Smart City Concepts in Curitiba
Innovation for sustainable mobility and energy efficiency

Project NEWSLETTER, November 2016
The Project

Overview

In 2013, KTH, the City of Curitiba, universities and the Federation of Industries of the State of Paraná signed a Memorandum of Understanding to develop projects in the areas of mobility, urban planning and environment. A consortium was formed in 2014, including KTH Royal Institute of Technology, VOLVO, COMBITECH, UTFPR (Federal University of Technology – Paraná), URBS (Urbanization of Curitiba S/A) and IPPUC (Urban Planning and Research Institute of Curitiba) to explore the deployment of technologies for improved mobility and energy efficiency in Curitiba, Brazil. The project newsletters provide insights into activities performed in the framework of the project Smart City Concepts in Curitiba – innovation for sustainable mobility and energy efficiency funded by VINNOVA and consortium partners. In this issue, we focus on activities and results from February to October 2016.

For more information on the project, please, check the link:

http://www.kth.se/en/itm/inst/energiteknik/forskning/ecs/projects/smart-city-concepts-

Large Potential to reduce Energy use and Emissions

In the BRT (Bus Rapid Transit) system in Curitiba

The city of Curitiba in Brazil has recently committed to introduce clean buses in its public bus fleet to reduce greenhouse gas emissions (GHG) and improve air quality in the scope of the C40 network.

We have analysed fossil energy consumption and greenhouse gas emissions scenarios for the BRT (bus rapid transit) system in Curitiba until 2030, using a Well-to-Wheel analysis (i.e. fuel production and city bus operation). The analysis covers 17 fuel pathways and seven different domestic feedstock for fuel production. The transport fuels analysed include biofuels (fatty acid methyl ester, hydro-treated vegetable oil, ethanol, compressed-, liquefied- and through synthesis converted biomethane), fossil fuels (petroleum diesel, compressed natural gas, liquefied natural gas, dimethyl ether, liquefied petroleum gas) and electricity. The study reveals a huge potential to reduce fossil energy consumption and emissions by switching to biofuels and electricity in the city’s BRT system. A business as usual track (BAU), i.e. no changes between 2016 and 2030, will result in an increase of both fossil energy consumption and GWP\textsubscript{100} (Global Warming Potential) by 24% compared to 2016. Increasing biodiesel in the bus fleet’s fuel mix from currently 20% (2016) to 40% or 60% (2030) can reduce the GWP\textsubscript{100} by 19% and 37% respectively, compared to the BAU scenario.

The use of electric buses up to 20% (2030) in the bus fleet can reduce both fossil energy consumption and GWP\textsubscript{100} by 33% compared to the BAU scenario.

Energetic and environmental impacts of transport fuels depend strongly on their Well-to-Wheel pathways. In any case, the BRT system in the city of Curitiba has a large potential to become more sustainable by using local renewable resources. An electrification of the bus fleet is particular beneficial due to the almost entirely electricity generation by hydropower in the region. Such a shift will help Curitiba meet its commitment under the C40.

Energy and Greenhouse Gas Emissions Scenarios for the Bus Rapid Transit System in Curitiba, Brazil

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Decarbonizing the bus fleet in Curitiba

- The city of Curitiba is part of the 4C6 Cities Climate Leadership Group (4C6) which includes commitments to promote sustainability. Public bus transport is an area of particular interest to the city.
- The accumulated distance driven by buses in the city’s bus rapid transit system (BRT) was 11.2 billion km in 2015. Fuel mix: 80% biodiesel, 20% biodiesel (FAME) [1].
- What impact will alternative fuels and advanced bus technologies have on the decarbonization of Curitiba’s BRT system?[2]

Methodology

- Pathways of 13 different transport fuels derived from 9 domestic feedstocks were analyzed using the GREET model [2].
- Energy and greenhouse gas emissions scenarios were modeled using the LEAP modeling tool [3].
- Real-world operation data for the BRT system were provided by the local public transport company in Curitiba [1].
- The business as usual (BAU) scenario is compared with potential future scenarios between 2016 and 2030.

Fuel Pathways – Feedstock

- Well-to-Wheel (WTW) fossil energy consumption accounts for all fossil energy consumed in a fuel pathway to produce and supply a fuel, covering all stages from feedstock recovery until refueling station (Well-to-Tank (WTM)) as well as the fuel use stage (Tank-to-Wheel (TTW)). Functional unit for WTW analysis: 1 Mio. passenger-kilometers (PKM) with electricity as a reference fuel. The energy content of renewable fuels is estimated based on the Energy Return on Investment (EROI) ratio.

