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

Updated in February 2021 for AaCTA workshop!

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

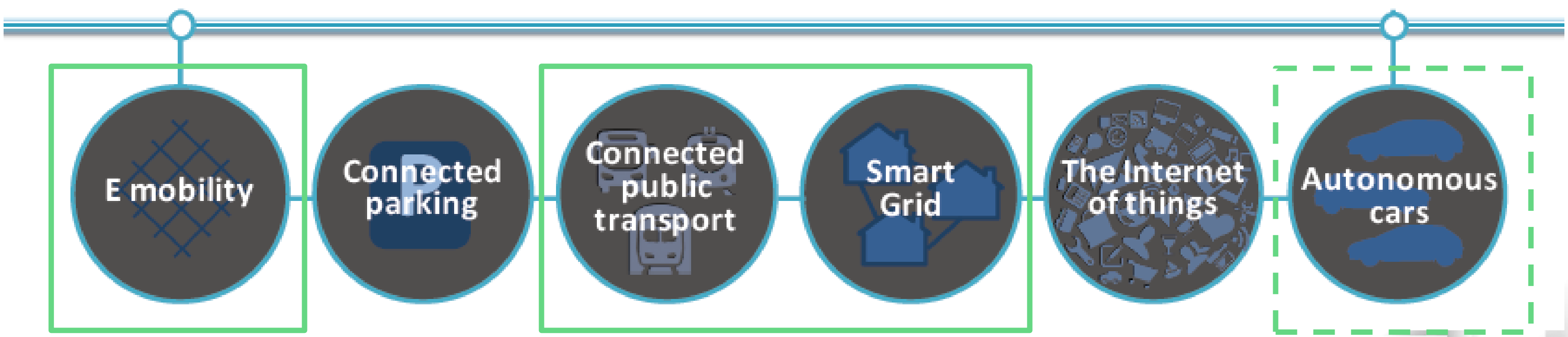
University of Zagreb

Presenter: Prof. Joško Deur, Ph.D.

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.

Vrste električnih vozila (EV)

Hibridno električno vozilo
*(**HEV**)*

Utično hibridno električno vozilo
*(**PHEV**)*

EV evolucija

Baterijsko električno vozilo
*(**BEV**)*

Električno vozilo proširenog dometa
*(**EREV**)*

Tekuće stanje tržišta u EU

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THE LEADERS

Europe's top-selling hybrids

Model	Sales (Jan.-Aug. 2020)	% change (Jan.-Aug. 2019)
1. Toyota Corolla	73,300	13%
2. Toyota C-HR	45,665	-20%
3. Toyota RAV4	45,665	-20%
4. Toyota Yaris	44,911	-36%
5. Kia Niro	20,835	-12%
6. Hyundai Kona	17,578	New model
7. Lexus UX	9,844	-1.6%
8. Honda CR-V	7,943	-22%
9. Toyota Prius+	7,442	-0.5%
10. Lexus NX	7,174	-29%

Source: JATO Dynamics

*Hibridno električno vozilo (**HEV**)*

THE LEADERS

Europe's top 5-selling plug-in hybrids, January-July

Model	Sales
1. Mitsubishi Outlander PHEV	16,211
2. Ford Kuga	13,963
3. VW Passat GTE	10,905
4. BMW 330e	10,742
5. Volvo XC60 Recharge	10,384
6. Volvo XC40 Recharge	9,255
7. Volvo V60 Recharge	9,012
8. Peugeot 3008 Hybrid4	8,276
9. Audi A3	7,292
10. BMW X5 xDrive45e	7,048

Source: JATO Dynamics

*Utično hibridno električno vozilo (**PHEV**)*

EV evolucija

THE LEADERS

The Renault Zoe helped the segment grow 34% in the half

Model	Sales H1 2020	% change H1 2019
1. Renault Zoe	36,573	53%
2. Tesla Model 3	31,949	-14%
3. VW e-Golf	17,535	39%
4. Peugeot e-208	13,304	New
5. Nissan Leaf	12,629	-21%
6. Audi e-tron	12,449	90%
7. Hyundai Kona EV	11,414	2.2%
8. Kia e-Niro	8,455	38%
9. BMW i3	8,339	-47%
10. VW e-Up	7,298	509%
SEGMENT TOTAL	**217,495**	**34%**

Source: JATO Dynamics

*Baterijsko električno vozilo (**BEV**)*

Segment	Market share (segment / total sales)
HEVs 2020 up to Oct.	335k / 8.4m **~3.9%**
PHEV Q1-Q3 2020	~4.1%
BEV Q1-Q3 2020	~4.9%
BEV+PHEV, Q1-Q3 2020	**~772k/8.472m --> ~9.1%**
Toyota HEVs share, Q1-Q3 2020	**62%** (JATO Dynamics)

"Toyota's command of the technology has pushed the hybrid share of its overall European sales to 62 percent, up from 20 percent in 2014, according to JATO. Sister brand Lexus counts on hybrids for 94 percent of its European sales."

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

Otklanjanje nedostataka (domet, cijena, vrijeme punjenja)

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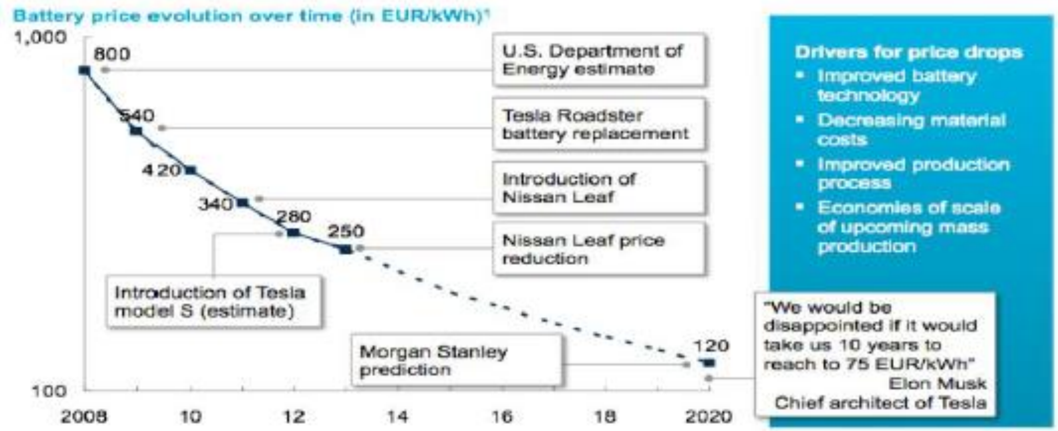


