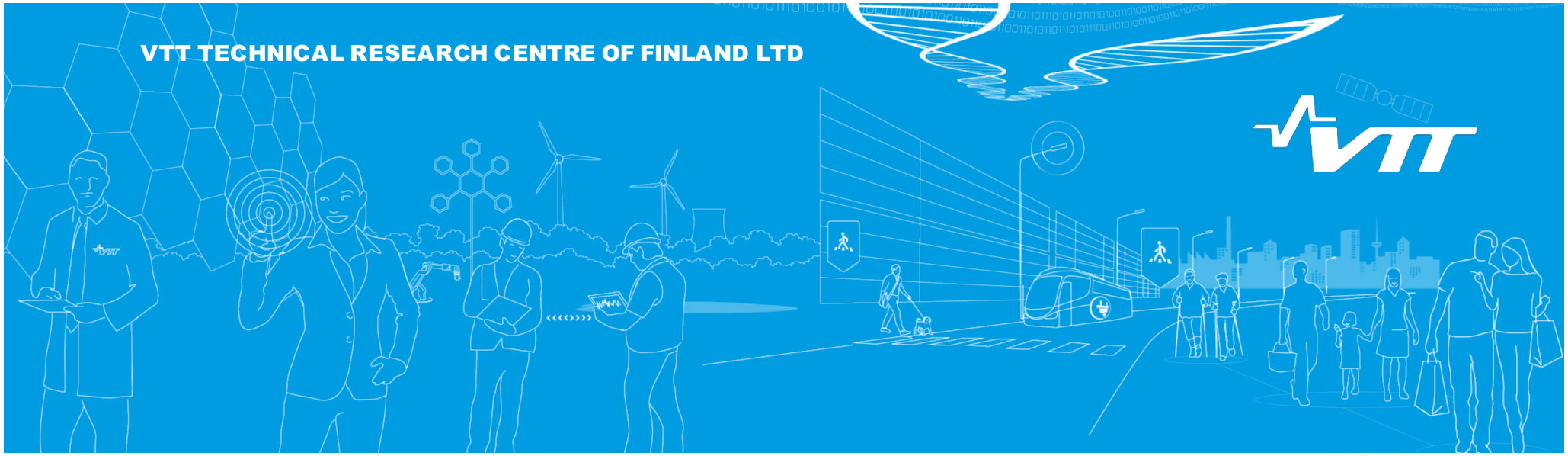


Planning of electric bus systems

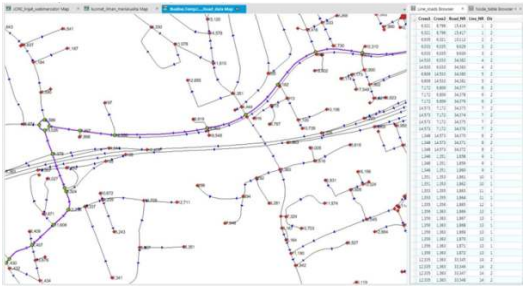
Latin American webinar: Centro Mario Molina Chile & UNEP

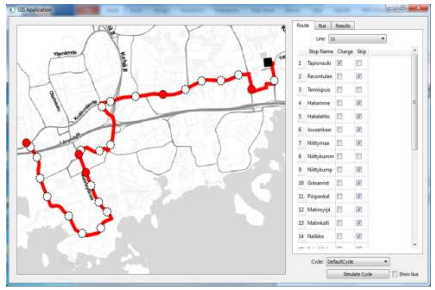
4th of September, 2017

Mikko Pihlatie, VTT
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Designing a cost-effective electric bus system















The transport system

How do electric buses fit into the public transport system? How to manage cost, emissions and productivity?

The vehicle

How to design electric buses? What is the power and energy needed?

Green Public E-Mobility

The energy supply

How and where to charge? How to scale up and manage the fleet?

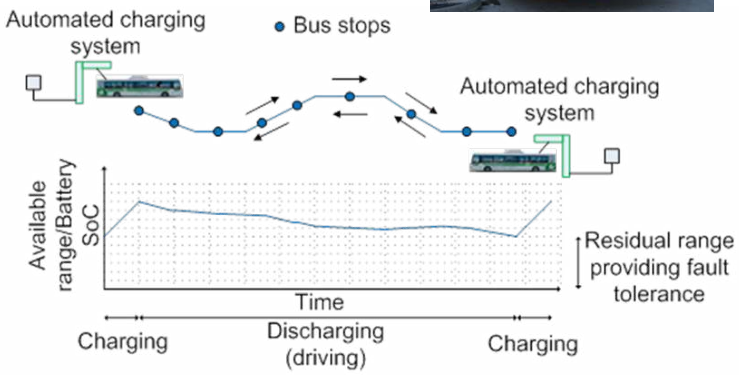
Main challenges in introducing electric buses in cities

- What is the cost of electric bus systems?
- Which bus lines to electrify?
- How to secure the reliability of the system?
- Where to place and how to dimension charging infrastructure?
- What are the operational (energy) margins and flexibility?
- How to prepare for disturbances?
- What happens in winter conditions?
- How to scale up (roll-out phase)?









Market entry point: electric city buses
Potential: electrification in urban logistics

- City buses are the sweet spot
  - Fixed route length and schedule
  - High number of medium-sized and large cities preparing to adopt
- High utilisation rate of commercial vehicles
  - Low energy cost
  - Possibility for profitability
- Emissions, noise, comfort, automation
- Multimodality potential: trolley, rail, tram
- EU27: 800.000 buses → 33 million goods vehicles
  - City buses: Finland ~1000 units, Europe ~100.000-200.000 units
  - Urban deliveries, logistics and freight
  - Utility vehicles and machinery (refuse, maintenance, ..)
  - Waterborne transport (boats, ships, ferries)









Electric bus system KPI's and requirements from PTA & PTO point of view

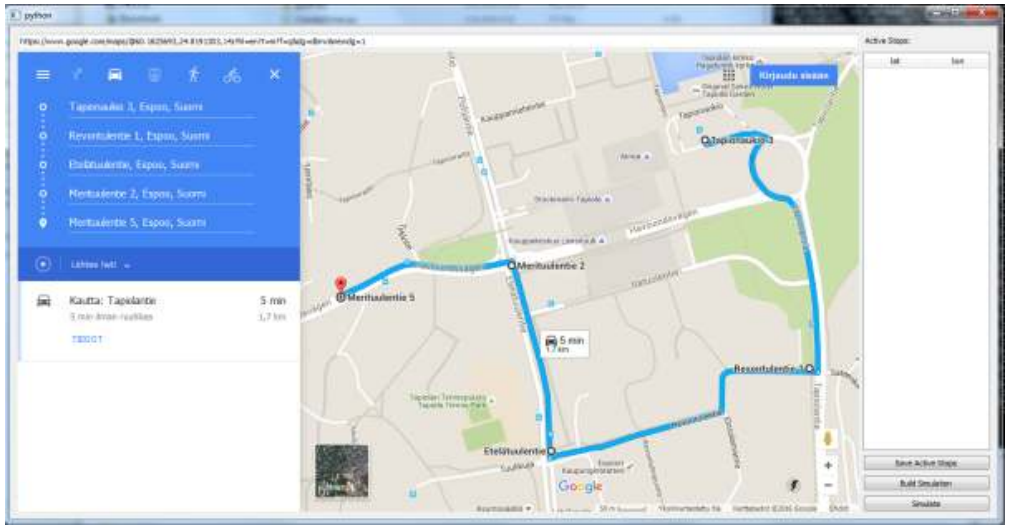
- Sustainability: positive environmental and societal impacts on emissions and noise
- Productivity: the size of the fleet or the number of drivers is not to be increased upon electrification (TCO – challenging!)
- Operability: the electric buses must be equally operable compared to conventional buses
- Reliability: high system-level reliability of both vehicles and charging
- Attractiveness and comfort: the level of service and passenger comfort need to be the same or better compared with conventional buses

