D7.2 trolley:2.0 Development scheme for IMC

Deliverable	Final report on trolley 2.0 business cases
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Summary Sheet

Programme	Electric Mobility Europe
Project Title	Trolley Systems for Smart Cities
Acronym	Trolley 2.0
Coordinator	trolley:motion
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Abstract	Trolleybus systems provide modern, zero-emission public transport for urban areas, however, lack the flexibility that battery-equipped electric buses provide. In the trolley:2.0 project the advantages of both systems were combined, developing trolleybuses further into hybrid-trolleybuses that allow for the partial off-wire operation while making more efficient use of the trolleybus catenaries to charge the batteries in-motion. Nine trolley:2.0 partners from public transport, industry, and research aimed to prove that battery-supported trolleybuses are a way forward towards electric public transport systems in European cities by demonstrating the new charging concept in-motion charging (IMC), that allows for the partial off-wire operation of hybrid-trolleybuses in remote sections of the networks.
Keywords	**Trolleybus, battery-electric bus, hybrid-trolleybus, in-motion charging**

Introduction to trolley:2.0

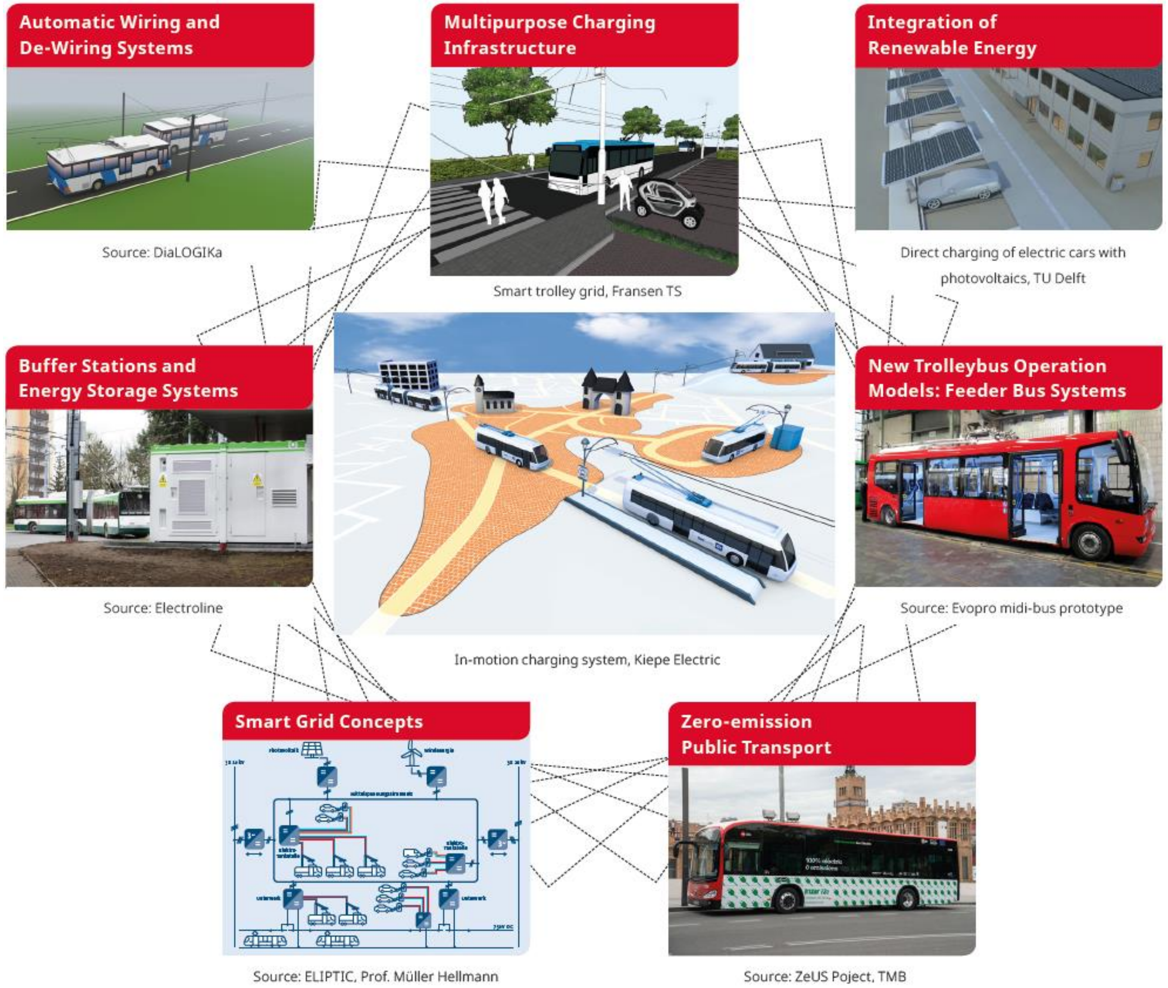
Trolleybus systems provide modern, zero-emission public transport for urban areas, however, lack the flexibility that battery-equipped electric buses provide. In the trolley:2.0 project the advantages of both systems were combined, developing trolleybuses further into hybrid-trolleybuses that allow for the partial off-wire operation while making more efficient use of the trolleybus catenaries to charge the batteries in-motion. The nine **trolley:2.0 partners from public transport, industry, and research aimed to prove that battery-supported trolleybuses are a way forward** towards electric public transport systems in European cities by demonstrating the new charging concept in-motion charging (IMC), that allows for the partial off-wire operation of hybrid-trolleybuses in remote sections of the networks. The trolley:2.0 use cases are located in four cities with existing trolleybus systems from different EU-countries, Szeged (HU), Arnhem (NL), Gdynia (PL) and Eberswalde (DE). Efficient public transport, flexible operation and simplified extension of trolleybus networks as well as the combined use of the existing trolley grid infrastructure for further electrification of mobility in cities was supported by trolley:2.0. The implementation of national and cross-country use cases are the core activities in the EMEurope partner countries NL, DE, HU and PL. The use case work projects are structured in the following areas:

- in-motion charging concepts,
- multi-purpose charging infrastructure and innovative energy storage systems
- integration of renewable energy solutions.

Executive summary

In this report the reader will find main lessons learnt from the TROLLEY 2.0 project and knowledge from the exchange with TROLLEY 2.0 User Forum members which are outlined in the following as elements of a development scheme for the deployment of in-motion charging (IMC) systems.

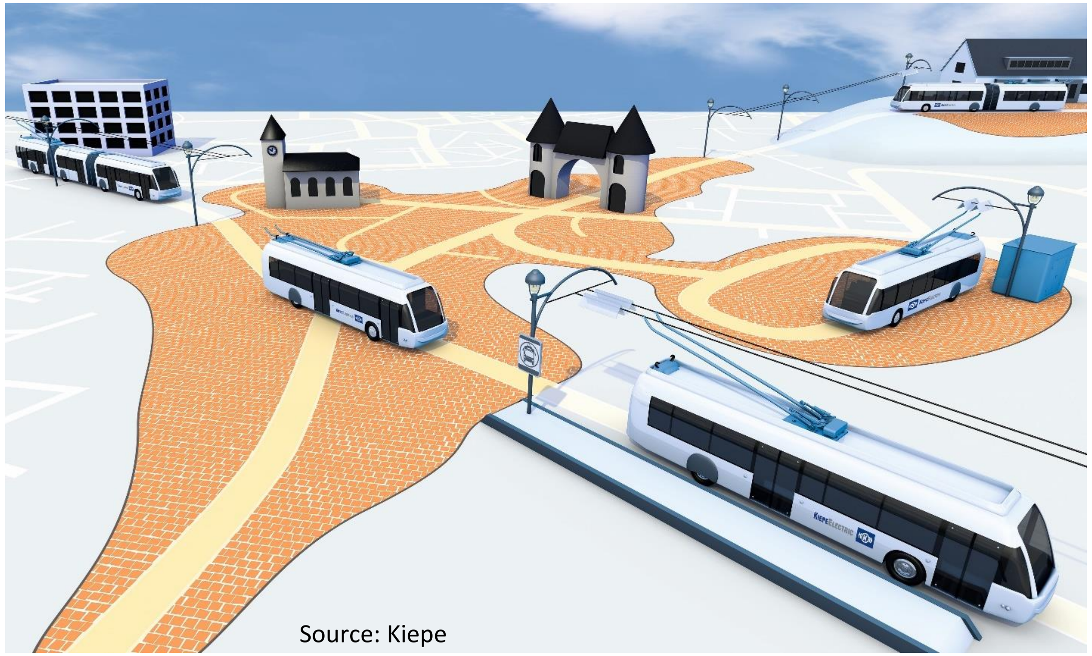
An entire community of practice has formed around trolleybus systems with the TROLLEY 2.0 partners and User Forum members in cooperation with UITP's Trolleybus Committee. Over the last 3 years a wealth of good practices around the deployment of IMC systems has been shared within this community; numerous presentations, and know-how are available on both the TROLLEY 2.0 project and trolley:motion's website (www.trolleymotion.eu); with the TROLLEY 2.0 User Forum a platform of major stakeholders and projects has been set-up (incl. the Clean Bus Europe support project APOLLO); and highly successful TROLLEY 2.0 events have been have been held in Solingen, DE (2018), Linz, AT (2019) and the final online conference (2020). Finally, IMC based trolleybus systems are increasingly seen as a real option for forward-looking cities to realise zero-emission public transport systems, and thus, batter-trolleybuses are considered as zero-emission vehicles in EU's Clean Vehicle Directive. The IMC concept is clearly a success story, but still many political decision makers are not aware of this solution, even though more and more cities are considering IMC-based trolleybus systems as a real option on their path towards carbon neutrality in 2050 (Green Deal Missions' goal). The following development scheme is a compilation of best practices and gathered knowledge - based on consultation with practitioners, and an active TROLLEY 2.0 community of practice - to support cities with the planning and deployment of IMC systems in the future.



