ELECTRIFICATION OF PUBLIC TRANSPORT – FROM PILOTS TO ROLL-OUT

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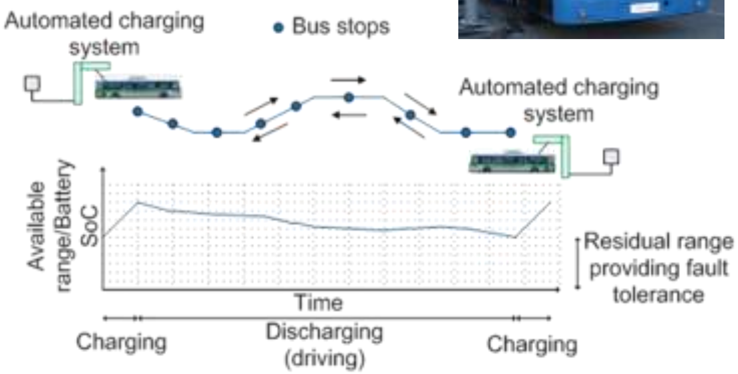
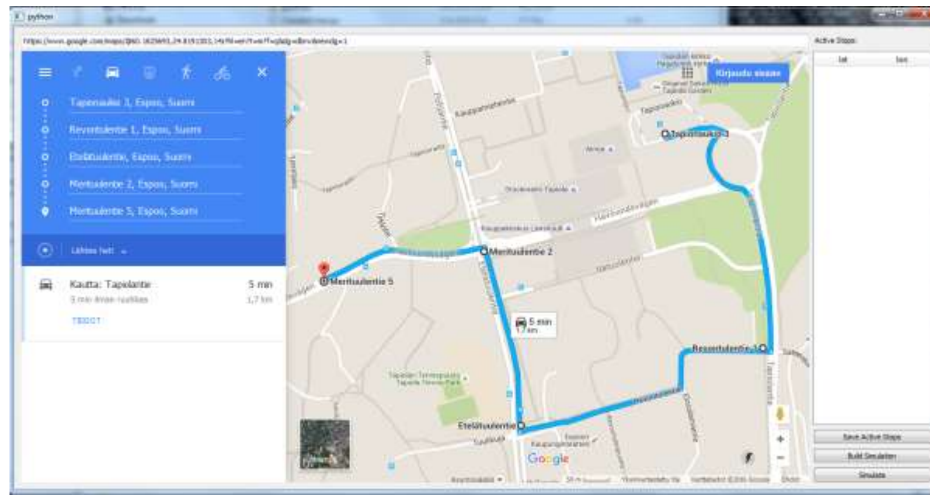
INTRODUCING ELECTRIC BUSES IN CITIES - QUESTIONS

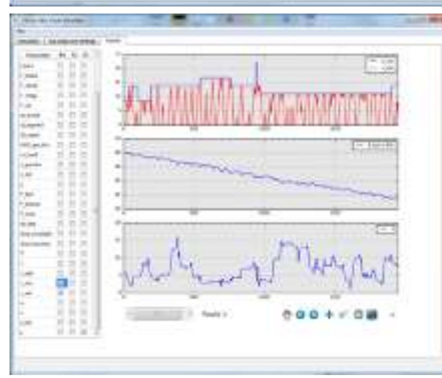
What is the cost of electric bus systems?
Which bus routes to electrify?
How to secure the reliability of the system?
Which technologies and operation concepts to adopt?
Where to place and how to dimension charging infrastructure?
What are the operational margins and flexibility?
How to prepare for disturbances?
How to procure, contract and finance?
How to scale up (roll-out phase)?

