Aalto University
School of Engineering

Evaluation of Electric Buses

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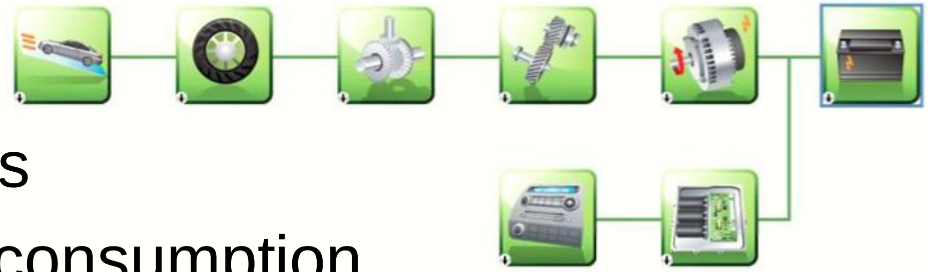
Aalto research in ECV-eBus



Modeling and simulation

- Dimensioning powertrain components
- Evaluating performance and energy consumption
- Thermal management of powertrain components

Comparison of powertrain technologies

- Different electric powertrain configurations
- Different powertrain technologies
  - Diesel, CNG, Parallel and series hybrid, Fuel cell hybrid, Electric
  - Energy consumption and cost effectiveness

Research challenges

Minimizing energy consumption

- Energy efficient powertrain and auxiliary devices
- Thermal management of components and interior space

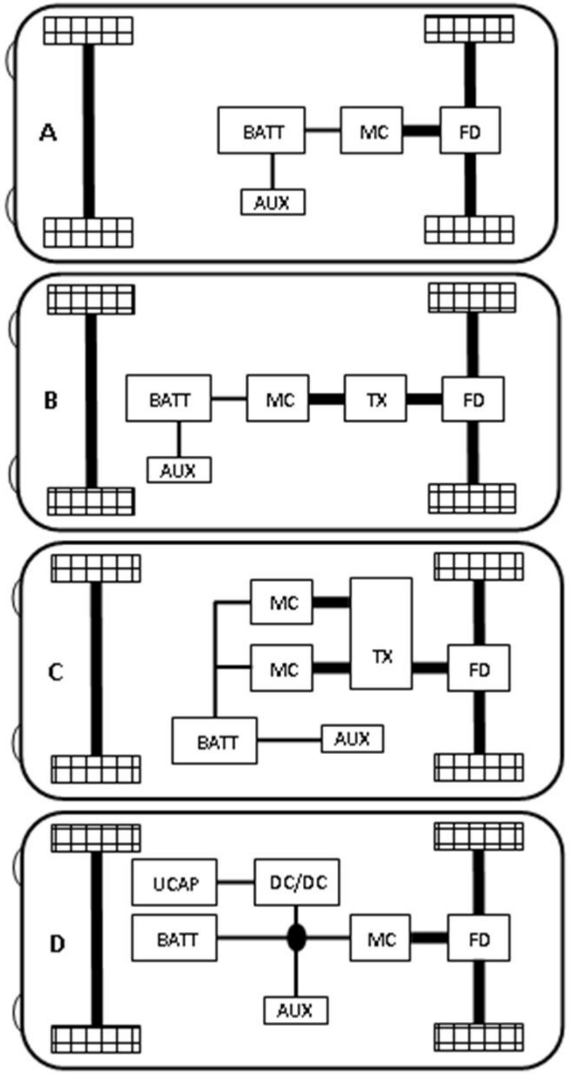
  → Modeling, simulation and prototype testing

Costs effective operation

- Battery capacity vs. charging method and power capacity
- Operation and fleet management

  → Electric bus route simulation

Alternatives for electric powertrains (1/2)