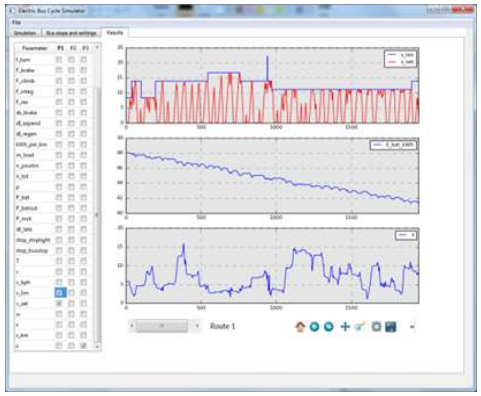
System and charging concepts

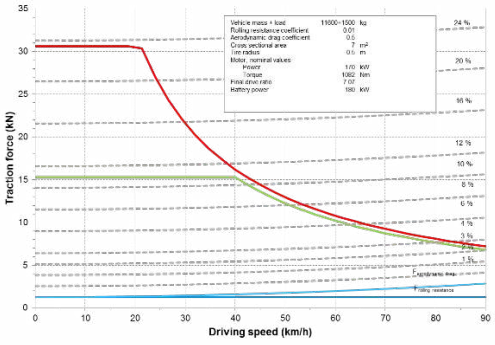
Charging concept	Infrastructure costs	Vehicle costs	Operation costs	Concept feasibility
1. Overnight charging in the depot	Low, Chargers only in the depot	High, Large battery capacity	High, low battery lifetime, high energy consumption	Possible in demonstrational phase
2. Overnight charging + fast charging during the day	Moderate, Chargers both in the depot and terminals	Moderate, slightly smaller battery capacity	Moderate, slightly longer battery lifetime, additional costs if extra buses and drivers needed	Possible in demonstrational phase, parking space in bus terminals limits in wider scale use
3. Opportunity charging (automatic high-power charging)	High, expensive charging systems in terminals	Moderate, small battery, expensive technology depending on system	Low, no changes into normal bus operations	Feasible only as a large system where there are enough vehicles to take advantage of the investment

GIS-based tool for the design of electric bus systems

- Combining open-source input with specific expertise
- Utilises existing data from environment, road network and public transportation system registers, schedules etc.
  - Any city, line or duty
- Electric bus database
  - Efficiency maps of components
  - Environmental conditions and energy use
  - Power curves in charging
- Validation by comparing to data collected from real operation

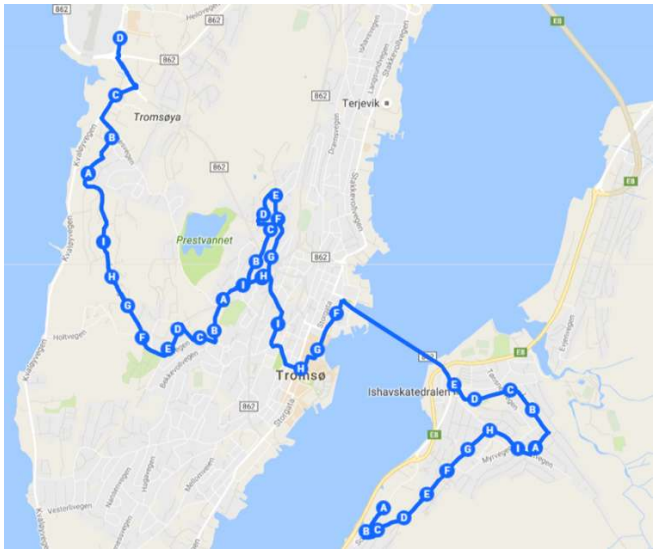


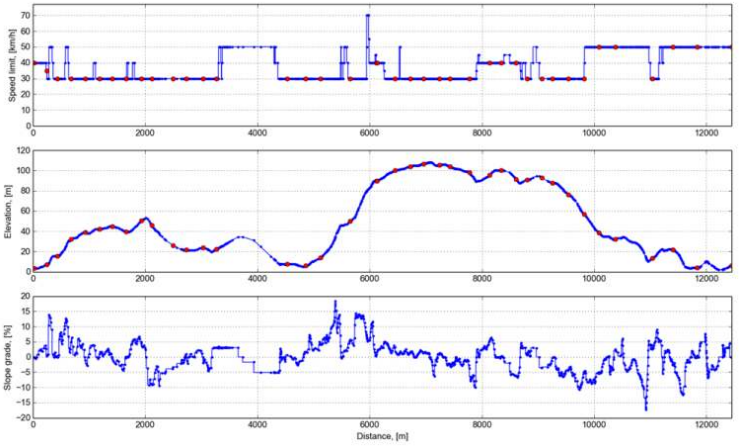




System solutions from specific and detailed analysis

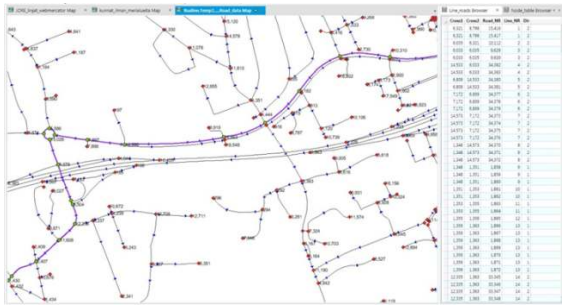
- Construction of bus lines / network from digital map data or open sources (e.g. google maps)
- Not limited to electric buses
  - Finding out most potential lines/cases to electrify
  - Dimensioning the vehicles and machines, batteries
  - Location and dimensioning the charging nodes
  - Analysing the sensitivity of operations and margins
- Finding the optimal solution for the case
- New features being implemented: analysis of fleets, statistical analysis, optimisation