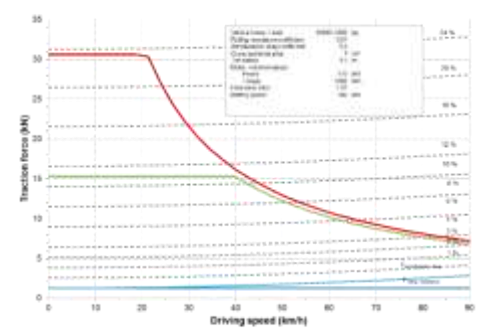


TOOLS FOR THE DESIGN OF ELECTRIC BUS SYSTEMS

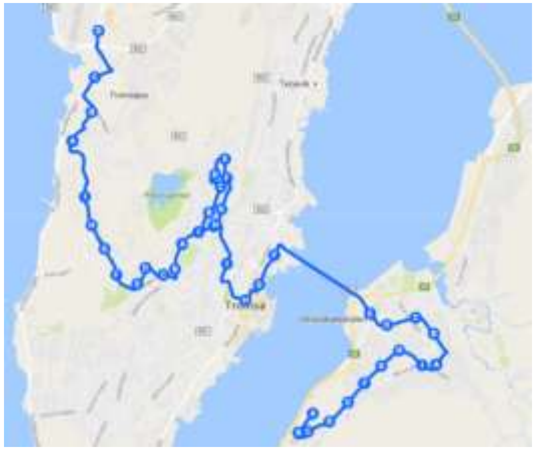
- **Global applicability: use of <u>open-source inputs</u>**
- **Utilise existing data from environment, road network and public transportation system registers, schedules, GTFS etc.**
  - Any city, route or duty
- **Technology database**
  - Efficiency maps of components
  - Environmental conditions and energy use
  - Connection times
- **Validation by comparing to data from real operation**

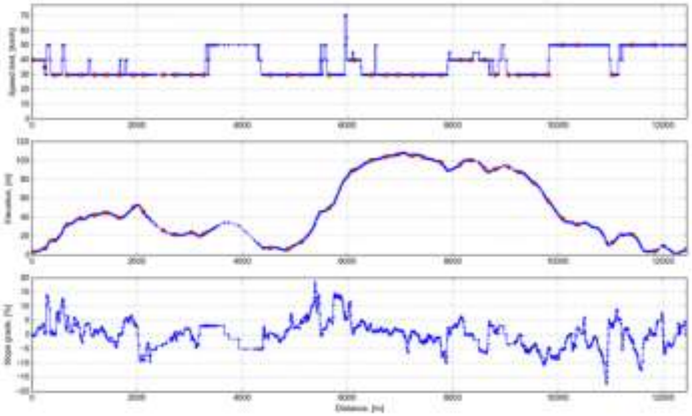






FROM GENERIC TO CITY-SPECIFIC ANALYSIS





Construction of bus routes / network from digital map data or open sources

- Finding out most potential routes to electrify
- Dimensioning the powertrains
- Location and dimensioning the charging nodes
- Analysing the sensitivity of operations and margins

Necessary when moving to roll-out: city-specific analysis

- ✓ analysis of fleets, operational scenarios
- ✓ statistical analysis, optimisation

ELECTRIC BUS SYSTEM KPI'S FROM PTA POINT OF VIEW

Sustainability: positive environmental and societal impacts on emissions and noise

Productivity: the size of the fleet and labour costs (the number of drivers) are critical for the TCO