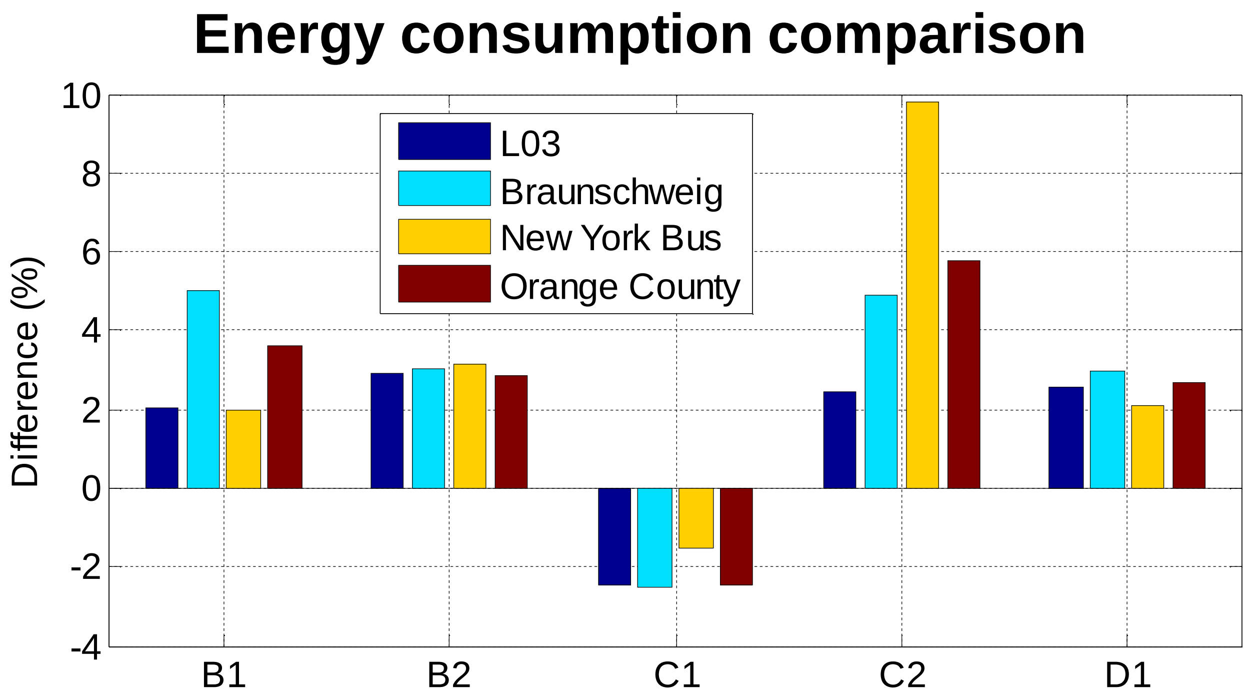


A) Battery and a single traction motor

B) Battery, a single traction motor and a multi-gear transmission

C) Battery and two traction motors with a single-gear transmission

D) Battery, ultracapacitors and a single traction motor

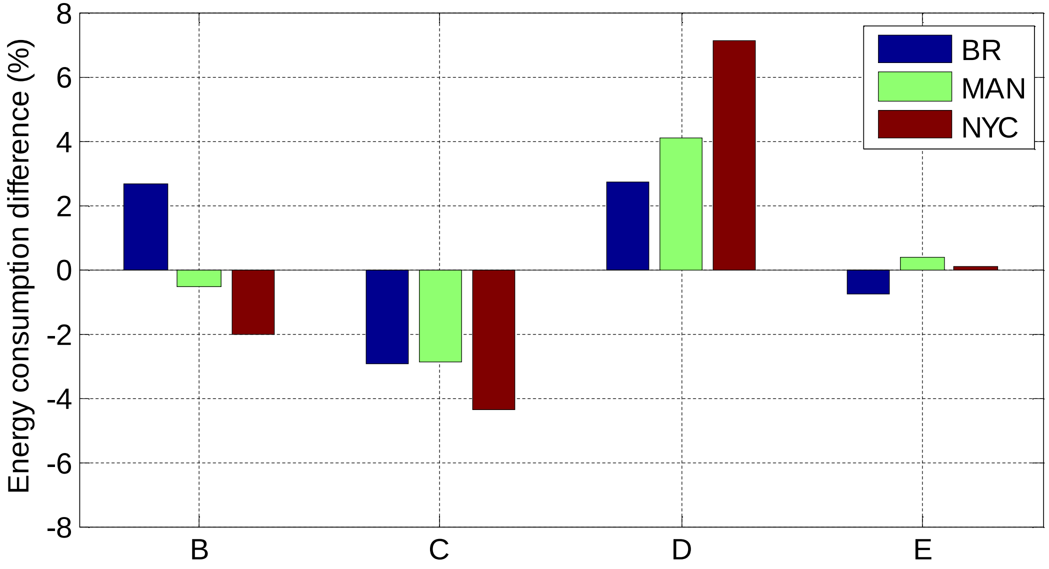


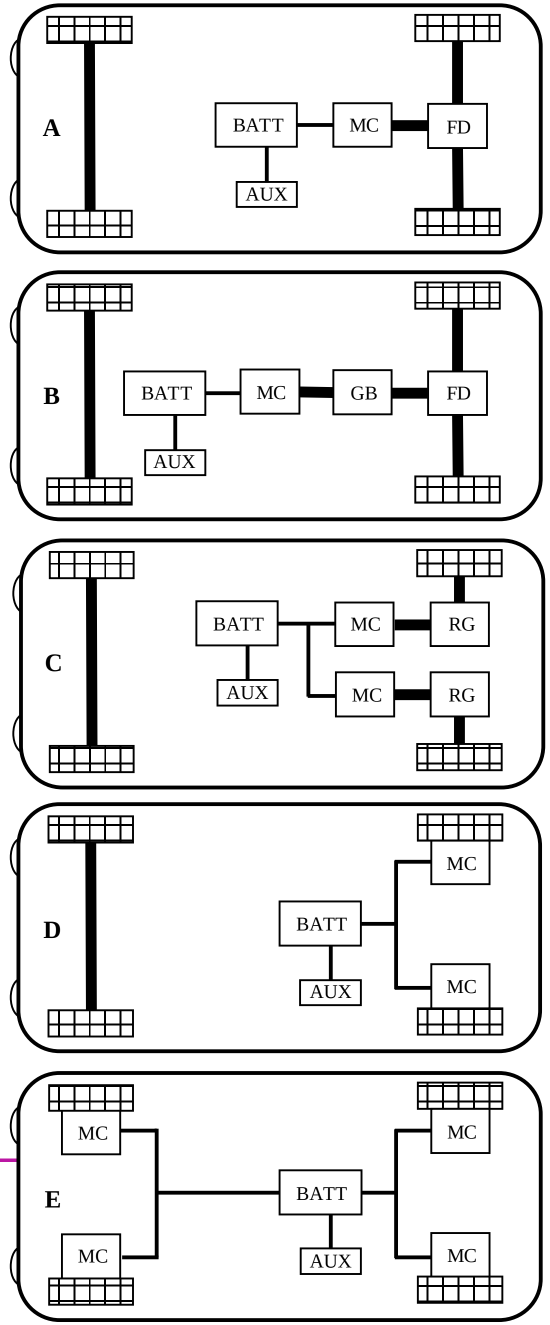
1) → Permanent magnet motor, **2)** → Induction motor

Lajunen, A., "Powertrain Design Alternatives for Electric City Bus," *IEEE Vehicle Power and Propulsion Conference (VPPC'12)*, Seoul, Korea, 2012.

Alternatives for electric powertrains (2/2)

A) Single traction motor and a final drive
B) Single traction motor, two-speed gearbox and a final drive
C) Two separate traction motors with reduction gears
D) Two separate in-wheel traction motors on rear wheels
E) Four separate in-wheel traction motors