Chevrolet Bolt: 55 Pre-Production Cars Made And Exceeding 200 Mile Range Target (2015)

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

→ 2020, Chevrolet Bolt 400+ km (EPA)

FEV luxury cars ("Tesla fighters") (2015) (2020)

- Audi R8 e-tron, 2016, 450 km, 92 kWh; → discontinued
- Audi Q6 e-SUV → Audi e-Tron 55 quattro , 436 km (WLTP)
- BMW i5, 2019 → I5 cancelled? iX3 in 2021, 460 km (WLTP)
- Jaguar (SUV) → I-Pace since 2018, 470 km (WLTP)
- Landrover → After 2021
- Porsche 717 → Taycan launched in 2020, 495 km (WLTP)
- Volkswagen (500 km range by 2020) → ID.3 launched in 2020, 550 km (WLTP)

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).

… Porsche Taycan omogućava i snagu punjenja od 350 kW (do 80%)

„There's a cost gap of about $12,000 between electric vehicles and internal-combustion-engine vehicles today (small to mid-size car segments). Our analysis shows that EVs have potential to reach cost parity by around 2025." McKinsey & Company 2019

6

Izvorni podaci: B. Witkamp (AVERE), CIVITAS FORUM, Ljubljana, listopad 2015.

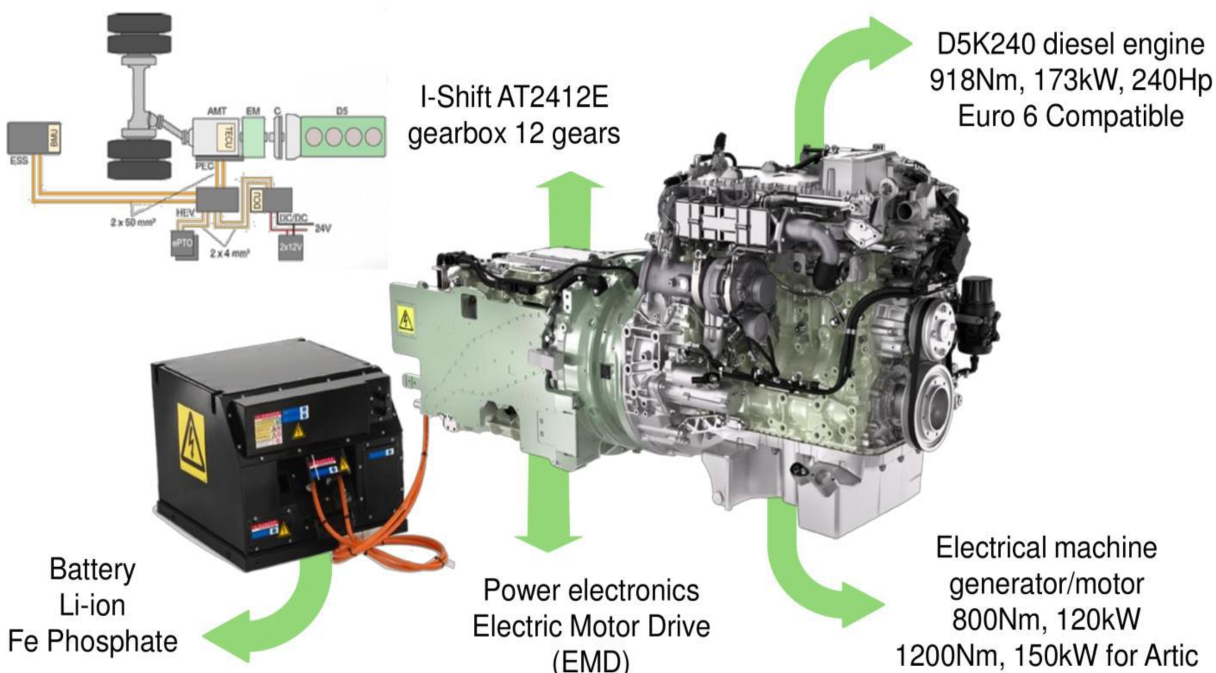
ELECTRIC BUS TYPES

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

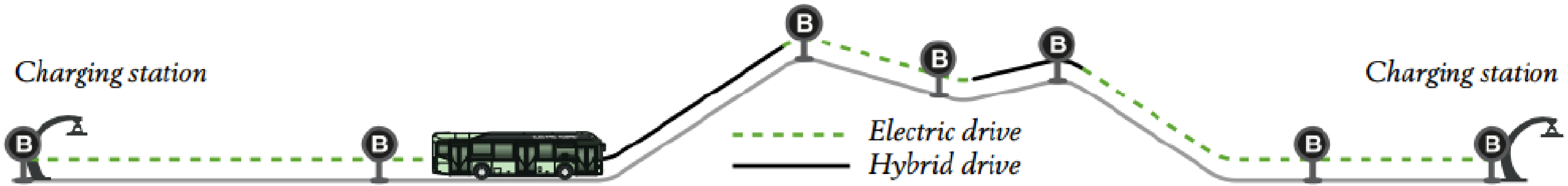
- HEV-bus (1.2 kWh battery)
- Paralell HEV drive:
  ICE-240 HP,
  EM-70 kW nominal,
  120 kW max.