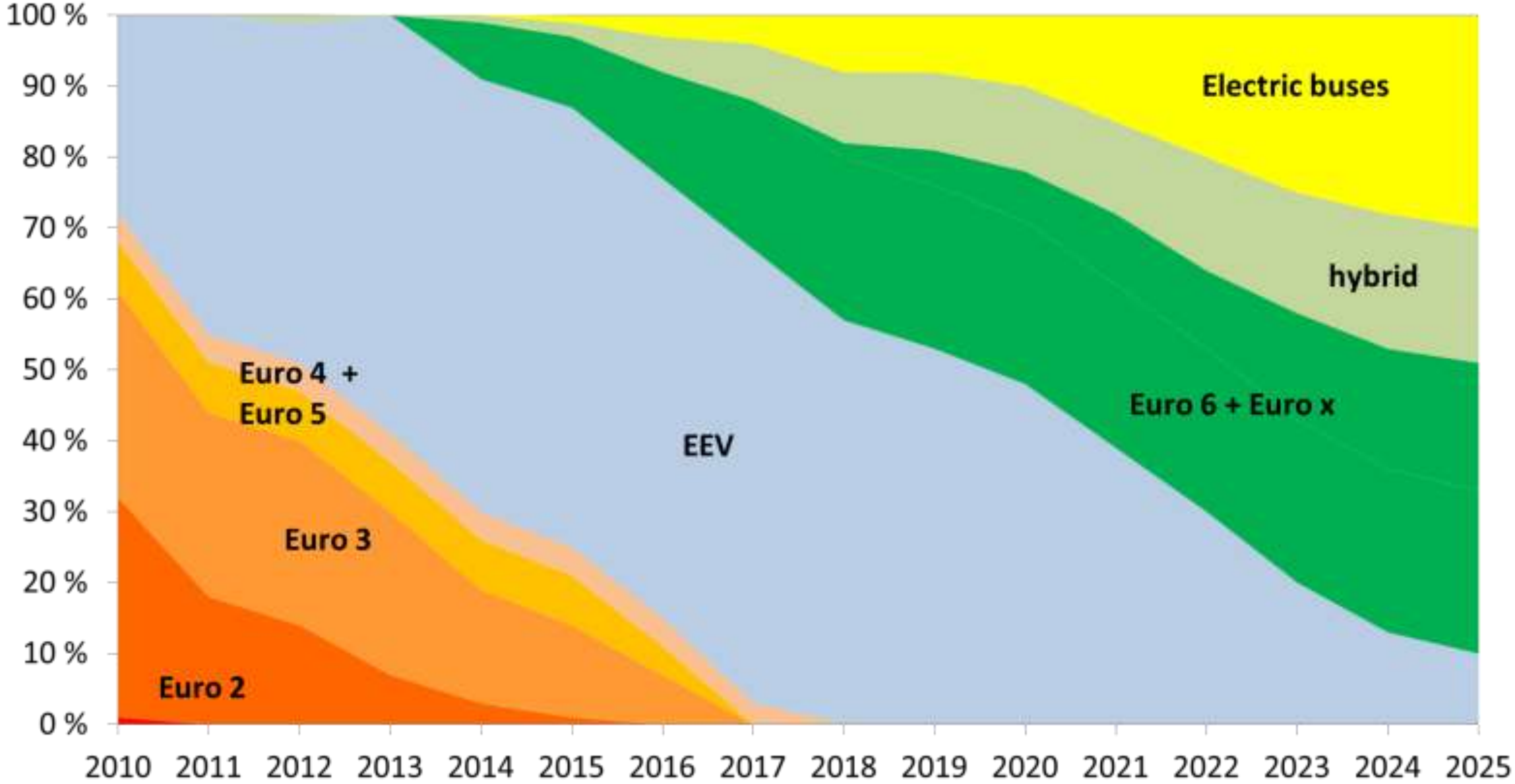
Operability: the electric buses have different energy management than diesel buses – range limitation

Reliability and availability: system-level reliability and availability of both vehicles and charging – critical for TCO

Attractiveness and comfort: the level of service and passenger comfort need to be the same or better compared with conventional buses

HELSINKI REGION ELECTRIC BUS PRE-COMMERCIAL PILOT

HELSINKI REGION TRANSPORT FLEET STRATEGY



Estimated effect on emissions by 2025 (compared to 2010): reduction of NO_x (-92%), PM (-95%), CO_2 (-90%)

- For conventional buses, biofuels are phased in and constitute 100% from 2020 onwards