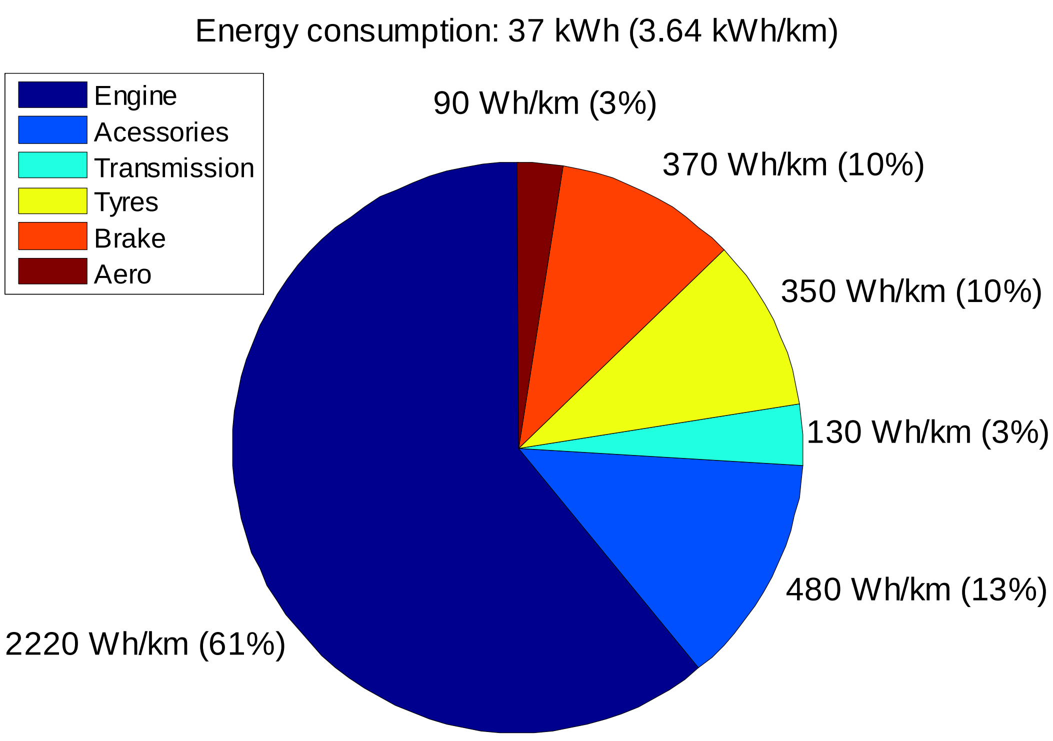




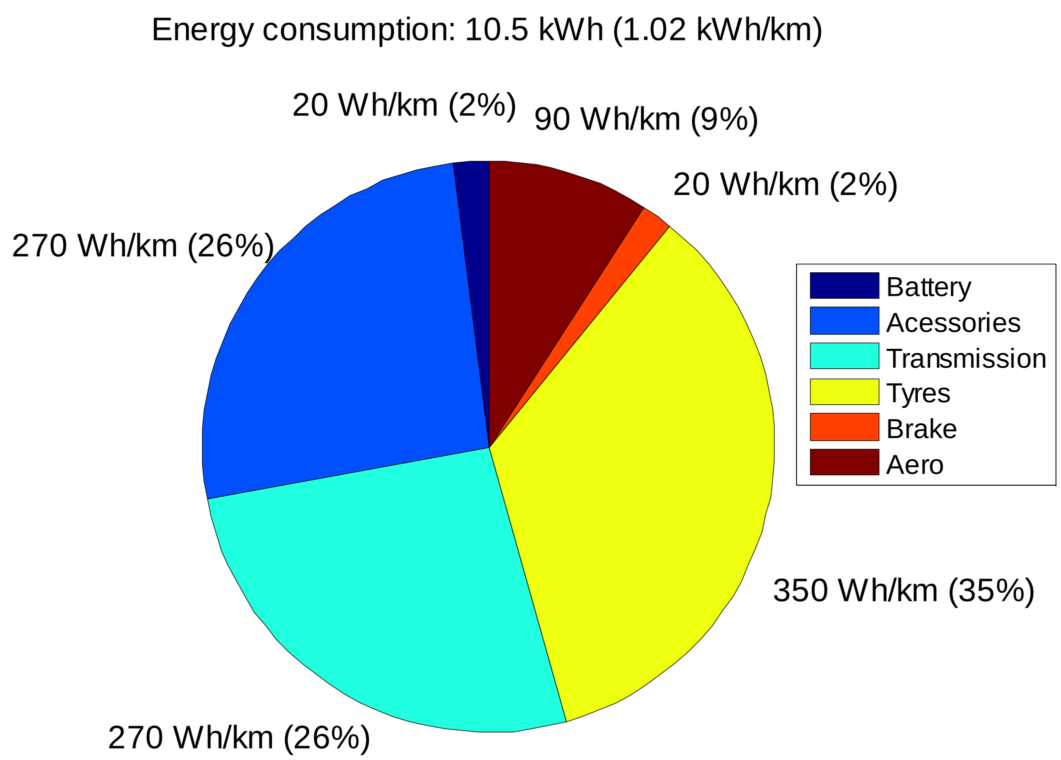
Lajunen, A., "Comparison of Different Powertrain Configurations for Electric City Bus," *IEEE Vehicle Power and Propulsion Conference (VPPC'14)*, Coimbra, Portugal, 2014.