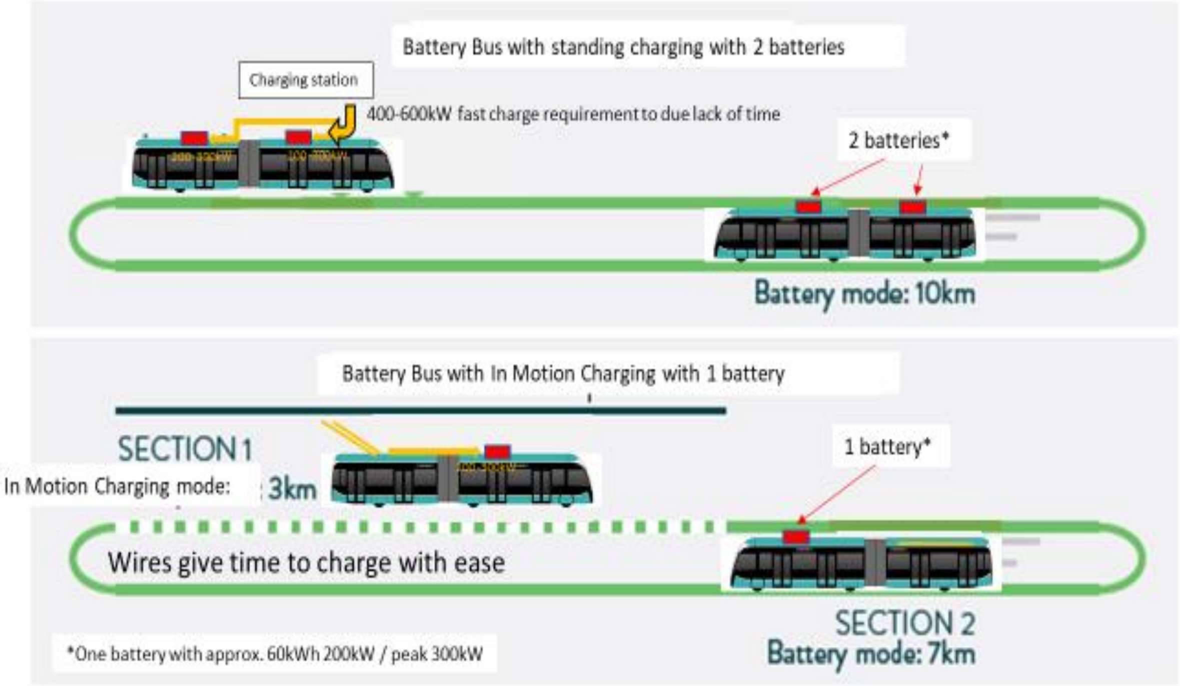
Development Scheme

trolley:2.0 for smart cities

Advantages of IMC



Source: Kiepe



COVERING 20 - 40% OF THE ROUTE BY OVERHEAD WIRES

- Up to 80% is autonomous driving
- Trolleybus functionality In Motion Charging
- No need to stop for charging
- Efficiency and flexibility
- No extra vehicles and drivers required for operating In Motion Charging
- Smaller battery capacity and more passengers
- The infrastructure is not just less expensive per km, but also by 60% - 80% shorter
- Infrastructure investment less expensive than in case of standard trolleybus and much less in comparison to tram
- Overhead wires infrastructure simpler and cheaper than in standard trolleybus route since expensive and maintenance intensive switches, crossings and even some curves can get avoided
- Balanced energy demand of the vehicles with batteries leads to higher utilisation of infrastructure

Source: UITP

Make use of existing infrastructure – extend trolley systems with IMC

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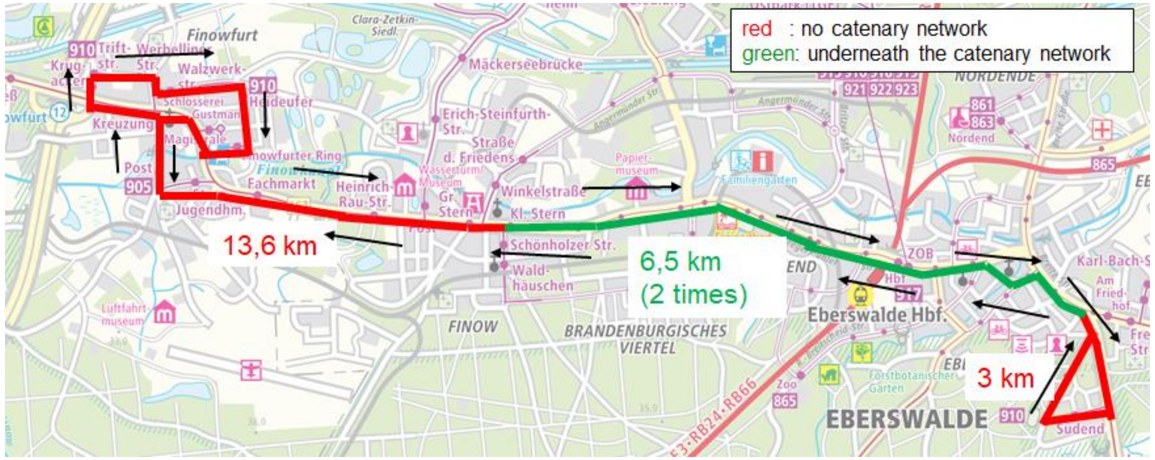
Best Practice Barnim Bus Company, Eberswalde, DE
Regional trolleybus line incl. IMC The bus network of BBG Eberswalde covers a far larger area than the city of Eberswalde itself with its 94km2 and 40,000 residents. Instead, Eberswalde integrates into a regional bus network covering numerous towns and cities in the northeast of Berlin. In contrast to entirely urban bus networks in densely populated cities, regional bus lines are characterized by long, continuous driving distances and low relative demand. Owing to these parameters, buses in regional operation are principally diesel-powered and electrification would present a major challenge. In Eberswalde however, trolleybuses have operated two inner-city bus lines for decades, meaning that there is an existing catenary grid on the trunk routes. With the goal to replace diesel buses not just in the urban but also in a regional context, Eberswalde can utilize in-motion-charging technology and its existing catenary grid to charge buses that operate on battery traction outside of the city. A feasibility study conducted in the ELIPTIC project has shown that it is feasible to convert existing diesel bus lines in Eberswalde to emission-free lines using hybrid trolleybuses. This business case describes the establishment of the 910 line as a hybrid trolleybus line that charges under the existing catenary in Eberswalde and services the neighboring city Finowfurt using only traction batteries. As a highly innovative approach to the electrification of inter-city public road transport, the business case focuses on gaining practical experiences and deriving key learnings for further development in Eberswalde and other cities that can use Eberswalde as precedent or best-practice example.

Quick facts	
Residents	41,000
PT % of modal split	13%
Trolleybus % of modal split	n/a
Total trolleybus fleet	12
t/o hybrid trolleybuses	8

Strategic environment & goals

- Zero-emission strategy in Barnim County (incl. emission reduction in PT)



Optimise the current system – efficient retrofitting

Efficient retrofitting for IMC upgrade: Batteries can easily be used instead of diesel auxiliary power units without having to make any changes to the chassis.

Compared with an opportunity & overnight charging concept, IMC requires smaller batteries size, i.e. reducing cost for battery deployment.

Source: BBG, Eberswalde

Determine the planning framework

Right: newly installed e-BRT line in Italy, connecting Rimini central station to the seaside resort of Riccione
Below: 24m trolleybus in Linz, AT

Ones system – many options:

- High capacity corridors
- e-BRT / BHNS
- Inter-urban lines
- Feeder lines
- …

IMC as highly suitable approach for BRT

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Source: Arnd Bätzner

What is the planning context?

