
Smart solutions for urban and regional mobility in Europe
Brno Exhibition Centre, June 6, 2019.

Updated in July 2019!

# Electrification of city bus transport: An overview and SOLEZ-gained experience

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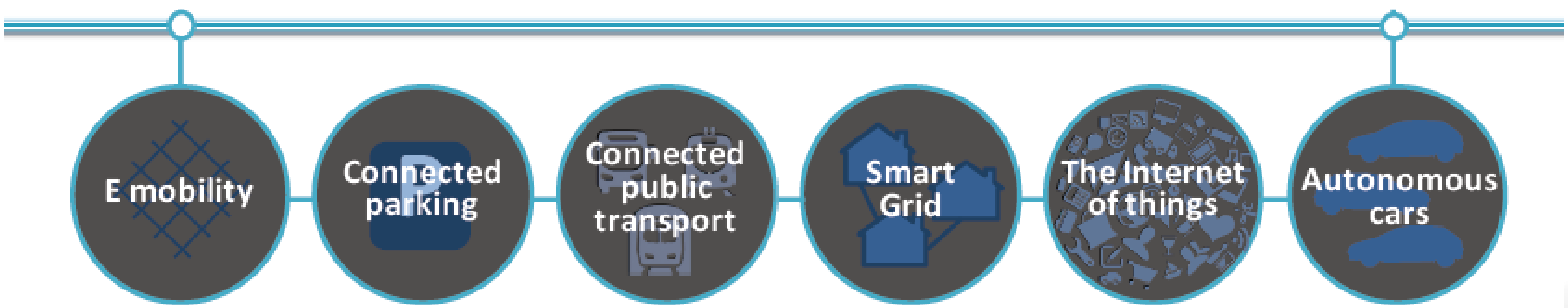
# A WIDER CONCEPT OF SMART CITIES

➢ Basic share characteristics of (larger) cities till 2025


➢ Basic Smart City functionalities




**+ Car sharing**

Source: *Zero Carbon Futures*: „Smart Solutions for Sustainable Tomorrow”, e-Mobility conference, Zagreb, November 2015.


*Hybrid Electric Vehicle (HEV)*


*Plug-in Hybrid Electric Vehicle (PHEV)*

***EV evolution***


*Battery Electric Vehicle (BEV)*

*Extended Range Electric Vehicle (EREV)*

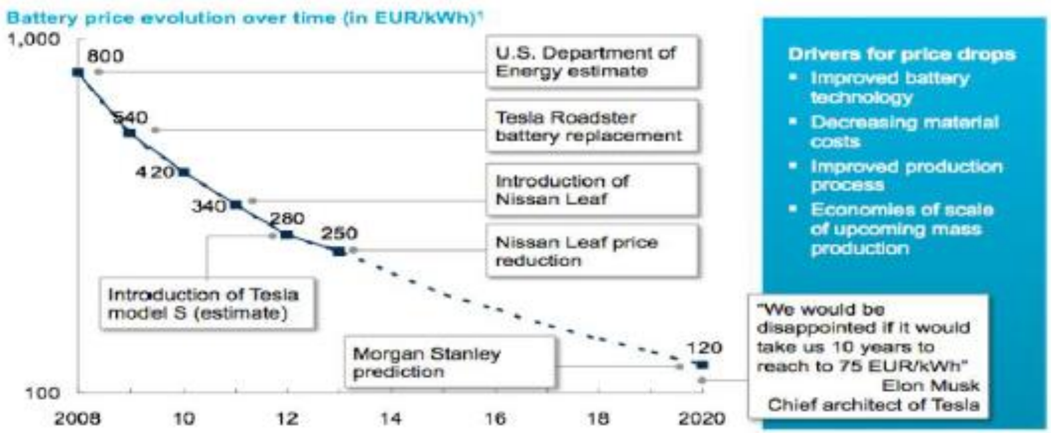
# ELECTRIC VEHICLES

## ADVANTAGES

- Virtually zero emissions of CO2 and pollutants
- 5-10 times lower energy cost (approx. saving of 1000-1500 EUR/year for C-class passenger car) and 50% lower maintenance costs
- Support to power utility system (via smart charging)
- Lower noise pollution, particularly at low velocities
- Much faster powertrain response – fun-to-drive
- Higher level of vehicle dynamics stability due to better front/rear mass balance and lower CoG (battery influence)
- Higher comfort level: e.g. better thermal comfort due to preheating/precooling while parked/charged
- High level of informatization and conectivity

# ELECTRIC VEHICLES

## HANDLING DISADVANTAGES (RANGE, PRICE, CHARGING TIME)




**Chevrolet Bolt: 55 Pre-Production Cars Made And Exceeding 200 Mile Range Target**

- 300+ km range (EPA): 2016 – 2018, $ 30 – 40k

FEV luxury cars ("Tesla fighters")

- Audi R8 e-tron, 2016, 450 km, 92 kWh;
- Audi Q6 e-SUV
- BMW i5, 2019
- Jaguar (SUV)
- Landrover
- Porsche 717
- Volkswagen (500 km range by 2020)

Audi says its E-tron Quattro, planned for 2018, will be able to charge at 150 kW, and Porsche says its Mission-E concept can handle 300 kW (Tesla's Superchargers, the fastest publicly available today, deliver up to 135 kW at some locations).

**Electric Cars To Cost Same As, Or Less Than ICE Within A Decade** Deutsche Bank, Dec 2014

Source: B. Witkamp (AVERE), CIVITAS FORUM, Ljubljana, October 2015.

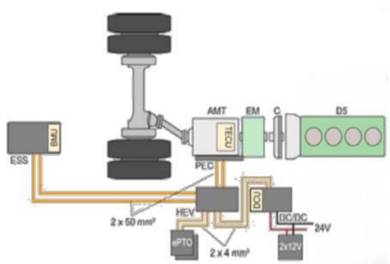
# ELECTRIC BUS TYPES

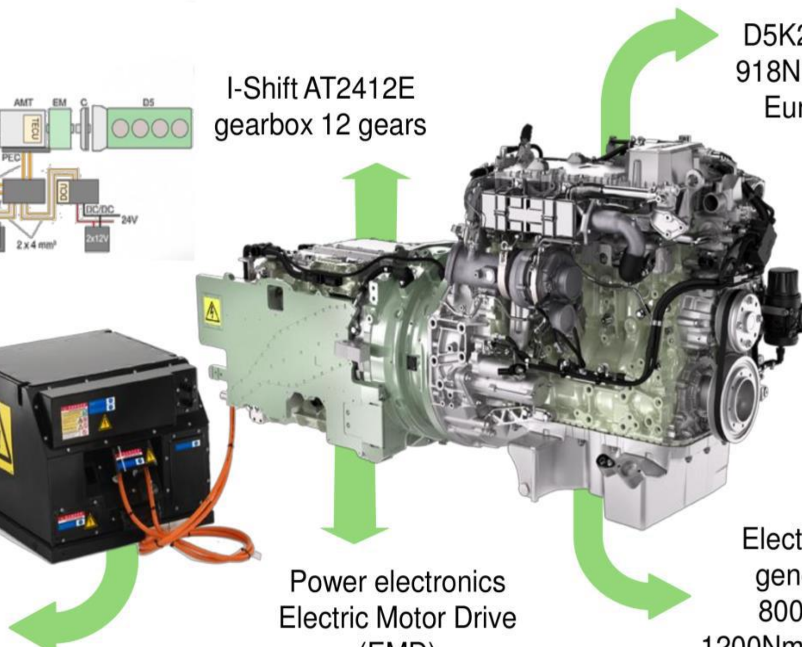
## EXAMPLE OF VOLVO 7900 SERIES: HEV AND BEV TYPES