Distribution of energy losses

Diesel bus

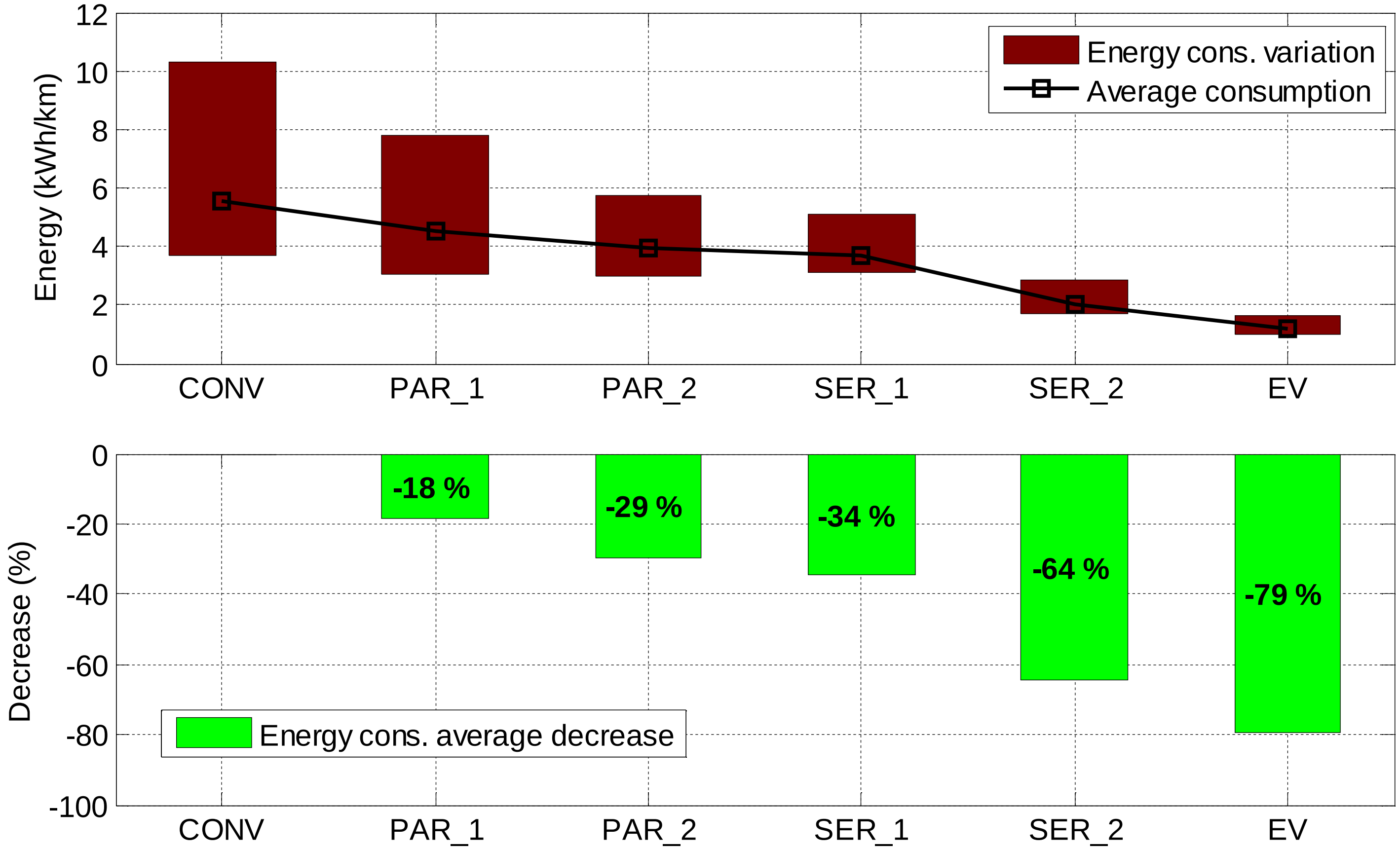


Electric bus



Espoo 11 cycle, bus total weight = 14250 kg, moderate auxiliary power consumption

Energy consumption comparison



Energy consumption variation due to different driving cycles

Comparison of six different powertrain technologies:
CONV = Diesel
PAR_1 = Parallel Hybrid (Ucap)
PAR_2 = Parallel Hybrid (Batt)
SER_1 = Series Hybrid
SER_2 = Series Hybrid (Plug-In)
EV = Battery Electric