”VEHICLES”: TECHNOLOGY DEMO

The aim was to find out usability of electric buses in commercial transport

Field study and laboratory research

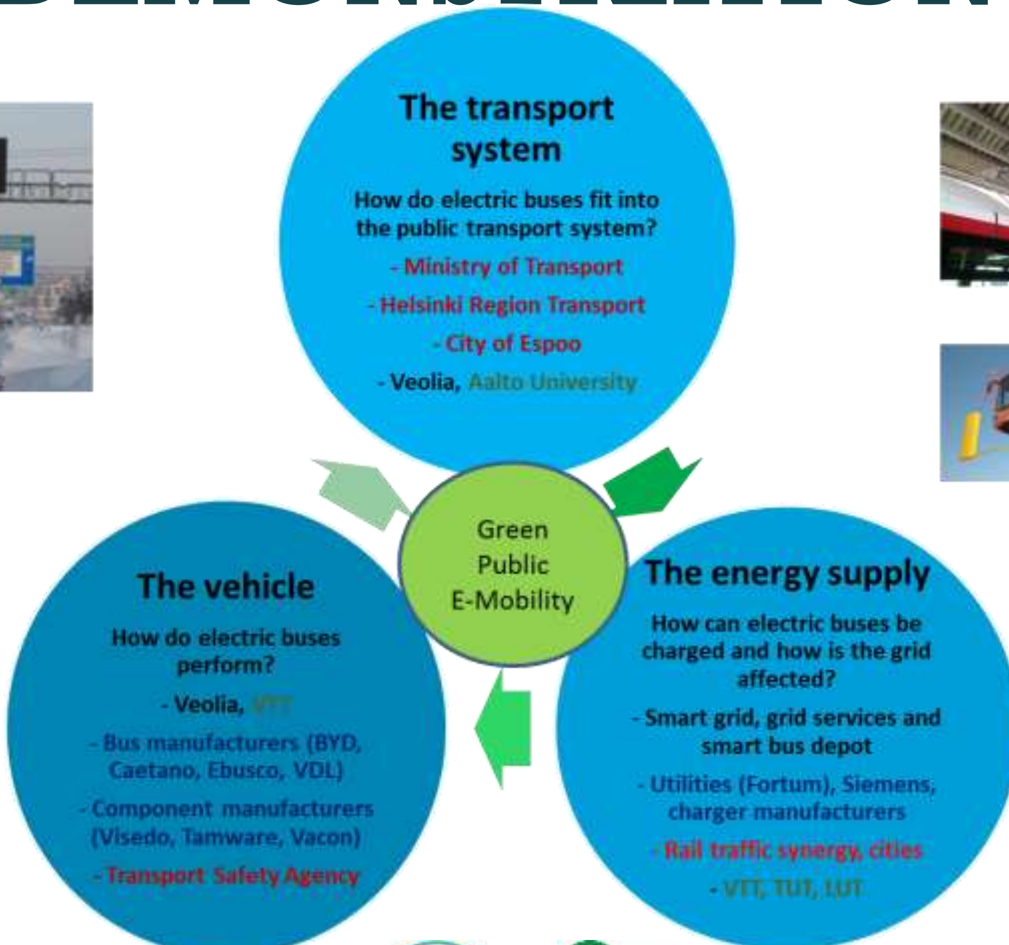
- Electric bus test line 11 Tapiola-Friisilänaukio
- Four commercial eBuses in operation
- Vehicle technology analysis
    - Full-size VTT-owned electric bus prototype as a development platform
- Battery laboratory
    - climatic chambers for components
- Simulation tools

