trolley:2.0
for smart cities

Electric Mobility Europe

trolley 2.0

Final conference

Cost benefit analysis of trolleybus development

Dr. Michał Wolański, Warsaw School of Economics
Paulina Kozłowska, Wolański sp. z o.o.
Prof. Marcin Wolek, University of Gdansk

Agenda

1. General outputs
2. General inputs
3. Externalities
4. Outcomes
5. Conclusions

trolley:2.0 for smart cities

Electric Mobility Europe

Directions of trolleybus transport development thanks to the in-motion charging : case of Gdynia (Poland): A need for the model approach

Extension of existing trolleybus lines with IMC [lines 29, 31]

Extension & rerouting of existing trolleybus lines with IMC [lines 21, 27, 33]

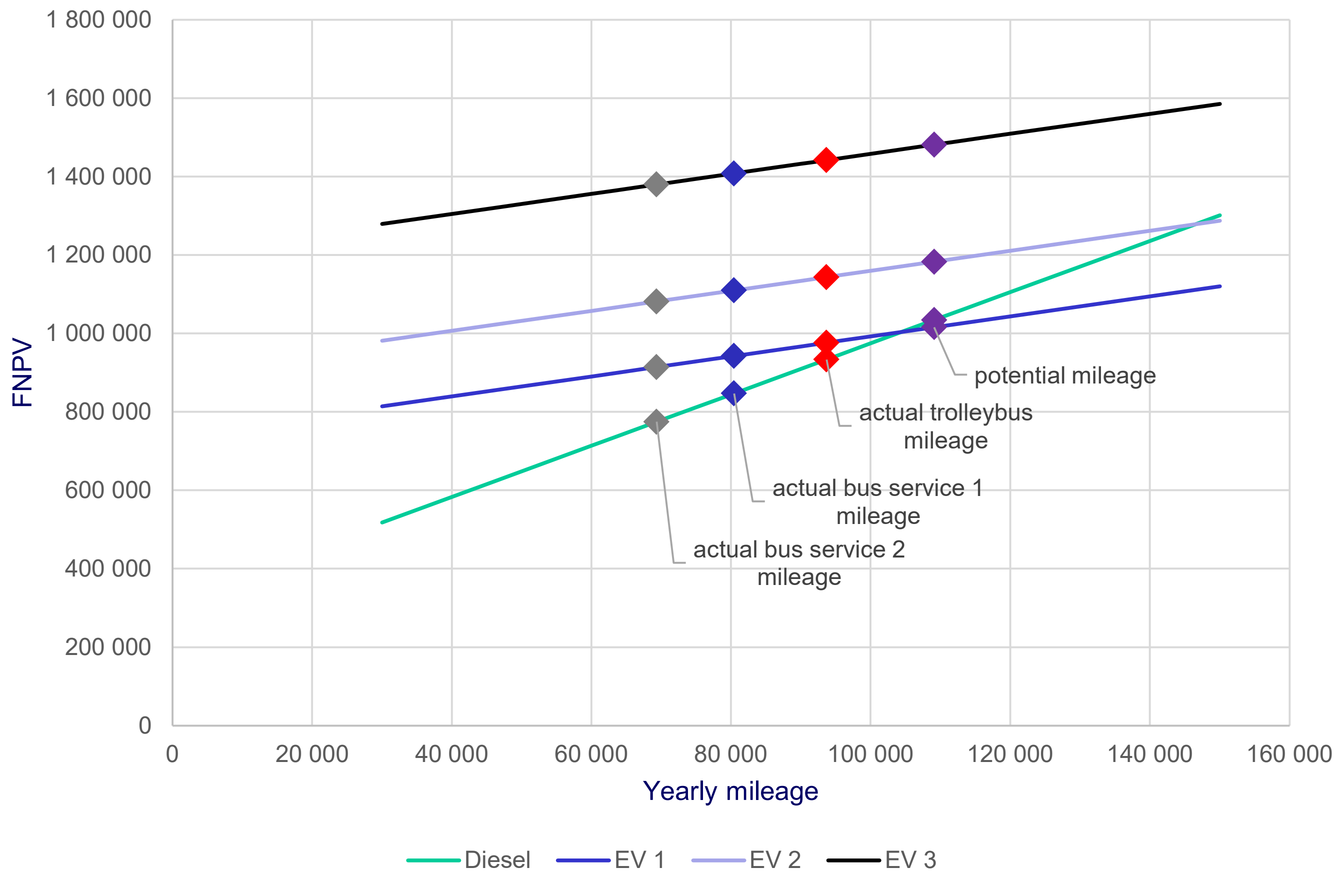
Development of new trolleybus lines partly independent from the catenary [line 34]

Replacing diesel buses with IMC trolleybuses and e-buses on existing bus lines [181, 170]

- **Replacement with e-buses (since 2021, bus lines: 128, 133, 150, 190, 282 + 2 night lines)**
- **Partly replacement with trolleys (line 181 since 2019)**
- **Full replacement with trolleys (line 170 since 09.2020)**

