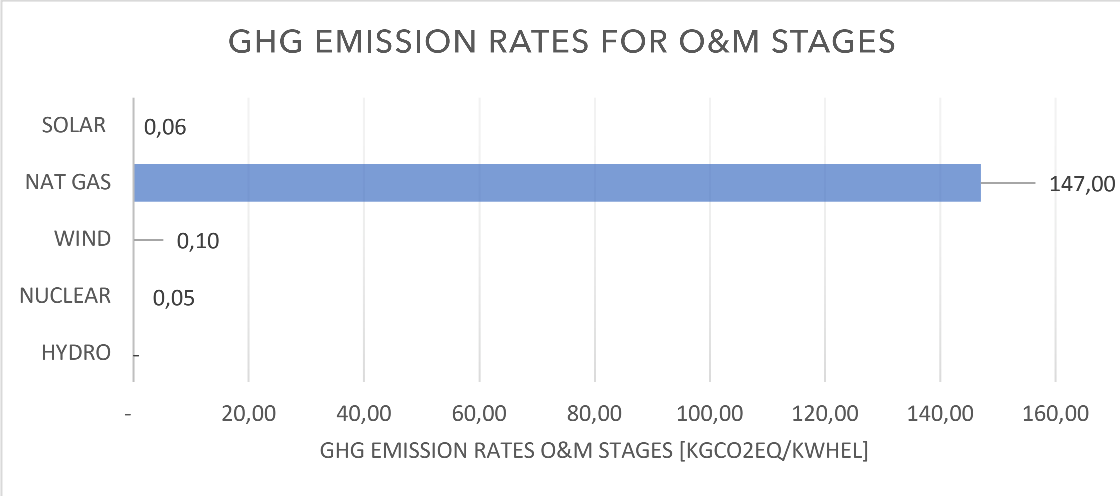
## 5.3 GHGs emissions for the Energy Mix scenario

Using the energy mix of the state of Ontario, mentioned earlier, it is now possible to calculate the contribution in terms of emissions made by each source of electricity. In fact, multiplying the percentages by the carbon dioxide equivalent values mentioned above, the weighted GHGs emissions per kilowatt-hour of electricity are obtained.

| | 1 kwh electricity | | | total energy demand |
|---|---|---|---|---|
| | ENERGY MIX [%] | GHG EMISSION RATES FOR O&M STAGES [gCO2 eq/kWhel] | WEIGHTED GHGs EMISSIONS [gCO2 eq] | WEIGHTED GHGs EMISSIONS [kgCO2 eq/year] |
| HYDRO | 0,23 | - | - | - |
| NUCLEAR | 0,35 | 0,15 | 0,05 | 3,12 |
| WIND | 0,13 | 0,74 | 0,10 | 5,71 |
| NAT GAS | 0,28 | 525,00 | 147,00 | 8.728,77 |
| SOLAR | 0,01 | 6,15 | 0,06 | 3,65 |
| Required energy [kWh/year] | 59.379,37 | | | |

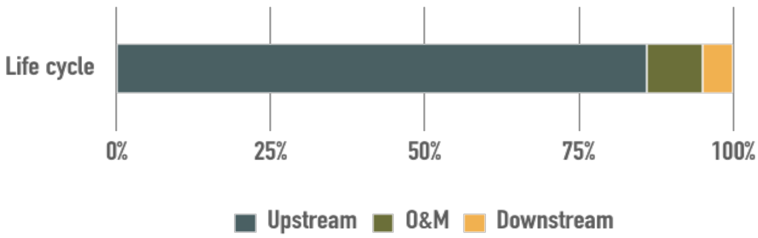
It is quite evident from the results that the emissions associated with the production of one kilowatt-hour of electricity in Ontario are almost exclusively due to the processing of methane gas, as well as to produce the entire energy required.






## 5.4 GHGs emissions for the Wind plant scenario

As regards the calculation of emissions for the second scenario (wind power plant), the entire life cycle was considered. As can be seen from the following table, the emissions associated with the full life cycle are approximately 450 kgCO2 equivalent per year. This value was calculated by comparing the emissions for the O&M phase, which represent 9% of the total, to the other two phases (upstream and downstream processes).




| | | GHG EMISSION RATES FOR O&M STAGES | FULL LIFE CYCLE | GHG EMISSION RATES FOR O&M STAGES | FULL LIFE CYCLE |
|---|---|---|---|---|---|
| | SHARES [%] | $gCO_2$ eq/kWhel | $gCO_2$ eq/kWhel | $kgCO_2$ eq/year | $kgCO_2$ eq/year |
| **Electricity production method** | | | | | |
| HYDRO | 23% | - | 10÷22 | 0 | Not considered |
| NUCLEAR | 35% | 0,15 | 4,8÷66 | 8,91 | Not considered |
| WIND | 13% | 0,74 | 10÷34,1 | 43,94 | 449,51 |
| NAT GAS | 28% | 525,00 | 435÷540 | 31.174,17 | Not considered |
| SOLAR | 1% | 6,15 | 32÷49,9 | 365,18 | Not considered |
| **Required energy** [kWh/year] | 59.379,37 | | | | |

# 6. DIESEL BUS COMPARISON

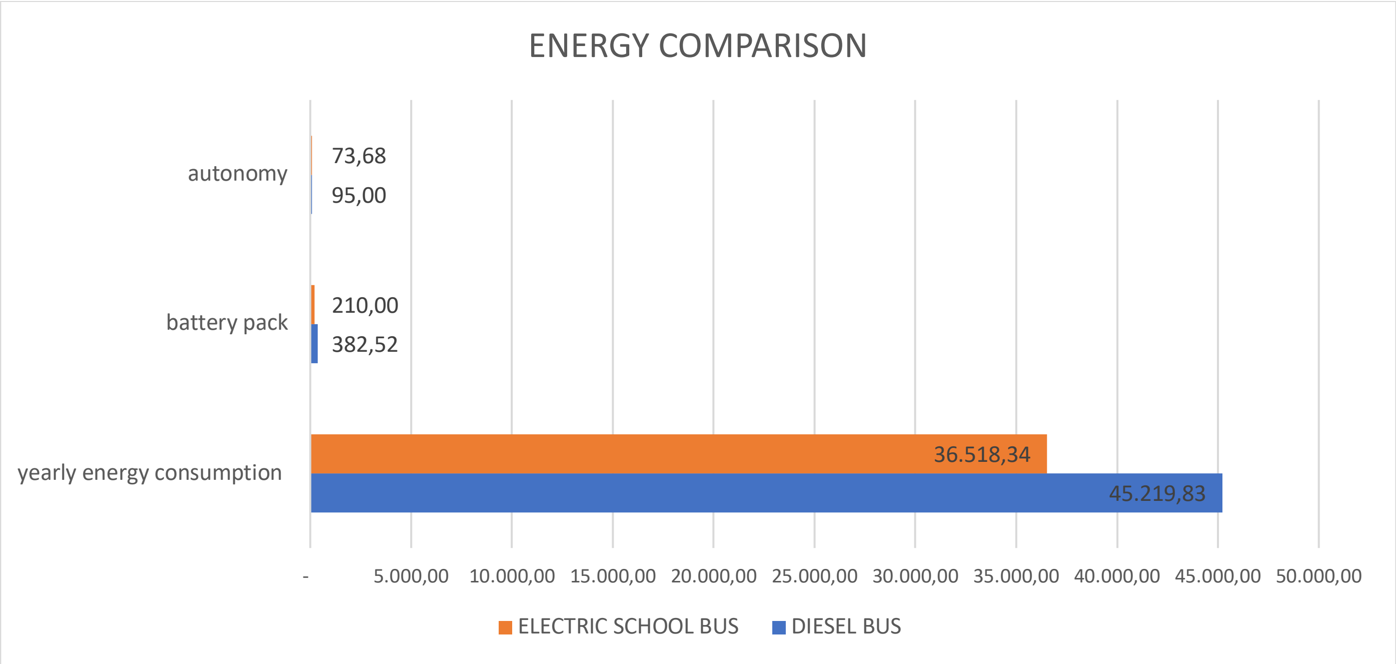
Since diesel busses are the most common mode of transport for school services in Canada, it is relevant to analyze how the adoption of an electric vehicle would impact the service's performances.