ELECTRIC BUS TYPES

EXAMPLE OF VOLVO 7900 SERIES: PHEV TYPE

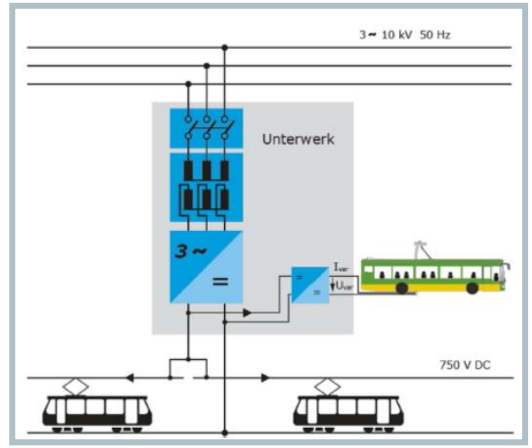
PHEV-TYPE BUS

- 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)

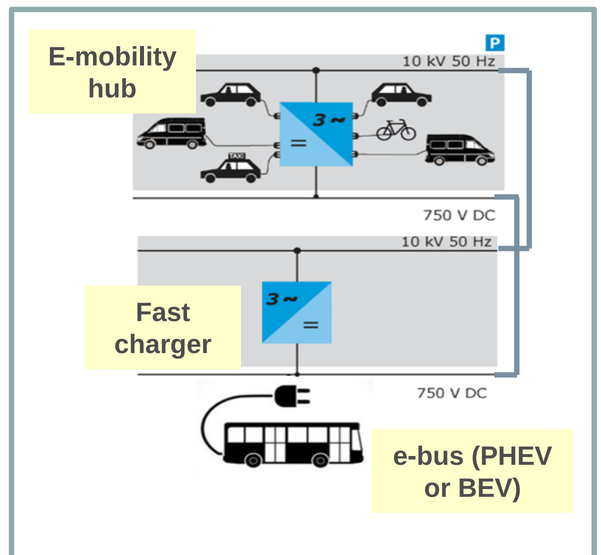


CHARGING INFRASTRUCTURE

PROJECTED EXAMPLES OF DUBROVNIK AND ŽILINA



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



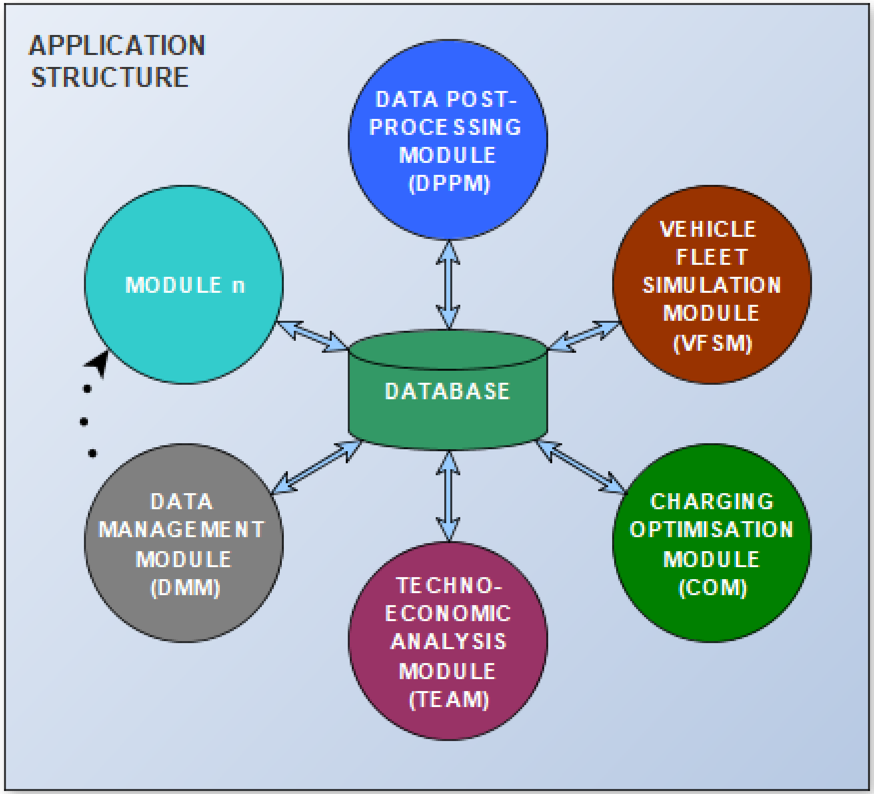
Use of e-bus fast charging power station as a city e-mobility hub (applicable to Dubrovnik)

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.