General outputs

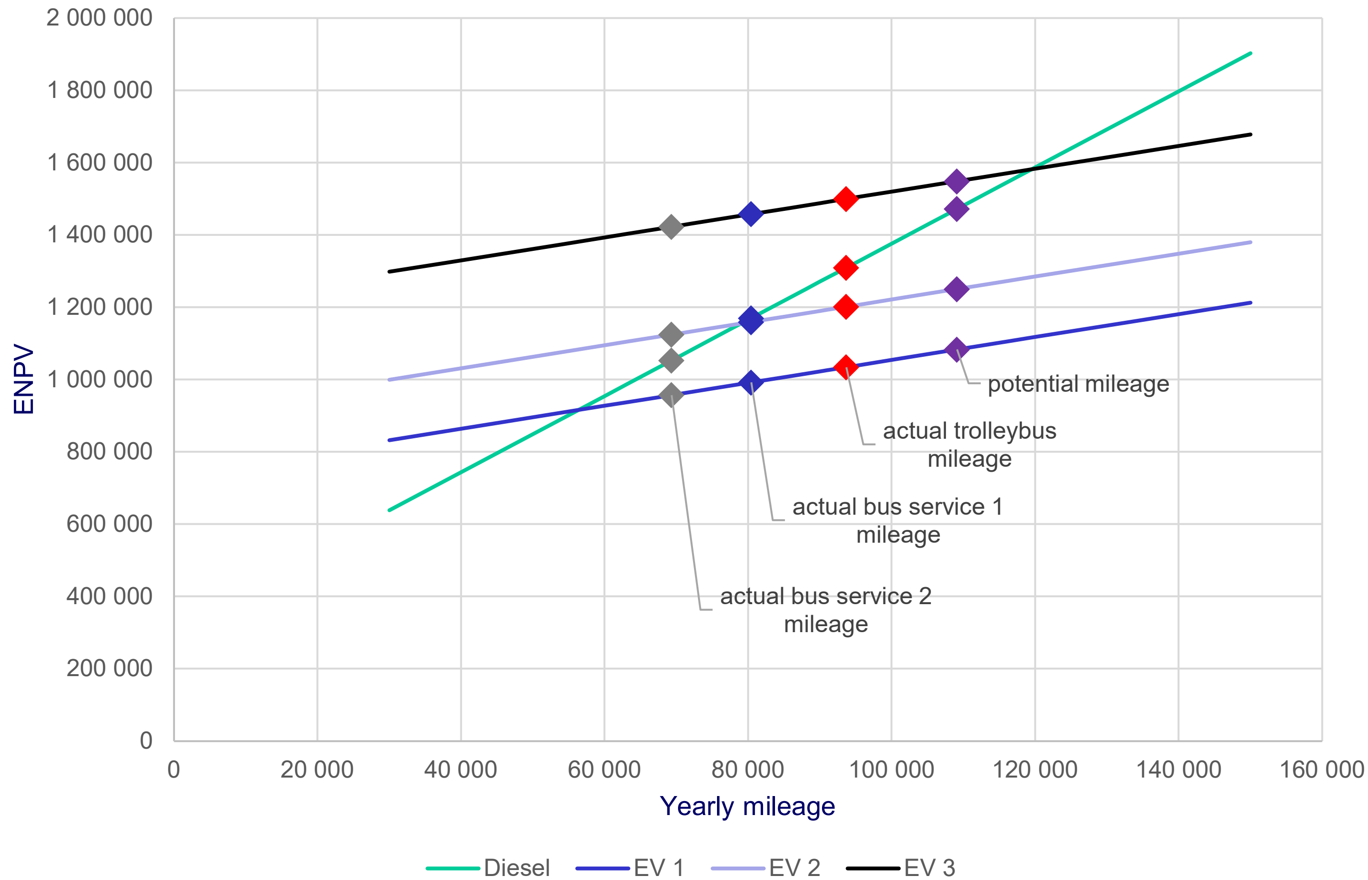
FNPV



EV 1 – no need of extra infra, EV 2 – a need of chargers (0,2 per bus), EV 3 – a need for 2 km overhead wires // 69 kWh battery in all cases

