Smart city concepts in Curitiba

Innovation for sustainable mobility and energy efficiency

EXECUTIVE SUMMARY

February 2018

Executive summary

This report provides the outcomes of the project ***Smart City Concepts in Curitiba – innovation for sustainable mobility and energy efficiency*** (henceforth denominated Project). The Project was developed between Oct 2014 and Dec 2018 by a consortium composed of partners from Sweden and Brazil operating in academia, as well as public and private sectors. In addition to the contributions of consortium partners, the Project received funds from the Swedish innovation agency VINNOVA.

The Project was conceived under the collaborative umbrella established in a MoU signed in November 2013 between KTH, the City of Curitiba, universities and Federation of Industries of the State of Paraná to promote innovative solutions for urban challenges.

The overarching objective was to explore innovative and sustainable solutions for urban mobility with potential to improve energy efficiency and reduce greenhouse gas emissions. The focus was on challenges related to electrification of public bus transport.

Two electric bus technologies were tested, their environmental impacts evaluated, and opportunities and challenges related to up-scaling electric bus systems were analyzed. The Project also explored the role of information technologies for improved planning and operation of public transport, connectivity and quality of mobility services.

The transformation of urban infrastructure needs to be orchestrated by planners in dialogue with different urban agents including politicians, planners, service operators, users, experts and citizens. Therefore, the Project was developed using a system approach and included the participation of multiple stakeholders. In this way, a transdisciplinary collaboration in search for co-creation of solutions and options for the city was established.

Launching of MoU to promote innovative solutions for urban sustainability in 12th Nov 2013

Launching of test-bed using the Volvo electric hybrid bus

Juvevê-Água Verde Route (285)

The Project team at launching event in Curitiba

June 2016

About Curitiba

Curitiba has approximately 1.74 million inhabitants and a long history of planning for sustainable development. The city has a legacy of transportation planning and is known as a *Sustainable City,* a title that is largely related to innovative urban planning concepts. Curitiba has developed and implemented urban concepts that have shaped the city landscape, including the creation of mass transport corridors and mobility solutions using bus rapid transit (BRT) systems. Curitiba aims at

transitioning to a low-carbon transport system in consistence with its historic legacy of sustainability. This is illustrated by its joining the C40 group in 2014 and committing to reduce greenhouse emissions. In this context, the city needs to take further steps to develop urban mobility, introducing new transport technologies and prioritizing among goals such as energy efficiency, local and global environmental impacts, safety, convenience, cost minimization, among others.

Buses constitute 1% of the road fleet in Curitiba but transport 45% of the population. Although other measures are needed to address sustainable mobility in the city, the electrification of the bus system holds significant potential for carbon abatement. Bus electrification can be a starting point also for car electrification, and serve to address problems such as air and noise pollution. Thus, further understanding is needed about opportunities, benefits and impacts of bus electrification. This has been a major motivation for this Project.

Major impact of the project

- The Project evaluated multiple dimensions of electro-mobility for public transport, systematically analyzing different aspects of electrification of bus transport in the context of Curitiba. The tasks implemented include demonstration of two electric buses in existing bus routes in Curitiba; analysis of the impacts of bus electrification on energy efficiency, greenhouse gas emissions, and local pollution and noise; and evaluation of the role of ICT infrastructure and digitalization in sustainable mobility. The results provide valuable insight to policy makers as they plan for the next step in the development of sustainable mobility. The impact is evident in the dialogue established between the university and the local technical offices, i.e. URBS and IPPUC.
- The Project contributed to the City of Curitiba adopting a policy of open data. This was key to the realization of the project and the engagement achieved among university students and researchers. The open data was useful for students to get involved in real problems of the city and to contribute solutions.

Many meetings, workshops, technical visits, and presentations to policy makers were carried out



- The Project served to develop a strong collaboration between the consortium partners which include KTH, UTFPR, the City of Curitiba, URBS, IPPUC, CISB and private companies (i.e. Volvo, Combitech). This was further extended to include other companies, i.e. Ericsson and bus operators. At the academic level, strong ties were created between KTH, UTFPR and other local universities. This contributed to exchange of researchers and faculty, the organization of seminars, pedagogical development in the form of joint courses, joint publications and conference participation, and collaboration in research proposals. The close cooperation with officials in the municipality paved the way for evidence-based policy development and improved transport service management. The participation of companies in the constellation of stakeholders helped build up trust and highlight their role in the transformation of the city.