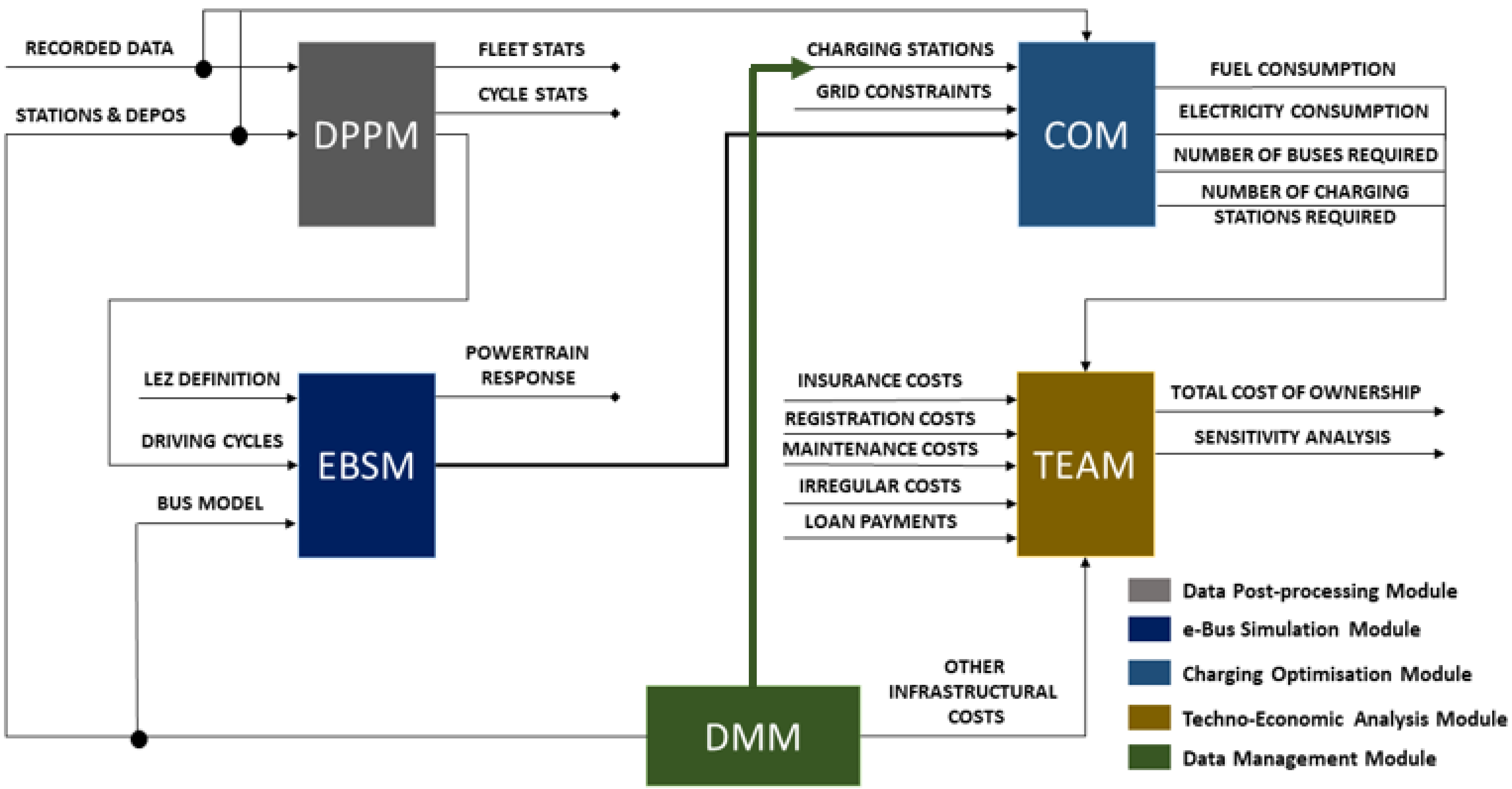
2. EBSM (E-bus Simulation Module)
Tool for simulation of various bus models (e.g. conventional, hybrid and electric ones).

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.)

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

\+

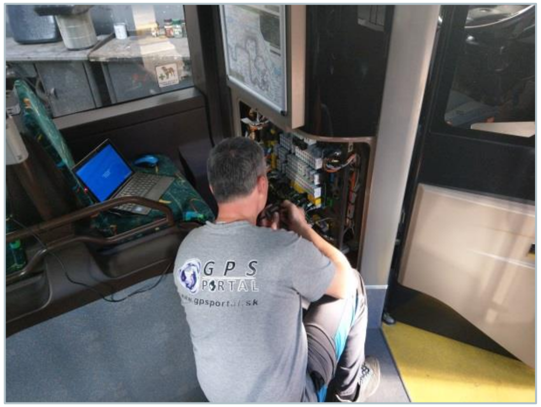
10x MAN Lion's City

Data recording started on:

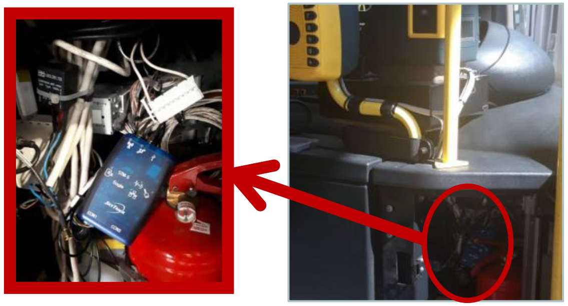
01/03/2018!

01/10/2018!

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



ZOOM



STM Eagle units built in buses (DUB)

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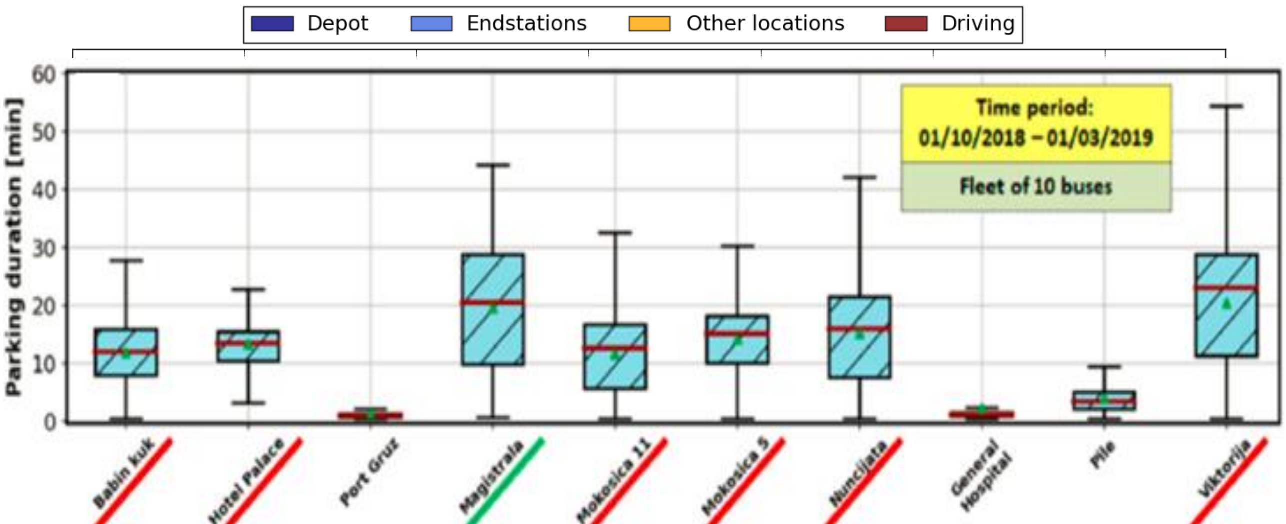
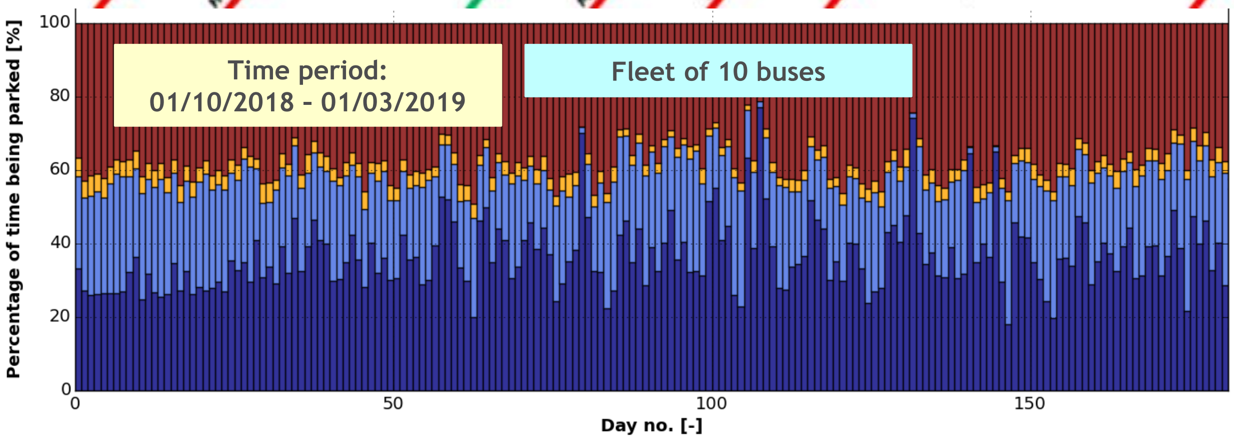
SOLEZ