General outputs

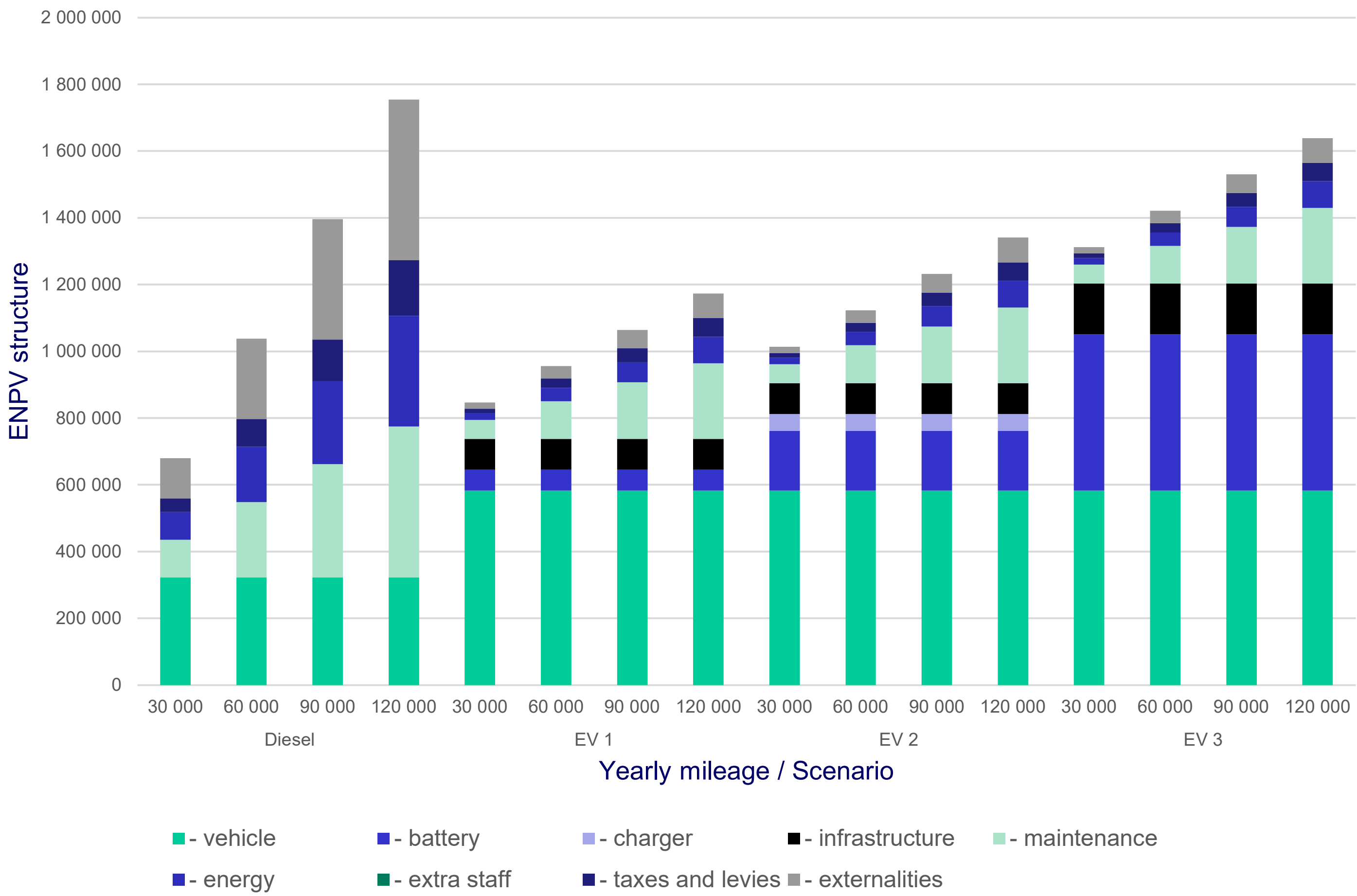
ENPV



EV 1 – no need of extra infra, EV 2 – a need of chargers (0,2 per bus), EV 3 – a need for 2 km overhead wires // 69 kWh battery in all cases

General outputs

Cost structure



EV 1 – no need of extra infra, EV 2 – a need of chargers (0,2 per bus), EV 3 – a need for 2 km overhead wires // 69 kWh battery in all cases

General inputs

Vehicle specific

Vehicle specific	Unit	Diesel	EV 1	EV 2	EV 3
Vehicle purchase price	EUR	260000	520000	520000	520000
Planned / actual lifetime of batteries	year	5	5	5	5
Project lifetime	year	30	30	30	30
Lifetime of a vehicle	year	15	20	20	20
Number of vehicles bought	vehicle	2	2	2	2
Share of residual value	%	0%	50%	50%	50%
Residual value	EUR	0	260000	260000	260000
Maintenace costs (excluding batteries) / km	EUR/km	0,4	0,2	0,2	0,2
Energy consumption / km	kWh/100 km	0	150	150	150
Energy unitary cost	EUR/kWh	0	0,08	0,08	0,08
Fixed cost of electric power (if any)	EUR/month	0	0	0	0
Multiplier for vehicles / kilometers	-	1	1	1	1
Multiplier for drivers only	-	1	1	1	1

General inputs

Service specific

trolley:2.0 for smart cities

Electric Mobility Europe

Service specific	Unit	Diesel	EV 1	EV 2	EV 3
Battery price	EUR	0	25143	72286	188571
Battery capacity required	kWh	0	16	46	120
Opportunity charger price	EUR	0	250000	250000	250000
Number of opportunity chargers required	pcs	0	0	0,2	0
New overhead wires and substations construction costs / km	EUR/kmtp	0	250000	250000	250000
Overhead wires and substations modernisation costs / km	EUR/kmtp	0	50000	50000	50000
New overhead wires required	kmtp	0	0	0	5
Modernised overhead wires required	kmtp	0	0	0	0
Distance travelled under new overhead wires	%	0	0%	0%	5%
Distance travelled under modernised overhead wires	%	0	0%	0%	0%
Overall distance travelled under overhead wires	%	0	50%	50%	50%