**Volvo 7900 series** (Hybrid/**HEV**, ElectricHybrid/**PHEV**, Electric/**BEV**

## BEV-TYPE BUS

- E-bus (150 kWh battery, 1500 kg)
- Energy consumption: 12 kWh per route (cycles)
- DUB-pre-study: One charging per night (slow) and one daily charging (fast)






## HEV-TYPE BUS

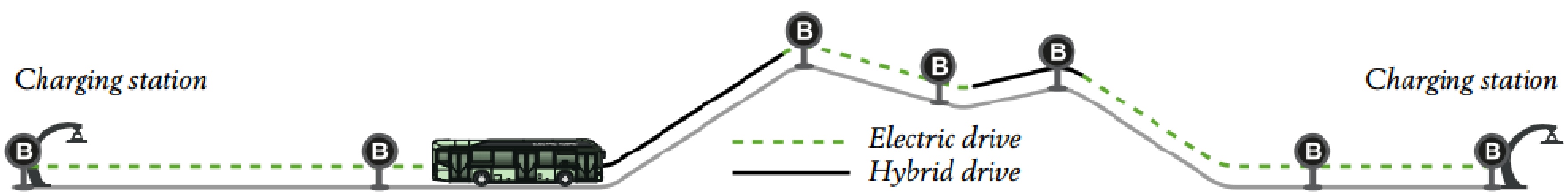
- HEV-bus (1.2 kWh battery)
- Paralell HEV drive:
  ICE-240 HP,
  EM-70 kW nominal,
  120 kW max.

# ELECTRIC BUS TYPES

## EXAMPLE OF VOLVO 7900 SERIES: PHEV TYPE

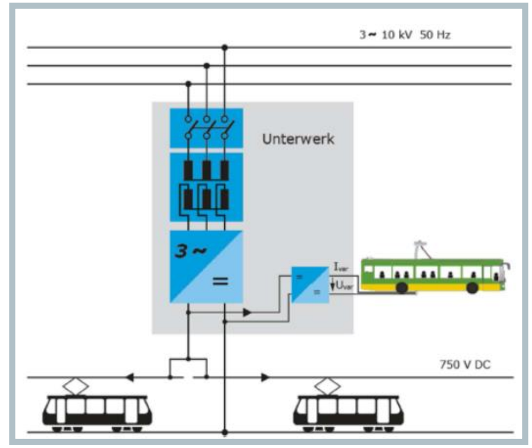

## PHEV-TYPE BUS

- PHEV-bus (19 kWh battery; ~ 7 km in full electric mode – eco zone)
- Paralell HEV drive: ICE – 240 HP, EM –150 kW max.
- Fast charging: max. power 150 kW (6 min, at end station, using pantograph)

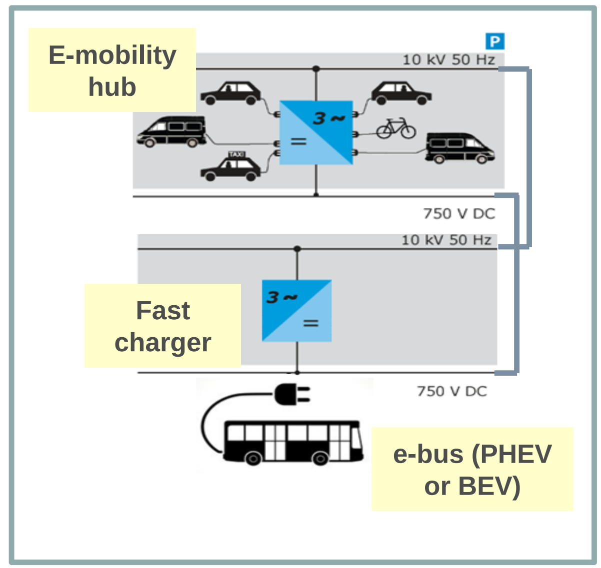


# CHARGING INFRASTRUCTURE

## PROJECTED EXAMPLES OF DUBROVNIK AND ŽILINA


Use of trolleybus grid for fast charging of e-buses (applicable to Žilina)



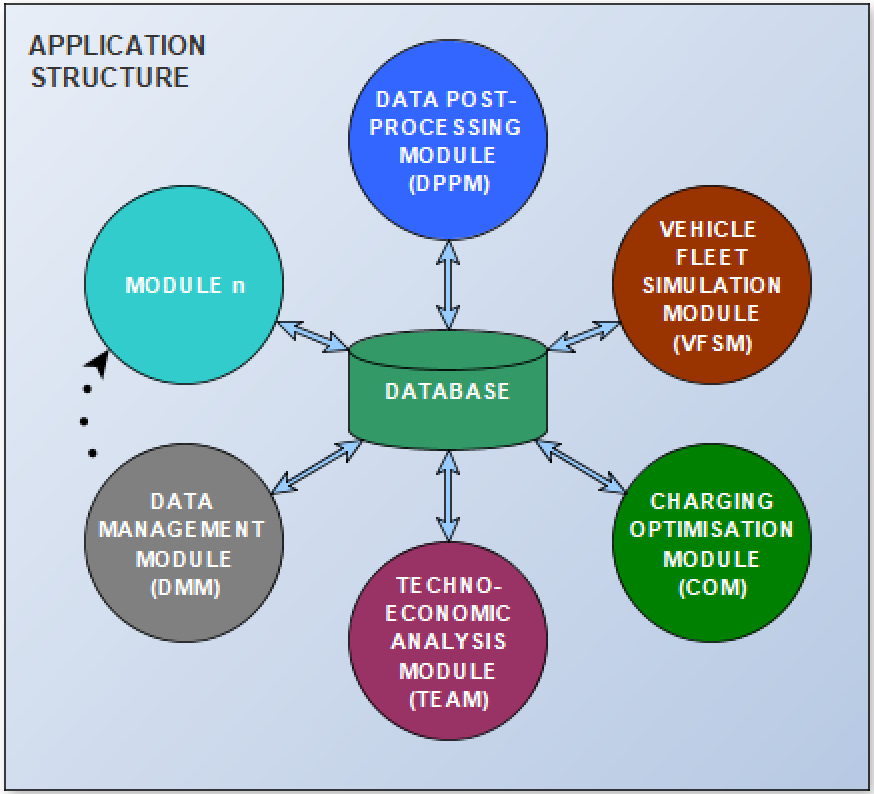

Use of e-bus fast charging power station as a city e-mobility hub (applicable to Dubrovnik)

# AN OVERVIEW OF SOLEZ-DEVELOPED TOOL

## ORGANISATIONAL STRUCTURE OF THE SOFTWARE APPLICATION

- Application is made as a set of software modules written in Python & C++.
- All modules share the same database.