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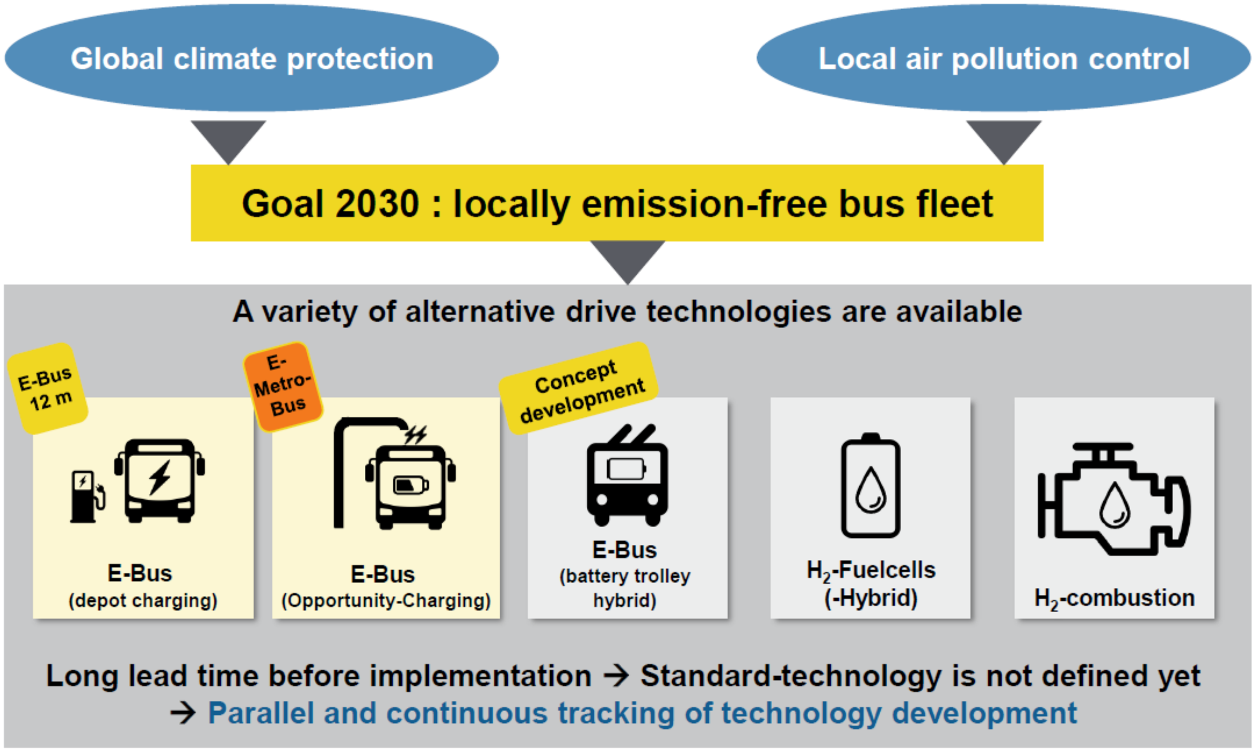

BVG

Main results

- The trolley-battery-hybrid technology enables the electric operation of **double-articulated** buses
- The Spandau network can be operated with **approx. 60% catenary**
- The **initial investment costs** are about 50% higher than the ones for other e-bus technologies
- From a **30 years-perspective** the anual **total costs are similar**. However with the operation of double-articulated buses the total costs per passenger can be reduced
- If necessary the infrastructure can be used for **future tramway projects**

IMC approach as an element for high-capacity corridors in BVG's (Berliner Verkehrsbetriebe, DE**) path towards a locally emission-free public transport system deploying different technologies.**

Source: BVG

What are the options for the future?
(merging of trolley and e-bus approaches)

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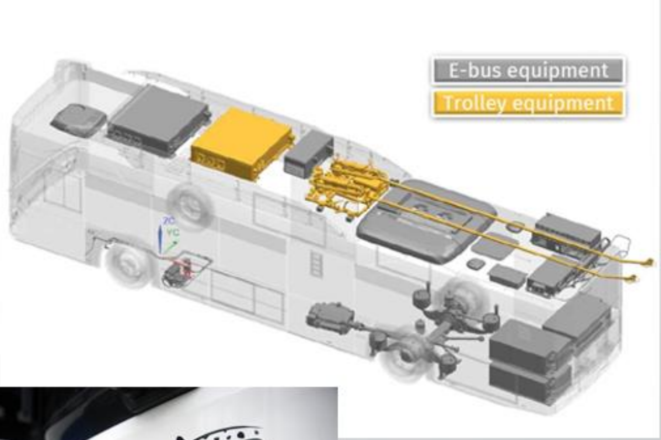
- The difference between the electric buses and trolleybuses are blurring.
- (Some) Hybrid trolleybuses are electric buses, with a DC-DC link and a current collector.
- Electric bus equipment is high series, cheaper in the long run.



Solaris Trollino 12 Electric
Gdynia, „Gepard” project

Left: Modulo EP095T, composite framed midi-bus with IMC; source: SZKT

evopro it's possible!

Universitas Scientiarum Szegediensis – Szegedi Tudományegyetem

SZEGEDI KÖZLEKEDÉSI TÁRSASÁG

Electric Mobility Europe

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Innovációs és Technológiai Minisztérium

Make use of existing tram infrastructure for IMC deployment

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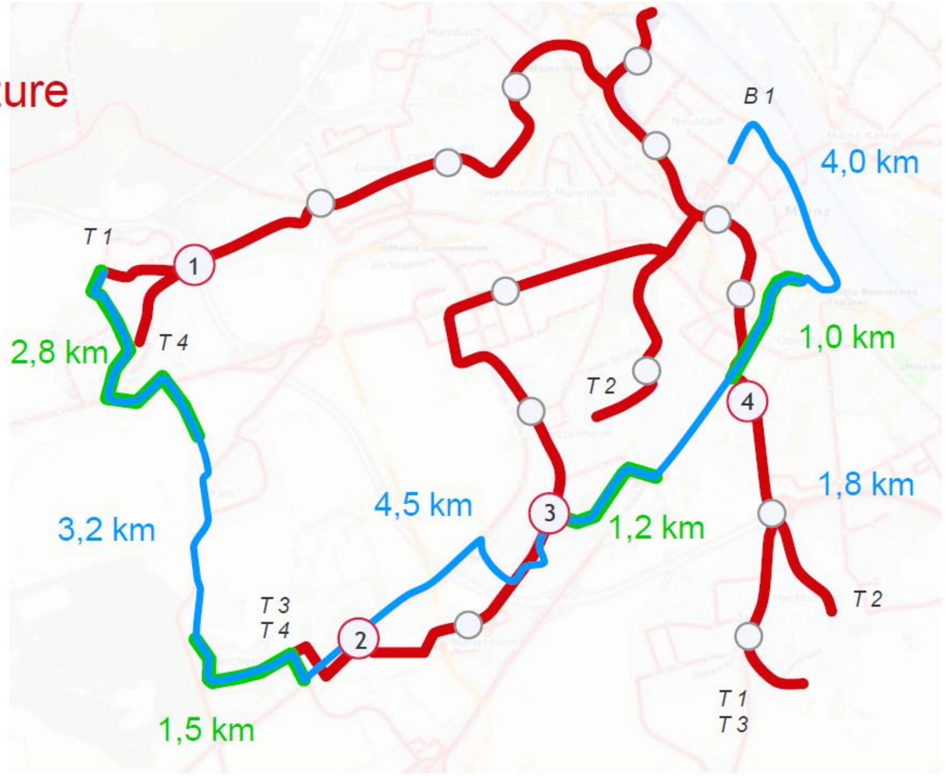
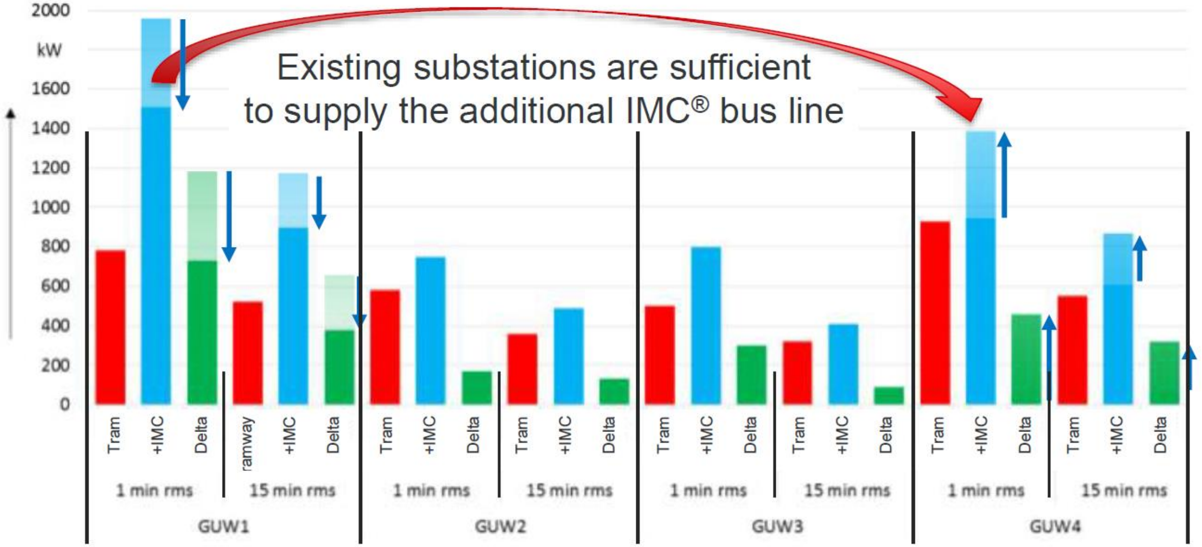
Example – Network structure