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!

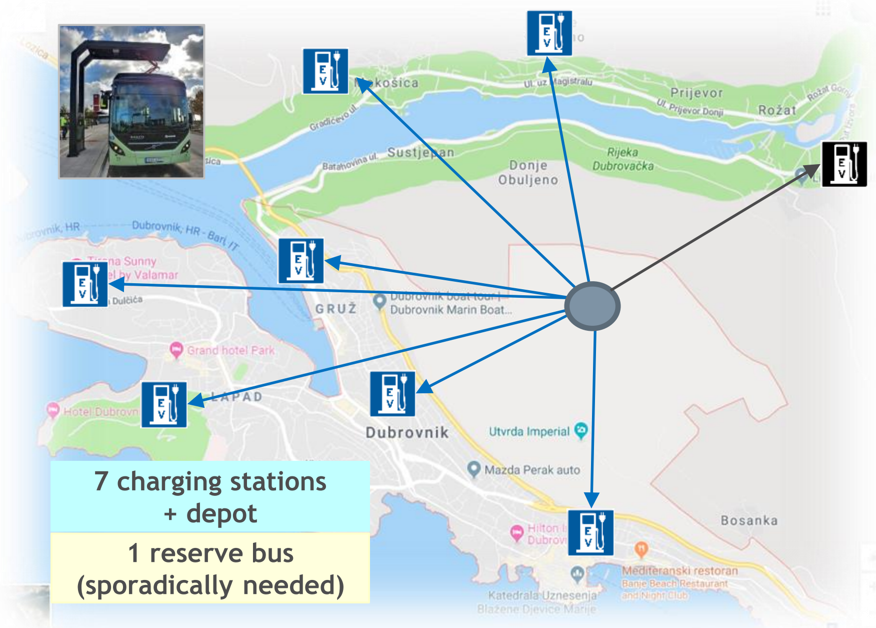
DUB

Daily parking ratios:

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

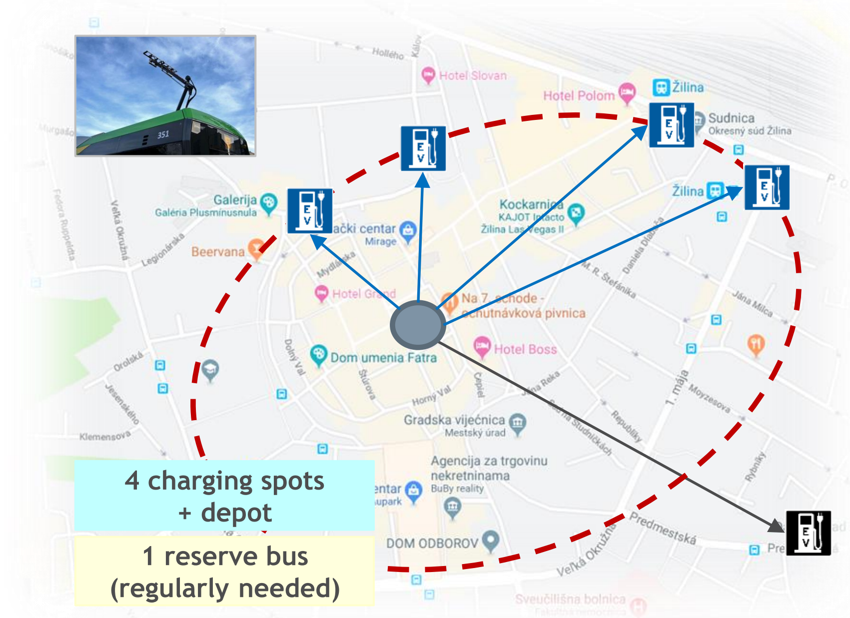
Fast charging at endstations would be appropriate!