General inputs

Other

Other	Unit	Value
Charger lifetime	year	30
Opportunity charger maintainace costs / charger	EUR/charger/year	10000
Wires lifetime	year	20
Overhead wires and substations maintainace costs / km	EUR/km/year	20000
Driver cost	EUR/h	8
Oil consuption / km	ltrs/100 km	44
Oil unitary cost	EUR/ltr	1
Average speed	km/h (including stops)	15
Network load	vkm	5270000
Overall number of vehicles	vehicle	92
Average mileage	km	57283
Overall wires infrastructure	kmtp	86,93
Network usage coefficient	-	0,00002

General inputs

Externalities & taxes

Externalities	Unit	Value
Externalities input set	-	Poland
Share of zero emission energy	% of 0 emission energy	100%
Type of city / traffic	-	Urban
Taxes	**Unit**	**Value**
Share of taxes and levies paid by non-household consumers for electricity	%	41
Excise duty na diesel oil	EUR	0,26
Fuel surcharge on diesel oil	EUR	0,07
Share of taxes and levies paid by non-household consumers	%	34

Model specification

t	0 - 30
r	10%
Yearly mileage	120000
Scenario	EV 3

Externalities

Holistic approach

- Externalities included:
  - TTW (Tank to Wheel) - emissions produced by the burning of the fuel and is emitted at the tail pipe of the vehicle
  - WTT (Well to Tank) - emissions emitted during fuel or electricity production and distribution
- Substances: CO, VOC, NO_X, PM10, CO_2eq, PM2.5, SO_2,
- Noise
- Most emissions specified for 28 EU countries
- PM2.5 emissions specified for rural, suburban and urban areas
- Price index and GDP dynamics adjustment (Polish guidelines for CBA)