Different applications and end users can benefit

- Public transport authorities and planning (PTA)
  - Cost and functionality analysis of electrifying the bus system
  - Reliability and sensitivity analysis
  - Requirements for charging point capacity
  - Connection to schedule planning
  - Support in strategy and roll-out
- Public transport operations (PTO)
  - Cost and functionality analysis of electric bus operation
  - Choosing right type of vehicles for each kind of duty
  - Operation flexibility and reliability
  - Interfaces for scheduling and planning tools (Hastus)
- Other commercial and utility electric vehicles, mobile machinery – operators and OEM's





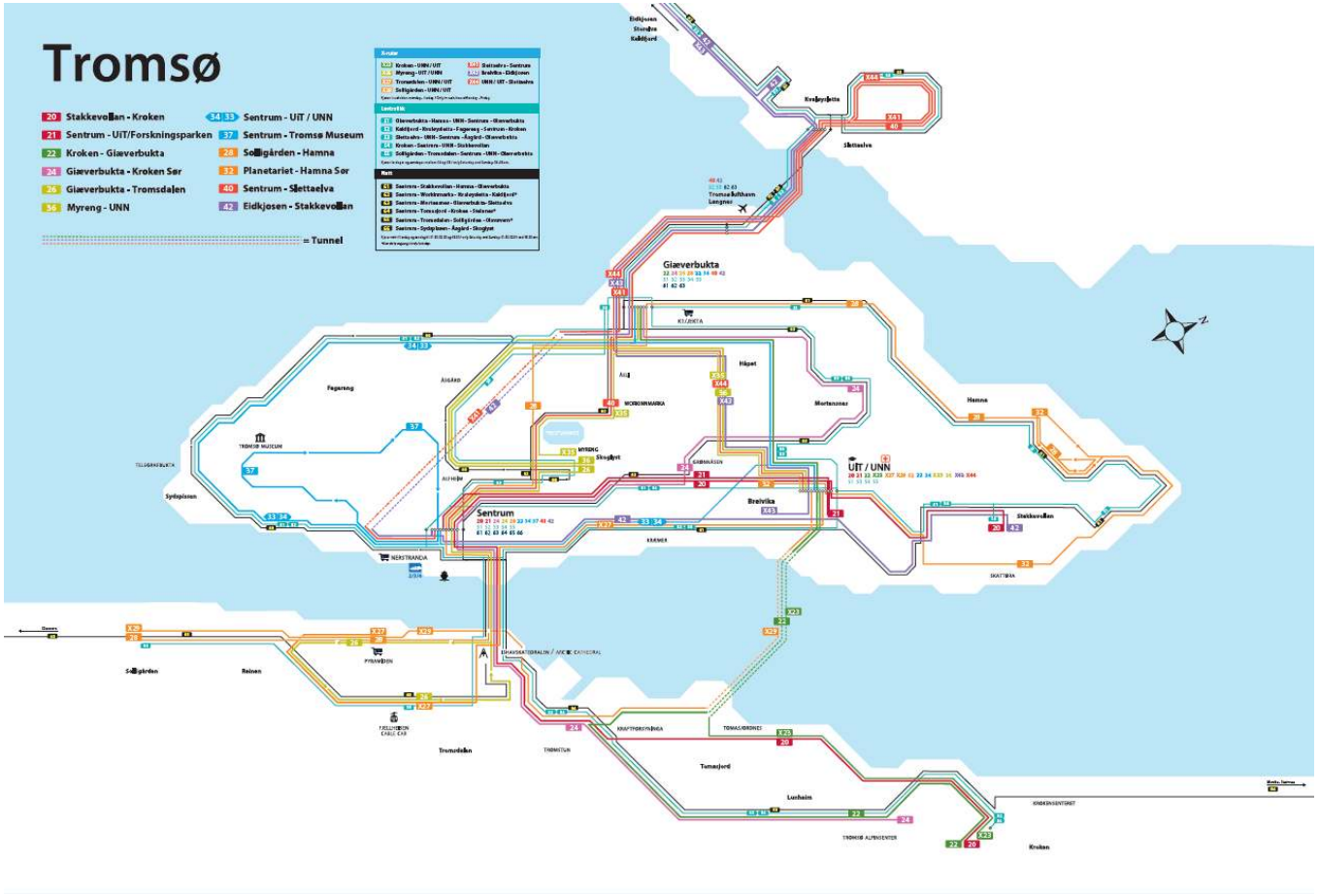


Case Tromsø, Norway

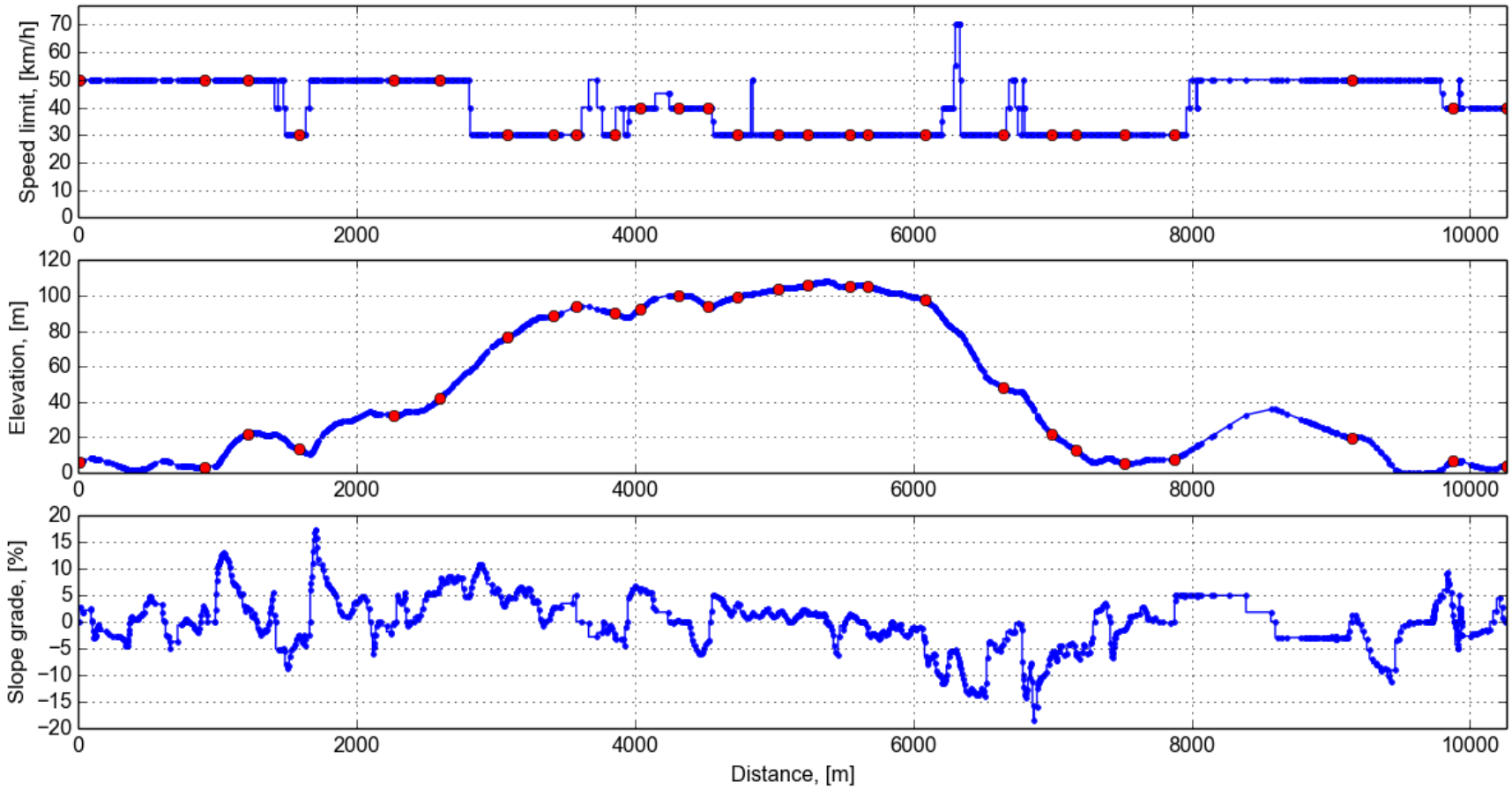
The task

- Study feasibility of electric buses in Tromsø
- What kind of buses would be suitable?
  - Depot charging or opportunity charging?
- Which bus lines suit best for the electric buses?
- How to design the operation?