It can be hypothesized that a diesel bus and an electric bus have similar, even if not identical, performances in terms of average speed and total time on the road.
For this reason, the aim of this analysis will be to compare energy consumption, pollutant emissions and the cost of the energy carrier.

## 6.1 Energetic comparison

The tables below show the main indexes considered for the comparison.

| DIESEL BUS | | | ELECTRIC SCHOOL BUS | | |
|---|---|---|---|---|---|
| specific fuel consumption | [l/100km] | 40,00 | specific energy consumption | [kwh/km] | 2,93 |
| specific fuel consumption | l/km | 0,40 | yearly energy consumption | [kwh/year] | 36.316,49 |
| yearly fuel consumption | [l] | 4.492,16 | yearly energy consumption | [MJ/year] | 130.739,37 |
| diesel density | [kg/l] | 0,84 | yearly energy consumption | [MJ/km] | 11,64 |
| consumption | [kg/km] | 0,33 | battery pack | [kWh] | 210,00 |
| LHV diesel | [MJ/kg] | 43,40 | autonomy | [km] | 71,73 |
| energy consumption | [MJ/km] | 14,50 | yearly emissions | [kgCO2] | - |
| yearly energy consumption | [MJ/year] | 162.791,39 | | | |
| yearly energy consumption | [kwh/year] | 45.219,83 | | | |
| Fuel tank capacity | [l] | 38,00 | | | |
| tank capacity | [MJ] | 1.377,08 | | | |
| tank capacity | [kWh] | 382,52 | | | |
| autonomy | [km] | 95,00 | | | |
| specific Carbon emissions | [kgCO2/km] | 1,06 | | | |
| yearly emissions | [kgCO2] | 11.883,77 | | | |



## 6.2 Environmental comparisons

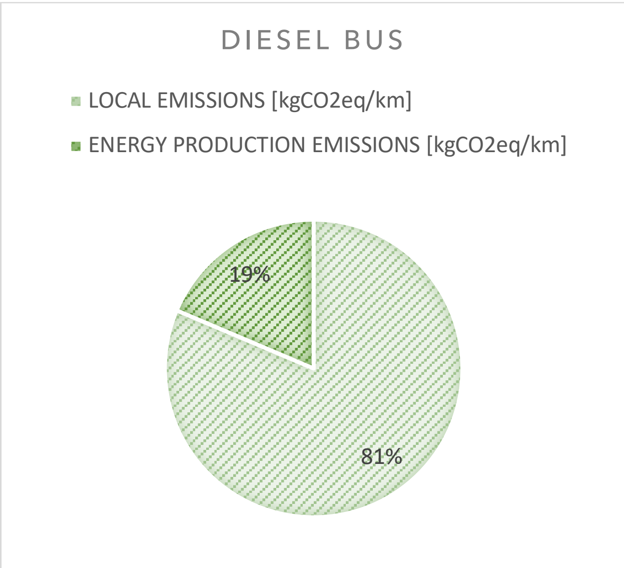
From the data abovementioned, the following emissions were calculated:

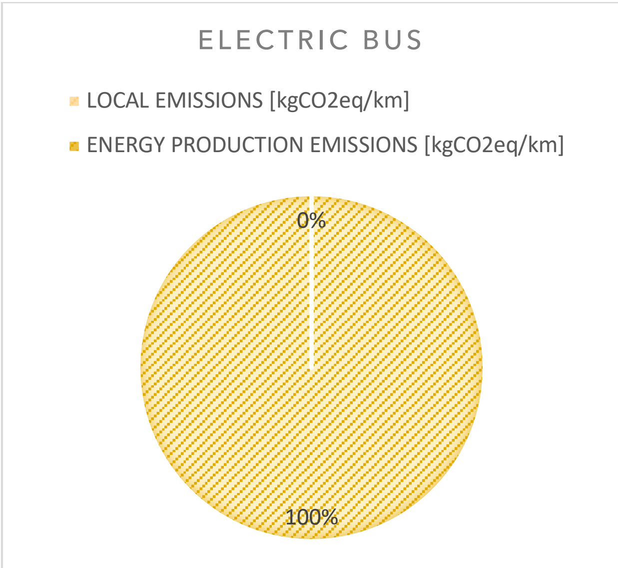
- Local emissions from the vehicle itself

- Global emissions from energy production (diesel and electricity)

Again, two different scenarios have been identified: the first concerns the purchase of energy from the grid and refers to the energy mix of the state of Ontario, while the second concerns the construction of a wind farm that will make up the energy demand for the school bus service.

| ENERGY MIX | ELECTRIC BUS | DIESEL BUS | |
|---|---|---|---|
| LOCAL EMISSIONS [kgCO2eq/km] | - | 1,06 | con 0,073 kgCO2/MJ |
| ENERGY PRODUCTION EMISSIONS [kgCO2eq/km] | 0,774 | 0,24 | con 0,0167 kgCO2/MJ |
| GLOBAL EMISSIONS [kgCO2eq/km] | 0,774 | 1,30 | |
| | | | |
| LOCAL EMISSIONS [kgCO2eq/year] | - | 11.883,77 | |
| ENERGY PRODUCTION EMISSIONS [kgCO2eq/year] | 8.692,93 | 2.318,61 | |
| GLOBAL EMISSIONS [kgCO2eq/year] | 8.692,93 | 14.202,38 | |