**1. DPPM** (Data Post-processing Module)
Tool for post-processing and analysis of recorded driving cycles.



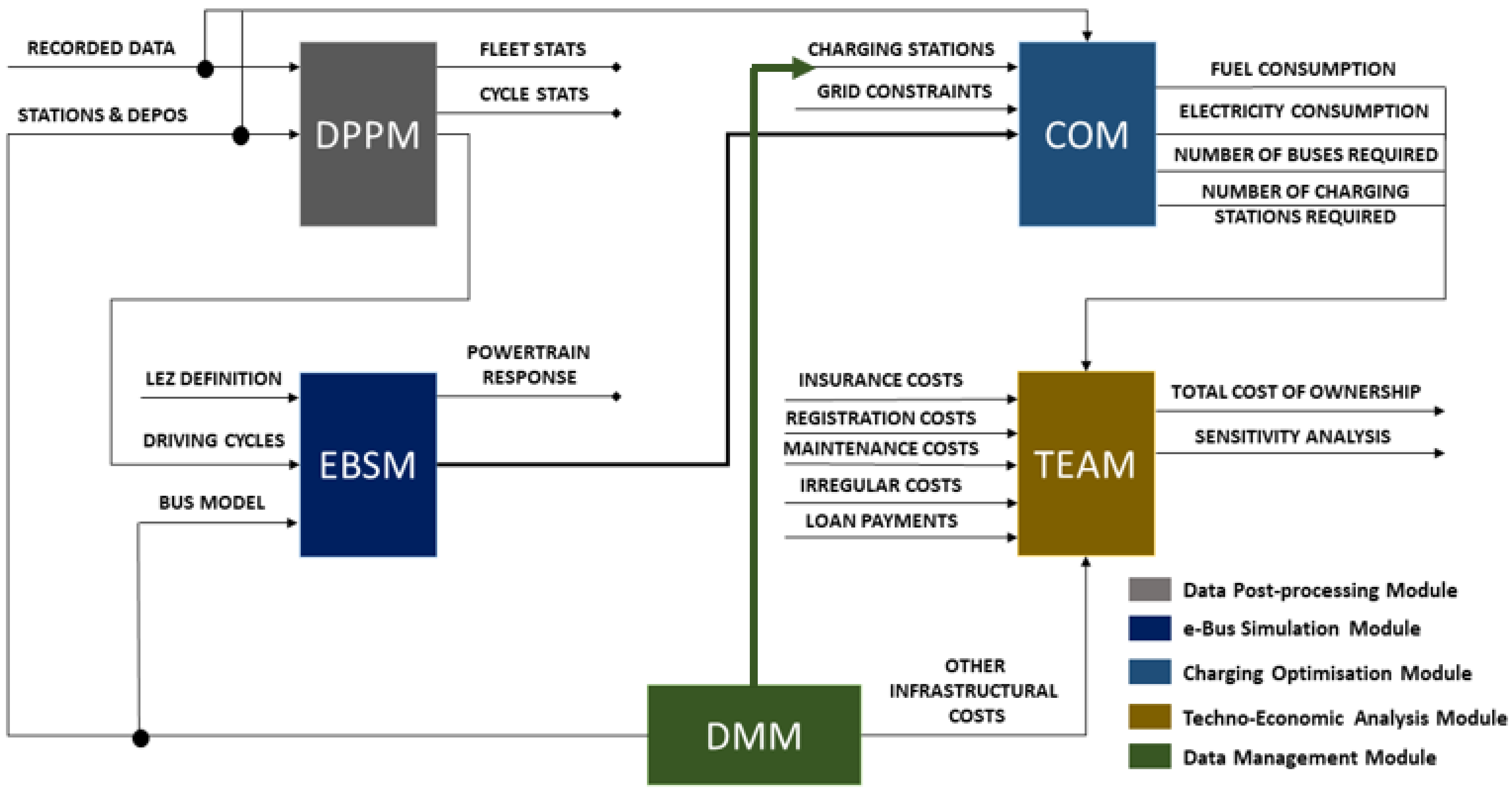

**2. EBSM** (E-bus Simulation Module)
Tool for simulation of various bus models (e.g. conventional, hybrid and electric ones).

**3. COM** (Charging Optimisation Module)
Tool for electric vehicle (EV) fleet charging optimisation.

**4. TEAM** (Techno-Economic Analysis Module)
Tool for techno-economic analysis related to the replacement of conventional vehicle fleet with electric one.

# AN OVERVIEW OF DEVELOPED ICT TOOLS

## BLOCK DIAGRAM OF SOFTWARE APPLICATION




The software tool is designed having in mind **transferability** to other cities/FUAs (it is **database** driven)

Includes **Data Management Module** for greater **flexibility** (bus model definition, station locations, etc.)

Interreg CENTRAL EUROPE European Union European Regional Development Fund SOLEZ

# Target cities for SOLEZ pilots

## Žilina (DPMŽ)

## Dubrovnik (Libertas)

# PILOT ACTIVITIES

## OVERALL APPROACH

### Necessary steps:

**Step 1**
- Equipping bus fleets with GPS/GPRS tracking modules (fast tracking, 1 sec sampling time)

**Step 2**
- Driving cycle data collection (24 h/day for 1 year).

**Step 3**
- Application of developed ICT tools to collected data (DPPM, EBSM, COM & TEAM).

**Step 4**
- A detailed techno-economic analysis for city bus transport electrification (TCO of EV fleet, and corresponding infrastructural costs)

### Data included:

| Label | ZIL | DUB |
|---|---|---|
| Timestamp | YES | YES |
| Coordinates (lat, lon) | YES | YES |
| Altitude | YES | YES |
| Engine state | YES | NO |
| Vehicle speed | YES | YES |
| Total mileage | YES | YES |
| Fuel consumed | YES | YES |
| Engine RPM | YES | YES |
| Accelerator pedal position | YES | YES |
| Engine temperature | YES | NO |
| Engine load | YES | YES |
| Vehicle weight | NO | YES |
| Clutch/break switch | NO | YES |
| Ambient air temperature | NO | YES |
| Selected/current gear | NO | YES |

# PILOT ACTIVITIES

## STATUS OF PILOT ACTIVITIES

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- Total of **25 buses (15 ZIL + 10 DUB)** are **equipped** with **GPS/GPRS** tracking equipment
- **Driving cycle** data were **processed** by the developed **ICT tools** in order to acquire the **most suitable city bus** transport electrification configurations for target cities and calculate the electrification cost

**5x** Solaris Urbino 12

\+

**10x** Karosa

\+

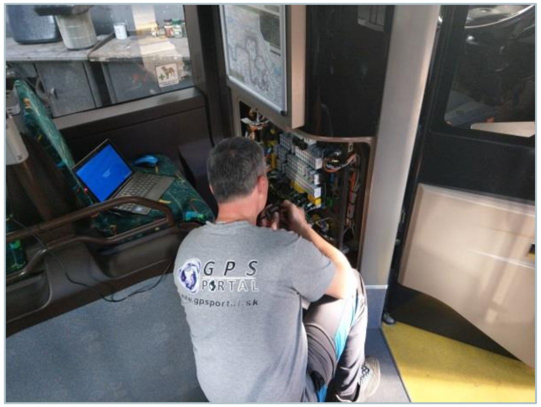
**10x** MAN Lion's City

**Data recording started on:**

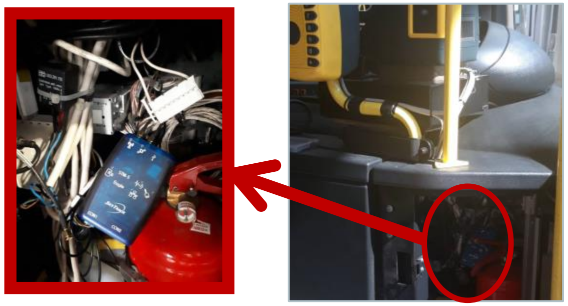
01/03/2018!

01/10/2018!