DUB | **Considered scenarios** | ZIL



7 charging stations
+ depot

1 reserve bus
(sporadically needed)



4 charging spots
+ depot

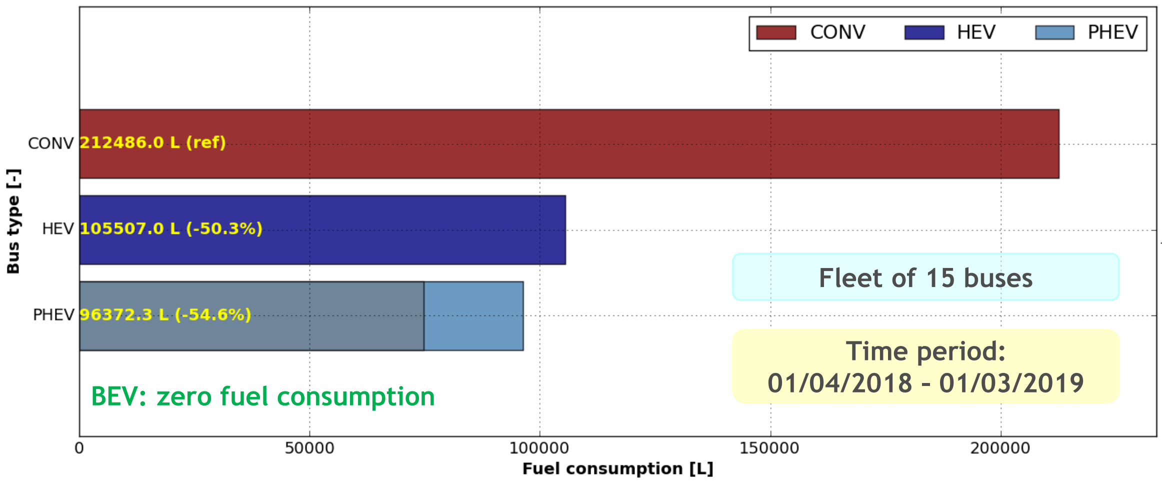
1 reserve bus
(regularly needed)

	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

Fuel consumption per fleet type

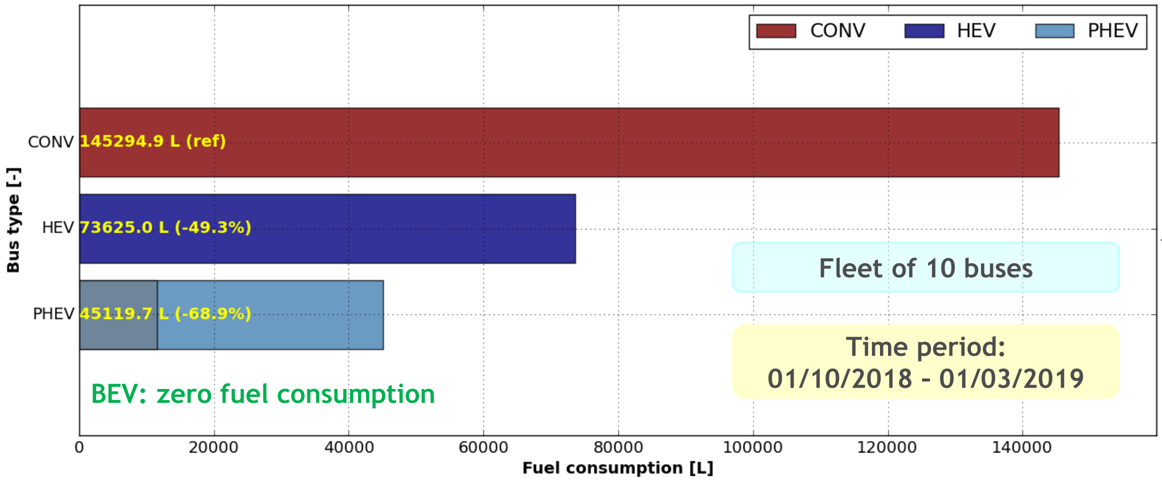


ZIL

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

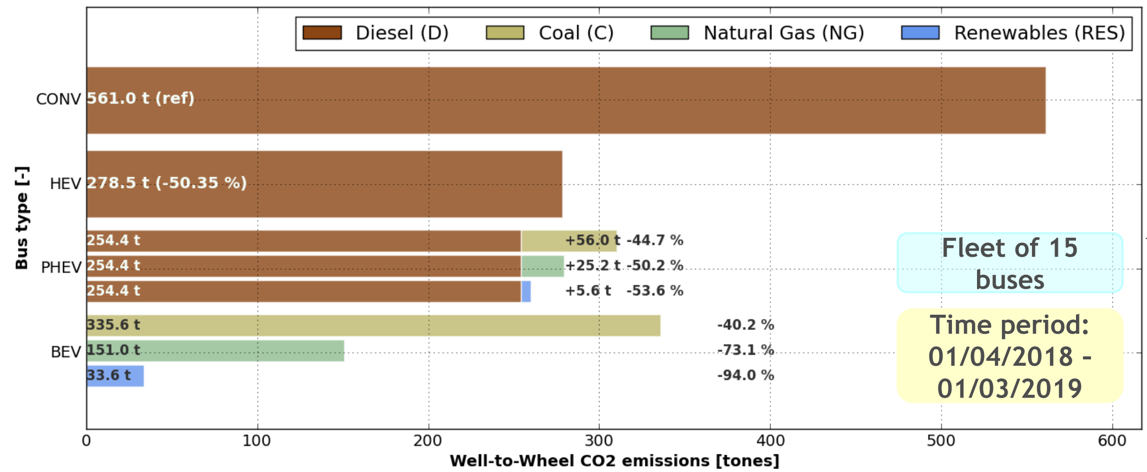
Relative fuel consumptions:

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

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

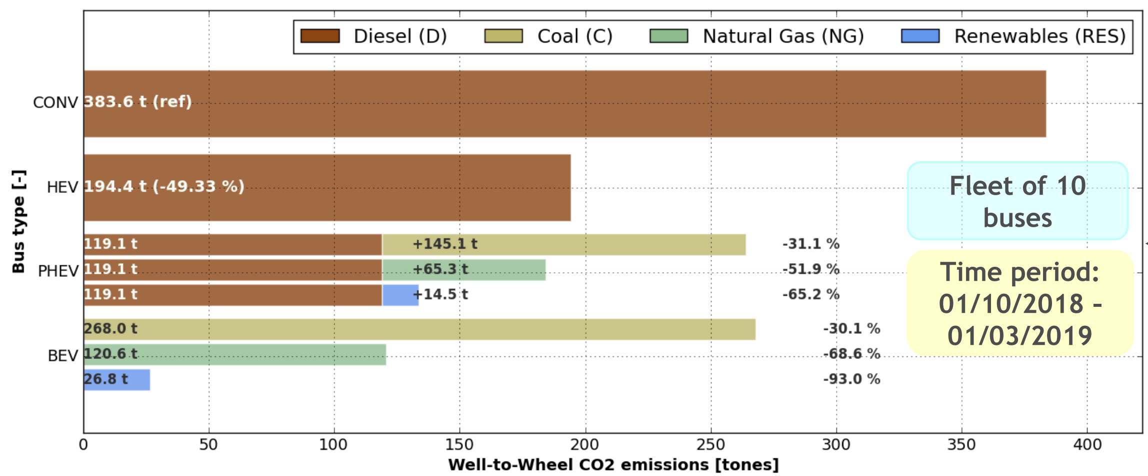
CS mode = (battery) charge sustaining mode; CD mode = charge depleting mode