- How to take into account the special conditions and terrain?
- What is the economic and environmental impact of electric buses in Tromsø
- Make a proposal for an electric bus pilot project in Troms Fylkeskommune

Tromsø bus lines



Bus route 26 (part one)



Bus models

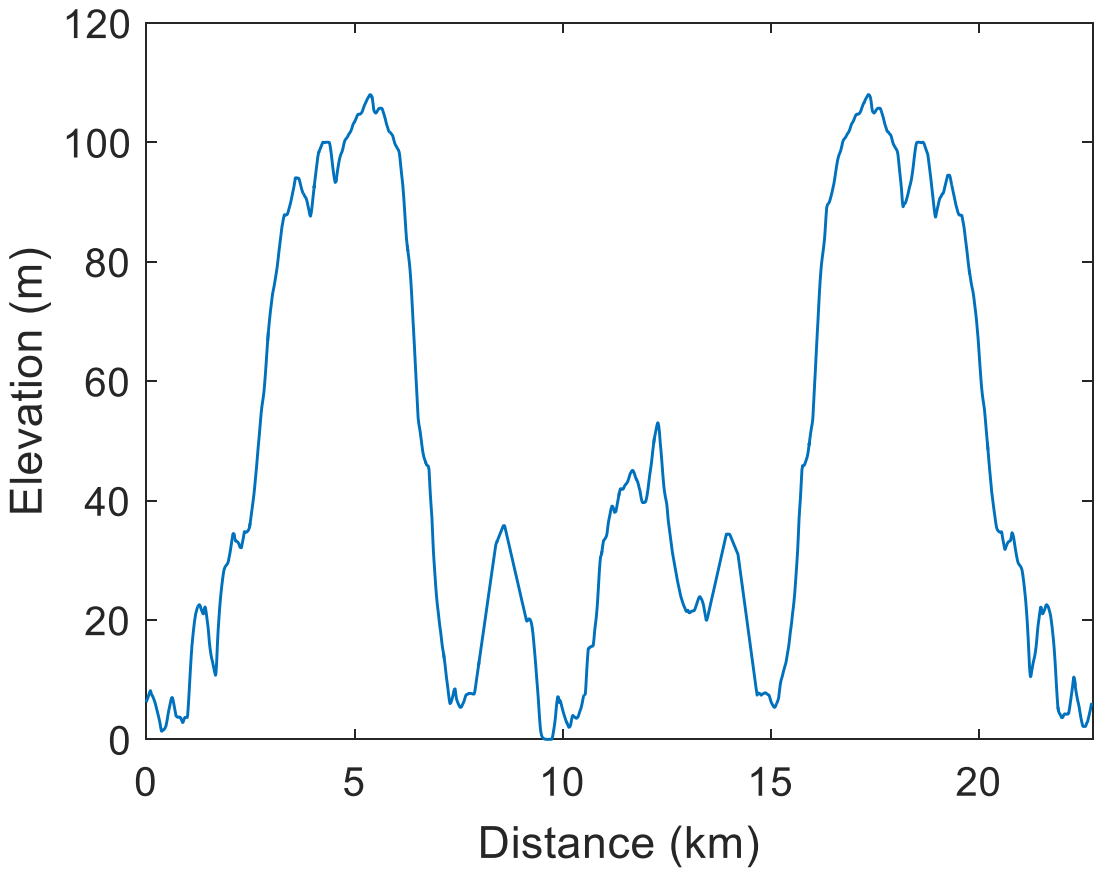
- Two 12 m long buses were analysed: depot charged bus (charging night time) and opportunity charged bus (charging at end bus stops)

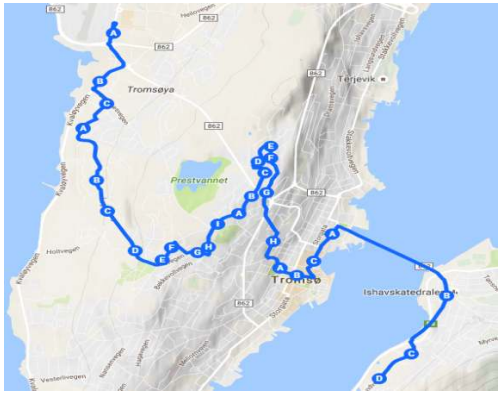
Bus type	Opportunity charged	Depot charged
Chassis weight (kg)	10000	10000
Battery capacity (kWh)	80	250
Bus mass (kg)	11600	15000
Maximum speed (km/h)	75	70

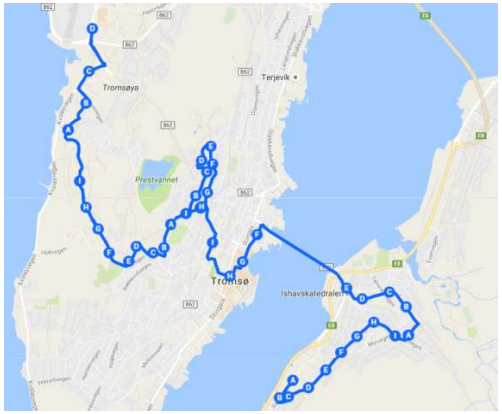
Simulations

- Simulations were performed on each bus route in different conditions
- The passenger load was varied from 0 – 90 passengers, corresponding to 0 – 6120 kg
- Stopping frequency was varied from half of bus stops to all bus stops
- Traffic incidents were modelled by random variations in the speed profile
- All cases were simulated both with and without snow chains