- Tramway network
- IMC®-Bus-route
- Trolleybus catenary
- Rectifier substation

Overhead contact line needed for around 32 % of IMC®-Bus-route





Increased potential with

» Reduced length of new overhead contact lines
» use of existing substations
→ for example: 44 cities in Germany with
» ≥ 50 000 residents and ≥ 15 km of tramway route
= ≥ 3 500 residents/km existing tram route

Source: Rail Power Systems GmbH

Winning public support

Plan to involve stakeholders and citizens more actively with a wider range of participation tools throughout the whole process (e.g. stakeholder events, internet forum, citizen panels)

Trolley infrastructure	
n	23
average	1,0
median	1
pleasant +3	6
+2	3
+1	3
0	9
-1	1
-2	1
disturbing -3	0

IMC instead of diesel bus infront of the building	quality of stay	life quality in flat	attractive-ness environment	quality of stay	life quality in flat	attractive-ness environment
n	17	12	17	17	12	17
average	1,9	1,8	1,5	1,9	1,8	1,5
median	2	2	2	2	2	2
would be better +3	8	4	4	8	4	4
+2	4	4	5	4	4	5
+1	1	2	3	1	2	3
0	4	2	5	4	2	5
-1	0	0	0	0	0	0
-2	0	0	0	0	0	0
would be worse -3	0	0	0		0	0

Source: SWS Solingen, DE / Neue Effizienz

Link with other planning processes

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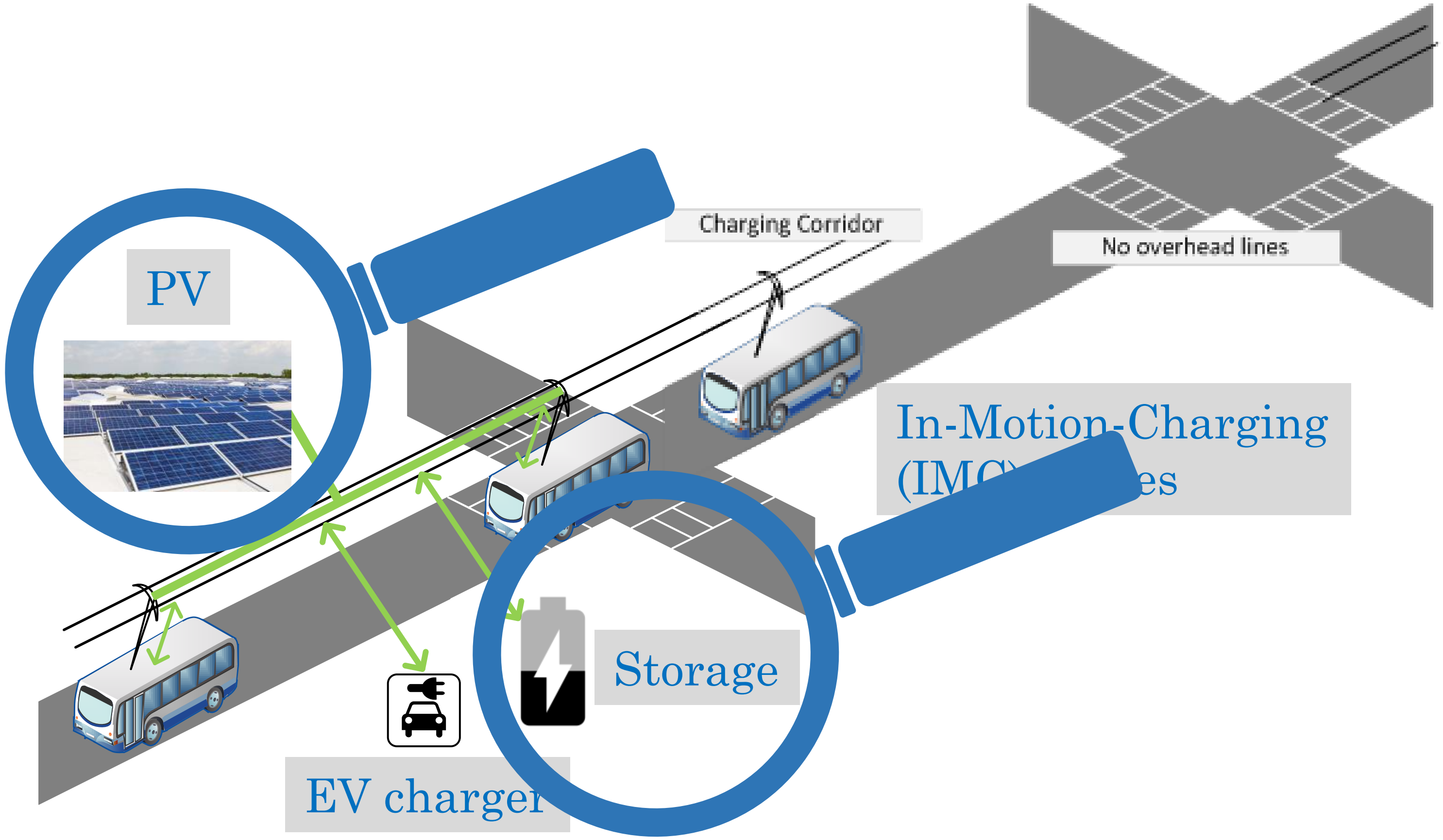
Develop common actions by integrating sectoral policies and practices & foster cooperation with actors from relevant policy fields. For example, energy planning with a focus on integration of renewable energy sources into electric public transport systems for future trolley grids.



Transport energy sector coupling policies for IMC systems:

- Make the grid 100% sustainable **(energy neutral)**
- Design a **decentralized** energy generation system
- Minimize use of (seasonal) **storage or the AC Grid**

Source: TU Delft

Smart trolley grids (physical and digital asset):

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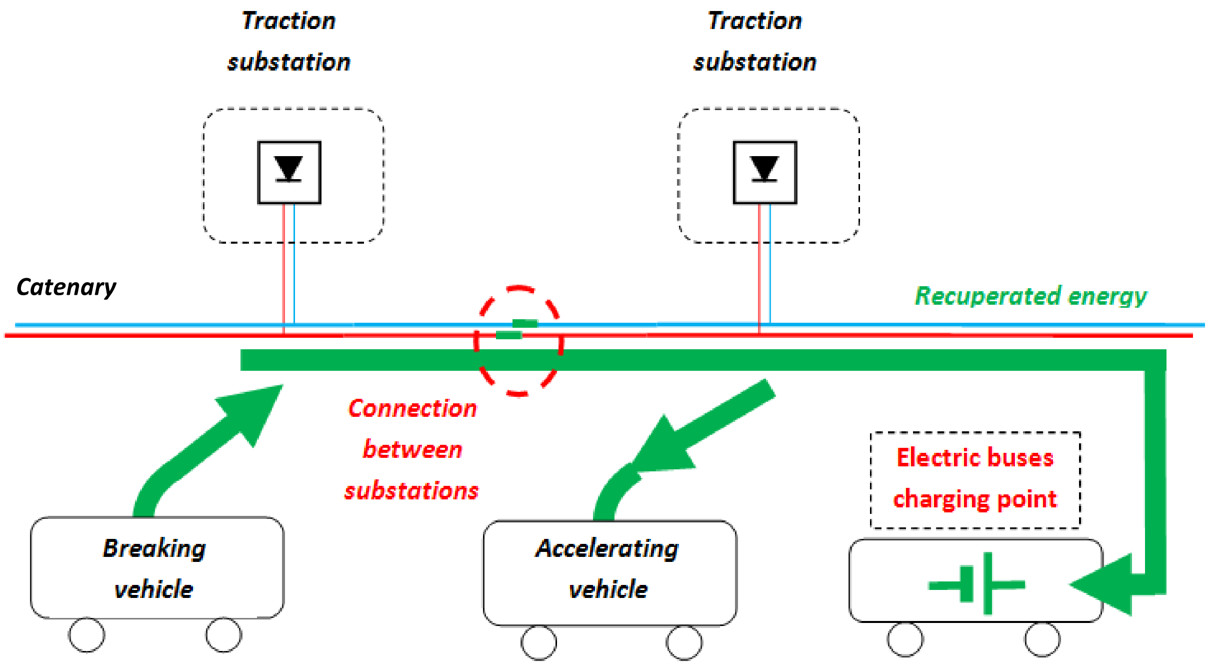

Billateral energy supply & optimised usage of recuperation energy by balancing energy flow and levelling voltage drops & testing of energy storage concepts integrated into trolley grid / substations (incl. 2nd life batteries) (Gdynia, Pilsen (EfficienCE))

Integration of RES into trolley grids (TU Delft, PRE, Uni Gdansk/ Gdynia)