GPS Portal employee connecting the tracking device on bus chassis (ZIL)

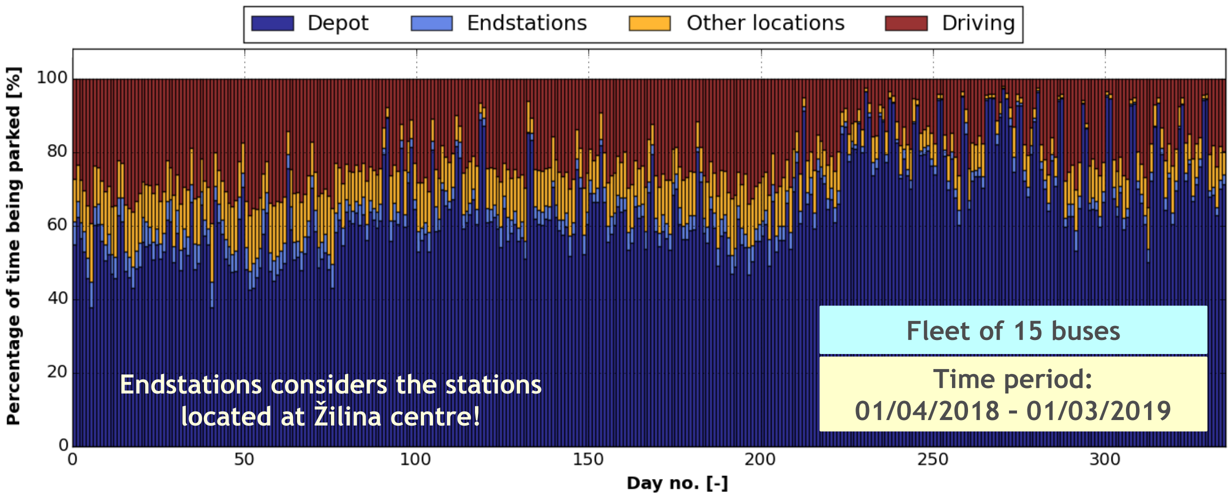


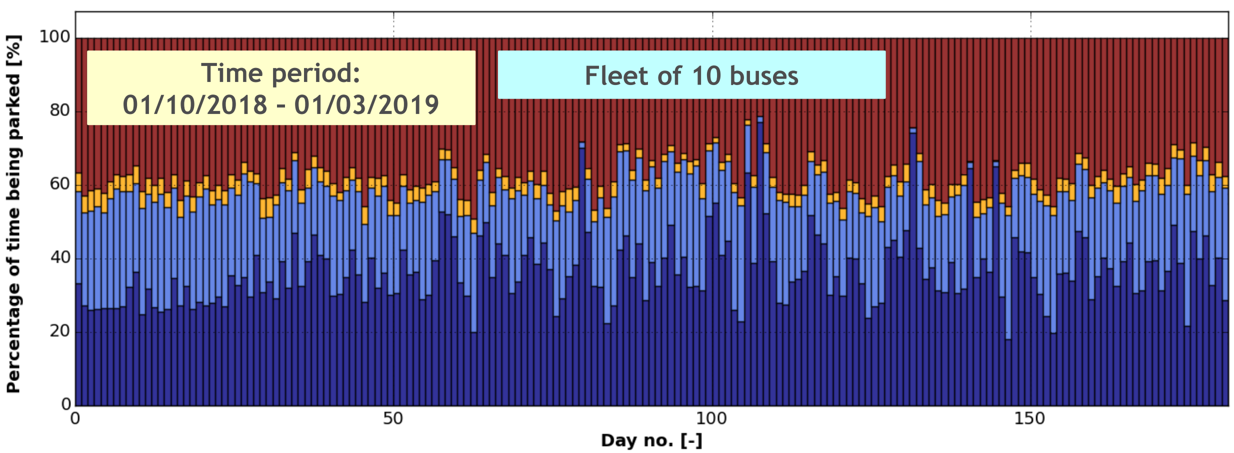
ZOOM



STM Eagle units built in buses (DUB)

## Proportions of buses parking times




### ZIL

Daily parking ratios:

- Depot: ≈ 60%
- Endstations: ≈ 5%
- Other locations: ≈ 10%
- Driving: ≈ 25 %

Cheap & efficient slow charging at depot would be appropriate!

### DUB

Daily parking ratios:

- Depot: ≈ 30%
- Endstations: ≈ 25%
- Other locations: ≈ 5%
- Driving: ≈ 40 %

Fast charging at endstations would be appropriate!

# PILOT ACTIVITIES

## COM - CHARGING SYSTEM OPTIMISATIONS

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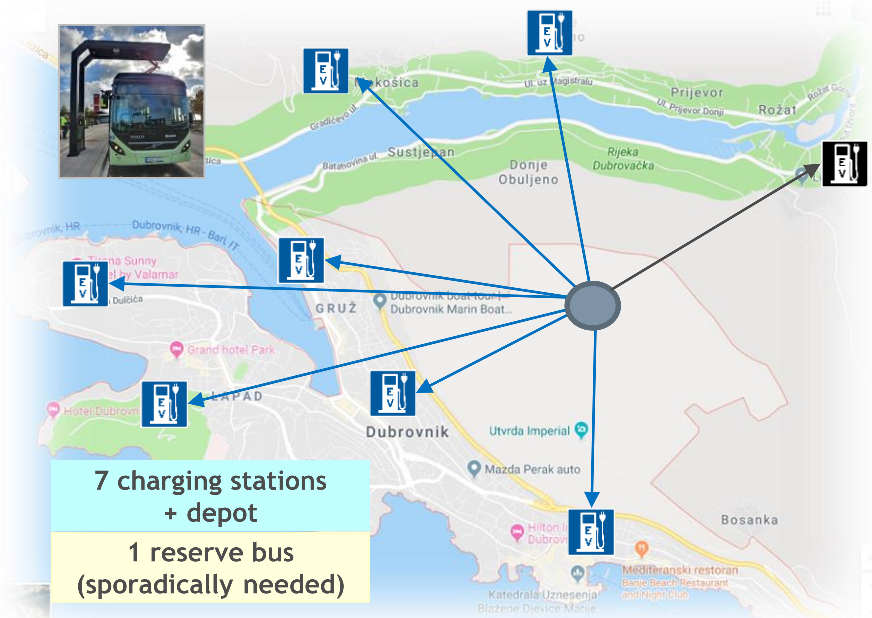
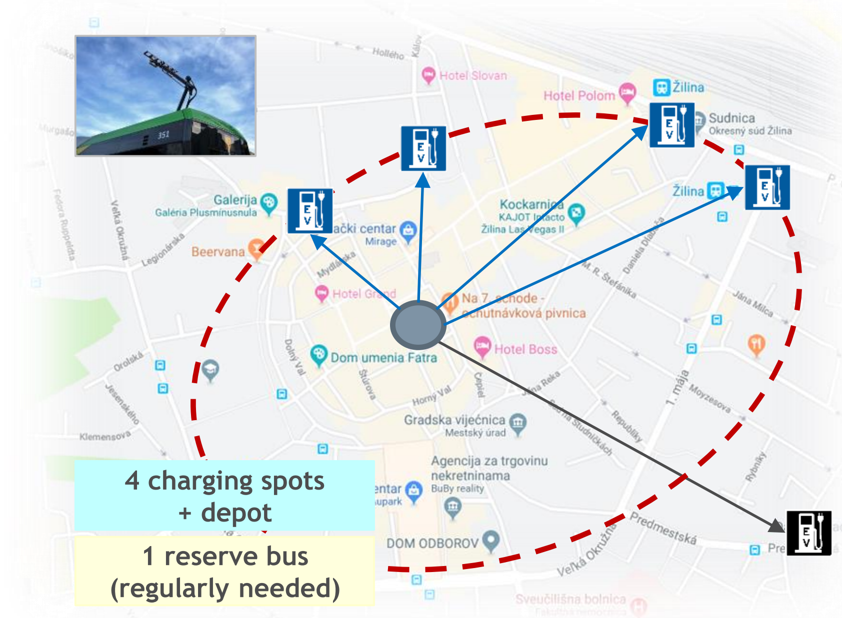
**DUB** | **Considered scenarios** | **ZIL**