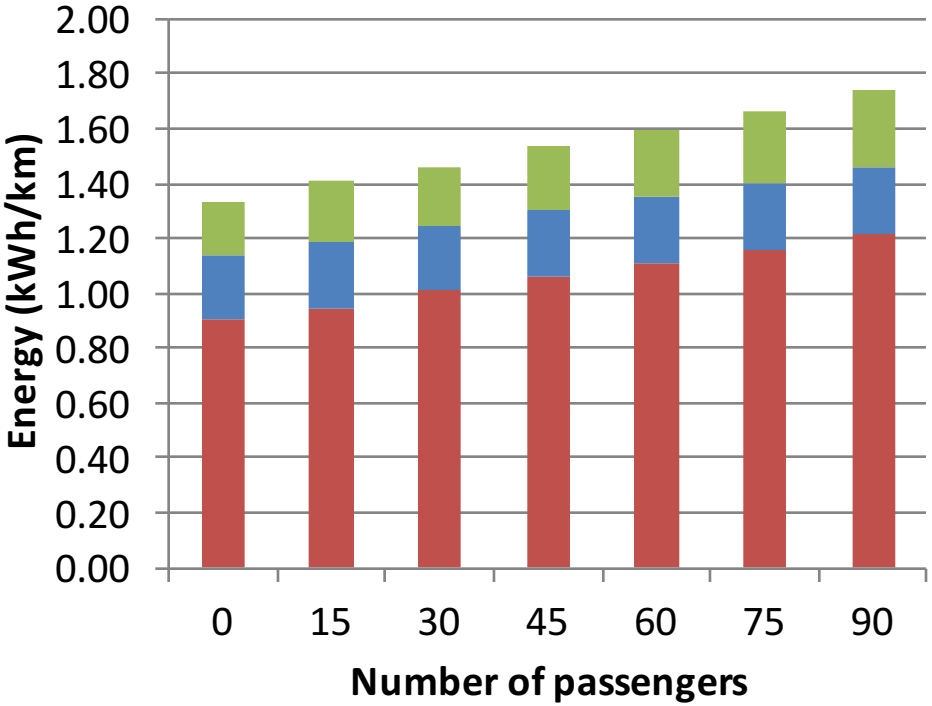
Elevation curve, route 26

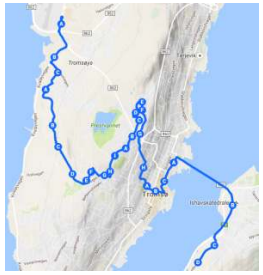


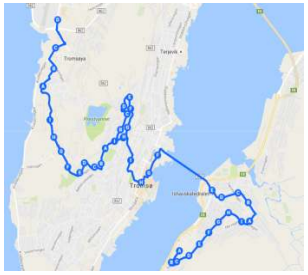




Simulation results on route 26, depot charged bus





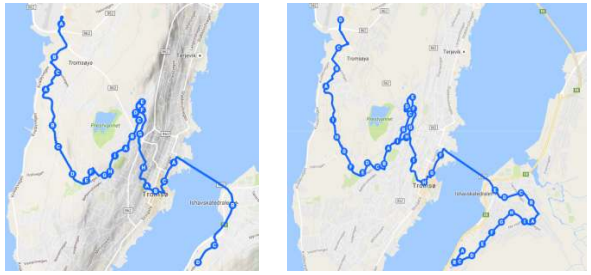


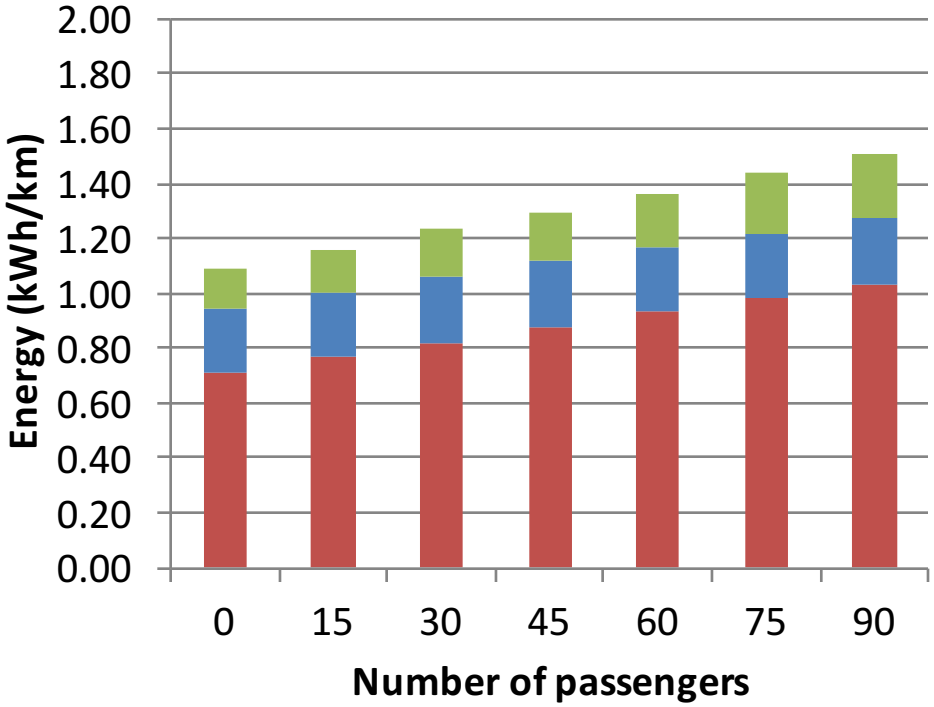
Energy due to snow chains

Auxiliary systems and HVAC

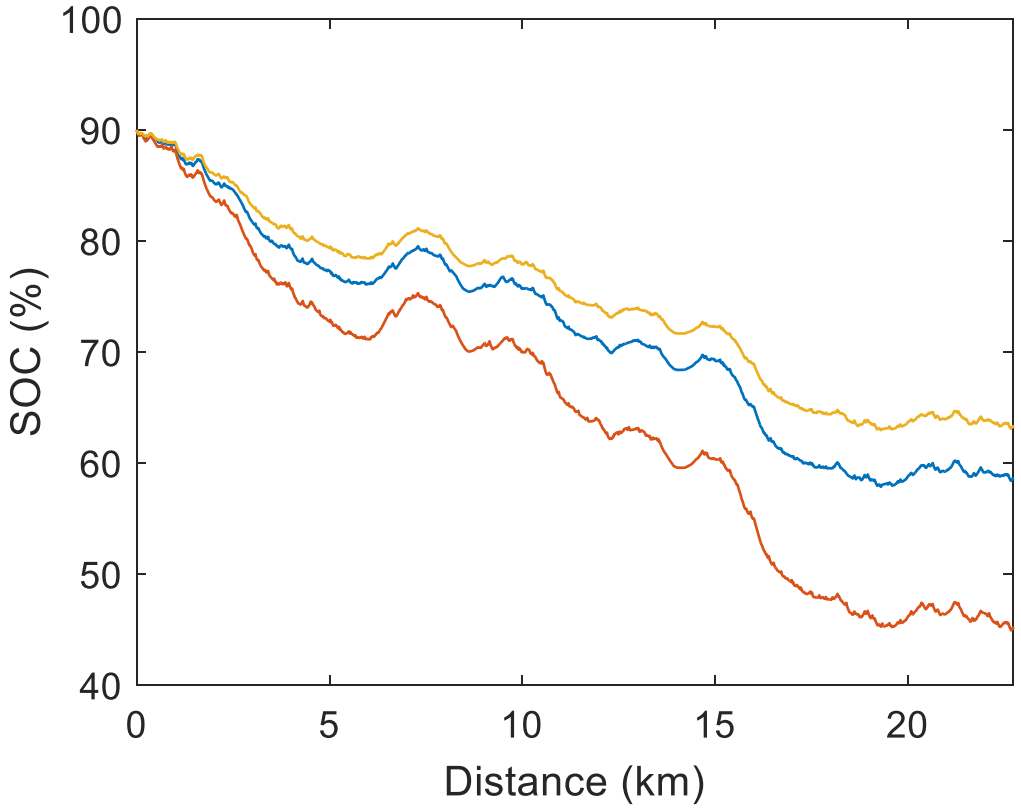
Energy for driving

Simulation results on route 26, opportunity charged bus





Battery state of charge on route 26, opportunity charged bus



- Yellow curve: good weather, empty bus
- Blue curve: good weather, 45 passengers
- Red curve: snow chains, 90 passengers

Simulation results, depot charged bus

Route	Total energy consumption (kWh/km)	Maximum range (km)	Maximum number of round trips	Typical number of round trips, diesel buses
26	1.14 – 1.84	136 – 219	5 – 8	12