Energy and Greenhouse Gas Emissions Scenarios 2030

- A business as usual track (BAU), i.e., with no changes between 2015 and 2030, will result in an increase of both fossil energy consumption and global warming potential on a 100-year horizon (GWP100) by 24% compared to 2015.
- Increasing biodiesel in the bus fleet’s fuel mix from currently 20% (2016) to 40% or 60% (2030) can reduce the GWP100 by 19% or 37% compared to BAU, respectively. In combination with a use of 40% hydrogen-based, the GWP100 can be reduced by 47%.
- Increasing the use of electric buses from 0% (2016) to 20% (2030) in the bus fleet can reduce both fossil energy consumption and GWP100 by 33% compared to BAU.

Conclusions

- Energy and environmental impacts of transport fuels depend strongly on their Well-to-Wheel pathways. The major advantage of biofuels is their exclusively bioenergy-based energy content that reduce enormously fossil energy consumption and CO2 emissions in the Tank-to-Wheel stage compared to fossil derived transport fuels.
- The BRT system in the city of Curitiba has large potential to become more sustainable by using local renewable resources. A partial electrification of the bus fleet is particular beneficial due to the almost entirely electricity generation by hydro power in the case of Curitiba.

References:

Download the poster here:

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Volvo Hybrid Electric and Hybrid Articulated buses

Demonstration tests in Curitiba

Two new types of city buses are operating in Curitiba in the scope of this project. The demonstration phase is planned for approximately six months. The “HibriPlus” (Volvo 7900 Hybrid Articulated) started operation on the 18th March 2016. This bus has capacity for 154 passengers and operates on the circular bus route Interbairros II (anti-clockwise) in Curitiba.

The “HibriPlug” (Volvo 7900 Electric Hybrid) started its operation on the 29th June 2016. This modern designed standard bus has capacity for 91 passengers, and offers WiFi. It operates on the Juvevê-Agua Verde passenger line, a 11.2 kilometers long route used by around 2200 passengers per day.

With plug-in technology in the “HibriPlug”, the hybrid-electric bus allows battery charges to be topped up at passenger boarding and debarkation points. The charging station is installed at a bus stop in a small square in Menezes Doria Street, neighbourhood Hugo Lange. The system reduces up to 75% the consumption of diesel and, consequently, emission of pollutants. In addition, the model’s total energy consumption is 60% lower than those powered by diesel, representing a huge environmental gain for the city.

“This is one more step taken by Curitiba towards sustainability. We want to increasingly incorporate new technologies and reduce the levels of emissions in the urban environment – we need to think about solutions that benefit a large number of people, and place the collective interest above the individual”, affirms Gustavo Fruet, mayor of Curitiba.

“This vehicle is one more step towards consolidating Volvo’s electro-mobility project in Latin America. We have a long track record of partnership with Curitiba, city where the Volvo Group’s Latin America headquarters are located, says Fabiano Todeschini, president of Volvo Bus Latin America.
The bus offers operational flexibility, and can operate in 100% electric mode in defined areas with no emissions of pollutants or noise, and in hybrid mode anywhere along the route, thanks to Zone Management. The vehicle data is monitored through telematics, using the Volvo fleet management system. The system provides information such as fuel consumption, emission of pollutants, distance covered in 100% electric mode, and use of energy generated through braking which charges the battery for the electric motor.

The tests being made include also collaboration with Siemens, Ericsson, SETRANSP (Bus Company Employer’s Union of Curitiba and Metropolitan Region), and the urban transport operators Redentor, Cidade Sorriso and Glória, in addition to the consortium partners in our project.

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Joint Planning of Small Cells and Optical Transport

Deployment in heterogeneous mobile networks

In order to cater for the exponential growth of mobile traffic, operators need to upgrade their mobile networks and provide higher capacity to the users. Improvements in the radio access technology alone (e.g., radio interfaces with higher spectral efficiency) might not be sufficient.

A promising alternative is to deploy heterogeneous networks (HetNets) that combine macro base stations (BSs) and small cells (SCs). In HetNets, macro BSs are used to provide wireless coverage, while a layer of SCs is employed to offer the required data-rate to the users. However, HetNets increase the complexity and the cost of the transport network (i.e., the network segment connecting the base stations to the evolved packet core (EPC) of the mobile operator) due to the large number of SCs that need to be connected. Consequently, it becomes important to investigate how to best dimension the radio and transport resources in order to reduce the network deployment cost in HetNets. We have looked at a heuristic for the joint dimensioning of radio (i.e., SCs) and transport (i.e., point-to-point fiber links) resources. Our heuristic aims at minimizing the overall network deployment cost, while guaranteeing the required data-rate to all the users in the network.