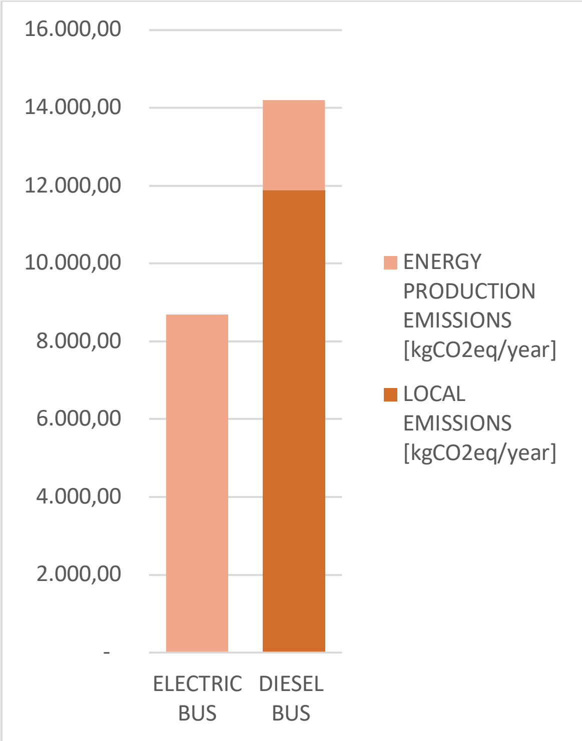



As can be seen, the electric bus has no local emissions while the diesel version emits around 1 kg of carbon dioxide per km. This figure has been calculated using the emissions associated with the consumption of one megajoule of diesel (0.073 $kgCO_2$/MJ).

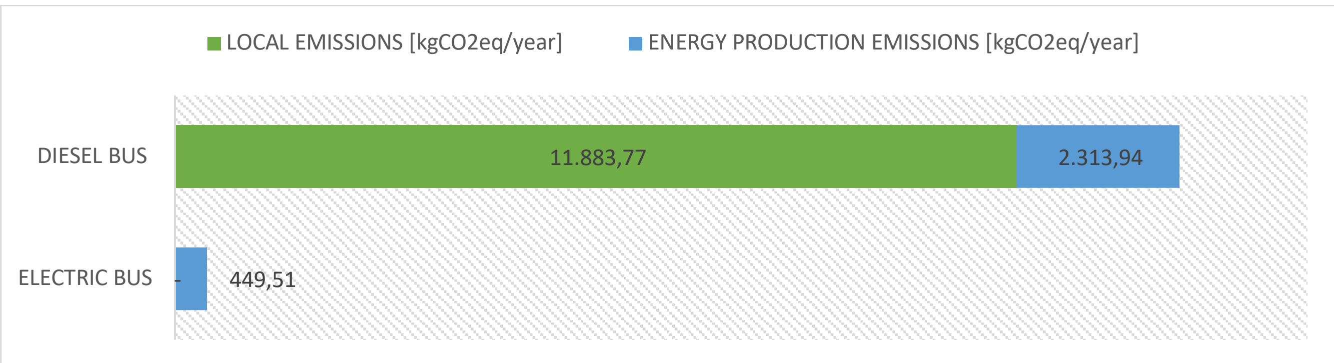
With regard to emissions related to energy production, it can be seen that the value associated with electricity is much higher than that associated with diesel. This result is justified by the fact that the production of diesel is an already widely developed technology where processes are fully optimized. On the other hand, in the electricity production chain, there are additional intermediate steps that reduce its efficiency, and in the case of renewable energy sources, which are still in the development phase, there is considerable room for improvement.

However, when looking at overall emissions per kilometer travelled, those associated with diesel buses are still around twice as high (+40.5%) as those associated with electric vehicles. This translates into emission savings of 5623 kgCO2 per year.




| WIND PLANT | ELECTRIC BUS | DIESEL BUS | |
|---|---|---|---|
| LOCAL EMISSIONS [kgCO2eq/km] | - | 1,06 | con 0,073 kgCO2/MJ |
| ENERGY PRODUCTION EMISSIONS [kgCO2eq/km] | 0,047 | 0,24 | con 0,014 kgCO2/MJ |
| GLOBAL EMISSIONS [kgCO2eq/km] | 0,047 | 1,30 | |
| | | | |
| LOCAL EMISSIONS [kgCO2eq/year] | - | 11.883,77 | |
| ENERGY PRODUCTION EMISSIONS [kgCO2eq/year] | 449,27 | 2.318,61 | |
| GLOBAL EMISSIONS [kgCO2eq/year] | 449,27 | 14.202,38 | |

For this comparison, the features associated to the diesel bus remain the same.
However, the emissions associated with electricity production are radically lower than in the previous case.



# 7. COST ANALYSIS

As the last step of the study, the cost analysis is presented. This analysis was carried out in two different scenarios:

1) the energy required to operate the service is purchased from the grid.

2) the energy required to operate the service is produced by a wind farm equipped with two turbines. The surplus energy produced is sold to the grid, generating additional revenue for the transmission company.

Depreciable costs

The infrastructure required for the service includes the school bus depot (about 500 sqm) where the charging stations are located.
- The cost per square meter of the depot of 250 euros is in line with market prices in the city of Ottawa.
- The cost of the charging stations refers to the price of a charging station with the same required characteristics on the market.


Multistandard Fast DC recharging station 24 kW

- Concerning the cost of the LION D electric school busses, it is assumed that these are purchased with public grants, hence the cost of the vehicles is going to be totally covered by the government[13]. This major financial aid is critical for the financial sustainability of the project since it covers the most important voice cost.
  For the reason mentioned above, vehicle purchase costs are not included in the depreciation calculation. Instead, the infrastructure is depreciated over a period of 30 years of service.

[13] "Zero Emission Transit Fund" (Chapter 2: Projects Eligible for Funding, page 6), Infrastructure Canada, Government of Canada, August 2021

Operating costs

There are two paid drivers as well as additional staff required for maintenance and surveillance and the value of the salary was calculated according to the average salaries of public transport drivers in Canada.

The value of energy required during the year refers to the results of the analysis under actual conditions conducted previously and the purchase cost from the grid for industrial (not household) applications was used.

| Canada electricity prices | Household, kWh | Business, kWh |
|---|---|---|
| Canadian Dollar | 0.140 | 0.122 |
| U.S. Dollar | 0.110 | 0.096 |

Revenues

Revenues include subscriptions and non-ordinary tickets. In particular, the revenues contain the subscriptions of children living in the Heron Gate neighborhood and that of the elderly/disabled who are assumed to use the service continuously.
For the wind plant scenario, the cost of one turbine is considered to be 250 000 euros, while the selling price of electricity is 0,3 euros/kWh that includes statal incentives for renewables.