32	1.06 – 1.76	141 – 234	7 – 12	14
33	1.14 – 1.84	135 – 220	7 – 12	18
34	1.10 – 1.78	140 – 227	7 – 12	18
37	1.18 – 1.94	129 – 212	22 – 36	34
40	1.23 – 1.88	133 – 202	6 – 9	16

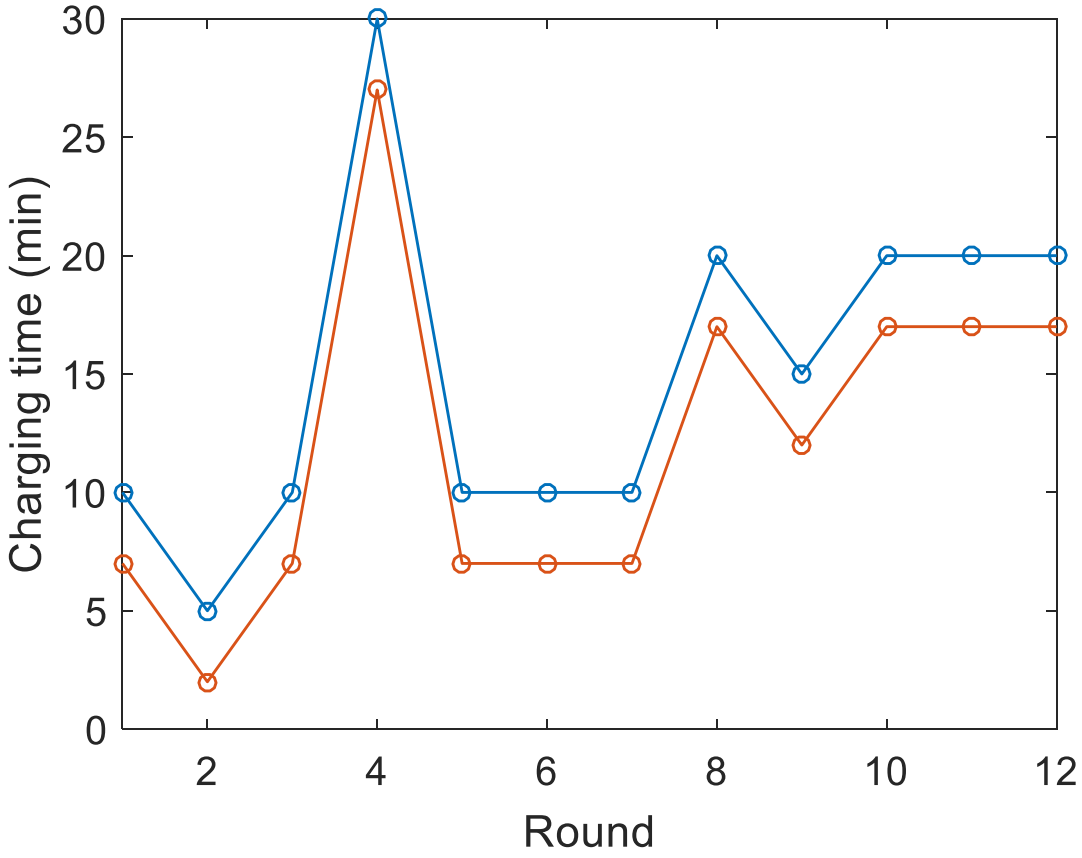
Summary of results for opportunity-charged bus

Line	ΔSOC (%)	Required charging time with 300 kW (min)	Required charging time with 400 kW (min)
26	26.8 – 45.0	4.8 – 7.7	3.7 – 5.9
32	20.7 – 36.3	3.8 – 6.3	3.0 – 4.9
33	20.8 – 35.2	3.8 – 6.1	3.0 – 4.7
34	20.4 – 34.2	3.8 – 6.0	2.9 – 4.6
37	7.1 – 12.2	1.6 – 2.5	1.4 – 2.0
40	27.1 – 43.8	4.8 – 7.5	3.8 – 5.8

Total energy consumption of depot charged and opportunity charged buses

Route	Opportunity charged bus (kWh/km)	Depot charged bus (kWh/km)
26	0.95 – 1.59	1.14 – 1.84
32	0.86 – 1.50	1.06 – 1.76
33	0.94 – 1.58	1.14 – 1.84
34	0.91 – 1.54	1.10 – 1.78
37	0.98 – 1.68	1.18 – 1.94
40	1.00 – 1.62	1.23 – 1.88