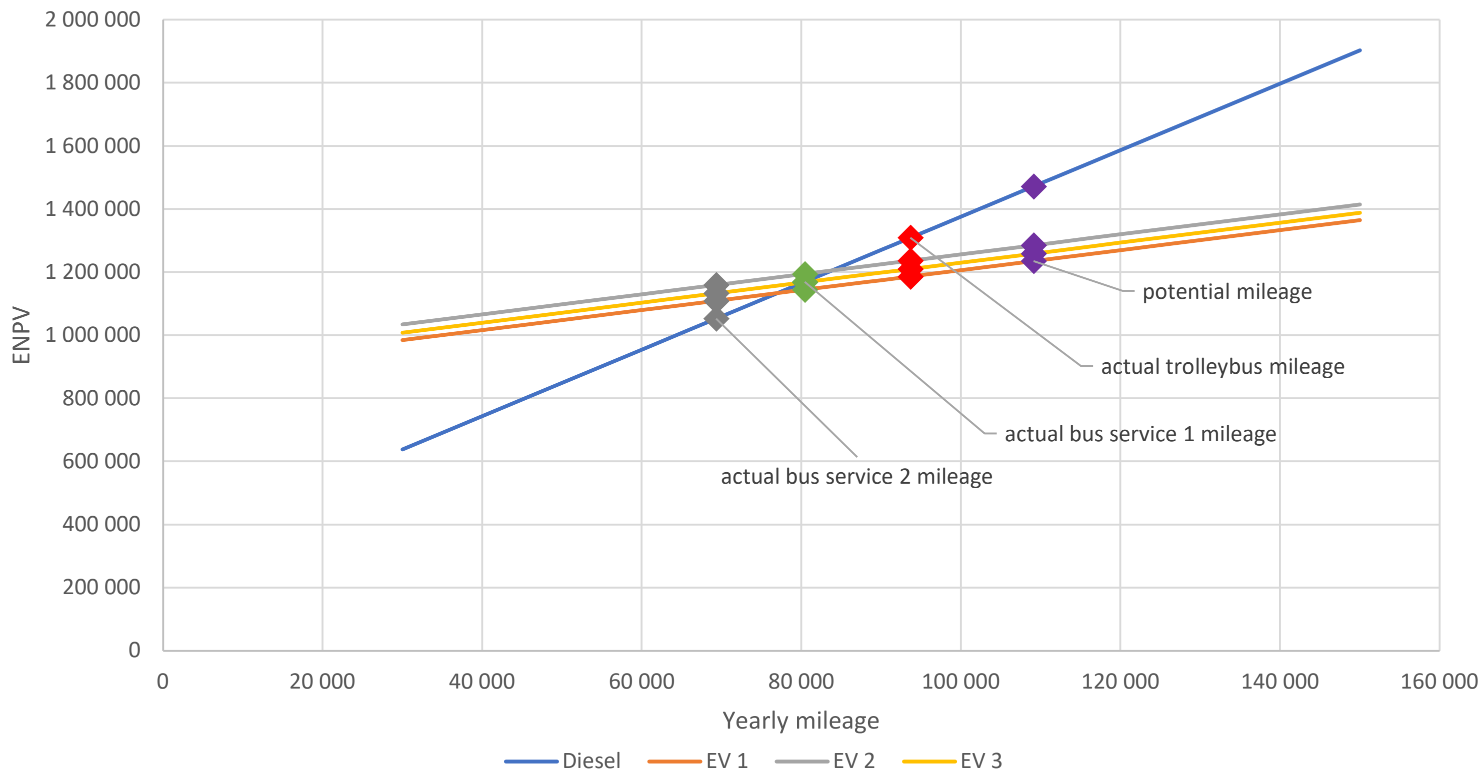
Externalities

Sources

- Emissions:
  - CIVITAS, Smart choices for cities. Clean buses for your city, 2013
  - F. Tong et al., Life cycle ownership cost and environmental externality of alternative fuel options for transit buses, Transportation Research Part D 57, 2017
- Costs:
  - Ricardo-AEA, Update of the Handbook on External Costs of Transport, Final Report, 2014
  - M. Gerbec et al., Cost benefit analysis of three different urban bus drive systems using real driving data, Transportation Research Part D 41, 2015
  - CUPT, Cost-benefit analysis of transport projects co-financed by the European Union, 2016

Outcomes

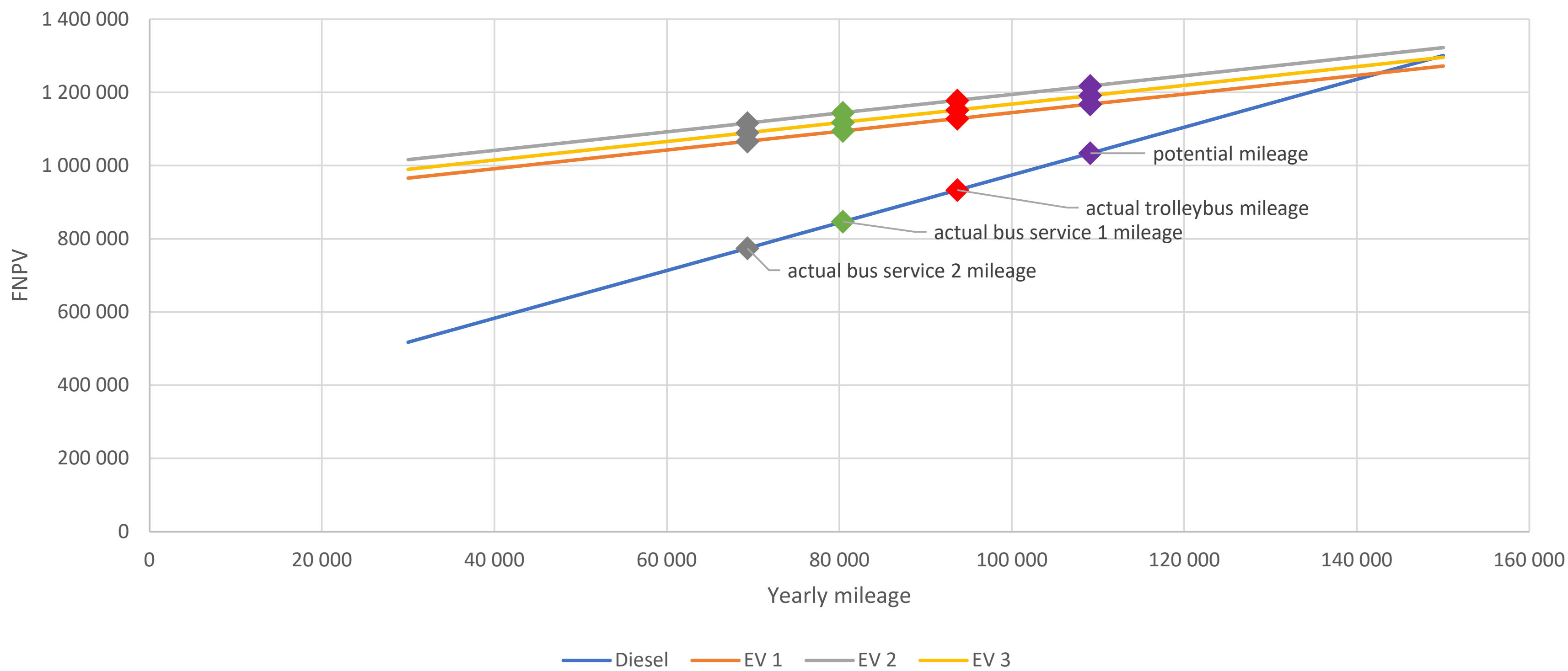
High economic break-even mileage
Little difference between e-Bus scenarios
Trolleybus network is a great start for e-Bus, but not a game changer



EV 1 – no need of extra infra, EV 2 – a need of chargers (0,2 per bus), EV 3 – a need for 2 km overhead wires // 69 kWh battery in all cases