## 7.1 First Scenario - Energy Mix scenario

DEPRECIABLE COSTS

| | | value | | unitary costs | | total cost |
|---|---|---|---|---|---|---|
| INVESTMENT COSTS | **Infrastructure** | | | | | 143.900,00 € |
| | warehouse | 500,00 | mq | 250,00 | €/mq | 125.000,00 € |
| | recharging station DC 24kW | 1,00 | station | 18.900,00 | €/station | 18.900,00 € |
| | **vehicles** | 3,00 | vehicles | 350.000,00 | €/vehicle | PUBLIC GRANTS |
| | | | | | **TOTAL** | **143.900,00 €** |

VARIABLE COSTS (not depreciable)

| | | value | | unitary costs | | total cost |
|---|---|---|---|---|---|---|
| OPERATINGL COSTS | **Personel** | | | | | **126.080,00 €** |
| | drivers | 2,00 | pp | 31.520,00 | €/pp | 63.040,00 € |
| | auxiliaries (O&M, security ..) | 2,00 | pp | 31.520,00 | €/pp | 63.040,00 € |
| | **energy** | 59.051,16 | kWh/anno | 0,09 | €/kWh | **5.019,35 €** |
| | | | | | **TOTAL** | **131.099,35 €** |

REVENUES

| | | value | | unitary costs | | total cost |
|---|---|---|---|---|---|---|
| REVENUES | **Kids subscription** | 417 | kids | 300 | € | 125.100,00 € |
| | **vulnerable and elders subscription** | 80 | pp | 200 | € | 16.000,00 € |
| | **energy sale** | - | kWh | 0,098 | € | 0,00 € |
| | | | | | **TOTAL** | **141.100,00 €** |

The following table shows the development of the commercial value of the infrastructure over 30 years, taken as a reference for the calculation of depreciation. The annual commercial value was calculated using the formula below:

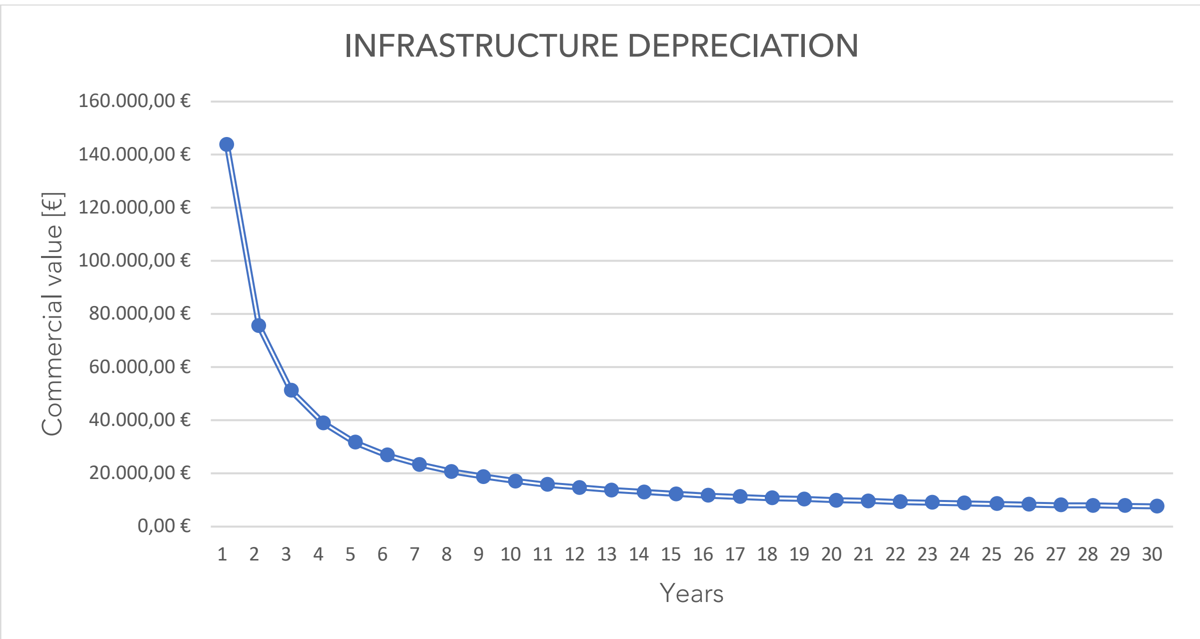
$$Commercial\ value = \frac{\mathrm{S} * (1+\mathrm{i})^{n} * i}{(1+\mathrm{i})^{n}}$$

Where:

- $S$ represents the investment costs
- $i$ represents the rate
- $n$ represents the year considererd

| YEAR | COMMERCIAL VALUE [€] | ANNUAL RATE [€] |
|---|---|---|
| 1 | 143.900,00 € | 0,00 € |
| 2 | 75.530,80 € | 68.369,20 € |
| 3 | 51.166,72 € | 24.364,07 € |
| 4 | 38.991,10 € | 12.175,62 € |
| 5 | 31.690,86 € | 7.300,24 € |
| 6 | 26.828,31 € | 4.862,56 € |
| 7 | 23.358,71 € | 3.469,60 € |
| 8 | 20.759,71 € | 2.599,00 € |
| 9 | 18.741,10 € | 2.018,61 € |
| 10 | 17.128,76 € | 1.612,34 € |
| 11 | 15.811,88 € | 1.316,88 € |
| 12 | 14.716,60 € | 1.095,28 € |
| 13 | 13.791,77 € | 924,83 € |
| 14 | 13.000,86 € | 790,91 € |
| 15 | 12.317,08 € | 683,78 € |
| 16 | 11.720,34 € | 596,74 € |
| 17 | 11.195,28 € | 525,06 € |
| 18 | 10.729,95 € | 465,34 € |
| 19 | 10.314,90 € | 415,05 € |
| 20 | 9.942,60 € | 372,30 € |
| 21 | 9.606,93 € | 335,67 € |
| 22 | 9.302,88 € | 304,04 € |
| 23 | 9.026,34 € | 276,54 € |
| 24 | 8.773,86 € | 252,48 € |
| 25 | 8.542,54 € | 231,32 € |
| 26 | 8.329,94 € | 212,60 € |
| 27 | 8.133,98 € | 195,96 € |
| 28 | 7.952,86 € | 181,12 € |
| 29 | 7.785,05 € | 167,81 € |
| 30 | 7.629,22 € | 155,84 € |