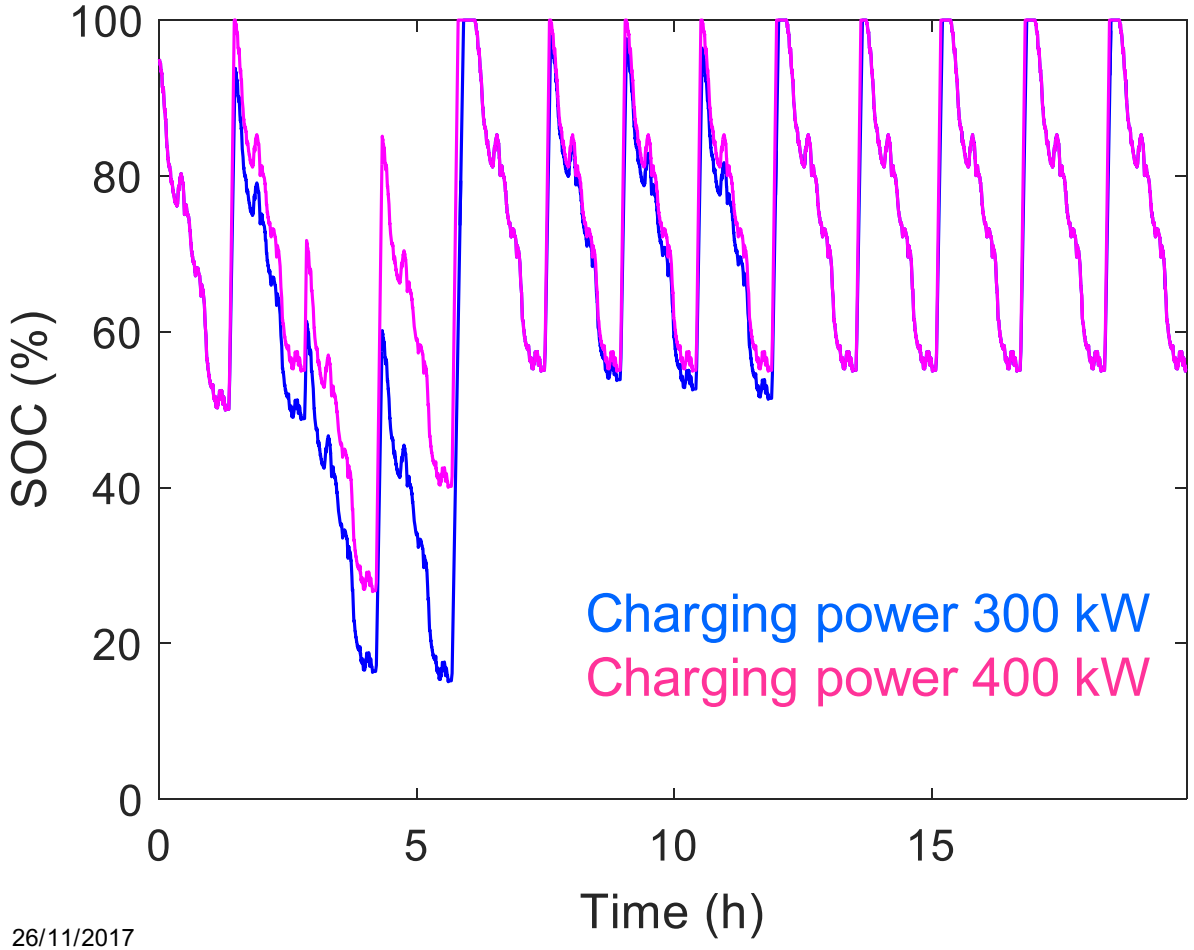
Sensitivity study – charging time available on route 26

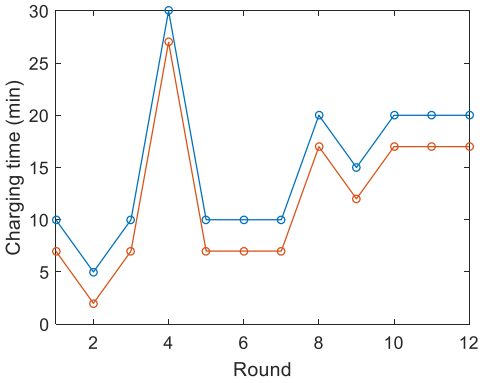


Maximum time at end bus stop (blue curve)

Time available for charging with 3 min delay (red curve)