As shown in the Figure A.1, we compare our heuristic to a benchmark approach that aims at minimizing only the cost related to the radio
network resources (i.e., SCs). Simulation results show that the proposed heuristic may deploy a higher number of SCs (i.e., when compared to the benchmark), but it is still able to reduce the HetNet deployment cost by up to 24%, thanks to its ability to re-use as much as possible the transport infrastructure connecting the SCs.

Students at UTFPR evaluate the Quality of Service (QoS)

Of WIFI connections offered inside the city buses HibriPlug and HibriPlus

The on-board service is provided by Ericsson in this test bed. The QoS perceived by the user depends not only on the WIFI access point supporting a number of users inside the bus but also on the quality of the mobile broadband uplink that connects the bus to the Telco operator, the user equipment, etc.

The field test considers the number, location, nominal power transmission from Telco base stations, signal reception on cellphones, geolocation

of the bus. During the test days, the signal reception was monitored by the students and the quality of experience (QoE) of the user considered while using apps through the free WIFI service inside the bus. Until now, the UTFPR had no access to data from the bus WIFI equipment. Figure B.1 shows the students taking the bus at the Terminal.

Figure B.2 shows the location of bus stops of Line Interbairros 2 (yellow dots) and the Base Stations of Vivo Telco operator (the one providing broadband data service to the bus).

A typical example of result from a test day is shown in Figure B.3. The test was carried out in the new Volvo articulated hybrid bus at the bus line Inter neighborhood 2 in Curitiba in distinct days of June 2016. The Base Station (BS) location were provided by the National Telecom agency (ANATEL).

Figure B.3. Location of Base Stations from the Telco operator Vivo nearby the bus route. Circles are related to GSM signal samples collected during the field test.

Figure B.4 shows a snapshot of differences on the signal reception (sample colours red to green).

Figure B.4. Example of measurements associated to a red dot sample.

Figure B.5 also shows details of the measurements on selected samples (note that the received signal came from distinct Cells).

The collected data is now under analysis and the same process will be done for future field tests related to the bus line 285 (electrical hybrid bus, plug in).
Analysis and Demonstrator Platform for Charging Logistics

For hybrid buses

The introduction of plug-in hybrid-electric buses in transportation systems creates new challenges. These buses are powered by a combination of diesel and electric engines, and their batteries need to be recharged during operation. Current technology allows full charging times around 6 min. However, this can cause serious drawbacks on bus schedules that usually set headways to 15 minutes in average. Therefore, efficient strategies are needed to coordinate charging of batteries during operation with minimum perturbation on time schedules while also providing enough autonomy in full electric mode to meet environmental and energy saving criteria.

The big picture considers a charging yard where several plug-in buses arriving at terminals with different time slots and battery levels should be coordinated to get their batteries charged. This project has involved people from the Federal University of Technology - Paraná (UTFPR) in Brazil, Combitech, and Volvo, with support from KTH and CISB. The addressed issues concern decisions on priorities for charging, charging times, and minimization of delays in bus schedules.

Gustavo Rodrigues de Souza, a MSc student from UTFPR, has been working on a simulation model that captures the dynamic behaviour of terminal Pinheirinho in Curitiba (Figure C.1). This terminal integrates 34 routes and 180 buses transporting approximately 102,000 passengers in a weekday from 5 am to 2 am. The results obtained so far simulates the current operation of terminal Pinheirinho. The bus traffic in the terminal has been evaluated and the first studies on placement of a charging station have been carried out. Currently, the work focuses on coordination strategies for allocating buses to a charging station by taking into account telemetry data for battery levels and estimates of bus arrivals as well as roundtrip distances and headways between buses, among others. The telemetry data is generated from the Volvo hybrid bus launched in Curitiba May 2016 - see report in this newsletter. Forthcoming activities should consider the integration of the simulation model into a commercial decision making product of Combitech as a test-bed for real-world applications in monitoring and control of transportation systems in a smart city.

Figure C.1. Simulation model for the dynamic behaviour of terminal Pinheirinho in the city of Curitiba.
Smart city concepts in Curitiba

Task 3: Analysis and demonstrator platform for charging logistics for hybrid buses

Federal University of Technology – Paraná (UTFPR), KTH, Combitech, CISB

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Abstract

A consortium of Swedish and Brazilian stakeholders will promote system innovation, combining information technology and smart grids to develop electrification, mobility, and energy efficient and low-carbon transport services in the city of Curitiba aiming at sustainable urban development. The project includes demonstration of technological solutions by VOLVO and Combitech to provide smart mobility and a platform for information monitoring and sharing. Research work is carried out by KTH and UTFPR to test and adapt concepts to the context of Curitiba. Task 3 has been designed to provide a demonstrator platform for studying the impact of introducing plug-in hybrid electric buses into a conventional terminal (or hub) integrating several bus routes. A discrete event simulation model is developed to provide information to a data acquisition system. Partial results obtained so far show the circulation of buses in Pinheirinho terminal that integrates 34 routes with 180 cars operating from 05:00 am to 02:00 am hours, and transporting approximately 162,000 passengers during a weekday.