| | |
|---|---|
| AMORTISED AMOUNT | 136.270,78 € |
| SALVAGE VALUE | 7.629,22 € |



| YEAR | REVENUES [€] | AMORTIZATION RATE [€] | OPERATIONAL COSTS [€] | ECONOMIC OUTTURN [€] | CUMULATIVE ECONOMIC OUTTURN [€] |
|---|---|---|---|---|---|
| - | | | | | -143.900,00 € |
| 1 | 141.100,00 € | 0,00 € | 131.099,35 € | 10.000,65 € | -133.899,35 € |
| 2 | 141.100,00 € | 68.369,20 € | 131.099,35 € | -58.368,55 € | -192.267,90 € |
| 3 | 141.100,00 € | 24.364,07 € | 131.099,35 € | -14.363,42 € | -206.631,32 € |
| 4 | 141.100,00 € | 12.175,62 € | 131.099,35 € | -2.174,97 € | -208.806,29 € |
| 5 | 141.100,00 € | 7.300,24 € | 131.099,35 € | 2.700,41 € | -206.105,88 € |
| 6 | 141.100,00 € | 4.862,56 € | 131.099,35 € | 5.138,10 € | -200.967,79 € |
| 7 | 141.100,00 € | 3.469,60 € | 131.099,35 € | 6.531,05 € | -194.436,73 € |
| 8 | 141.100,00 € | 2.599,00 € | 131.099,35 € | 7.401,65 € | -187.035,08 € |
| 9 | 141.100,00 € | 2.018,61 € | 131.099,35 € | 7.982,04 € | -179.053,04 € |
| 10 | 141.100,00 € | 1.612,34 € | 131.099,35 € | 8.388,31 € | -170.664,73 € |
| 11 | 141.100,00 € | 1.316,88 € | 131.099,35 € | 8.683,77 € | -161.980,96 € |
| 12 | 141.100,00 € | 1.095,28 € | 131.099,35 € | 8.905,37 € | -153.075,59 € |
| 13 | 141.100,00 € | 924,83 € | 131.099,35 € | 9.075,82 € | -143.999,77 € |
| 14 | 141.100,00 € | 790,91 € | 131.099,35 € | 9.209,74 € | -134.790,03 € |
| 15 | 141.100,00 € | 683,78 € | 131.099,35 € | 9.316,87 € | -125.473,15 € |
| 16 | 141.100,00 € | 596,74 € | 131.099,35 € | 9.403,92 € | -116.069,24 € |
| 17 | 141.100,00 € | 525,06 € | 131.099,35 € | 9.475,59 € | -106.593,65 € |
| 18 | 141.100,00 € | 465,34 € | 131.099,35 € | 9.535,32 € | -97.058,33 € |
| 19 | 141.100,00 € | 415,05 € | 131.099,35 € | 9.585,61 € | -87.472,72 € |
| 20 | 141.100,00 € | 372,30 € | 131.099,35 € | 9.628,35 € | -77.844,38 € |
| 21 | 141.100,00 € | 335,67 € | 131.099,35 € | 9.664,98 € | -68.179,40 € |
| 22 | 141.100,00 € | 304,04 € | 131.099,35 € | 9.696,61 € | -58.482,79 € |
| 23 | 141.100,00 € | 276,54 € | 131.099,35 € | 9.724,11 € | -48.758,68 € |
| 24 | 141.100,00 € | 252,48 € | 131.099,35 € | 9.748,17 € | -39.010,51 € |
| 25 | 141.100,00 € | 231,32 € | 131.099,35 € | 9.769,33 € | -29.241,18 € |
| 26 | 141.100,00 € | 212,60 € | 131.099,35 € | 9.788,05 € | -19.453,13 € |
| 27 | 141.100,00 € | 195,96 € | 131.099,35 € | 9.804,69 € | -9.648,44 € |
| 28 | 141.100,00 € | 181,12 € | 131.099,35 € | 9.819,54 € | 171,10 € |
| 29 | 141.100,00 € | 167,81 € | 131.099,35 € | 9.832,84 € | 10.003,94 € |
| 30 | 141.100,00 € | 155,84 € | 131.099,35 € | 9.844,81 € | 19.848,75 € |

## 7.2 Second scenario – Wind Plant scenario

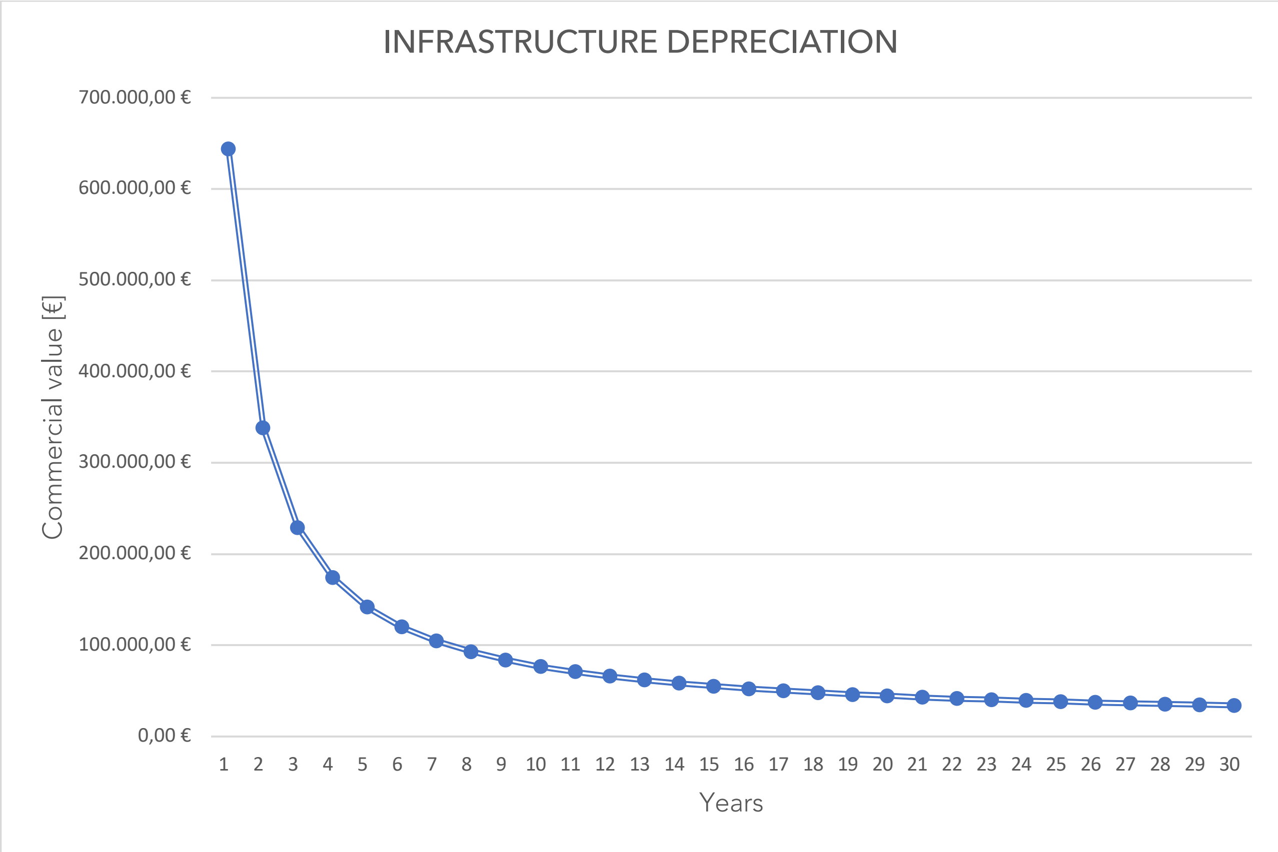
| DEPRECIABLE COSTS | | value | | unitary costs | | total cost |
|---|---|---|---|---|---|---|
| INVESTMENT COSTS | **Infrastructure** | | | | | 643.900,00 € |
| | warehouse | 500,00 | mq | 250,00 | €/mq | 125.000,00 € |
| | recharging station | 1,00 | station | 18.900,00 | €/station | 18.900,00 € |
| | wind mill | 2,00 | turbines | 250.000,00 | €/turbine | 500.000,00 € |
| | **vehicles** | 3,00 | vehicles | 350.000,00 | €/vehicle | PUBLIC GRANTS |
| | | | | | **TOTAL** | **643.900,00 €** |