Optimise efficiency & cost effectiveness

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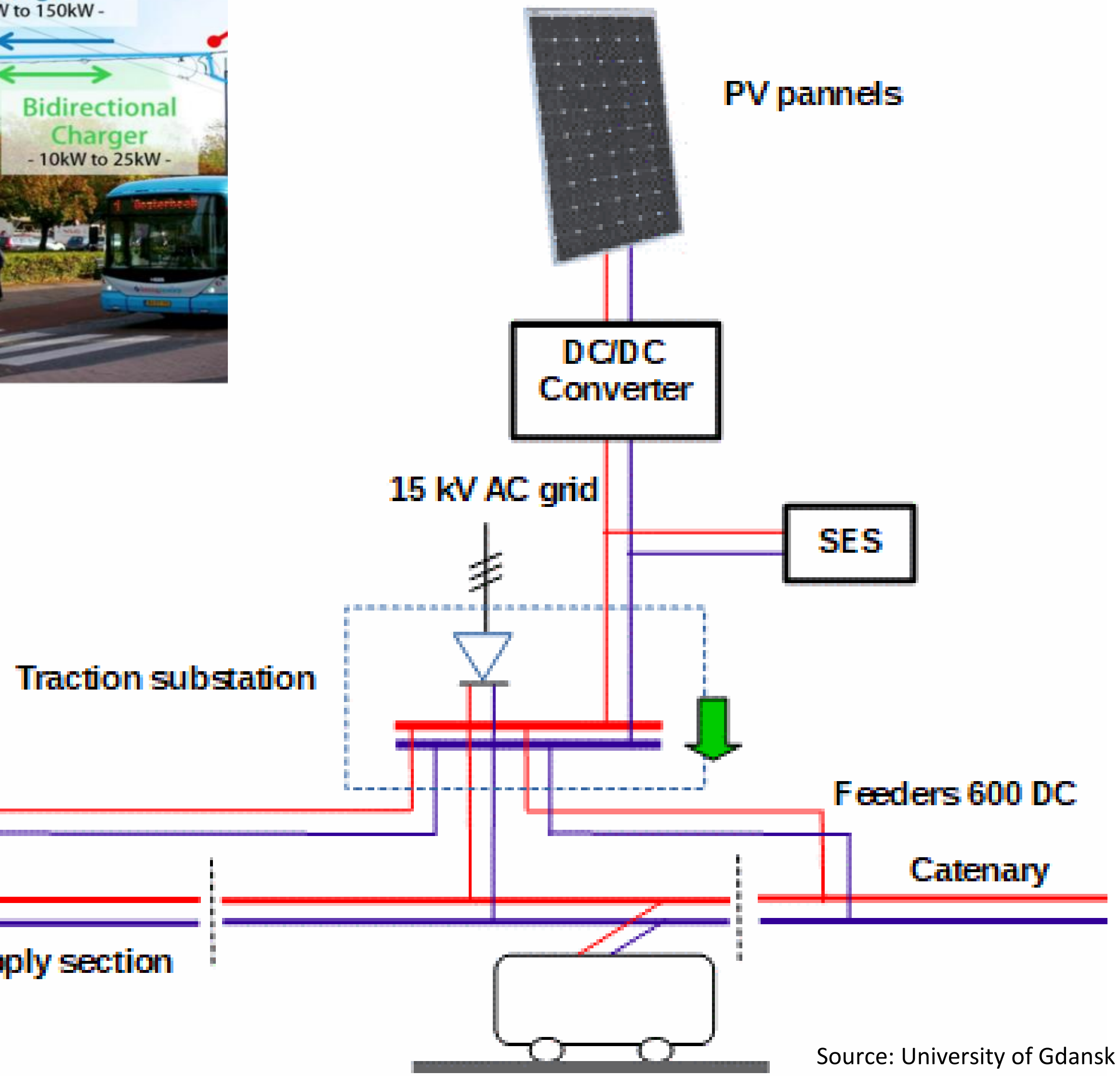
- (local) renewable energy sources (RES) and stationary energy storage (SES) systems as key elements of smart trolley grids
- reducing the peak power demand of a traction substation or optimizing the utilization of solar energy related to the mismatch between generated and load power



Source: University of Gdansk

Integrate new technologies and new approaches, e.g. circular economy

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Buffer Storage in Pilsen, CZ, to

- balance the voltage level
- turn-off or power-cut from the substation for higher power consumption scenarios incl. charging of the IMC trolleybus batteries, use of air-conditioning, etc.

Source: Interreg EfficienCE project

Use case for Solingen, DE:

BOB

Second Life Use Case for former Trolley bus battery systems

- Development of processes to certify already used traction batteries from trolley busses for stationary second life applications.
- Exploit new business cases.
- Gather additional knowledge about the cell chemistries and cells in general traditionally used in trolley busses.
- Detailed testing of cells and previous used modules at their EoL; ambitious climatic and electric tests like Impedance Spectroscopy.
- Building of two ~530 V ESS with 63 kWh (1) and min. ~100 kWh (2).

Source: Voltabox

Electric public transport as a backbone of smart cities

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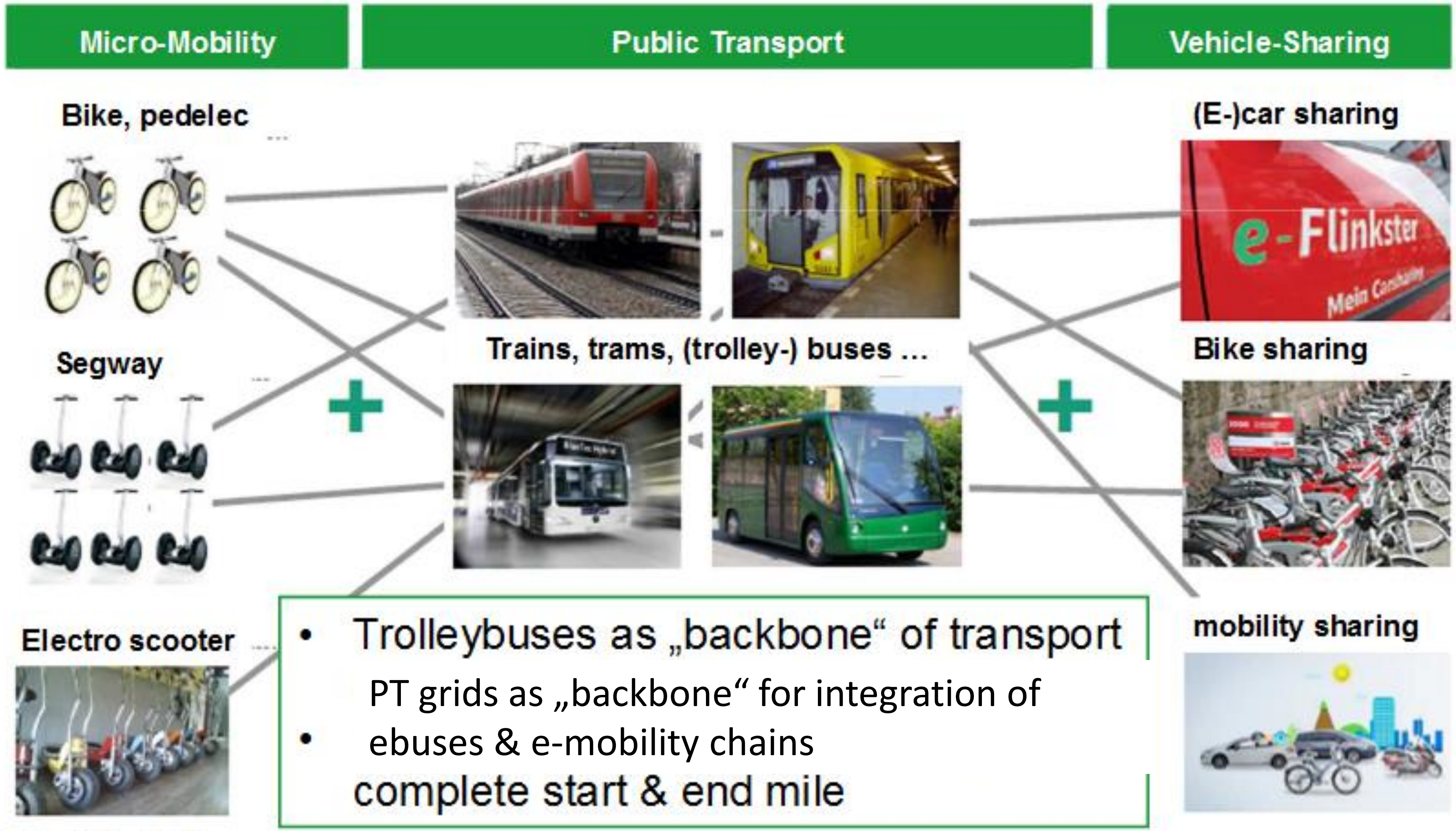

Source: Spath, IAO, 2011

Make use of existing trolley/IMC infrastrucutre

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for smart cities

<u>DC-DC Charge solutions for E-Mobility: </u>e-car fast charger from the overhead contact line in Arnhem, NL

<u>DC-AC catenary solutions</u>, power solutions for charging machines for public transport cards, WiFi access points and dynamic travel information that's powered by the overhead contact line in Arnhem, NL

GEMEENTE Arnhem

VENEMA
Venema Technisch Bedrijf BV

connexxion

Quick facts

- Saving cost in dealing with local power suppliers
- Input DC Voltage: DC Voltage 600 - 840V / peak power 1600 W
- No digging to connect to the local power grid
- No problems, time and costs requesting a power connection
- Better use power capacity of the trolley network

Integrate new innovations/ technologies to make IMC more efficient and to optimise cost structure