- The Project led to formation of a transdisciplinary Swedish-Brazilian platform that serves to catalyze multiple projects on topics related to urban sustainability. From a triple-helix model involving academia, public and private organizations from both Sweden and Brazil, the Project evolved into a transdisciplinary effort allowing the participants to innovate together, and form new constellations for collaborative projects. In addition, the collaboration has provided the basis for enhanced Swedish-Brazilian cooperation at state level (i.e. State of Paraná).

Testing electric buses in Curitiba

Two test-beds were implemented along existing bus routes for (i) a hybrid-electric and (ii) a plug-in hybrid-electric bus. They served to demonstrate new bus technologies in Curitiba, and collect insights on operational requirements. The benefits of electrified bus transportation such as increased energy efficiency, reduced greenhouse gas emissions and silent driving were quantified. Insights were provided in relation to the challenges implied in up-scaling bus electrification.

Buses tested in Curitiba for the first time, and details of the safety zone and routes circulated

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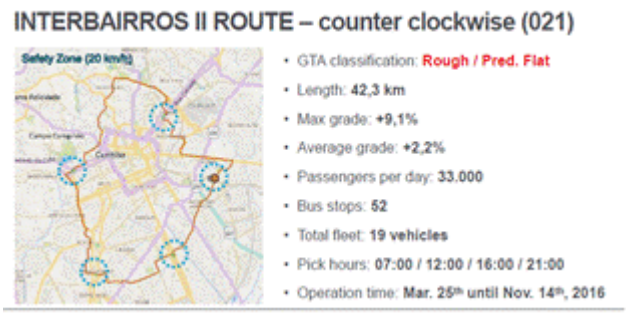
Volvo 7900 Hybrid Articulated in Curitiba, operations started on 18th Mar 2016</td>
<td> 
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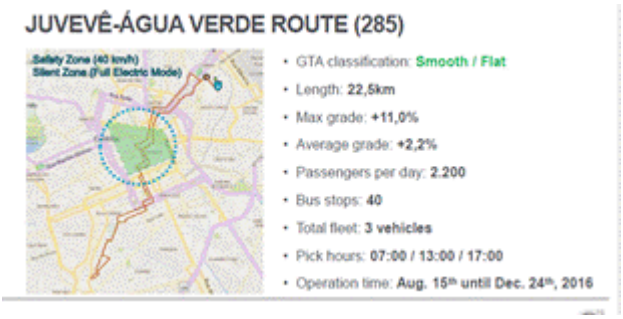
Volvo 7900 Electric Hybrid in Curitiba, operations started on 29th Jun 2016</td>
<td> 
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The Volvo 7900 Articulated Hybrid has a passenger carrying capacity of 154 passengers and operated on the circular bus route Interbairros II. The Volvo 7900 Electric Hybrid has a passenger carrying capacity of 91 passengers. It was operated on the bus route Juvevê-Agua Verde (route 285), a long route of 11.2 kilometers used by around 2,200 passengers per day. A charging station was installed at a final bus stop in a small square in Menezes Doria Street. The buses could operate in full electric mode in pre-defined safe zones downtown Curitiba.

The analysis of energy efficiency and greenhouse gas emissions reductions potentials carried out covered the different types of city buses used in Curitiba: conventional two-axle city bus, hybrid-electric two-axle city bus, plug-in hybrid-electric two-axle city bus, conventional bi-articulated city bus, and a hybrid-electric articulated city buses. The assessment was done on the whole fuel-cycle,

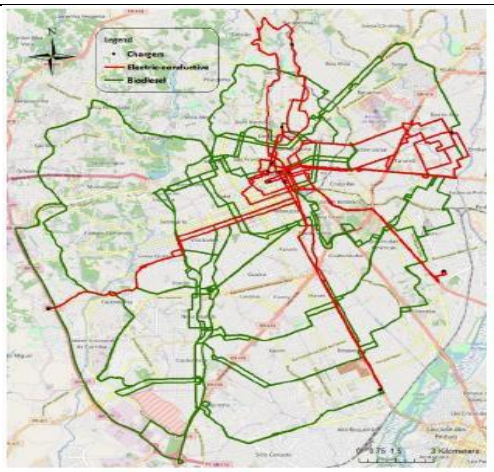
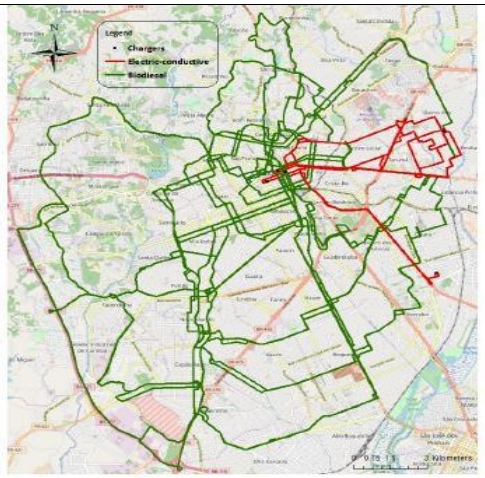
i.e. Well-to-Wheel (WTW) which in turn includes Well-to-Tank (fuel production and supply) and Tank-to-Wheel (vehicle operation). Real-world driving patterns were collected and provided by URBS in Curitiba, and different operation times and bus routes were considered.