Outcomes

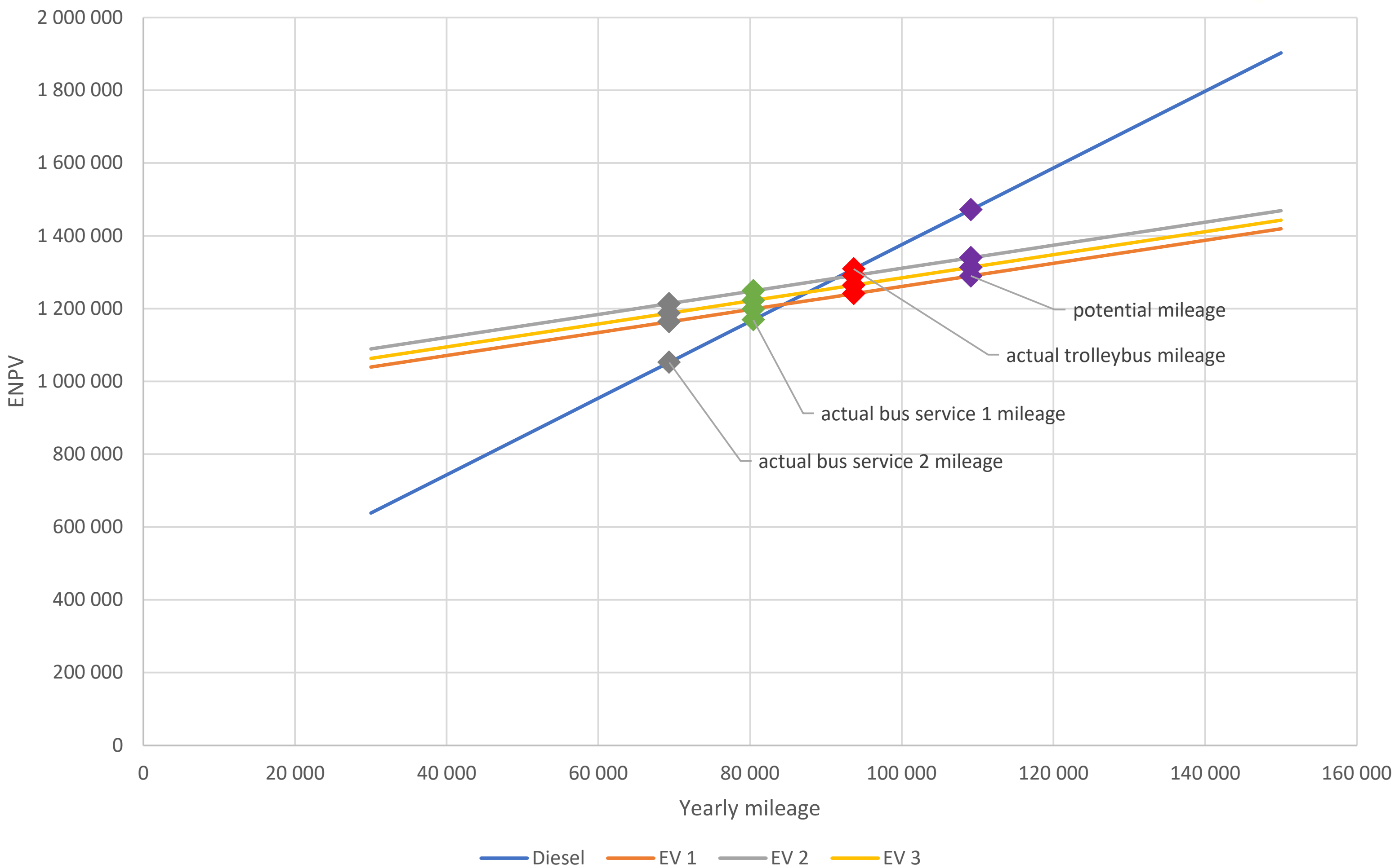
No financial viability – need of public co-financing



EV 1 – no need of extra infra, EV 2 – a need of chargers (0,2 per bus), EV 3 – a need for 2 km overhead wires // 69 kWh battery in all cases