Challenging weather conditions

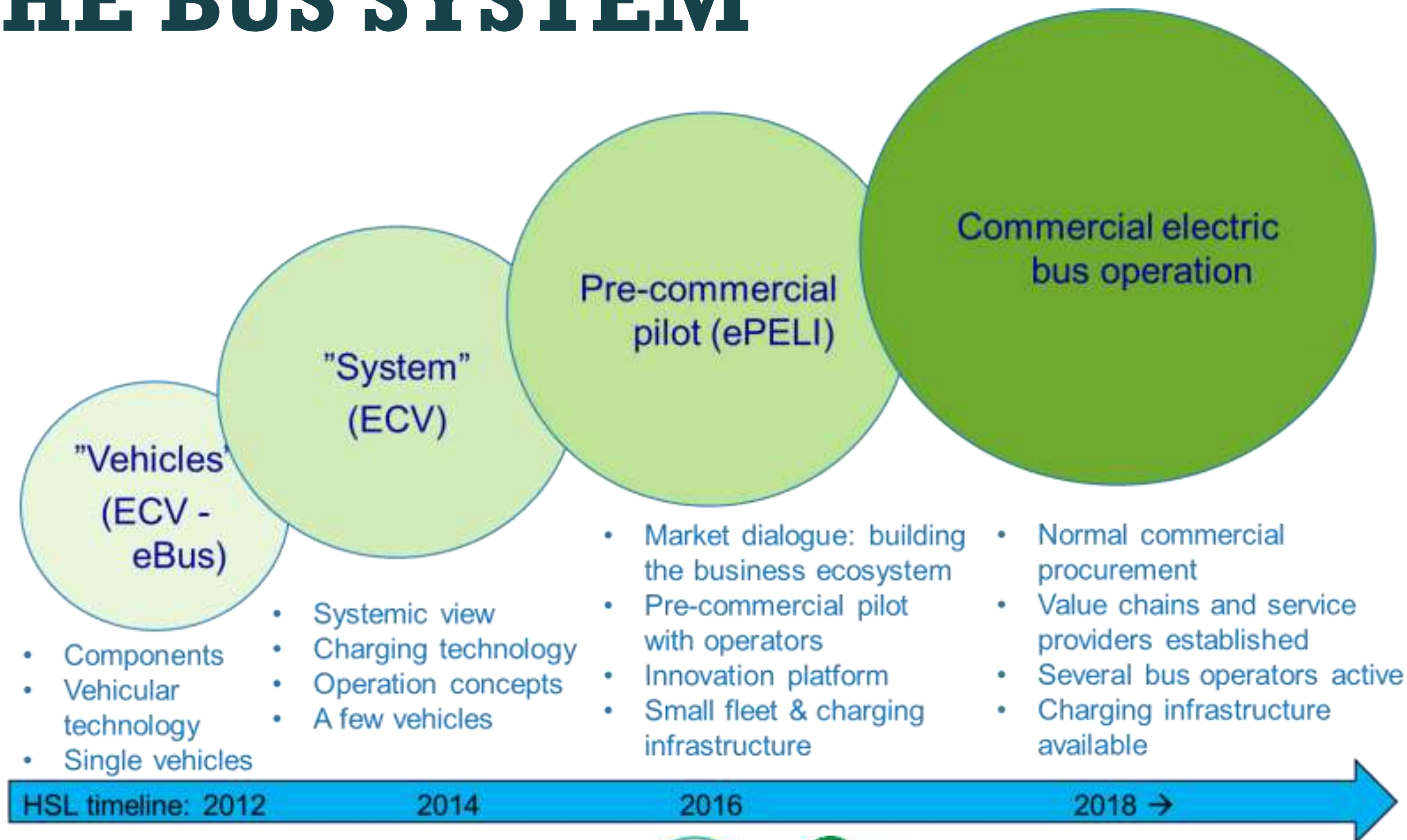
The prototype bus became so good it was operating one week in commercial passenger traffic in 5/2014

”SYSTEM”: CITY OF ESPOO DEMONSTRATION

Public sector
Private sector
Bus operator
Research



STEPS INTO ELECTRIFYING THE BUS SYSTEM



PRE-COMMERCIAL PILOT IN HELSINKI

Possible approaches for both pilot and roll-out

A. PTA defines the system and opens up market dialogue (procurer-supplier)

B. The market (PTO / OEM) decides the concept and technology (concession)

HSL (option A) procures 12 electric buses using direct procurement

- ✓ Direct procurement allowed when activity is related to R&D
- ✓ In the commercial phase, the operators will buy the buses, not HSL

The cities of Espoo and Helsinki set up the charging infrastructure

- ✓ The Ministry of Economic Affairs and Employment provides financial support both for vehicles and chargers