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

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

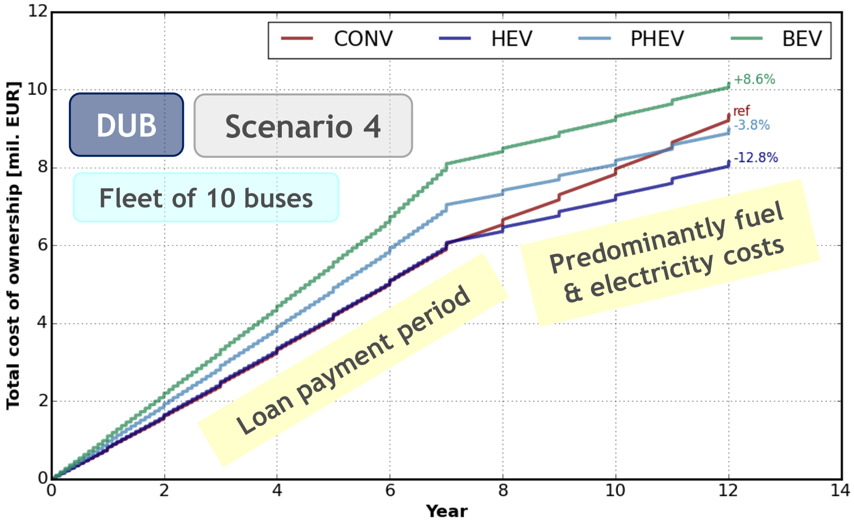
Fast charging station (150 kW - PHEV)	45,000€ (PS) + 80,000€ = 125,000 €
Fast charging station (300 kW - BEV)	45,000€ (PS) + 120,000 € = 165,000 €
Battery replacement costs (every 6 years)	HEV: 15,000 €; PHEV: 25,000 €; BEV: 80,000 €

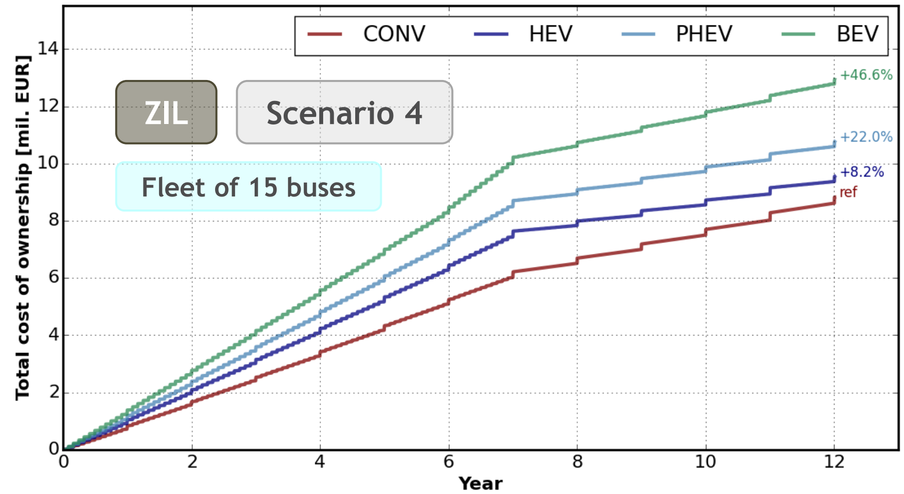
DUB Case unless otherwise stated

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





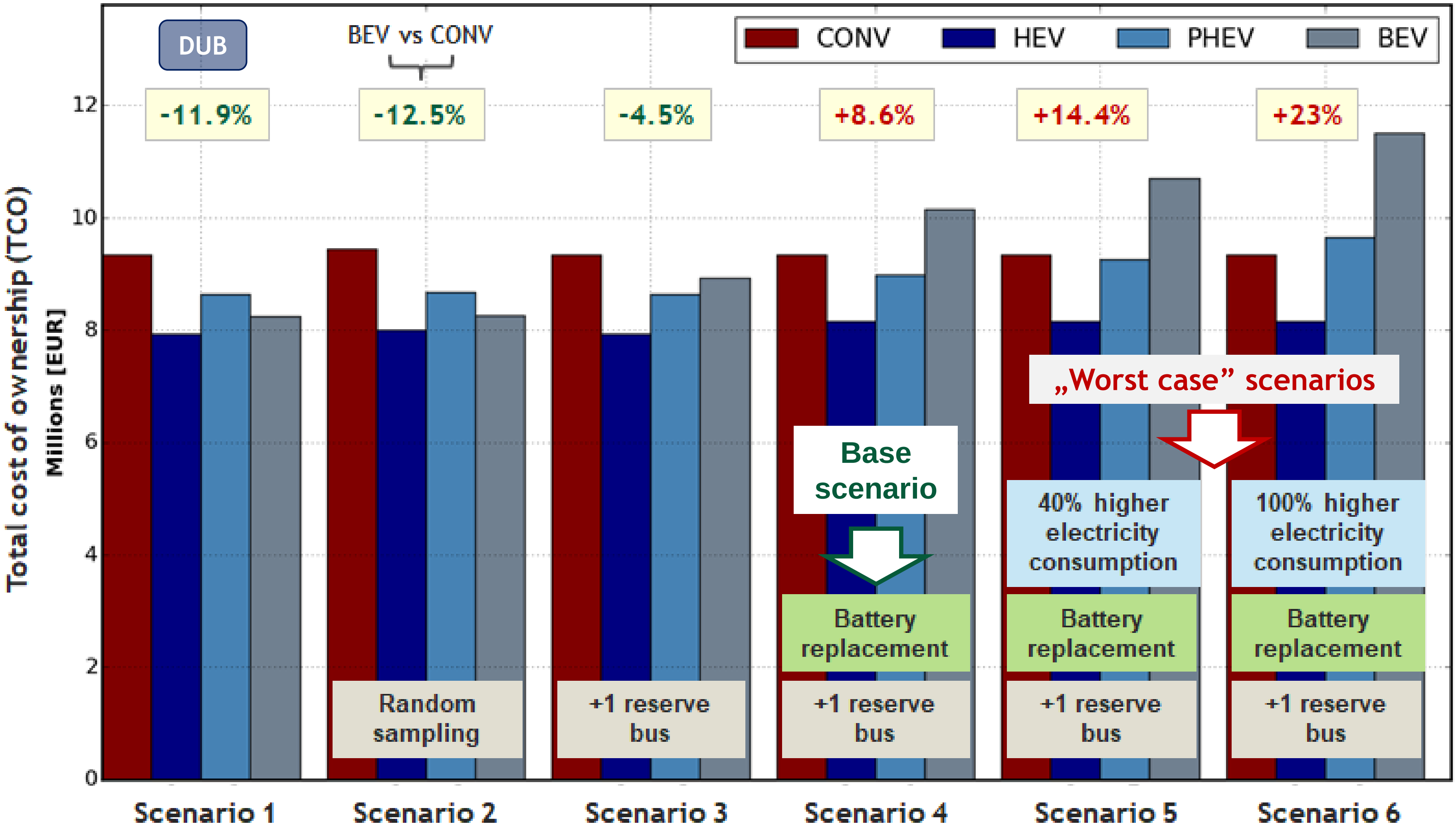
Fleet type	Total cost of ownership [mil. €]	
	DUB	ZIL
CONV	9.3 (ref)	8.8 (ref)
HEV	8.1 (-12.8%)	9.5 (+8.2%)
PHEV	9.0 (-3.8%)	10.7 (+22.0%)
BEV	10.1 (+8.6%)	12.9 (+46.6%)