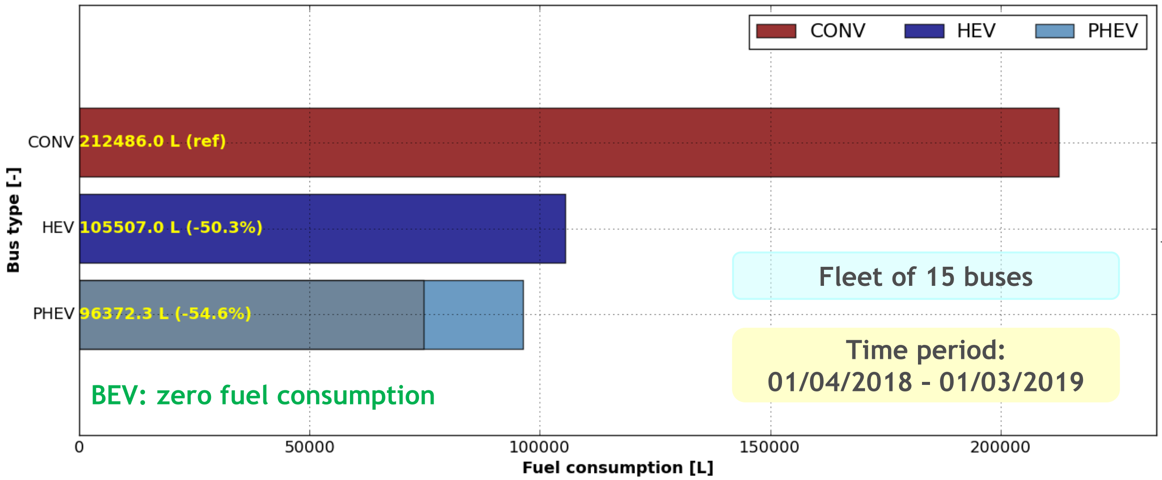

| | DUB | ZIL |
|---|---|---|
| Considered charging station locations | Selected endstations | Selected stations in the city centre ring |
| Charging power (PHEV / BEV) | 150 / 300 [kW] | 150 / 300 [kW] |
| Battery capacity for BEV | 76 kWh | 250 kWh |

- EBSM simulations were performed for fleets of Conventional (CONV), Hybrid (HEV), Plug-In Hybrid (PHEV) and Battery (BEV) electric buses
- Repetitive simulations in COM module gave an optimal number of charging stations

Depot | Charging station/spot

## COM – FUEL CONSUMPTIONS FOR DIFFERENT FLEET TYPES

# Fuel consumption per fleet type

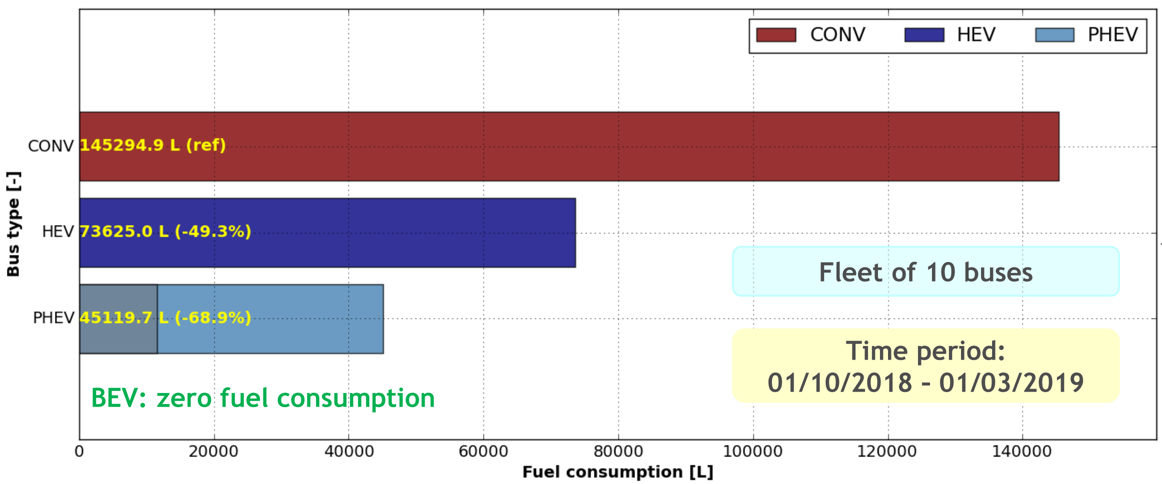



## ZIL

Relative fuel consumptions:

- HEV vs CONV: ≈ 50% lower
- PHEV vs CONV: ≈ 55% lower

**High proportion of driving in CS mode for PHEV (≈70%)!**
Due to lack of chargers at endstations (uneconomical / impractical) and short stays of buses at charging spots located in city centre




Fuel consumed in CS mode (PHEV)

## DUB

Relative fuel consumptions:

- HEV vs CONV: ≈50% lower
- PHEV vs CONV: ≈70% lower

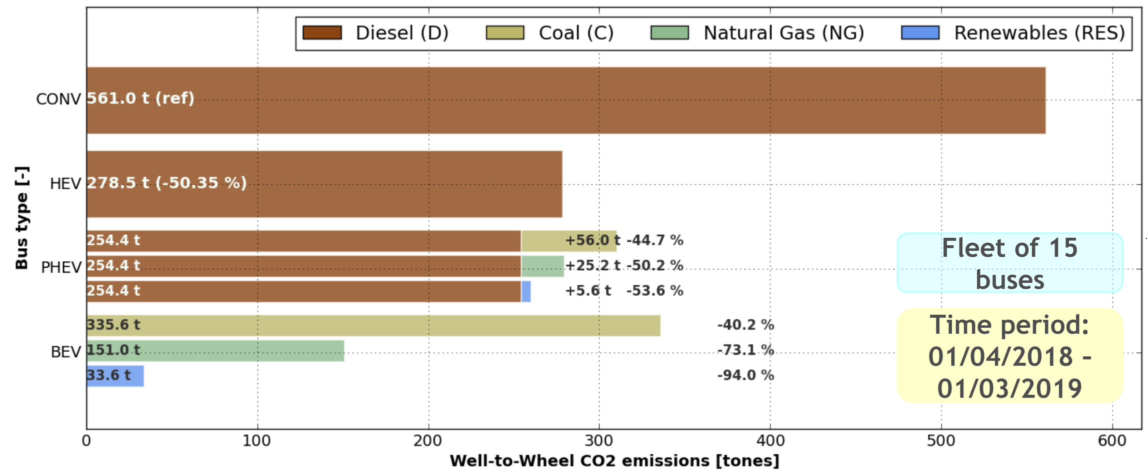
**High proportion of driving in CD mode for PHEV (≈75%)!**