| VARIABLE COSTS (not depreciable) | | value | | unitary costs | | total cost |
|---|---|---|---|---|---|---|
| OPERATIONAL COSTS | **Personel** | | | | | **126.080,00 €** |
| | drivers | 2,00 | pp | 31.520,00 | €/pp | 63.040,00 € |
| | auxiliaries (O&M, security ..) | 2,00 | pp | 31.520,00 | €/pp | 63.040,00 € |
| | **energy** | - | kWh/anno | 0,085 | €/kWh | **0,00 €** |
| | | | | | **TOTAL** | **126.080,00 €** |

| REVENUES | | value | | unitary costs | udm | total cost |
|---|---|---|---|---|---|---|
| REVENUES | **Kids subscription** | 417,00 | kids | 300,00 | €/subscription | 125.100,00 € |
| | **vulnerable and elders subscription** | 80,00 | pp | 200,00 | €/subscription | 16.000,00 € |
| | **energy sale** | 241.159,19 | kWh | 0,30 | €/kWh | 72.347,76 € |
| | | | | | **TOTAL** | **213.447,76 €** |

| YEAR | COMMERCIAL VALUE [€] | ANNUAL RATE [€] |
|---|---|---|
| 1 | 643.900,00 € | 0,00 € |
| 2 | 337.972,75 € | 305.927,25 € |
| 3 | 228.952,41 € | 109.020,34 € |
| 4 | 174.470,96 € | 54.481,45 € |
| 5 | 141.805,05 € | 32.665,91 € |
| 6 | 120.046,88 € | 21.758,16 € |
| 7 | 104.521,70 € | 15.525,18 € |
| 8 | 92.892,11 € | 11.629,59 € |
| 9 | 83.859,57 € | 9.032,55 € |
| 10 | 76.644,93 € | 7.214,64 € |
| 11 | 70.752,39 € | 5.892,54 € |
| 12 | 65.851,40 € | 4.900,99 € |
| 13 | 61.713,12 € | 4.138,28 € |
| 14 | 58.174,09 € | 3.539,03 € |
| 15 | 55.114,44 € | 3.059,65 € |
| 16 | 52.444,27 € | 2.670,18 € |
| 17 | 50.094,81 € | 2.349,45 € |
| 18 | 48.012,61 € | 2.082,21 € |
| 19 | 46.155,43 € | 1.857,18 € |
| 20 | 44.489,50 € | 1.665,93 € |
| 21 | 42.987,49 € | 1.502,02 € |
| 22 | 41.627,01 € | 1.360,48 € |
| 23 | 40.389,58 € | 1.237,42 € |
| 24 | 39.259,81 € | 1.129,77 € |
| 25 | 38.224,75 € | 1.035,06 € |
| 26 | 37.273,45 € | 951,30 € |
| 27 | 36.396,58 € | 876,87 € |
| 28 | 35.586,15 € | 810,43 € |
| 29 | 34.835,27 € | 750,88 € |
| 30 | 34.137,96 € | 697,31 € |