Sensitivity analysis – one day on route 26 in extreme conditions

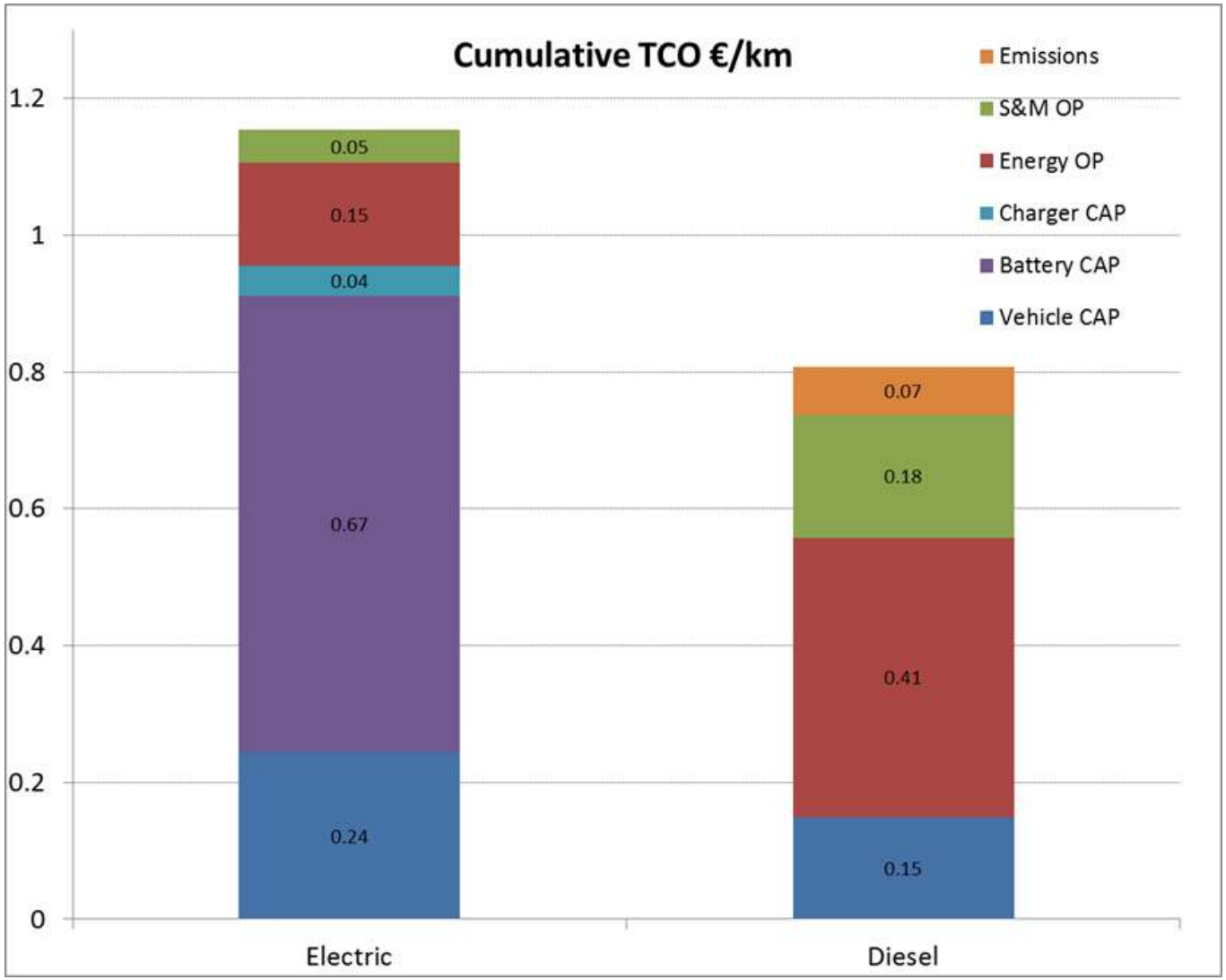




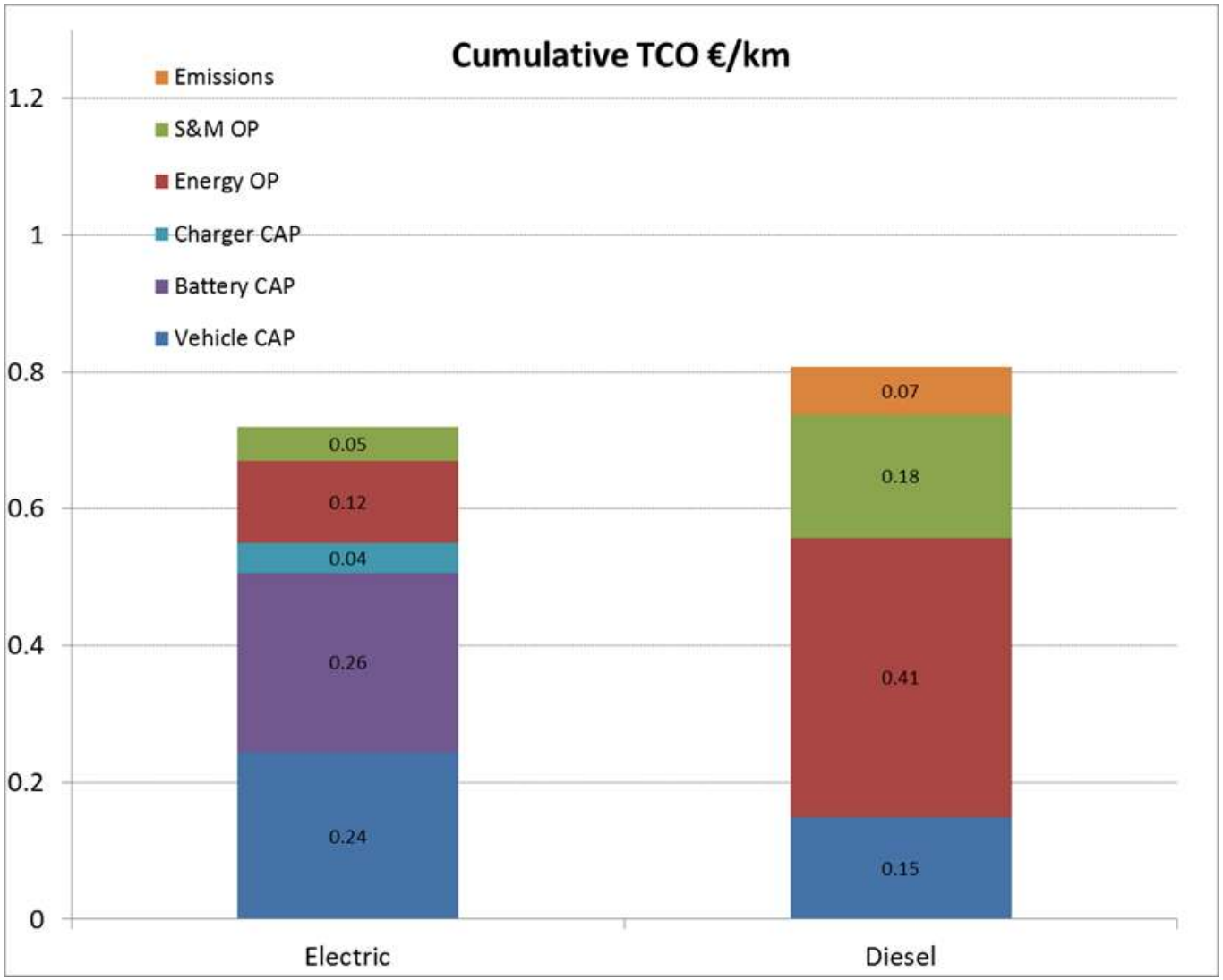


Results – TCO of the Troms subfleets

Average depot charged bus in group 26-37-40



Average opportunity charged bus in group 26-37-40



Summary – Tromsø case

- The studied bus routes in Tromsø are relatively long, about 20 km (except for line 37)
- The terrain is very demanding with steep hills
- Climate conditions can be very demanding with icing and slippery roads
- Our analysis clearly recommends opportunity charged electric buses
- Most of the routes could have one clear main charging node and a possibility to utilise another charging node if needed
- All routes except for 37 use about 25 – 40% of the battery capacity (80 kWh) per roundtrip

Summary

- High differences in specific energy consumption have been measured previously
- Energy consumption correlates with vehicle (total) weight and powertrain efficiency
- The maximum charging power is limited by the battery (or powertrain inverters)
- Lifetime of the battery depends on the way it is loaded
- It is recommended to have opportunity charging power of at least 300 kW, preferably more (400-500 kW)
- Larger batteries increase weight and reduce passenger capacity
- Final optimisation of the vehicle and powertrain was not done in this study

  → Recommendation: final vehicle design after data from the pilot

On uncertainties in the analysis

Parameter	Trend expected	Significance	Impact on e-bus competitiveness
E-bus vehicle price	Decrease	moderate/large	improve
Battery price	Decrease	moderate	Improve
Battery lifetime	Increase	Moderate	Improve
E-bus S&M	Increase?	Moderate	Impair
Charger price	decrease	Moderate	Improve
E-bus vehicle lifetime	increase	Moderate	Improve
Oil price	Increase	moderate	Improve
Price of emissions	increase	moderate	Improve
??			

Summary – system and economy

- Electric bus systems are fast entering from pilot to open tenders
- Opportunity charging concept appears as the most competitive solution
- Daily mileage is the most sensitive parameter for TCO
  - →High utilisation rate is beneficial for electric buses!
- With careful systems engineering and optimised parameter combinations, electric buses can become highly competitive
- A key factor in the final vehicle and charging design is to analyse the PTA requirements for bus schedules, rotation and available charging times
  - →If the buses are to run continuously in service, opportunity charging is more potential
- Further issues: scalability in roll-out, interoperability, grid impacts

Conclusions

- Electric buses show remarkable promise in public transport
- The technology is not yet mature and proven at systemic level
- Productivity and reliability of electric bus system to be proven
- Level of interoperability and standardisation is low but progressing
- Electric buses and commercial vehicles have different design bases than passenger EV's
- System-level requirements for vehicle, battery and charging design need to be properly understood
- The optimal battery, powertrain and vehicle solution in terms of efficiency and TCO is designed from the system-level requirements and frame
- Extensive experimental verification and modelling support is necessary, especially lifetime management and safety


TECHNOLOGY FOR BUSINESS