Outcomes

5 years battery lifetime
Model is sensitive to battery capacity and lifetime

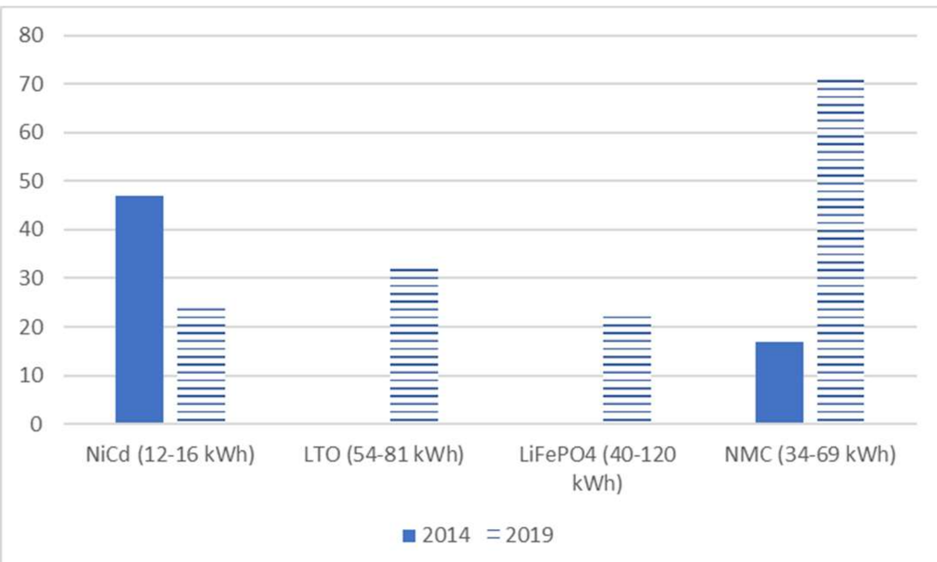


trolley:2.0 for smart cities

Electric Mobility Europe

Battery: a game-changer in the spread of IMC technology

In 2019, 63% of trolleybuses in Poland was equipped with traction battery



Changes in the number and structure of trolleybus batteries in Poland between 2014 and 2019

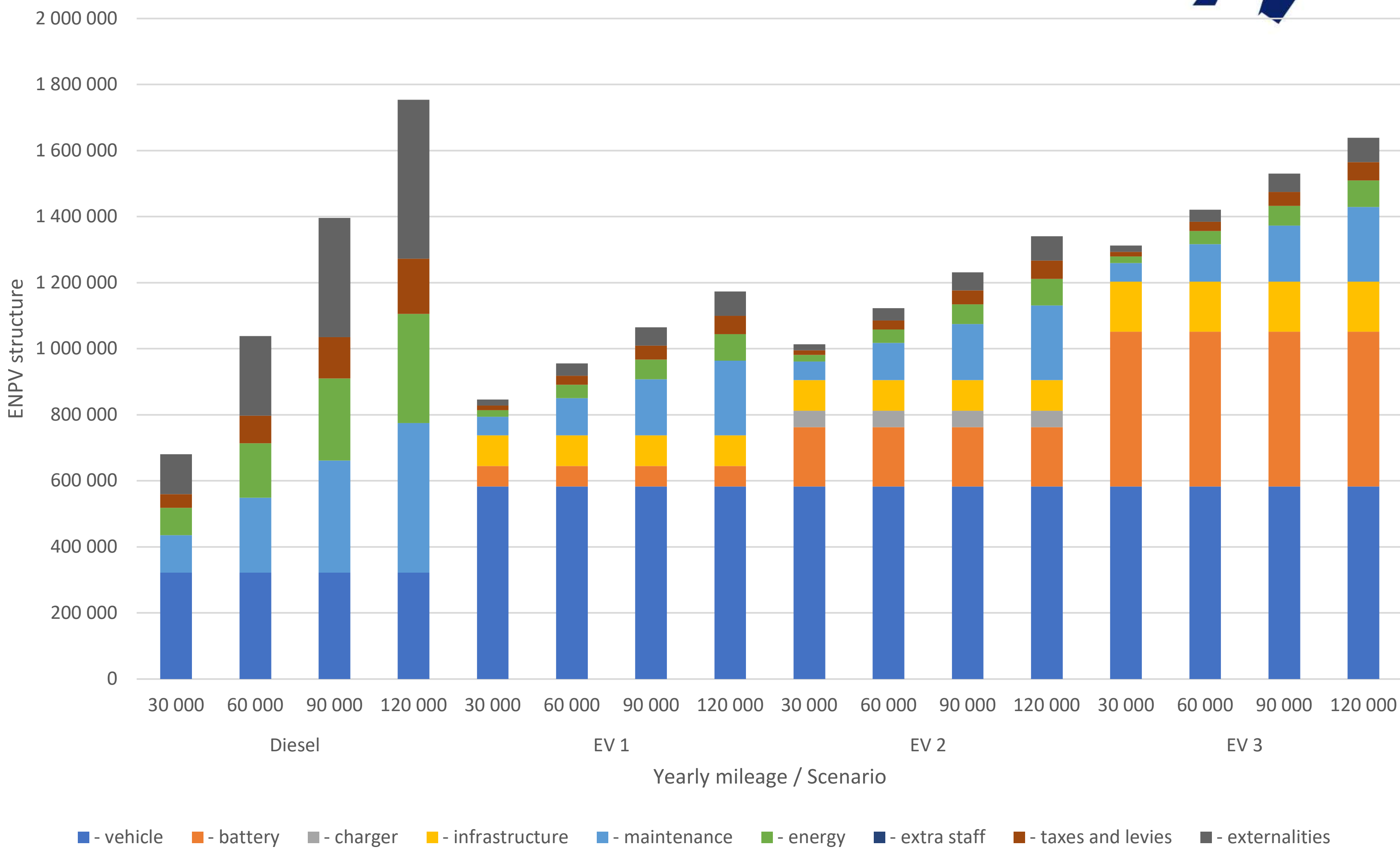
- A key factor determining the development of IMC technology - progress in traction batteries
- Critical question: increase in battery capacity but at what cost?
- Increase in average battery capacity is accompanied by a change in the generic structure in which NMC and, to a lesser extent, LTO batteries predominate