Energy consumption decrease on average

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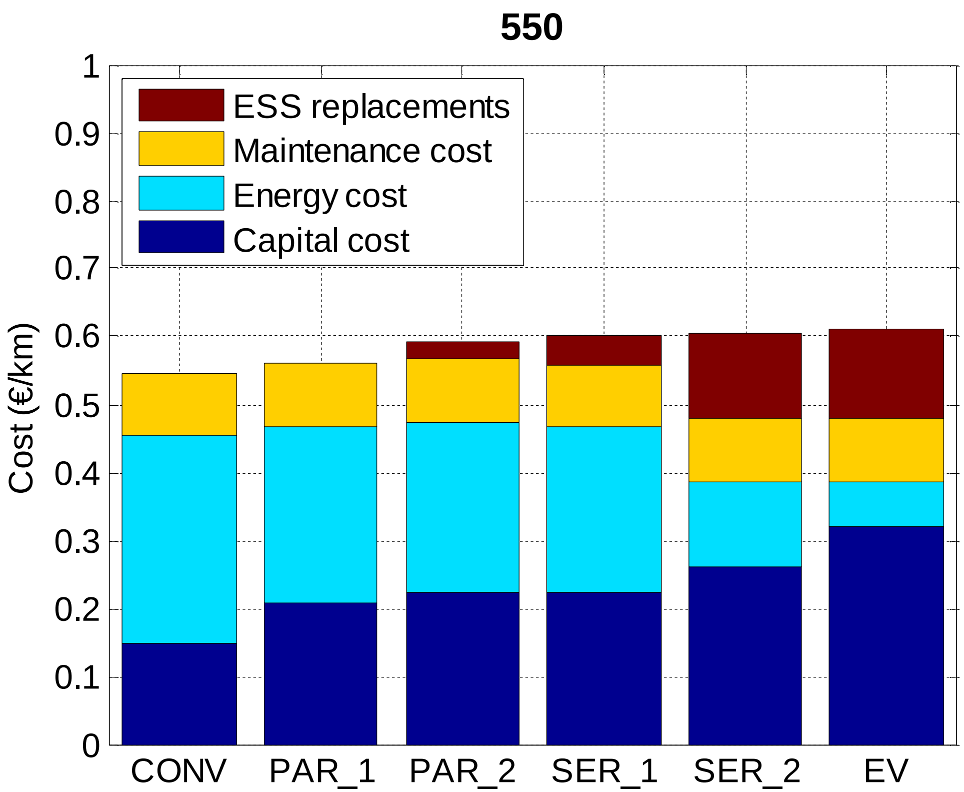
Lajunen, A., “Energy Consumption and Cost-benefit Analysis of Hybrid and Electric City Buses,” *Journal of Transportation Research, Part C*, vol. 38, pp. 1–15, Jan. 2014.

