The Deployment of Battery Electric Buses: Benefits, Challenges and Methods

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## Introduction

- Continuous increase in CO2 emissions
  - Increase in global energy demand

- Air Quality concerns in European cities
  - Diesel Vehicles ~ 40% of NOx emissions.

- Public Transport ~ 6% of GHG emissions

- Cities are banning Diesel Vehicles:

### Battery Electric Buses

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Source: European Energy Agency – Air Quality Report 2019

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Outline

❖ Introduction

❖ Benefits of Battery Electric Buses

❖ Challenges Facing Battery Electric Buses

❖ Method

❖ Results and Discussions

❖ Conclusion
Benefits of Battery Electric Buses

- Environmental Performance
  - 41 – 98% reduction depending on electricity generation mix

- Energy Consumption
  - 10 – 50% reduction thanks to powertrain high efficiency

- Superior energy and environmental performance over diesel buses and other alternative bus technologies
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Challenges Facing Battery Electric Buses

- Economic Performance
- Refueling Time
- Driving Range
- Infrastructure Needed

Despite their superior environmental performance and highly efficient operation, BEB are subject to many challenges limiting their massive market penetration.
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Method: Outline

Step 1: Energy Model and Analysis

Step 2: Techno-Economic Analysis
Step 1: Energy Modeling and Analysis

Introduction

Benefits

Challenges

Method

Results

Conclusions

Legend

Mechanical Connection

Electric Connection

Signal Routing

Fluid Flow

Battery Thermal Management System

Power Source Battery

TCU

MG

RG

Final Drive Brakes

Cabin

Propulsion System

Cabin - HVAC

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Step 1: Energy Modeling and Analysis

- **Total bus Energy Consumption**
  - a. Maximum Passengers Occupancy [100%]
  - b. Average Passengers Occupancy [50%]
  - c. Low Passengers Occupancy [10%]
Step 2: Techno-Economic Analysis

Total Cost of Ownership

- Battery Costs
- Energy Costs
- Demand Charge
- Infrastructure Costs
- Battery Replacement Costs
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BEB Line Specifications
- Bus line 21 in Paris
- 20 BEBs
- Stade Charlety Paris 13ème to Gare Saint Lazare Paris 8ème

Driving Conditions
- One-way trip is 9.7 km.
- Average duration is 1°, 25’.
- 34 Stop stations / direction
- Depot is One terminal station

Passenger’s Occupancy
- Passengers’ flow data
- Collected over a 3-week period
- June-July 2019

Schedule

<table>
<thead>
<tr>
<th>Time [hh:mm]</th>
<th>Bus Frequency [mins]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:30 - 7:00</td>
<td>15</td>
</tr>
<tr>
<td>7:00 - 8:30</td>
<td>8</td>
</tr>
<tr>
<td>8:30 - 13:15</td>
<td>10</td>
</tr>
<tr>
<td>13:15 - 17:45</td>
<td>12</td>
</tr>
<tr>
<td>17:45 - 20:00</td>
<td>8</td>
</tr>
<tr>
<td>20:00 - 00:30</td>
<td>15</td>
</tr>
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</table>

Cost Model Parametrization

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Cost of battery pack</td>
<td>580 €/kWh</td>
</tr>
<tr>
<td>Electric energy tariff</td>
<td>0.17 €/kWh between 6:00 – 23:00</td>
</tr>
<tr>
<td>0.13 €/kWh between 23:00 – 6:00</td>
<td></td>
</tr>
<tr>
<td>Battery max capacity fade</td>
<td>0.2 (20%)</td>
</tr>
<tr>
<td>BEB end lifetime</td>
<td>12 years</td>
</tr>
</tbody>
</table>
Results

- Maximum allowable charging power decreases:
  - Reduction in:
    - Infrastructure Costs
    - Battery Replacement Costs
    - Demand Charge Costs.

- Battery size increases:
  - Additional Battery Costs and Energy Costs
  - Increase in Punctuality Index → lower charging frequency
Results

- **Trade-off(s) between costs and operability**

  - Maximum allowable charging power decreases:
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### End-Line Charging

<table>
<thead>
<tr>
<th>TCO [€/km]</th>
<th>Punctuality Index [%]</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>80</td>
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<tr>
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<td>85</td>
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<tr>
<td></td>
<td>100</td>
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<td></td>
<td>105</td>
</tr>
</tbody>
</table>

- **Kb**: 120 kWh, 150 kWh, 200 kWh, 250 kWh
- **P_Max**: 100 kW, 120 kW, 150 kW

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The proposed methodology could be applied to any BEB fleet.
Thank You

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