CS mode = (battery) charge sustaining mode; CD mode = charge depleting mode

# PILOT ACTIVITIES

## COM – SAVINGS OF CO2 EMISSIONS FOR DIFFERENT FLEET TYPES

Emissions of CO2 (well-to-wheel)

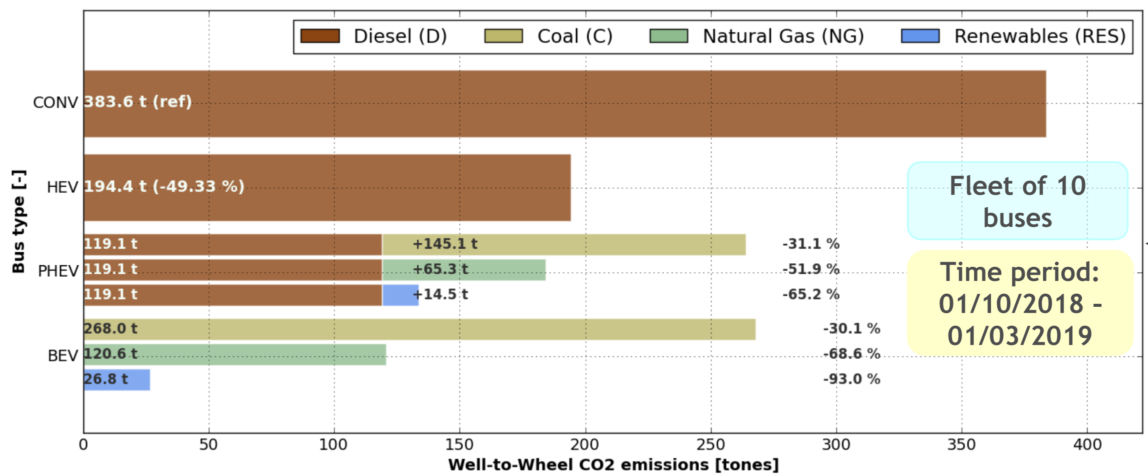



ZIL

HEV: ≈ 50% lower

PHEV: ≈ 45% to 55% lower

BEV: ≈ 40% to 95% lower




DUB

HEV: ≈ 50% lower

PHEV: ≈ 30% to 65% lower

BEV: ≈ 30% to 90% lower

Approx. emissions:

| | |
|---|---|
| Diesel | 2.64 g/L |
| Coal | 1.00 g/kWh |
| Natural Gas | 0.45 g/kWh |
| Renewables | 0.10 g/kWh |

# PILOT ACTIVITIES

## COM – DAILY FUEL & ELECTRICITY CONSUMPTIONS FOR DIFFERENT BUS TYPES

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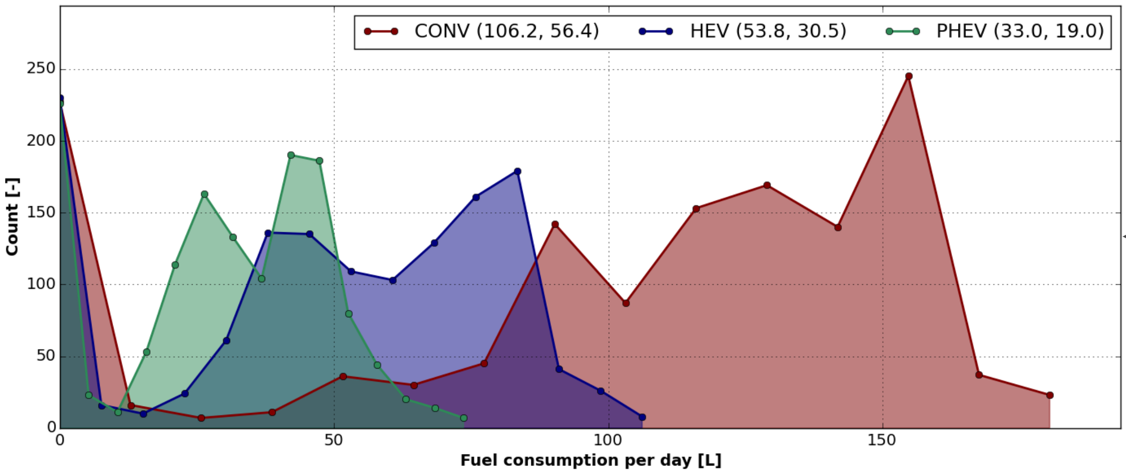
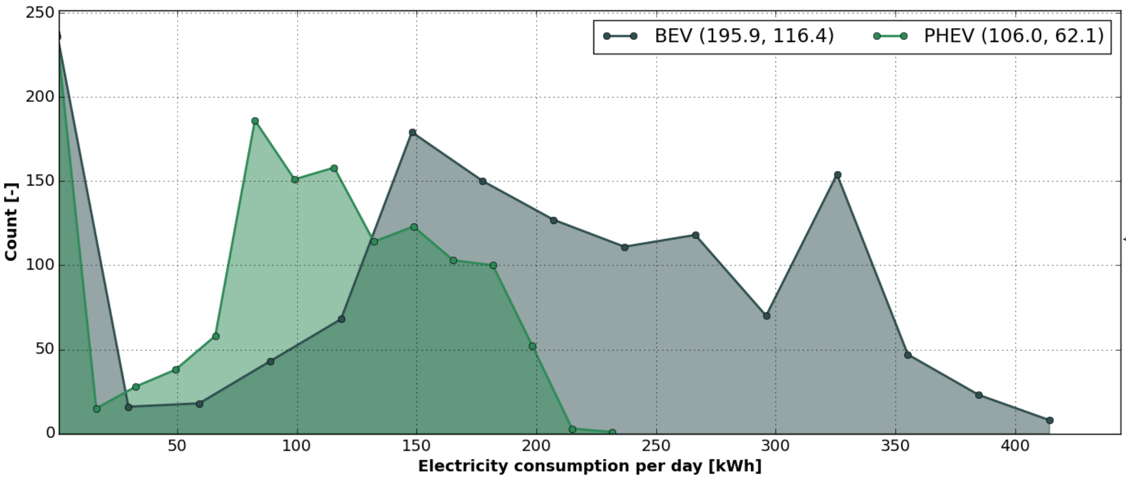
## Distributions of fuel & electricity consumption per bus per day




### DUB

Energy consumption (average):

- CONV: 106.2 L/day
- HEV: 53.8 L/day
- PHEV: 33 L/day + 106 kWh/day
- BEV: 195.9 kWh/day

**Buses rest in depot only for a few hours, and cross 300 km/bus per day on average!**

### ZIL

Energy consumption (average):

- CONV: 42.3 L/day
- HEV: 21 L/day
- PHEV: 19.2 L/day + 11.1 kWh/day
- BEV: 66.8 kWh/day

**Buses are resting at depot significantly longer than in the case of DUB, and cross 110 km/bus per day on average!**

# PILOT ACTIVITIES

## TEAM - SETUP FOR TECHNO-ECONOMIC ANALYSES

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### Considered TCO scenarios:

| Scenario | Buses no. | Reserve buses no. (BEV only) | Battery replacement | Random sampling | Lift of BEV electricity consumption |
|---|---|---|---|---|---|
| 1 | DUB: 10 ZIL: 15 | 0 | Not included | No | 0% |
| 2 | | 0 | Not included | Yes | 0% |
| 3 | | 1 | Not included | No | 0% |
| 4 | | 1 | Included | No | 0% |
| 5 | | 1 | Included | No | 40% |
| 6 | | 1 | Included | No | 100% |

Electricity consumption may be higher than simulated due to high summer temperatures and seasonal tourist peaks!