Lifecycle cost



Capital cost factor	40%	50%	50%	60%	100%

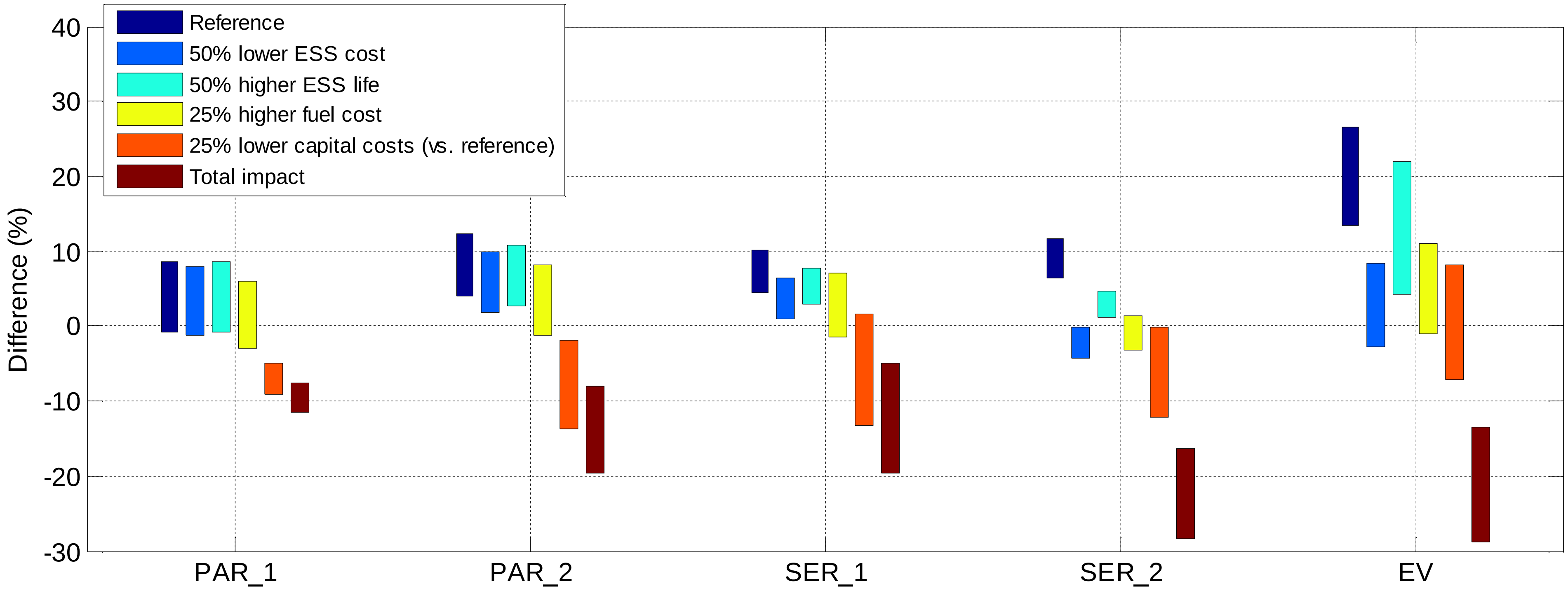
Cost parameters

Parameter	Value
Diesel city bus capital cost (€)	225000
Diesel fuel cost without VAT (€/l)	1.185
Electricity cost without VAT (€/kWh)	0.10
Maintenance cost for diesel bus (€/km)	0.14
High power battery cost (€/kWh)	1000
High energy battery cost (€/kWh)	750
Ultracapacitor system cost (€)	15000
Operation time in a year (h)	4000
Service life in years	12
Discount rate (%)	7

Lajunen, A., "Energy Consumption and Cost-benefit Analysis of Hybrid and Electric City Buses," *Journal of Transportation Research, Part C*, vol. 38, pp. 1–15, Jan. 2014.

Cost effectiveness

Capital and energy storage costs have the major impact on the cost effectiveness of hybrid and electric buses



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Lajunen, A., “Energy Consumption and Cost-benefit Analysis of Hybrid and Electric City Buses,” *Journal of Transportation Research, Part C*, vol. 38, pp. 1–15, Jan. 2014.