Public support for research and monitoring activities

- ✓ Innovative procurement of e-bus systems
- ✓ Verifying the performance of e-bus systems

The pilot offers an open platform for innovation and sharing

- ✓ Partner cities in Finland are Espoo, Helsinki, Vantaa, Tampere and Turku
- ✓ The PTA is also sharing information with Santiago de Chile

TOTAL COST OF OWNERSHIP – SYSTEM-LEVEL ANALYSIS CASE SANTIAGO DE CHILE

THINGS TO ADDRESS IN TCO

System analysis of the service to be electrified

- Route analysis, characteristic energy use, topography, power grid, operational scenario, timetable and traffic, daily mileage

The operation concepts for the fully electric buses

- Depot charging vs opportunity charging
- Location, number, power and cost of the charging points

Powertrain & vehicle design and performance

- Energy efficiency of the vehicle, lifetime, price

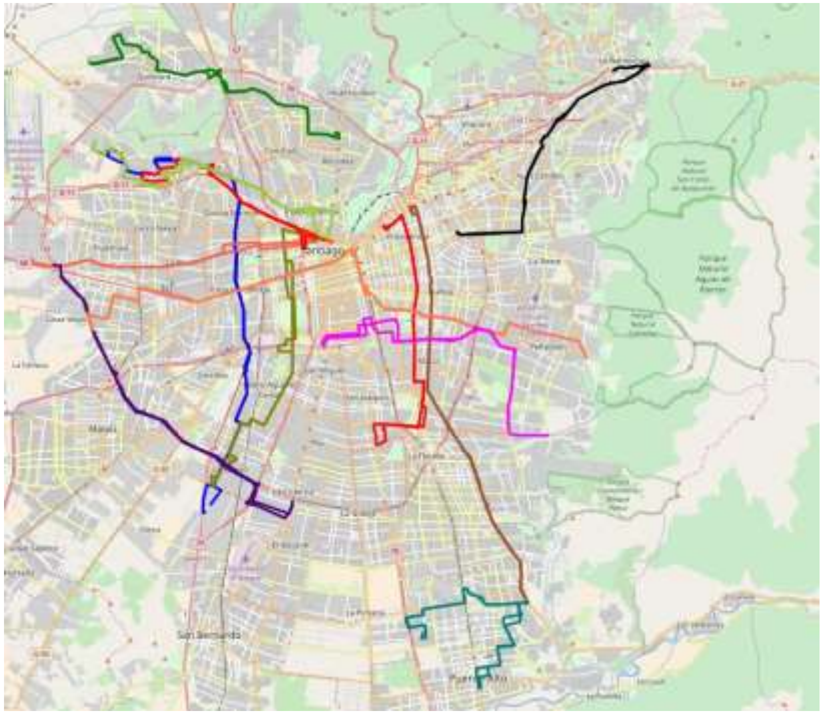
Traction battery type selection and dimensioning

- Battery type size and price, cycle life in duty, residual value?

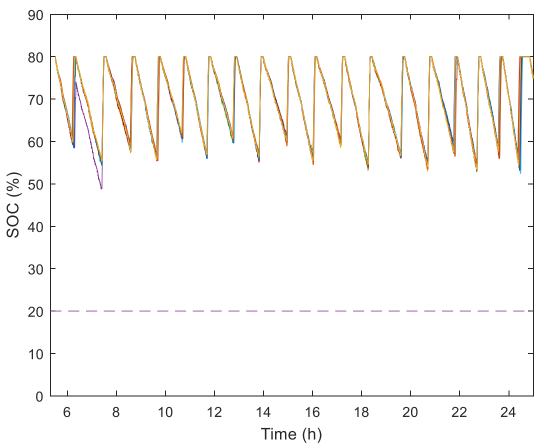
Availability, reliability and productivity of the system (labour, wages, number of vehicles electric vs diesel)