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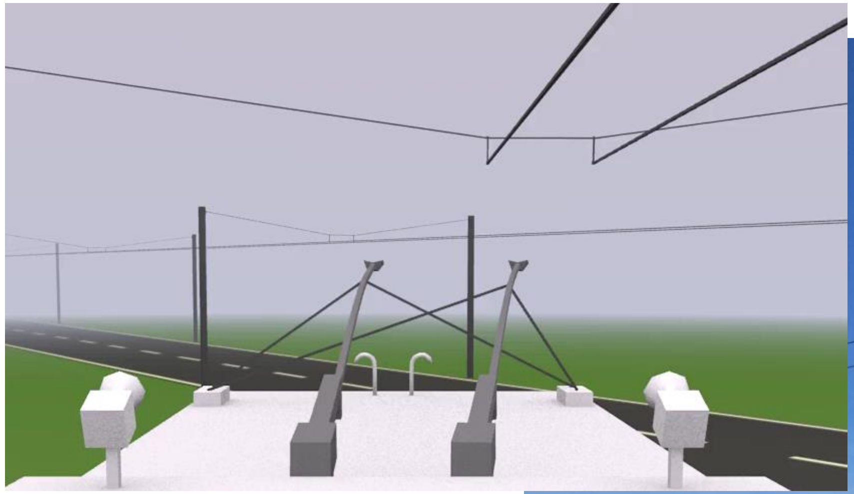

Source: Libroduct

Increasing flexibility through automated wiring technology:

- Reduce infrastructure cost for crossings, switches, curves, historic squares and
- Enable overtake scenarios in high-capacity corridors

Testing of automated wiring in Szeged, HU:

- First ride in the line network (TRL7)
- Software and hardware are stable
- Fault tolerance still needs to be improved

Develop scenarios of potential futures

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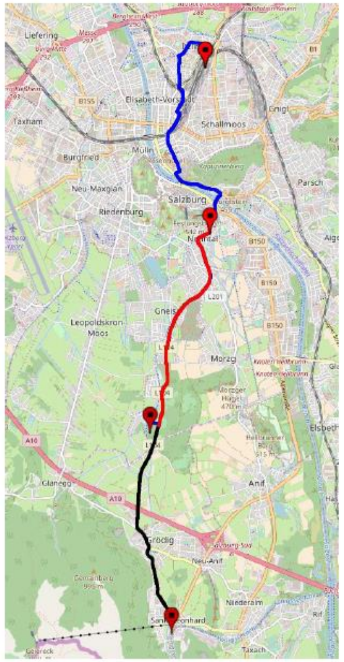
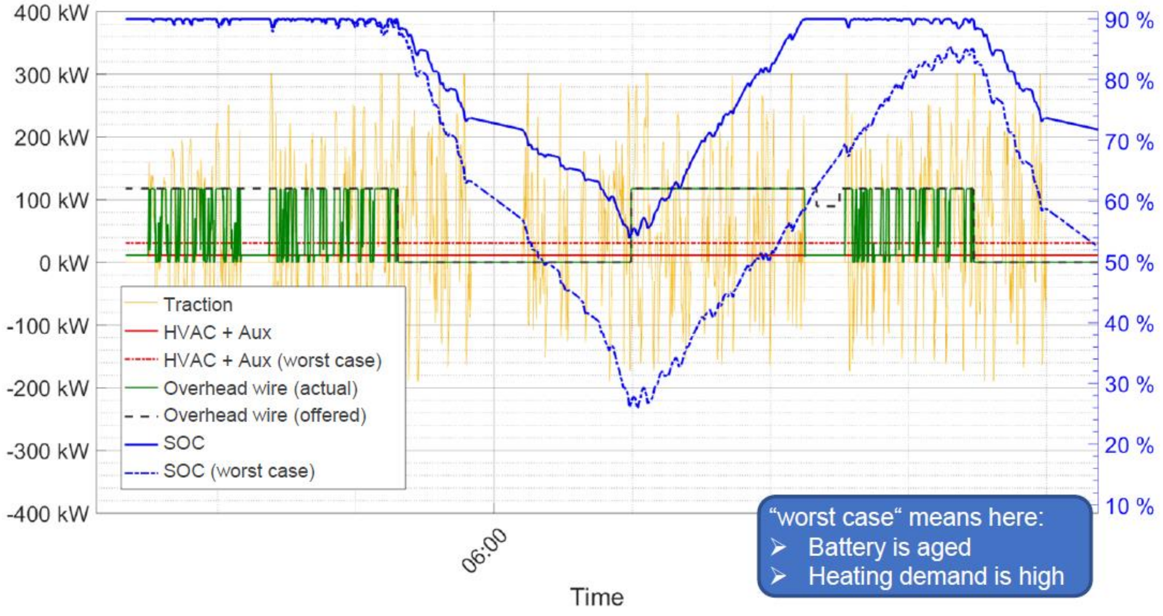
SALZBURG AG

■ Simulation of operations





Scenario: Existing catenary system
→expand electric operation

Use innovative planning and optimisation tools to make electric public transport reliably plannable.

Source: ebusplan

Develop scenarios of potential futures

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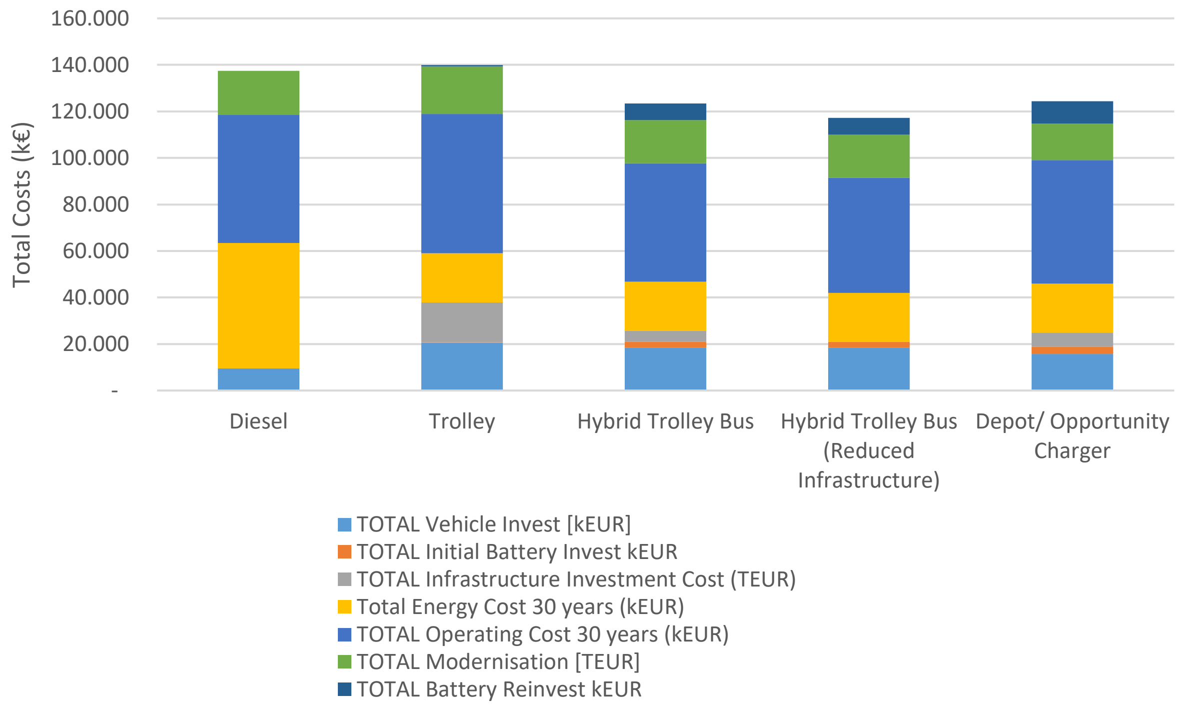
Optimised paramters for an IMC scenario



Line Parameters:

- Increase Vehicle Frequency to 5 minutes per vehicle
- Increase Line length to 20 km
- Distribute catenary free sections evenly
- Decrease speed under catenary
- Increase number of yearly km to 100.000 km
- 30% electrified

Vehicle Parameters

- Decrease vehicle investment cost by 10%
- Increase Diesel consumption to 50 L/ 100 km (from 40 L/ 100km)
- Decrease charging time for Opportunity Chargers from 10 Min to 7 Min

Source: Richard Kayser, TU Dresden

Assess current and future performance

Total Costs of IMC – categories and elements

- **Investment**
  - Vehicles
    - Initial Investment
    - Reinvestment
    - Modernisation
  - Batteries
    - Initial Investment
    - Reinvestment
  - Catenary / Charging Infrastructure
    - Initial Investment
  - Energy / Power Supply
    - Initial Investment
- **Operation**
  - Vehicles
  - Catenary / Charging Infrastructure
    - Refurbishment Masts
    - Refurbishment Catenary
  - Energy / Power Supply
    - Operation of Substation
- **Energy**
  - Vehicles
    - Traction Energy
    - HVAC