| | |
|---|---|
| AMORTISED AMOUNT | 609.762,04 € |
| SALVAGE VALUE | 34.137,96 € |



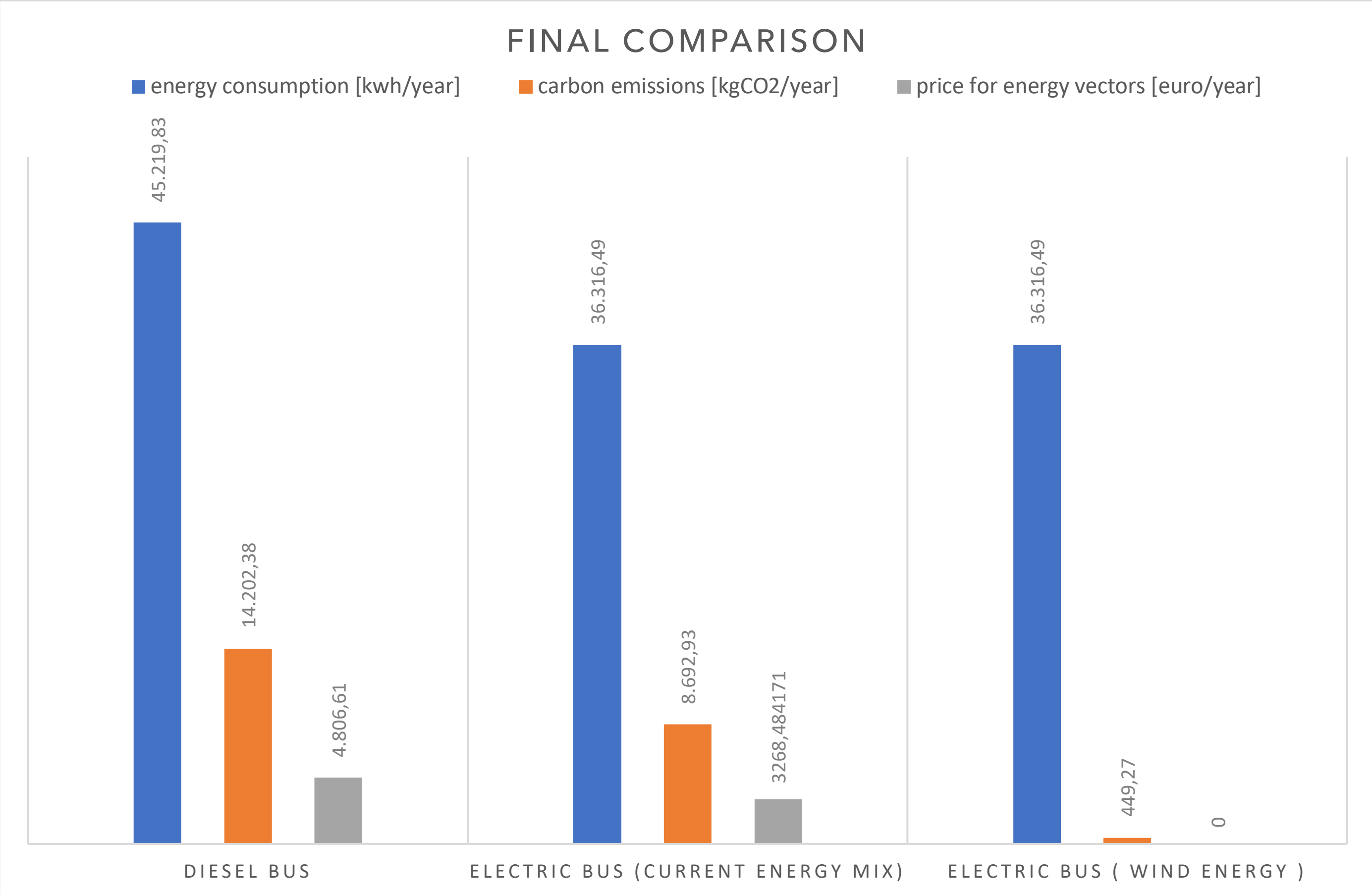

| YEAR | REVENUES [€] | AMORTIZATION RATE [€] | OPERATIONAL COSTS [€] | ECONOMIC OUTTURN [€] | CUMULATIVE ECONOMIC OUTTURN [€] |
|---|---|---|---|---|---|
| - | | | | | -643.900,00 € |
| 1 | 213.447,76 € | 0,00 € | 126.080,00 € | 87.367,76 € | -556.532,24 € |
| 2 | 213.447,76 € | 305.927,25 € | 126.080,00 € | -218.559,49 € | -775.091,73 € |
| 3 | 213.447,76 € | 109.020,34 € | 126.080,00 € | -21.652,58 € | -796.744,32 € |
| 4 | 213.447,76 € | 54.481,45 € | 126.080,00 € | 32.886,30 € | -763.858,01 € |
| 5 | 213.447,76 € | 32.665,91 € | 126.080,00 € | 54.701,84 € | -709.156,17 € |
| 6 | 213.447,76 € | 21.758,16 € | 126.080,00 € | 65.609,59 € | -643.546,58 € |
| 7 | 213.447,76 € | 15.525,18 € | 126.080,00 € | 71.842,57 € | -571.704,00 € |
| 8 | 213.447,76 € | 11.629,59 € | 126.080,00 € | 75.738,17 € | -495.965,83 € |
| 9 | 213.447,76 € | 9.032,55 € | 126.080,00 € | 78.335,21 € | -417.630,62 € |
| 10 | 213.447,76 € | 7.214,64 € | 126.080,00 € | 80.153,12 € | -337.477,50 € |
| 11 | 213.447,76 € | 5.892,54 € | 126.080,00 € | 81.475,22 € | -256.002,29 € |
| 12 | 213.447,76 € | 4.900,99 € | 126.080,00 € | 82.466,77 € | -173.535,52 € |
| 13 | 213.447,76 € | 4.138,28 € | 126.080,00 € | 83.229,48 € | -90.306,04 € |
| 14 | 213.447,76 € | 3.539,03 € | 126.080,00 € | 83.828,73 € | -6.477,32 € |
| 15 | 213.447,76 € | 3.059,65 € | 126.080,00 € | 84.308,11 € | 77.830,79 € |
| 16 | 213.447,76 € | 2.670,18 € | 126.080,00 € | 84.697,58 € | 162.528,37 € |
| 17 | 213.447,76 € | 2.349,45 € | 126.080,00 € | 85.018,30 € | 247.546,67 € |
| 18 | 213.447,76 € | 2.082,21 € | 126.080,00 € | 85.285,55 € | 332.832,22 € |
| 19 | 213.447,76 € | 1.857,18 € | 126.080,00 € | 85.510,58 € | 418.342,80 € |
| 20 | 213.447,76 € | 1.665,93 € | 126.080,00 € | 85.701,83 € | 504.044,63 € |
| 21 | 213.447,76 € | 1.502,02 € | 126.080,00 € | 85.865,74 € | 589.910,37 € |
| 22 | 213.447,76 € | 1.360,48 € | 126.080,00 € | 86.007,28 € | 675.917,65 € |
| 23 | 213.447,76 € | 1.237,42 € | 126.080,00 € | 86.130,33 € | 762.047,98 € |
| 24 | 213.447,76 € | 1.129,77 € | 126.080,00 € | 86.237,98 € | 848.285,97 € |
| 25 | 213.447,76 € | 1.035,06 € | 126.080,00 € | 86.332,69 € | 934.618,66 € |
| 26 | 213.447,76 € | 951,30 € | 126.080,00 € | 86.416,46 € | 1.021.035,12 € |
| 27 | 213.447,76 € | 876,87 € | 126.080,00 € | 86.490,89 € | 1.107.526,01 € |
| 28 | 213.447,76 € | 810,43 € | 126.080,00 € | 86.557,33 € | 1.194.083,34 € |
| 29 | 213.447,76 € | 750,88 € | 126.080,00 € | 86.616,87 € | 1.280.700,21 € |
| 30 | 213.447,76 € | 697,31 € | 126.080,00 € | 86.670,44 € | 1.367.370,65 € |


A comparison of the two business plans shows that the contribution in revenues from the sale of surplus electricity to the grid is crucial to the company's return on investment. As a matter of fact, in the first case, the company would be able to pay back the investment after 28 years, which would be halved in the second scenario. The main parameter affecting the return on investment is the operating costs, which are very high compared to the revenues of the service, which, being public, offers subsidized tariffs.

# 8. CONCLUSIONS

## 8.1 Final considerations about the introduction of the electric service compared to the current situation

The aim of the analysis was to analyze the feasibility of a school bus service for children and elderly people. The following graph compares the current situation with our two project scenarios.




In both cases (scenario in which the electricity is purchased from the grid and scenario in which the energy is produced by the owned wind farm), diesel is always the worst solution from the point of view of energy consumption, costs, and emissions.

The energy consumption of the diesel solution is 20% higher than that of the other two solutions.

However, some considerations are necessary. Although diesel consumes more kWh, its range is approximately 21 km longer since the diesel tank allows to store more energy (382,52 kWh vs 210 kWh; +54%)

Furthermore, although diesel is by far the worst environmental solution, there is a substantial difference between the energy mix scenario and the wind plant scenario. In fact, wind plant emissions, calculated in $kgCO_2$ per year, are negligible compared to those associated with energy mix production (representing only 3% of the total).