ELECTRIC BUS SIMULATIONS IN SANTIAGO

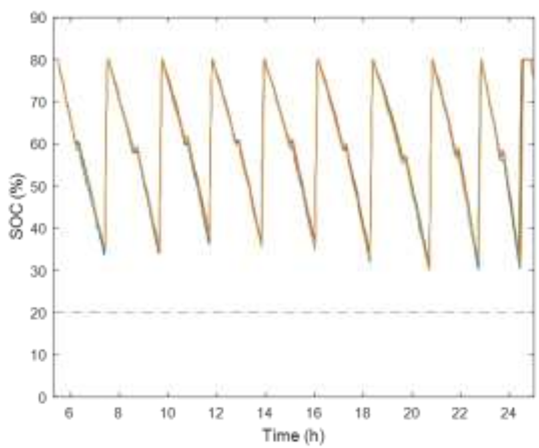
- **Bus routes were simulated with both varying and constant passenger loads**
  - Additionally, all routes were simulated with maximum load as a worst case scenario
- **Cycles for a whole day were created based on frequency and average speed**
- **Different bus concepts were studies: depot charging and opportunity charging**



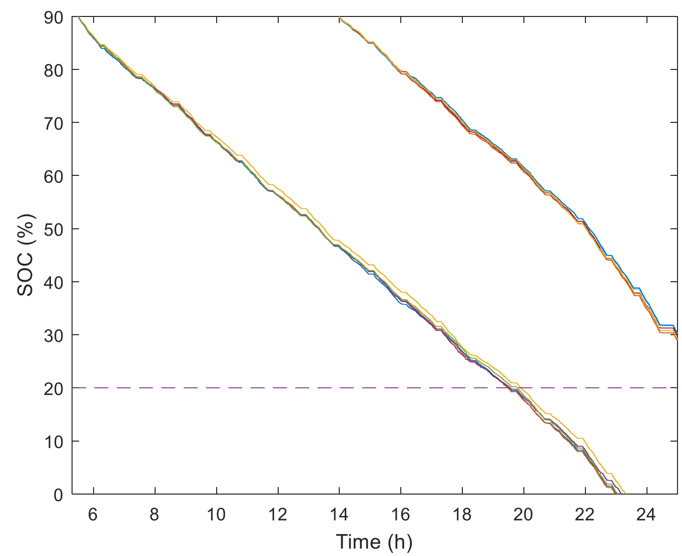
BATTERY STATE OF CHARGE ON SANTIAGO ROUTE B06



Opportunity charged bus, two chargers



No charger at the end of direction 0



Depot charged bus

GENERAL PRINCIPLES OF THE ANALYSIS

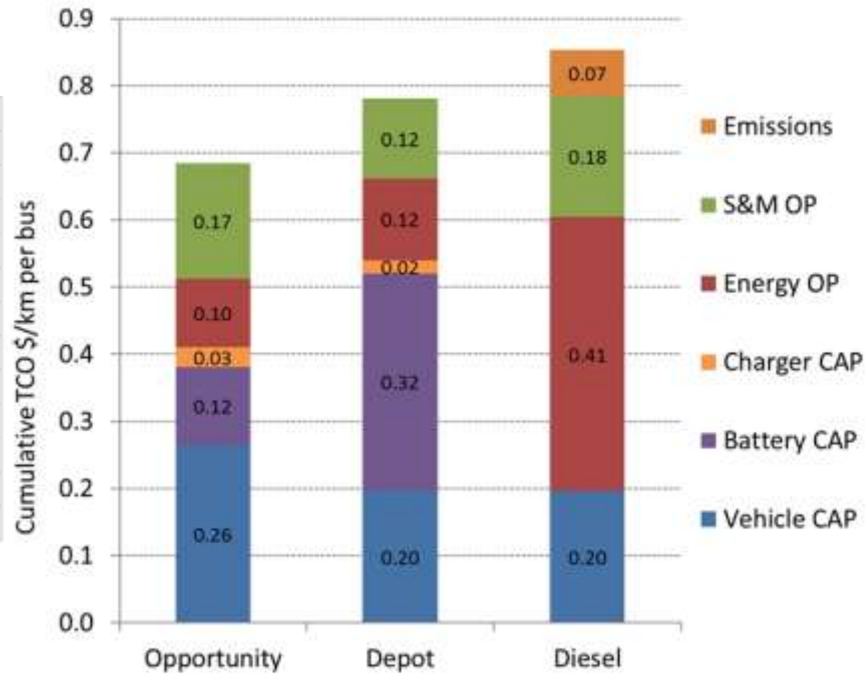
- The TCO on 10 routes was analysed from a service-level approach
- It is assumed that for each route, a service of 15 electric buses is required
- The operational scenario is deduced from city input and through the simulations as accurately as possible
- The size of the fleet needed for the required service depends on the availability of the vehicles, chargers and the range limitation in the case of depot charged buses (not known)
- The complete cost from the fleet is assessed based on operational and capital costs (excluding wages)
- This approach should reflect the real costs to be anticipated when introducing electric buses in the public transport system