The results show that a hybrid-electric two-axle city bus can reduce WTW fossil energy use per kilometre by 30%, and a plug-in hybrid-electric two-axle city bus by 75% compared to a conventional city bus of similar size. Thus a bus substitution would give a reduction of 1.1 kg of CO_2 equivalent for every driven kilometre. Although the conventional bi-articulated city bus does not operate in any electric mode, it can still be beneficial to operate it during peak-hours when many passengers are carried. In this case, it can achieve lower energy consumption than hybrid-electric buses in terms of energy use per passenger-kilometre. However, bus driver behaviour, passenger load and fuel prices fluctuation can affect the overall environmental benefits.

Since plug-in hybrid-electric buses are powered by a combination of diesel and electric engines, the on-board battery needs to be periodically recharged to power the electric motor. This is required in order to benefit most from the electric buses. Current charging technology can recharge the on-board battery within 6 minutes. Therefore, a strategy is needed to effectively coordinate opportunity charging of batteries during operation, with minimum perturbation on the operation timetable, while also providing enough autonomy in full electric mode to meet environmental and energy savings criteria.

Priorities for charging, charging times, and minimization of delays in bus schedules, or even change in bus schedules, have to be considered to guarantee the logistic flow as electric buses are introduced. Currently, Curitiba's terminals are optimized for non-electric buses, and lack the charging infrastructure required to operate the electric buses. For an efficient use of hybrid electric buses in local bus lines, infrastructure requirements for the terminals need to be considered together with a support system for real time planning of the logistics of battery charging.

Scenarios for introduction of electric buses in the city of Curitiba

	
Energy optimization scenario. 12 bus lines (out of 26 pre-selected) are electrified. This requires 12 charging stations. Energy consumption is reduced by 12% and CO_2 emissions by 74%.	Cost optimization scenario. If electricity cost is reduced by 40%, six bus lines are electrified. Five charging stations will be needed. The cost of the charging station could be overcome if infrastructure is shared.

An efficient strategy is needed to coordinate the charging of batteries during the bus service operation. It is also important that the electric bus is provided with enough autonomy for operation in full electric mode to meet environmental and energy savings criteria, not least in the safe zone

(i.e. low pollution and low noise levels) defined for the city. Such a strategy will have to be conceived as the city plans for up-scaling the use of energy efficient technologies such as electric buses.

Up-scaling bus electrification can be achieved but requires attention to minimize costs and maximize the benefits. This is a key issue for decision makers as they contemplate multiple options to address transport needs and costs, and environmental requirements. An analysis of scenarios for the dissemination of electric bus technologies in Curitiba identified 26 routes for electrification. In an energy optimization scenario, 12 lines are electrified resulting in 12% reduction in energy consumption and 74% in CO_2 emissions compared to diesel (B7). There is a total cost increase of 9% when compared to the business-as-usual scenario. This is most related to higher vehicle costs and somewhat lower energy efficiency for biodiesel when compared to fossil diesel.

Electricity cost is high in Brazil and the higher efficiency of electric traction alone cannot compensate for that. Therefore, at present, electrification of bus transport is not cost-competitive. This could be changed if electricity prices are reduced and/or diesel subsidies are eliminated. As for the infrastructure, it will be very important to take an integrated approach in planning for the electrification of bus routes so as to use the charging stations in an efficient way, and reduce infrastructure costs.