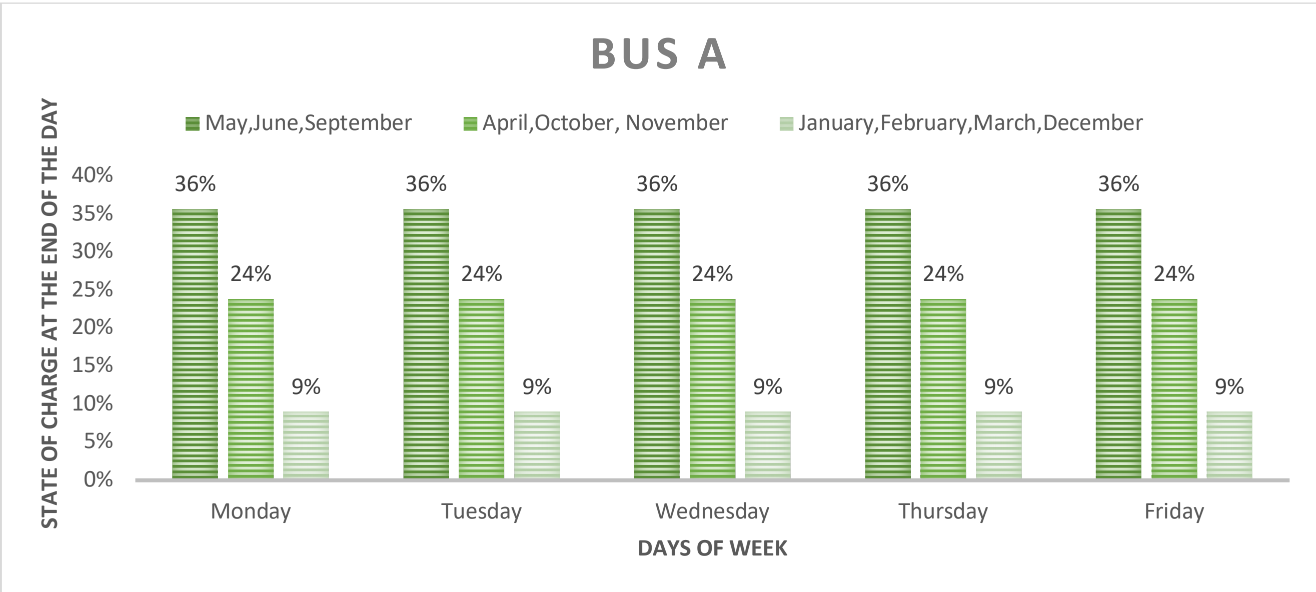
As far as price is concerned, the result of the Wind Plant project scenario is probably underestimated: it is true that the energy is produced by the owned wind farm and is not paid for, but plant charges should be included in the comparison. These charges are not to be counted for the diesel solution and the energy mix.

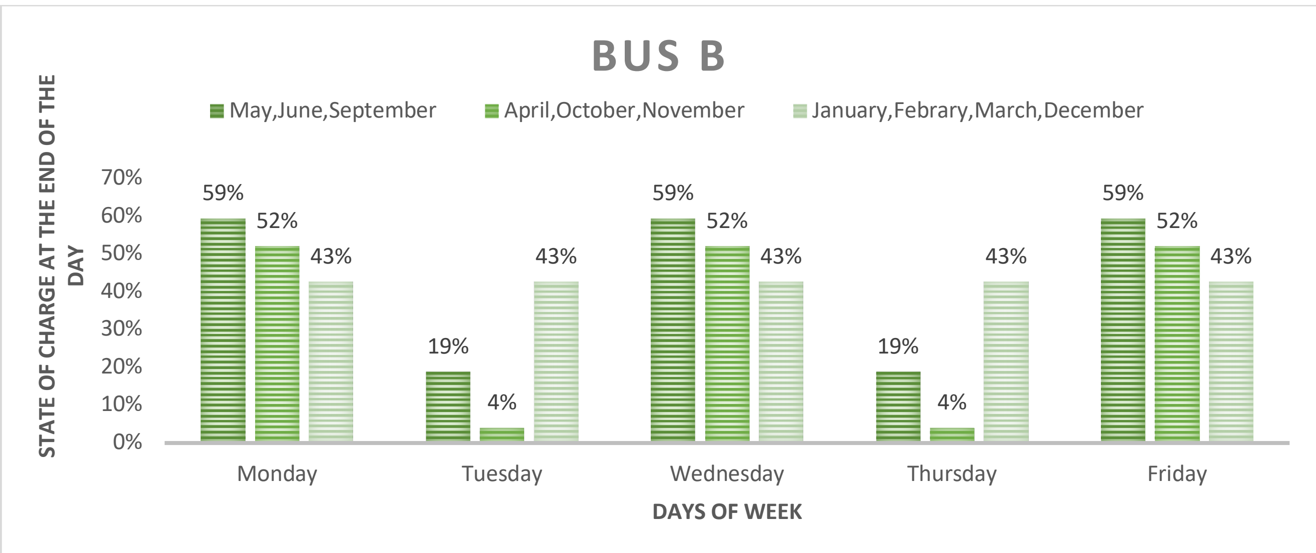
## 8.2 Final Results

Focusing only on the project proposal, the full results of the analysis will now be presented.

The number of electric buses required for the service is two, of which one provides the full service (school service and public service for elderly/disabled people) and the second provides only the school service. For this reason, the buses have different consumption and recharging needs.

The energy analysis was carried out under real conditions throughout the year, taking into account the influence of temperature in the coldest months, the different power requirements of the auxiliaries and the reduction of regenerative braking.




As can be seen from the graphs, the full-service bus needs to be recharged every day, regardless of external conditions. The other bus only requires a daily recharge during the coldest months (January, February, March and December).

It is not possible to swap school bus service A for school bus service B, optimizing the charging schedule by unloading the batteries as much as possible. This is because the battery of the school bus has a capacity of 210 kWh and the daily consumption for bus A, even in the best case, is 135 kWh, while the minimum energy required to complete the school service alone is 85.20 kWh (residual autonomy of 75 kWh).

As far as the recharging infrastructure is concerned, the main focus of the analysis was to define a strategic positioning for the construction of the depot. The site, which was then chosen, is in fact characterized by a high potential for a possible power grid implementation.
First of all, this choice allows to keep open the option of creating a smart grid, thus increasing the reliability, availability, and efficiency of the whole system.
Secondly, the site is provided with the space needed for the construction of a low-power wind farm, that would supply the hub with completely clean energy, making the system more sustainable.

With regard to energy supply, two scenarios were investigated. These two scenarios led to different results both in terms of costs and pollutant emissions. As a matter of fact, if one chooses to buy energy from the grid, the payback time of the investment is 28 years, whereas if one builds the wind farm, despite the construction costs, the sale of the energy manages to halve the payback time compared to the other case. However, the analysis does not take into account the direct maintenance of the plant, thus leading to an underestimation of the total costs.

As a conclusion, it is possible to say that the proposed solution is feasible from a technical and financial point of view. Regarding the environmental impact, the results show that both the "Energy mix" and the "Wind plant" scenarios are advantageous if compared to the current situation. Furthermore, the "Energy mix" solution could be even more environmentally sustainable in the event that the energy production in Ontario becomes cleaner and more reliant on renewable and nuclear energy.
Moreover, beyond the abovementioned technical aspects, the solution could bring several benefits to the community; above all, the improvement to the public transit accessibility for the vulnerable.

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