MAIN INPUT PARAMETERS IN THE TCO ANALYSIS

	Depot charged	Opportunity charged	Diesel bus
Charger availability (average, %)	95	90	
Vehicle availability (average, %)	95	85	98
Vehicle depreciation time (years)	14	14	10
Charging efficiency (including battery efficiency, %)	93	91	-
Charger depreciation time (years)	14	14	-
Battery type	LFP	LTO	-
Battery capacity (kWh)	320	70	
Battery price ($/kWh)	250	1100	
Vehicle price (without battery, $)	300.000	360.000	220.000
Charger power (kW)	~50	300 – 400 (opp.) 5 – 10 (depot)	-
Charger unit price ($)	20.000	300.000 (opp.) 3000 (depot)	

SANTIAGO ROUTE B06, SERVICE LEVEL 15 BUSES

Fleet cost of 15 bus service over lifetime 14 years	Opportunity BEB	Depot BEB	Diesel
Multiplier for fleet size due to limited range	1	1.2	
Number of buses needed for service	19.6	20.7	15.3
Bus fleet cost	7 058 824	6 221 260	4 714 286
N of batteries in fleet (during bus lifetime)	31	53	
Total battery cost	2 348 584	4 222 916	
Charger costs	658 824	622 126	
Energy costs	2 456 917	2 921 086	9 616 320
Maintenance costs	4 128 264	2 868 264	4 415 657
Total cost w/o operating costs and maintenance	10 066 231	11 066 303	4 714 286
Total cost	16 651 412	16 855 653	18 746 263
Yearly cost	1 189 387	1 203 975	1 339 019
Cost per bus in service per year	79 292	80 265	89 268



Note: the TCO presented above contain site-specific parameters and assumptions and are not generally applicable.

SOME COMMENTS AND NOTES TO THE TCO RESULTS

Electric buses appear attractive for the Santiago transit system

Choice between depot and opportunity charging should be discussed carefully

Several important and partly also unknown parameters have an impact on the TCO

- Availability and reliability of vehicles
- Availability and reliability of chargers (both depot and opportunity)
- Energy consumption and loads may vary (most impact on depot charging buses)
- Energy price, power tariffs, grid stability and connection costs
- Choice and dimensioning of the battery: for example, a larger battery of about 120 kWh was not studied for the opportunity charging

SUMMARY AND CONCLUSIONS

- ✓ Forerunner cities are fast moving from pilots to roll-out
- ✓ Key KPI's still to be proven in large-scale deployment
- ✓ The type and operational scenario of the route affects a lot the optimal type of bus concept
- ✓ Charger and vehicle availability are key factors
- ✓ Equally, battery lifetime, vehicle and powertrain price and deprecation times have impact on the results
- ✓ Validation of the results, especially on real-life reliability and availability of the systems is essential
- ✓ General recommendation – proceed stepwise: plan and execute a pilot with both depot and opportunity charging e-bus (possibly on the same route)
- ✓ Transferability of the "pilot-to-roll-out" approach between leader-follower-learner cities to be studied – local ecosystem always needed

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THANK YOU!!

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