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

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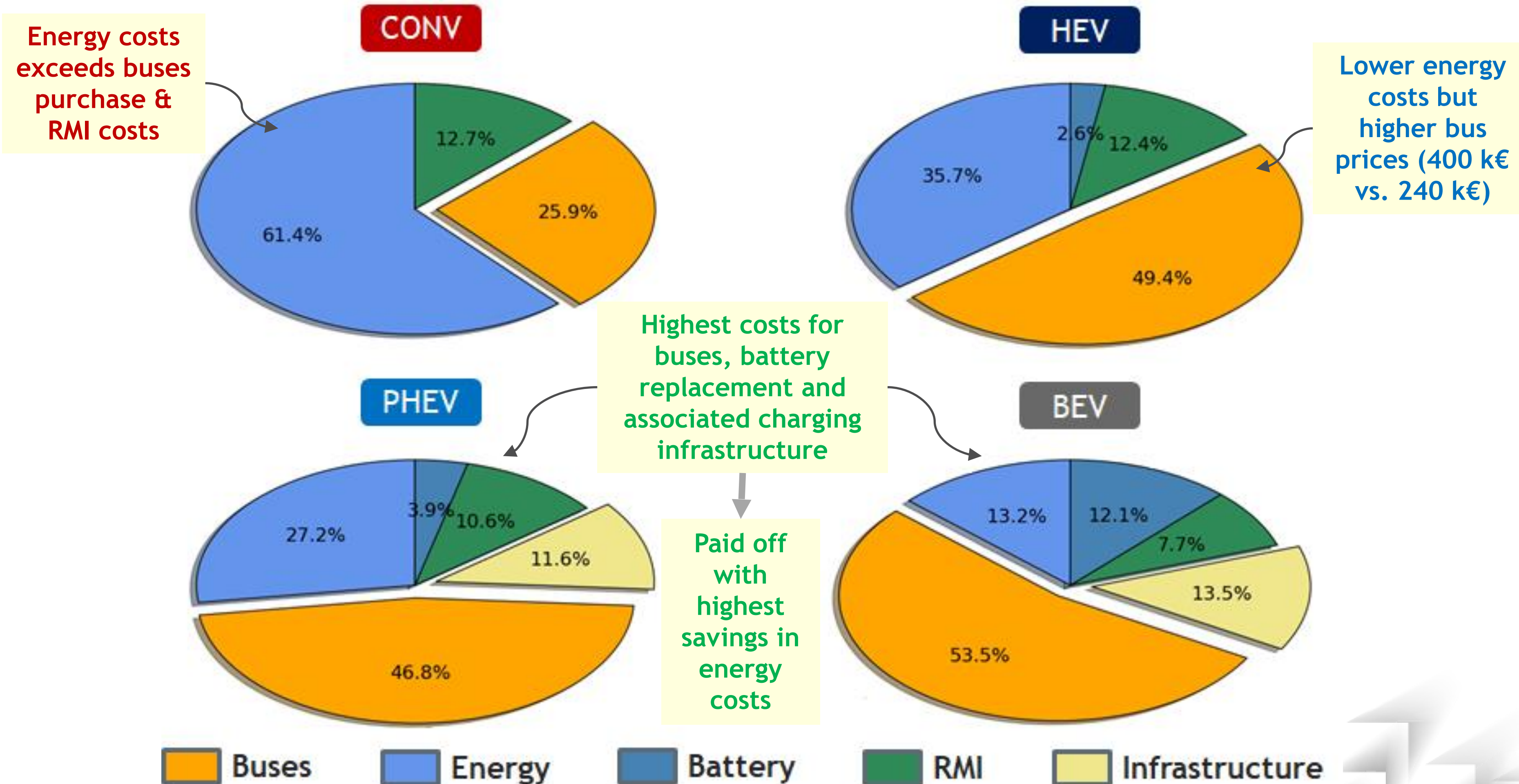
DUB | Scenario 4

Cost ratios for different type of fleets



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

CONCLUSION REMARKS

- 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

josko.deur@fsb.hr