Source: Richard Kayser, TU Dresden

Arrange for monitoring and evaluation

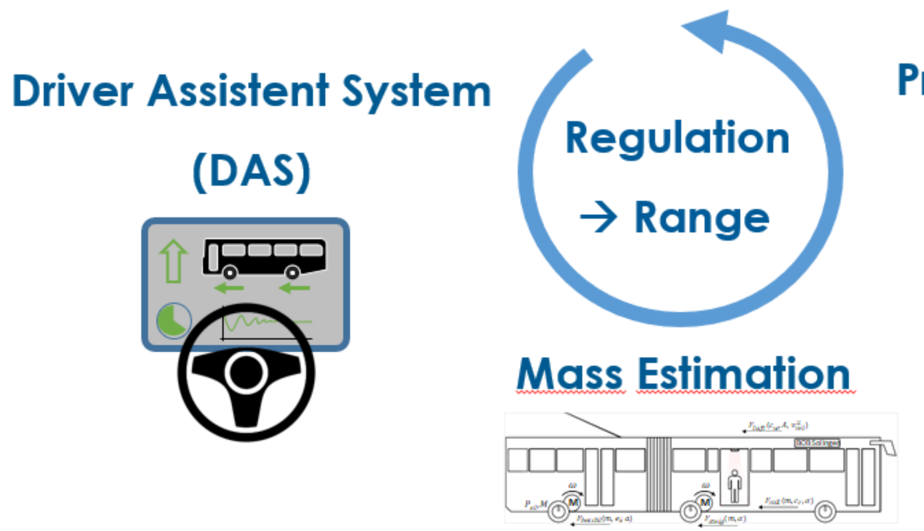
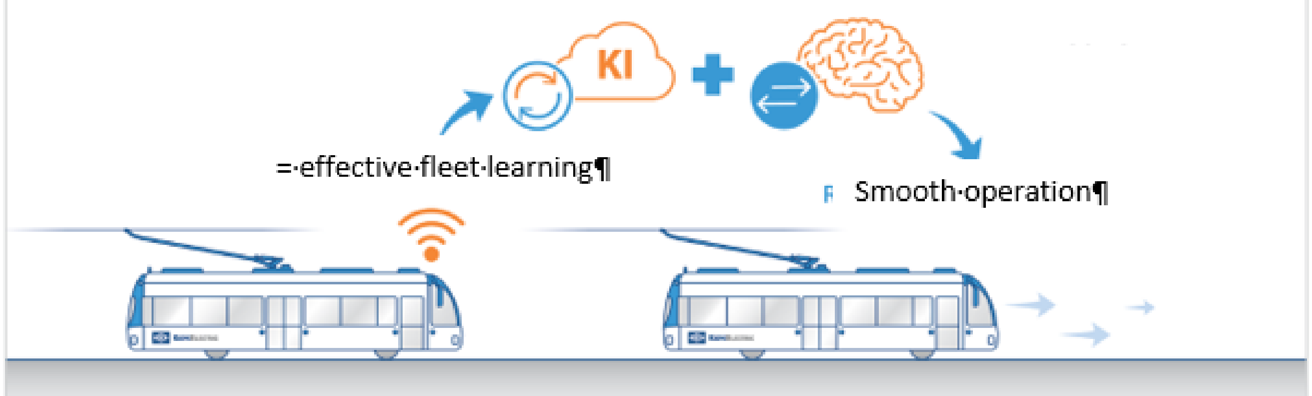


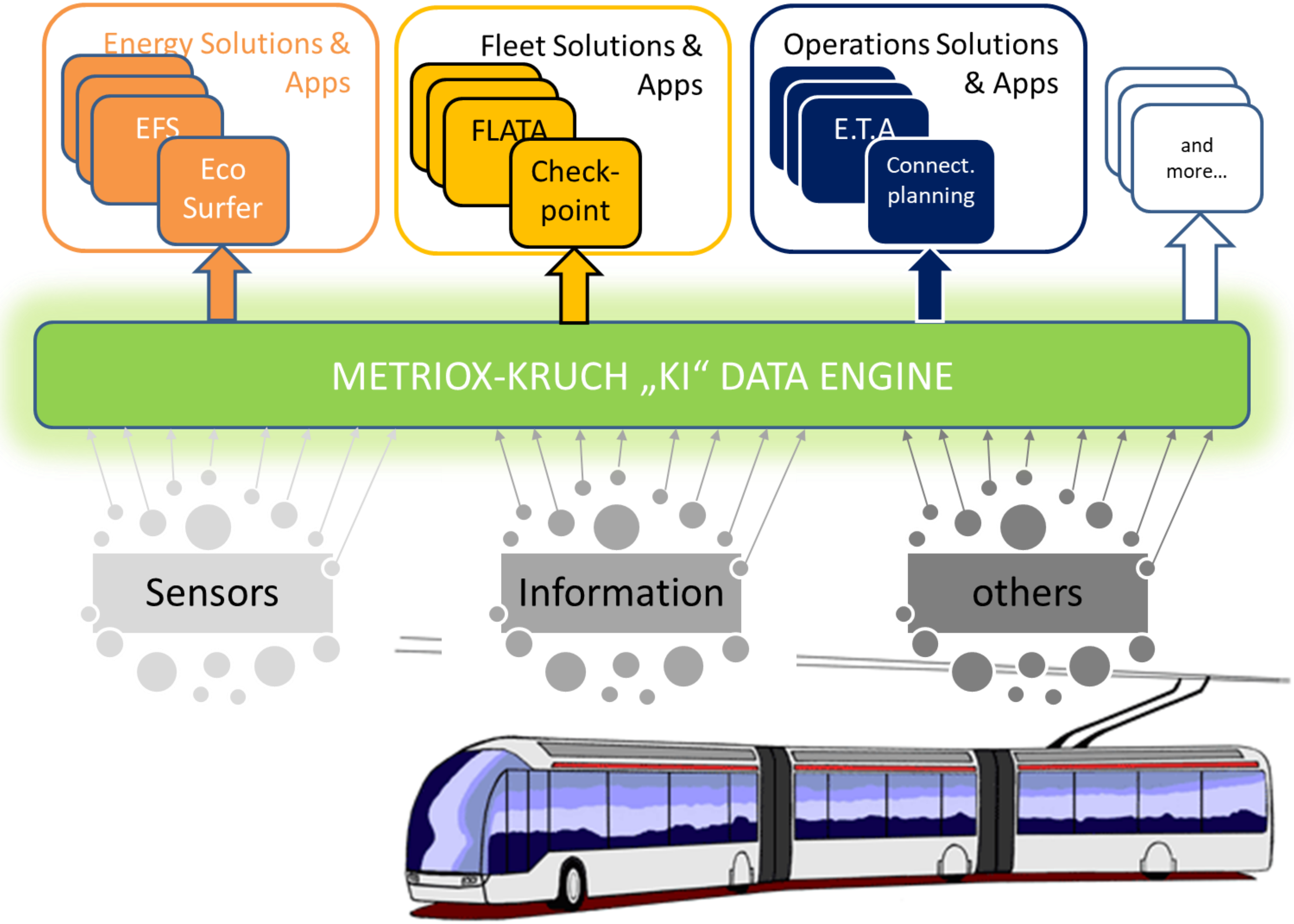
Figure: School of Electrical Information and Media Engineering, EES, BUW



Intelligent fleet learning with SFM: The operation of the IMC bus, i.e. the vehicle itself and within the line network, is automatically controlled – as a function of the situation as well as the state of the vehicle and the traffic situation (Figure 1: Kiepe Electric).