Keywords: Plug-in hybrid electric bus, battery charging logistic, discrete event simulation, data acquisition system.

Introduction

The changing requirements for the terminals as well as a probable need of a support system for the real time planning of the logistic process regarding charging is studied in this task. The overall purpose is to allow the efficient use of hybrid electric buses and the associated charging stations. When adding charging infrastructure for electrical buses to a terminal the flow of the terminal is changed in a number of ways:

- Charging stations are a limited shared resource among the electric buses;
- A bus can’t get access to a charging station immediately when entering the terminal and is queued for charging;
- Charging stations might not be placed with passenger’s pick-up stops, which increases the time spent at the terminal;
- To compensate for buses tied up in the charging process it might be necessary to add additional buses to the fleet to meet timetables.

The objective of Task 3 is to develop a study regarding suitable strategies for yard management and dimensioning of charging infrastructure when using hybrid electric buses as well as a demonstration platform illustrating a possible Charging Yard Management System for the real time management of the charging logistics.

Methodology

The behavior of arrivals and departures of buses in Pinheirinho Terminal is simulated by Simio\(^1\) (a discrete event simulation software). The simulation model is developed to capture the behavior of buses in the terminal that affects their timetables such as stops for boarding of passengers, time for charging batteries as well as conflicts generated by shared paths.

![Diagram process](image)

Figure 01 – Diagram process

The simulation is then used to generate information to a data acquisition system which is able to monitor operational variables such as charging demand, utilization of charging stations and priorities to provide a suitable coordination of charging activities based on different criteria.

Pinheirinho Terminal

![Pinheirinho Layout](image)

Figure 02 – Pinheirinho Layout

Results

<table>
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<tr>
<th></th>
<th>Time (min)</th>
<th>Time Recharging (min)</th>
<th>Time at station (min)</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
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<td>0</td>
<td>5</td>
<td>120</td>
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<tr>
<td>Depart</td>
<td>12</td>
<td>2</td>
<td>7</td>
<td>180</td>
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<tr>
<td>Enter</td>
<td>15</td>
<td>4</td>
<td>9</td>
<td>240</td>
</tr>
<tr>
<td>Exit</td>
<td>18</td>
<td>7</td>
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<tr>
<td>Overall</td>
<td>36</td>
<td>16</td>
<td>31</td>
<td>540</td>
</tr>
</tbody>
</table>

Table 01 – Comparative Results

Conclusion

Task 3 is designed to provide a demonstrator platform for studying the impacts of introducing plug-in hybrid electric buses in Pinheirinho terminal which is part of Curitiba public transportation in Brazil. This platform is currently implemented by a simulation model that will be eventually integrated with a data acquisition system providing tools for monitoring and coordinating battery charging tasks. The partial results obtained so far show the current behavior of circulation of buses in the terminal and consider an initial proposal for a charging station. Future work will detail the dynamics of battery charging as well as a proposal for integration with the SAFE\(^2\) platform used for charging yard management.

Acknowledgement

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\(^1\)Simio is trademark of Simio LCC.

\(^2\)SAFE is trademark of SAAB AB.
Other Activities related to KTH and Curitiba Cooperation

How successful has the BRT system been in Curitiba?

Klara Bergman, a KTH master’s student spent 2.5 months in Curitiba doing research on the BRT system. Klara works with Professor Joel Frankling from KTH and Professor Tatiana Gadda from UTFPR. The goal of the research is to measure the success of the BRT system through statistical and spatial analysis using GIS (geographic information system). The connection between land use and BRT is important when looking at the property development patterns in relation to BRT accessibility benefits and density regulations. The analysis focuses on building data close to the structural axis, traveller data of the BRT system for the past 40 years and environmental concerns of the system in relation to the city plan. In 1966, the city of Curitiba approved a master plan for urban development that included a strong focus on public transportation in connection to land use. The creation of structural axes with high building densities close to public transportation was in the core of the plan. From the mid 1970’s, the plans started being implemented, and a bus system was created, eventually growing into a full-scale BRT (bus rapid transit) system. The BRT system in Curitiba is one of the oldest BRT systems in the world and provides interesting lessons about the potential of BRT systems.

Smart City Concepts in Curitiba

Key-objectives of the project

- Demonstration of new technology for mass transport corridors
- Planning of plug-in hybrid-electric bus operation
- Providing high-capacity wireless broadband along Curitiba transportation corridors
- Energy and climate scenarios with improved environment and mobility
- ICT infrastructure for Open Data integration and interactive information sharing
- Planning of electro-mobility in Curitiba