Wi-Fi connection was provided in electric buses tested in Curitiba, and the Quality of Service (QoS) was evaluated. The QoS perceived by the user depends not only on the Wi-Fi access point inside the bus but also on the mobile broadband that connects the bus to the operator, the user device, and other connectivity issues. This means that, to offer good quality Wi-Fi experience on board the electric buses, certain requirements for hardware infrastructure, connectivity along the route and seamless software connections need to be met. Efficient and very high capacity wireless broadband connectivity has to be provided along the transport corridors so that high-quality wireless broadband services can be provided to the users, thus enhancing the experience during the journey.

Evaluation of connectivity for provision of Wi-Fi on board of electric buses

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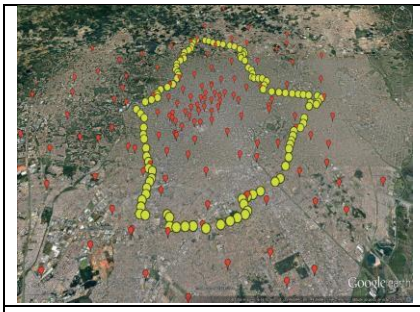
<td>  </td>
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<td>Stations along the route 21
(Source: ANATEL)</td>
<td>Quality of signal received inside the bus</td>
<td>Quality of signal received inside the bus in a specific sample</td>
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The road ahead

Cities are struggling to concomitantly provide good public transport services, improve local air quality and mitigate greenhouse emissions. While integrated concepts are being tested worldwide to improve the energy efficiency in cities and mitigate climate change, there is still much to do to achieve the goals stated in global agendas. Most of all, implementation of solutions remain a bottleneck ranging from planning, to research and funding. Sustainable transformations will require innovation at multiple levels. Along the past decades, Curitiba has been pro-active, exploring

innovative solutions to improve the quality of transport services for its citizens. However, a more stringent climate and development agendas requires low-carbon concepts.

In this Project, we took the challenge to promote action together with the City of Curitiba, and developed two test-beds for modern electric buses commercially. We aimed at demonstrating the new technologies and also at investigating functional, cost-efficient and environment-friendly concepts for taking new leaps in sustainable mobility in Curitiba. Our analysis shows that, while the use of hybrid electric buses can help to improve sustainability at local and global level, collaboration among many stakeholders is needed to actually realize the existing potential. Well-articulated urban mobility concepts will help improve the quality of services in the urban area, reduce environmental impacts and open new areas for development.

Fortunately, through the Project, a strong collaborative platform has evolved which resulted in increasing engagement among many stakeholders. It showed that trust can be built, data and information shared, and innovative concepts can be made reality. Joint efforts are needed so that actions are designed in an attractive and implementable way. They also need to be monitored so as to guarantee their effectiveness. This requires good and common understanding of the urban problems, collaborative planning processes, and methodologies for effective participatory actions.

The adoption of the triple-helix model in a bi-lateral project was innovative and delivered multiple benefits. The Project has become an international reference, and paves the way for enhanced cooperation between Swedish and Brazilian stakeholders in Curitiba and other cities in Brazil. Once more Curitiba proved to be in the innovative frontier as this model was further developed into a transdisciplinary model. In the latter, a collaborative platform composed of public, academic and private stakeholders from Sweden and Brazil was established, creating engagement and trust for the co-creation of solutions.

New challenges lie ahead to continue building institutional capacity for such a cooperative model, and implementing new concepts for sustainable mobility. The sustainable development agenda is a global agenda, but the trade-offs between immediate needs and long term objectives will have to be effectively addressed in the cities. Only then can a transformational and participatory urban agenda for sustainability become a clear path to the future of humanity.

Project presented in Nordic high-level meeting, COP 22 Climate Convention, Marrakech, Nov 2016

Summer School in Stockholm, Sept 2017 – a multi-stakeholder initiative

Partners

KTH Royal Institute of Technology (www.kth.se)
Volvo Buses AB (www.volvo.com)
Combitech AB (www.saabgroup.com)
City of Curitiba (http://www.curitiba.pr.gov.br/)
URBS – Urbanização de Curitiba S.A. (transport operations) (http://urbs.curitiba.pr.gov.br/)
UTFPR – Universidade Tecnológica Federal do Paraná (http://portal.utfpr.edu.br/)
CISB – Swedish Brazilian Innovation Centre, (www.cisb.org)
IPPUC – Curitiba Research and Urban Planning Institute (http://www.ippuc.org.br/)
VINNOVA (www.vinnova.se)

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Visit the project homepage at:
https://www.kth.se/en/itm/inst/energiteknik/forskning/ecs/finalized/smart-city-concepts-curitiba