**Buses service life: 12 years**

**Loan period (buses + stations): 7 years**

### Main costs components:

| | ZIL (on-board charger) [EUR] | DUB (off-board charger) [EUR] |
|---|---|---|
| CONV | 240,000 | 240,000 |
| HEV | 400,000 | 400,000 |
| PHEV | 470,000 | 420,000 |
| BEV | 545,000 | 495,000 |

| | |
|---|---|
| Bus types | **Volvo 7900 series** |
| Fuel price [€/L] | 1.0243 €/L |
| Electricity prices (HT, LT) | 0.1215/0.1084 [€/kWh] |
| Battery lifetime | 6 years |

Infrastructure

| | |
|---|---|
| Fast charging station (150 kW - PHEV) | 45,000€ (PS) + 80,000€ = 125,000 € |
| Fast charging station (300 kW - BEV) | 45,000€ (PS) + 120,000 € = 165,000 € |
| Battery replacement costs (every 6 years) | HEV: 15,000 €; PHEV: 25,000 €; BEV: 80,000 € |

**DUB Case unless otherwise stated**



Note: Maintenance, insurance & registration costs for BEV, PHEV, HEV are 40%, 20% and 15% lower than CONV, respectively (BEV → 90% less moving parts than CONV, reduced CO2 emissions)

# PILOT ACTIVITIES

## TEAM - TIME PROGRESS OF TCO FOR DUB & ZIL FLEETS

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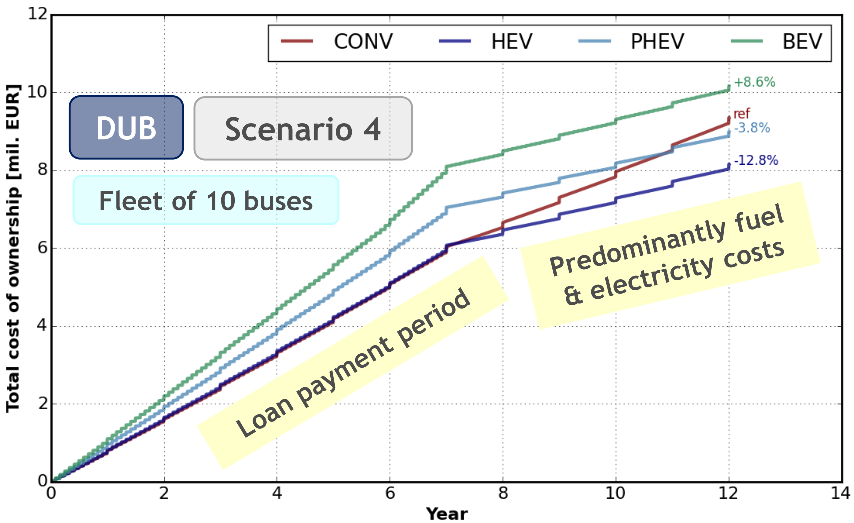
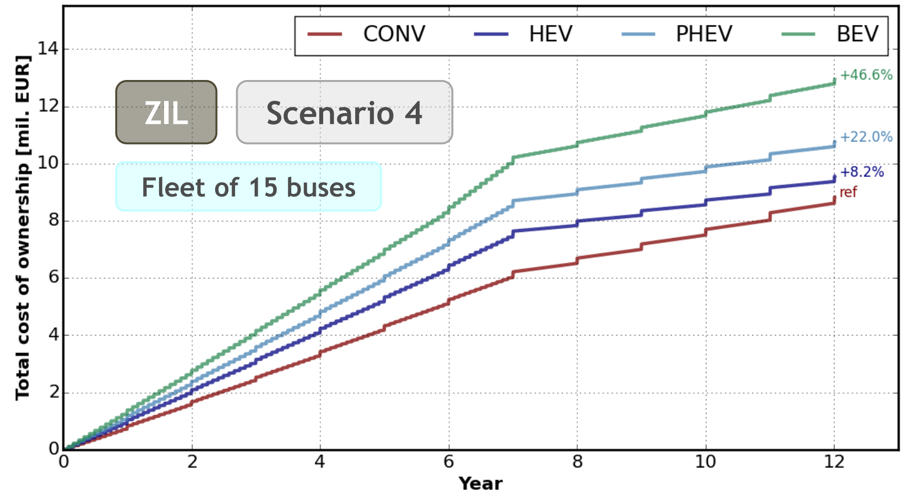