Outcomes

Externalities vs. taxes

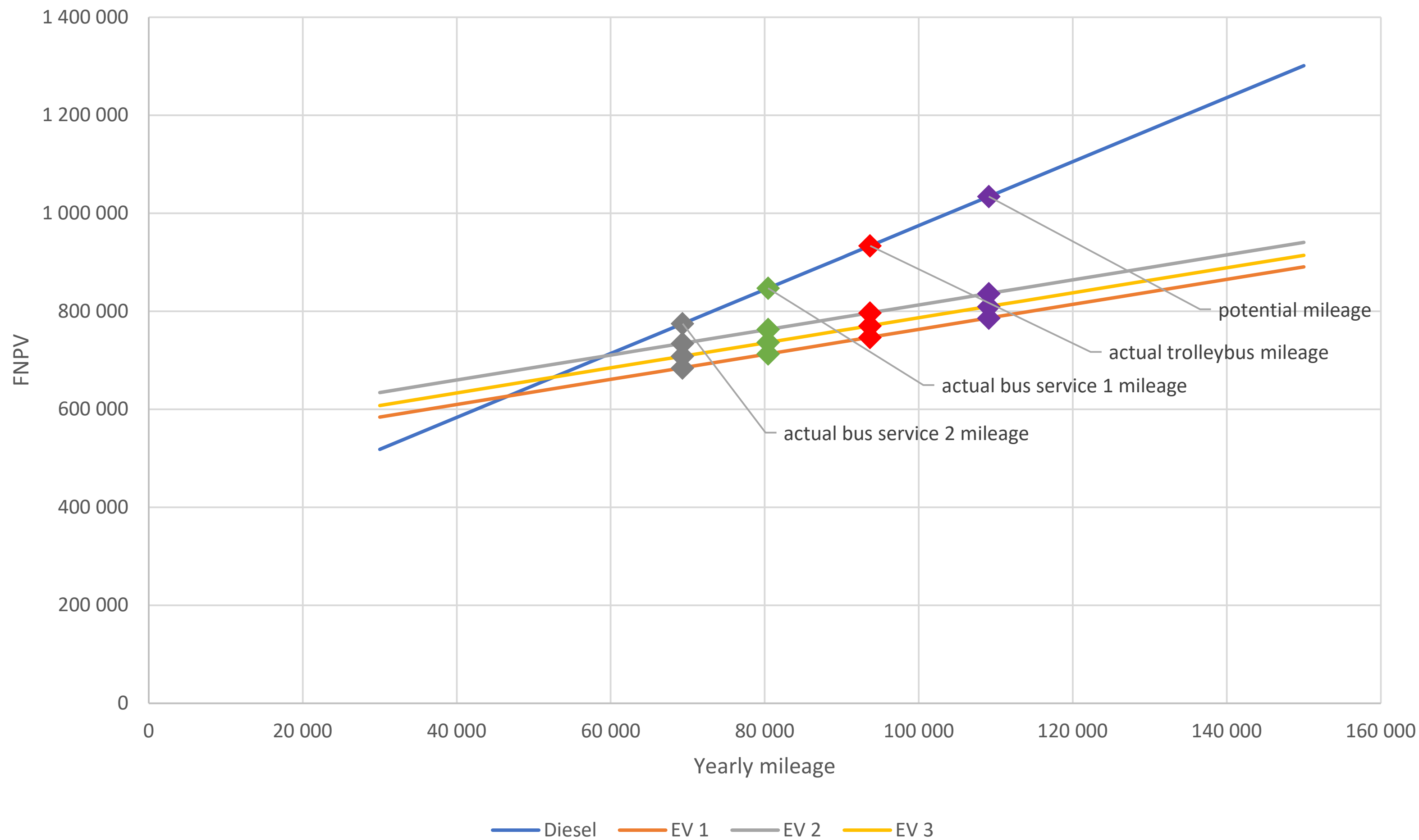
trolley:2.0 for smart cities

Electric Mobility Europe



Outcomes

75% co-financing lowers financial break-even to ca. 50 kkm/year



Conclusions

- Much depends from the point of view and sources of Energy
- Increase the share of renewables (confirms other TROLLEY 2.0 findings)
- Don’t kill Diesel now (unless you have too much public money)
- Work on cheaper eBuses and charging infrastructure, as well as electricity
- Minimise battery capacity (Focus on line(s) instead of general system)
- Maximise the use of existing and planned infrastructure and vehicles:
    - use as much as possible existing overhead network and trolleybuses
      (ex. night lines, weekends, all-day tasks)
    - use chargers on busy enough terminals
      and overhead wires on busy enough roads
- Calculate cost and benefits before decision: focus on particular line(s)

Thank you for your attention

Title picture – chombosan/Shutterstock