Ongoing research

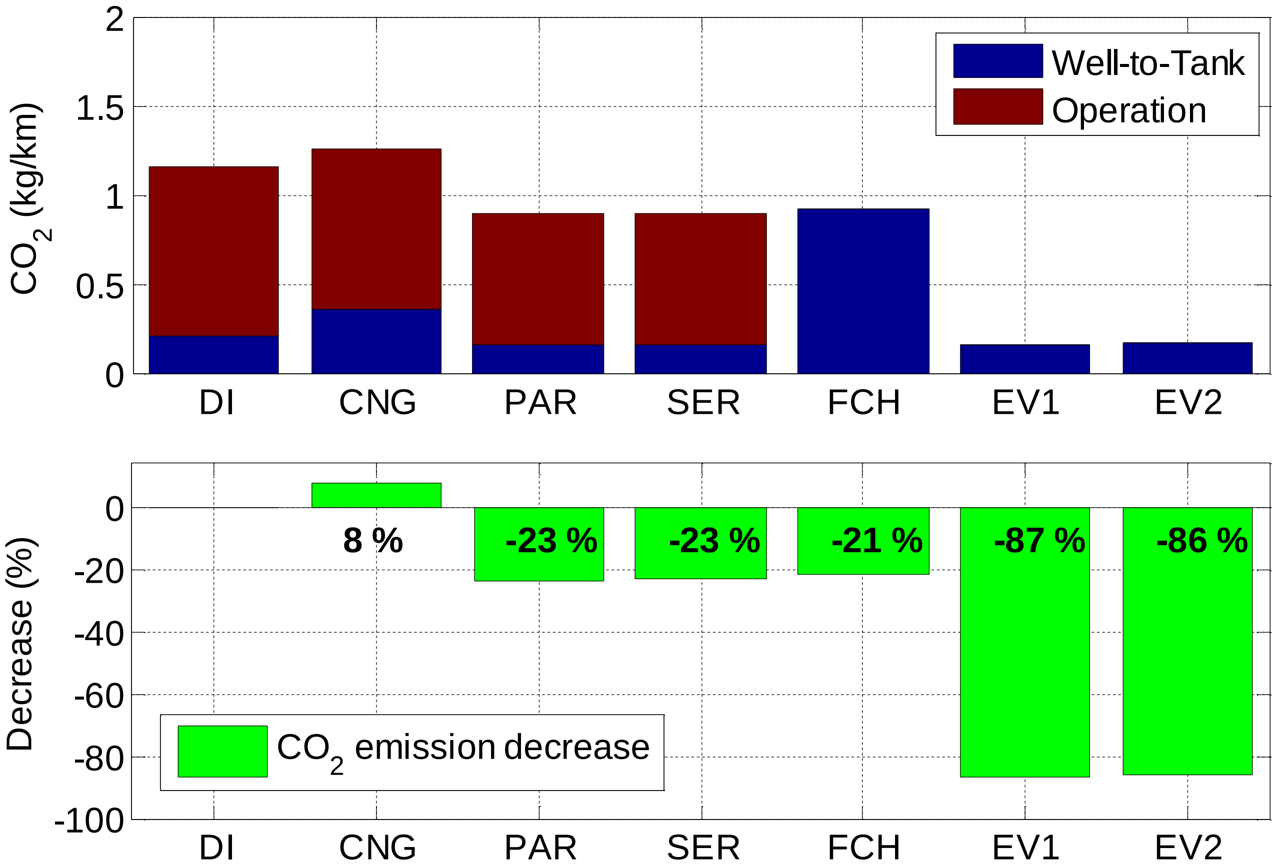
Electric bus route simulations

1. What kind of electric buses should be selected for achieving energy and cost efficient operation in given operating conditions?
2. How to define requirements of the charging infrastructure for the operation of electric buses?

Comparisons of city buses

- Energy consumption, costs and CO_2 emissions (with UC Berkeley)
- Including Natural Gas and Fuel Cell hybrid buses
- Finland and California as case studies for costs and CO_2 emissions
- Manuscript to be submitted in March 2015

CO_2 emission results (case Finland)



Energy pathways for Finland

Energy	Model
Diesel	(Edwards et al., 2013)
Natural gas	CNG imported by pipeline
Hydrogen	Reforming on-site from CNG
Electricity	Finnish electric grid mix

Electric buses have potential to decrease CO_2 emissions more than **85%** in comparison to diesel buses

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Edwards, R., Larivé, J-F., Rickeard, D., Weindorf, W., 2013. Well-to-Tank Report Version 4.0, JRC Technical Reports.

Summary

- **Electric city buses have a significant potential to increase energy efficiency and decrease CO_2 emissions**
- **High purchase cost is the main barrier for the electric buses**
- **Thermal management is a challenge which needs dedicated research and advanced solutions**
- **Electric city buses can be more cost efficient than diesel buses already in the near future**

Related publications

- **Lajunen, A.**, “Improving the Energy Efficiency and Operating Performance of Heavy Vehicles by Powertrain Electrification,” *Doctoral Dissertation*, Aalto University, 2014.
- **Lajunen, A.**, “Energy Consumption and Cost-benefit Analysis of Hybrid and Electric City Buses,” *Journal of Transportation Research, Part C,* vol. 38, pp. 1–15, Jan. 2014.
- **Lajunen, A.**, “Comparison of Different Powertrain Configurations for Electric City Bus,” *IEEE Vehicle Power and Propulsion Conference (VPPC'14),* Coimbra, Portugal, 2014.
- **Lajunen, A.**, “Energy-Optimal Velocity Profiles for Electric City Buses,” *IEEE International Conference on Automation Science and Engineering,* Madison, WI, USA, 2013.
- **Lajunen, A.**, “Powertrain Design Alternatives for Electric City Bus,” *IEEE Vehicle Power and Propulsion Conference (VPPC'1)*, Seoul, Korea, 2012.
- **Lajunen, A.**, “Development of Energy Management Strategy for Plug-in Hybrid City Bus,” *IEEE Transportation Electrification Conference and Expo (ITEC’12)*, Dearborn, MI, USA, 2012.
- **Lajunen, A.**, “Evaluation of battery requirements for hybrid and electric city buses,” *Electric Vehicle Symposium (EVS26)*, Los Angeles, CA, USA, 2012.