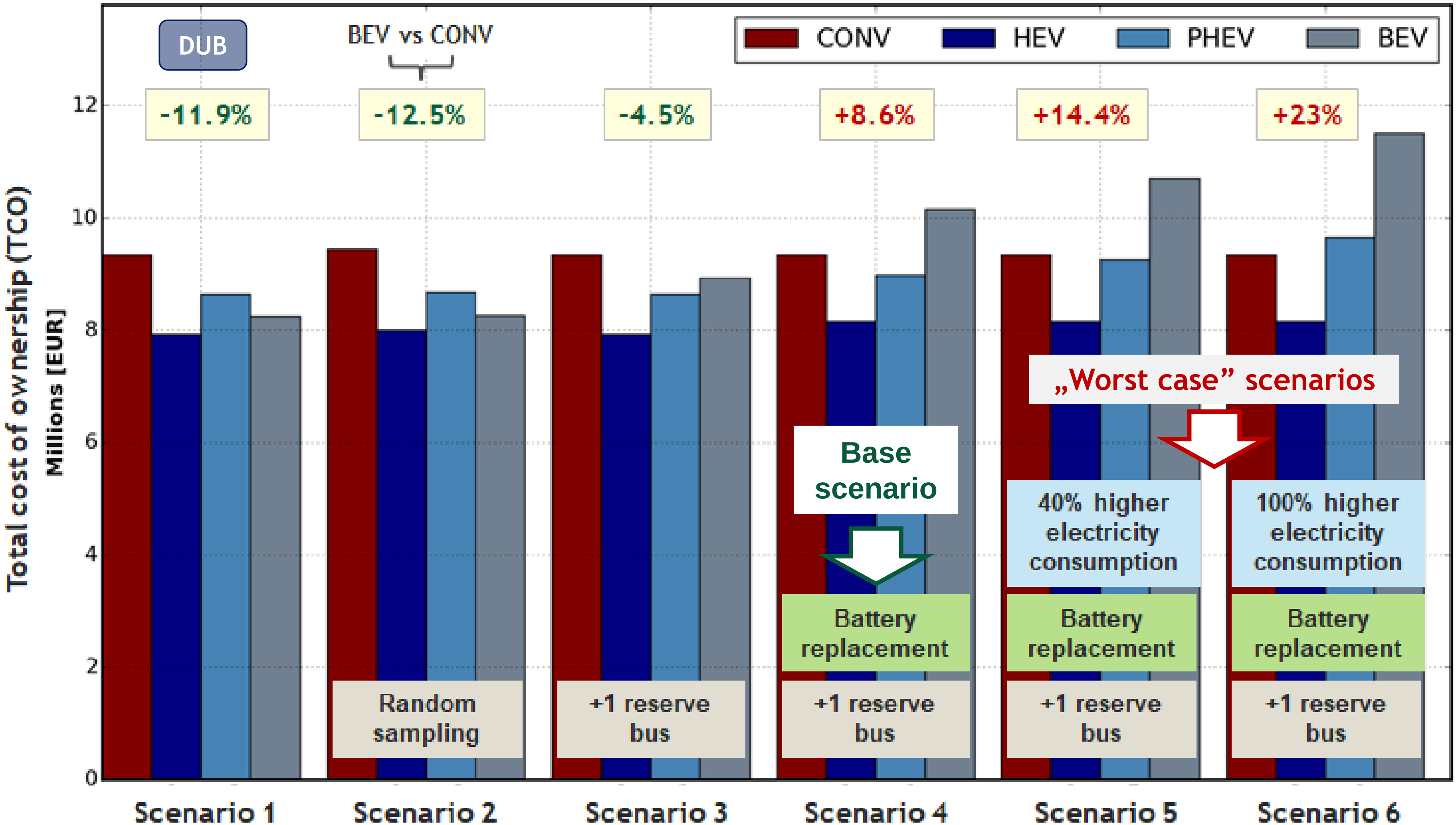

| Fleet type | Total cost of ownership [mil. €] | |
|---|---|---|
| | DUB | ZIL |
| CONV | 9.3 (ref) | 8.8 (ref) |
| HEV | 8.1 (-12.8%) | 9.5 (+8.2%) |
| PHEV | 9.0 (-3.8%) | 10.7 (+22.0%) |
| BEV | 10.1 (+8.6%) | 12.9 (+46.6%) |

### Main reasons for higher TCO in case of ZIL:

- ❑ Lower exploitation of buses while compared to DUB case
- ❑ Higher price of PHEV & BEV buses due to integrated on-board chargers

# PILOT ACTIVITIES

## TEAM - TCO SENSITIVITY WITH RESPECT TO DIFFERENT SCENARIOS



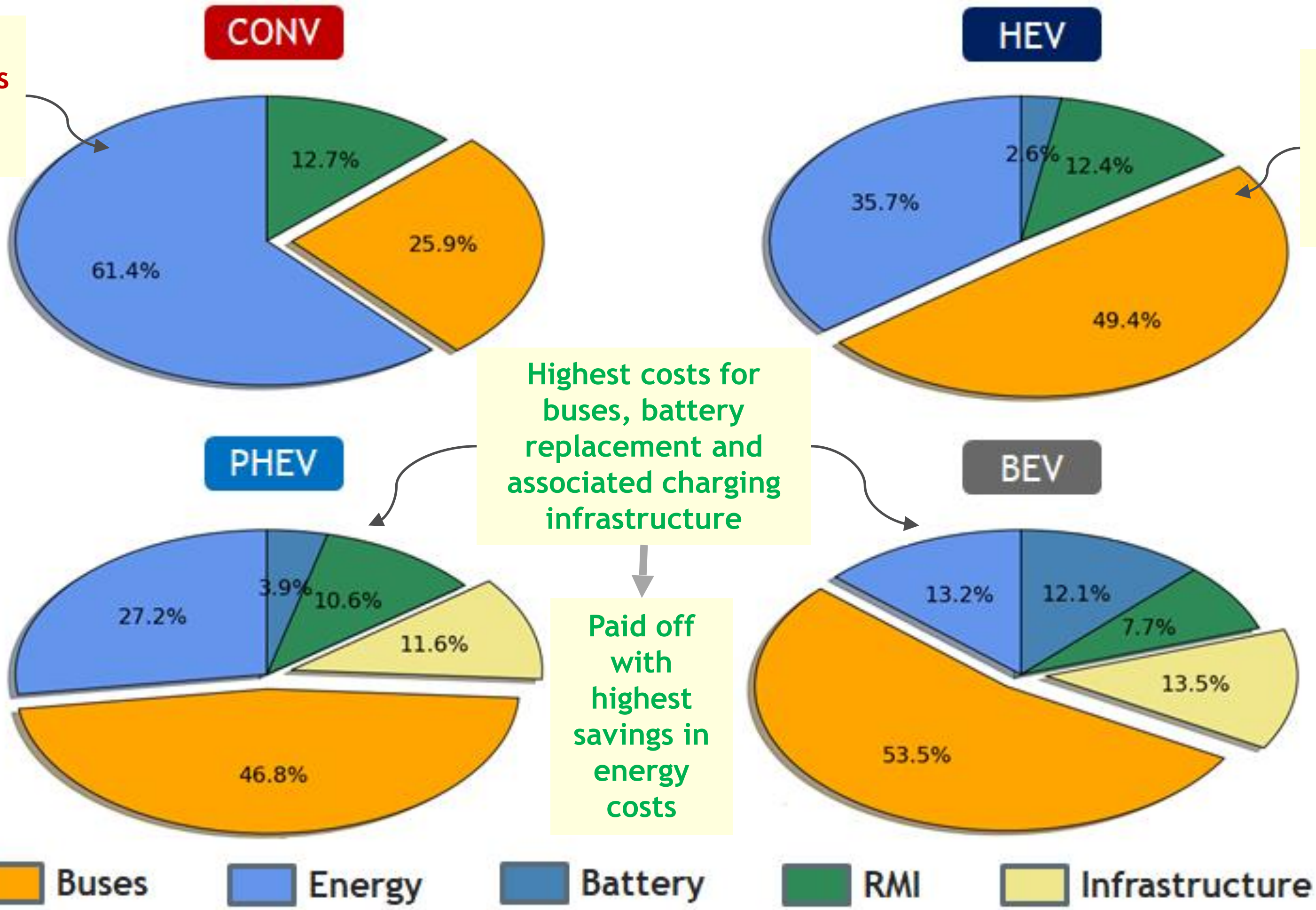
# PILOT ACTIVITIES

## TEAM - SHARES OF INDIVIDUAL COSTS FOR DIFFERENT FLEET TYPES

DUB | Scenario 4

### Cost ratios for different type of fleets

Energy costs exceeds buses purchase & RMI costs




- Energy = fuel & electricity cost
- RMI = registration, maintenance & insurance cost

# CONCLUSION REMARKS

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- It has been shown that **hybridisation/electrification** of the existing (Diesel) fleet can **reduce** overall **fuel consumption** by up to **50%** in the case of **HEV**, **70%** in the case of **PHEV** and **virtually 100%** in the case of **BEV**; and thus achieve significant savings in **$CO_2$ emissions**: up to **50%** in case of **HEV**, **65%** in case of **PHEV** and **95%** in case of **BEV**.

- An **optimal charging system** configuration for **DUB** (10 buses fleet) is considered to be the one consisting of (BEV or PHEV) buses with **lower battery capacity** (e.g. Volvo 7900 Electric; 76 kWh) and **fast chargers** located at **7 most pronnounced endstations** (including depot), while **ZIL** (15 buses fleet) requires BEV buses with **higher battery capacity** (e.g. 250 kWh) and **on-board chargers** connected to trolleybus grid, along with the ability to charge at **4 charging spots in city center** (due to the multitude of trolleybus lines that pass through the city center).

- Finally, results of **techno-economic analyses** have shown that the **profitability** of **investment** in the **fleet electrification** can be viable**,** and it depends mostly on **degree of fleet exploitation** → the greater the exploatation, the more it will be saved on energy (i.e. fuel & electricity).

- The **SOLEZ developed ICT tool** has been **proven** through the **two pilots**, and it is made to be **transferable to other cities**.


# Thank you for your attention

Looking forward to future cooperation
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