Optimise energy efficiency of IMC systems with monitoring and machine learning

Arrange for monitoring and evaluation



Integration of
- **real-time data**
- **simulation and**
- **historical data**

for optimising the entire systems‘ energy effciency

Source: Kruch

Take into account relevant goals at the regional, national and EU level

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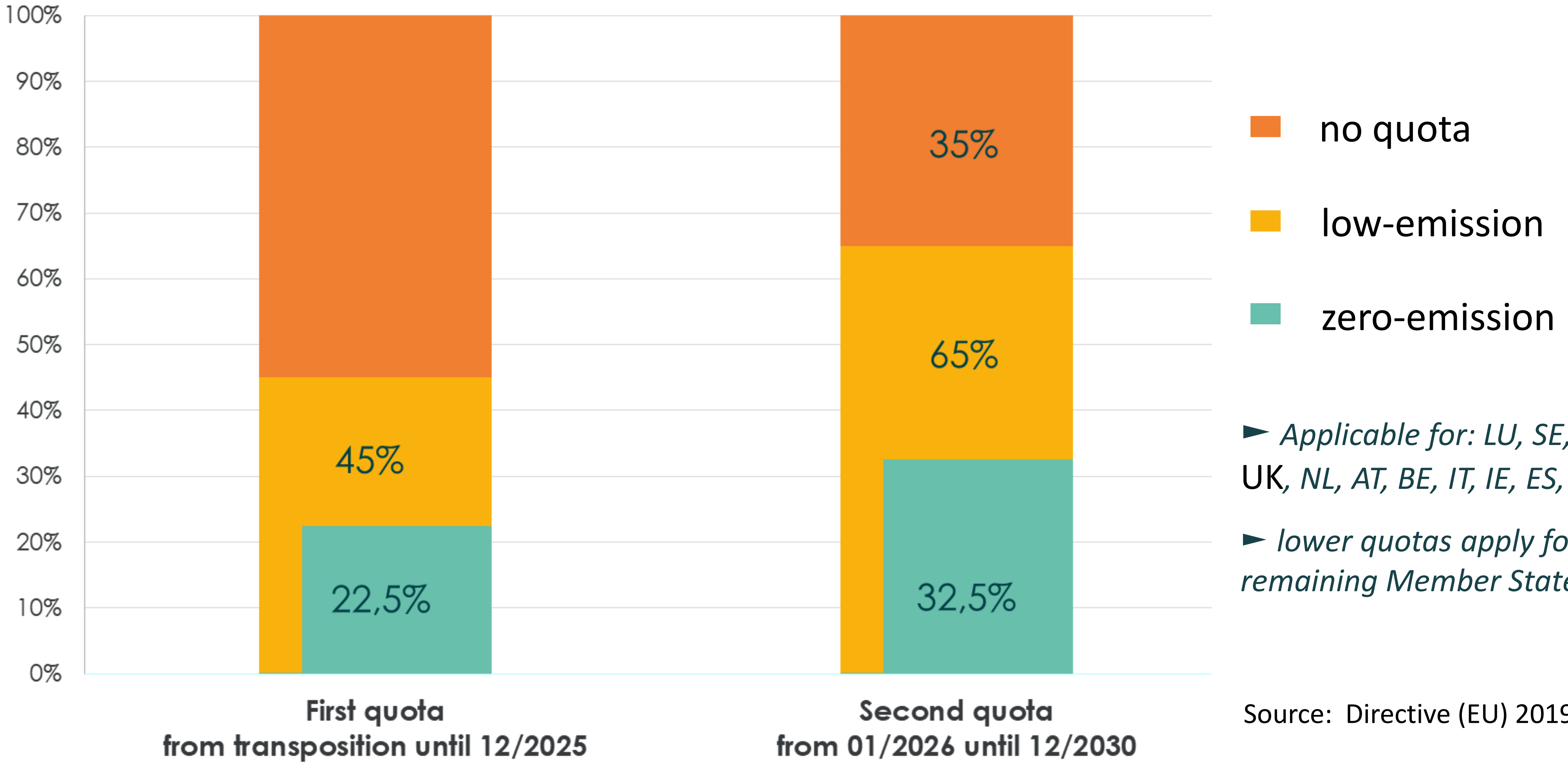
The Clean Vehicle Directive:



► *Applicable for: LU, SE, DK, DE,* UK, *NL, AT, BE, IT, IE, ES, CY, MT*

► *lower quotas apply for remaining Member States*

Source: Directive (EU) 2019/1161

Clean Bus Deployment Initiative

- In 2017 the EC launched the Clean Bus Deployment Initiative to speed up the introduction of clean buses across Europe.
- Elements for the scale up:
  - Policy framework
  - Financial & funding framework
  - Exchange of best practices and knowledge.
- The Clean Bus Europe Platform is the strategic line of action to develop, implement and support the transition towards clean bus fleets.

Source: UITP, House of the Regions, Brussels (BE)

Get external support

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Webinars on general & specific aspects of CBD

Study tours to Host Cities

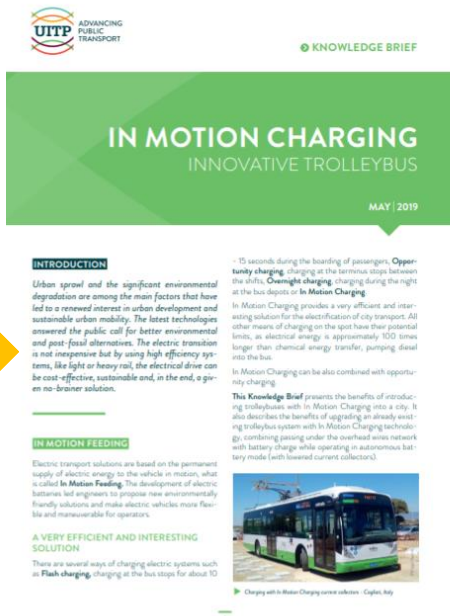
Market Places Industry & Financing

Technical support: meetings with local experts

Social Dialogue activities

Market evolution, tenders, orders, deploymt

Specific products, material, info


UITP ADVANCING PUBLIC TRANSPORT

KNOWLEDGE BRIEF

IN MOTION CHARGING

INNOVATIVE TROLLEYBUS

MAY | 2019

INTRODUCTION

Urban sprawl and the significant environmental degradation are among the main factors that have led to a renewed interest in urban development and sustainable urban mobility. The latest technologies answered the public call for better environmental and post-fossil alternatives. The electric transition is not inexpensive but by using high efficiency systems, like light or heavy rail, the electrical drive can be cost-effective, sustainable and, in the end, a given no-brainer solution.

IN MOTION FEEDING

Electric transport solutions are based on the permanent supply of electric energy to the vehicle in motion, what is called **In Motion Feeding**. The development of electric batteries led engineers to propose new environmentally friendly solutions and make electric vehicles more flexible and maneuverable for operators.

A VERY EFFICIENT AND INTERESTING SOLUTION

There are several ways of charging electric systems such as **Flash charging**, charging at the bus stops for about 10 - 15 seconds during the boarding of passengers, **Opportunity charging**, charging at the terminus stops between the shifts, **Overnight charging**, charging during the night at the bus depots or **In Motion Charging**.

In Motion Charging provides a very efficient and interesting solution for the electrification of city transport. All other means of charging on the spot have their potential limits, as electrical energy is approximately 100 times longer than chemical energy transfer, pumping diesel into the bus.

In Motion Charging can be also combined with opportunity charging.

This Knowledge Brief presents the benefits of introducing trolleybuses with In Motion Charging into a city. It also describes the benefits of upgrading an already existing trolleybus system with In Motion Charging technology, combining passing under the overhead wires network with battery charge while operating in autonomous battery mode (with lowered current collectors).

CLEAN BUS EUROPE PLATFORM

Winning political committment

- Search for good examples beyond your own city and country
- Invite practitioners from other places to your city for advice
- Take your local decision makers on a site visit

www.cleanbusplatform.eu

www.assured-project.eu

www.fuelcellbuses.eu

www.trolleymotion.eu/trolley2-0

www.e-lobster.eu

www.eliptic-project.eu

www.zeeus.eu

www.ebsf2.eu

Sources: UITP, TROLLEY 2.0

The future smart TROLLEY grid

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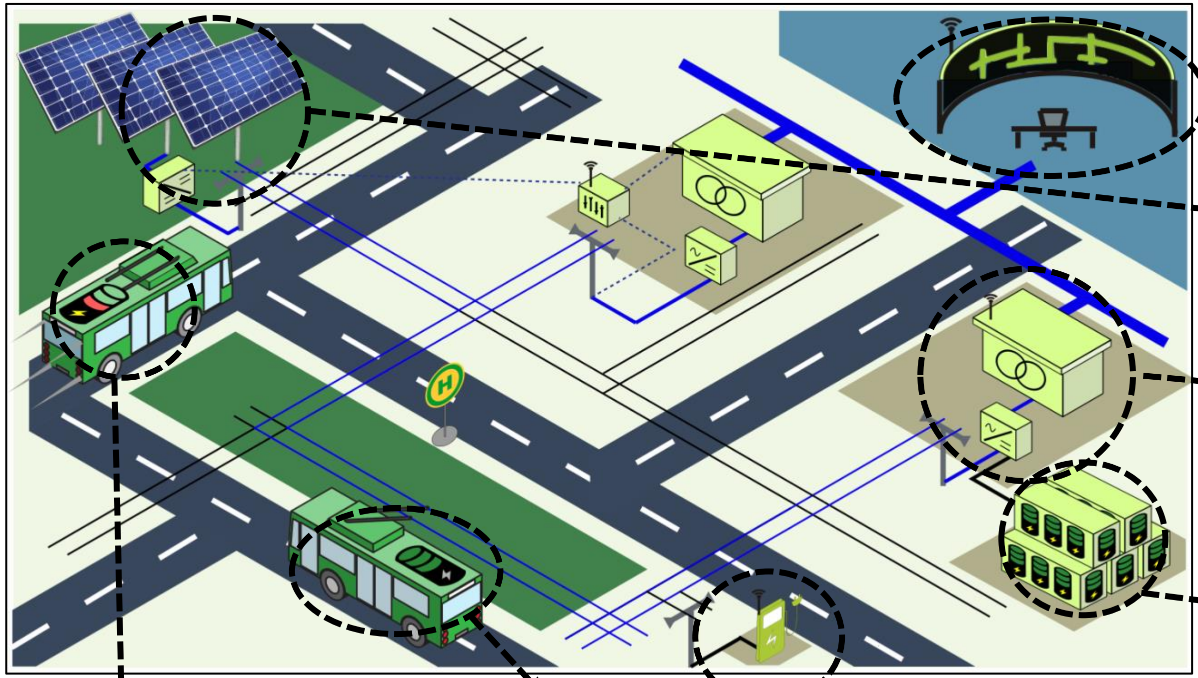
Working with a systemic approach …



Server (automated regulation)

PV systems

Substation (bidirectional)

Stationary battery storage

Battery trolleybus
discharging charging

Charging stations for EVs & pedelecs

BOB

Source: SWS Solingen, DE / Neue Effizienz