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The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
17th-20th November 2013

Electromobility Potential Index for 46 Major Cities

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TUM CREATE

Organized by Fira Barcelona avele
Hosted by AVERE mea Ajuntament de Barcelona
In collaboration with EVAAP EDTA
Supported by European Commission

Challenges in Megacities

Individual boundary conditions

Air Pollution

Traffic

Energy Supply

Climate Conditions

Misbalance between rich and poor

Source: http://mjperry.blogspot.sg/; smashingdesign.net; http://photoblg.nbcnews.com

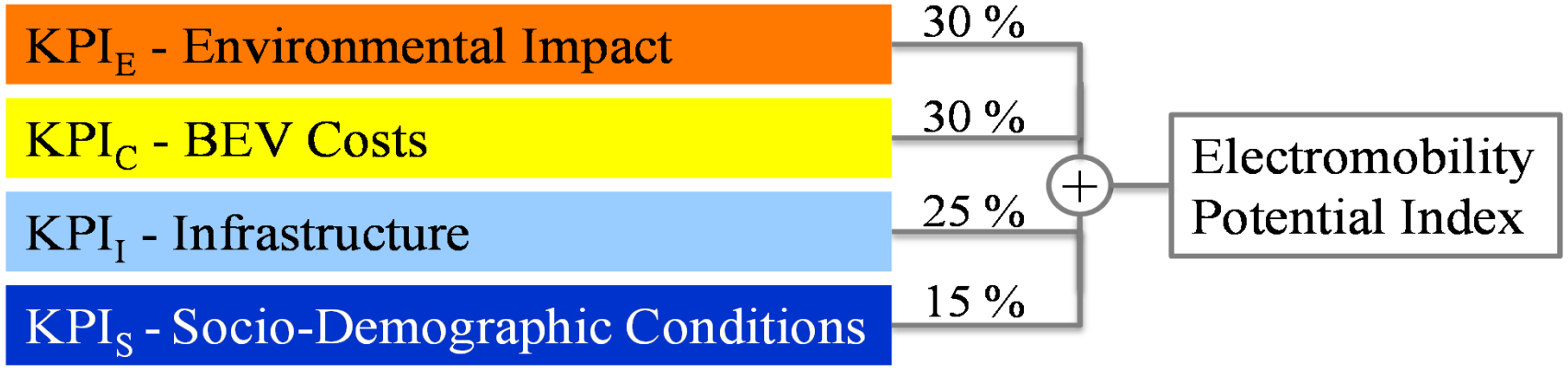
In which cities does it really make sense to introduce electric vehicles?

Electromobility Potential Index - Definition

Electromobility Potential Index (EMPI)

The EMPI evaluates the potential for sustainable success of electric vehicles (BEV) in cities from a city's point of view.

Based on the key topics "sustainability", "user acceptance" and "readiness", the following key performance indicators (KPI) and weightings were defined:



Electromobility Potential Index - KPI_E

Environmental Impact

KPI_E analyses global balance of CO_2 emissions between BEV and ICEV and locally respects any pressure for urgent improvement of air quality due to pollution.

$$KPI_{\mathrm{E}} = PI_{\mathrm{E}}(Em_{\mathrm{bal}}) + \Delta Pr_{\mathrm{Pm10}}(PM_{10}, Em_{\mathrm{bal}})$$

$$Em_{\mathrm{bal}} = \frac{Em_{\mathrm{BEV}}}{Em_{\mathrm{ICEV}}} = \frac{\overbrace{Em_{\mathrm{WtT,BEV}}}^{\text{Dependent on local Energymix}} \times W_{\mathrm{BEV}}}{\left(Em_{\mathrm{WtT,ICEV}} + Em_{\mathrm{TtW,ICEV}}\right) \times \underbrace{W_{\mathrm{ICEV}} \times LHV_{\mathrm{Petrol}}}_{\text{Fuel Consumption}}}$$

- Saving of CO_2 emissions ($Em_{\mathrm{bal}} < 1$) are rewarded in KPI_E

Electromobility Potential Index - KPI_C

BEV Costs

KPI_C compares total cost of ownership (TCO) between BEV and ICEV. Wealth of a city (PI_{GDP}) and governmental encouragement (PI_{Enc}) also influence evaluation.

$$KPI_{\mathrm{C}} = 0.5\ PI_{\mathrm{TCO}} + 0.15\ PI_{\mathrm{GDP}} + 0.35\ PI_{\mathrm{Enc}}$$

$$PI_{\mathrm{TCO}} = \frac{TCO_{\mathrm{BEV}}}{TCO_{\mathrm{ICEV}}} = \frac{CostAcq_{\mathrm{BEV}} + \overbrace{CostOwn_{\mathrm{BEV}}}^{\text{Incl. local electricity price}}}{CostAcq_{\mathrm{ICEV}} + \underbrace{CostOwn_{\mathrm{ICEV}}}_{\text{Incl. local fuel price}}}$$

$$CostAcq_{\mathrm{BEV}} = CostAcq_{\mathrm{Base}} + \underbrace{CostAcq_{\mathrm{EMot}} + CostAcq_{\mathrm{PowEl}} + CostAcq_{\mathrm{Bat}}}_{\text{Fulfilling local requirements}}$$

Electromobility Potential Index - KPI_I

Infrastructure

KPI_I considers transport conditions such as traffic flow and public transport, as well as a city's efforts to build up a charging infrastructure for BEV.

$$KPI_{\mathrm{I}} = 0.3\ PI_{\mathrm{Road}} + 0.3\ PI_{\mathrm{PT}} + 0.4\ PI_{\mathrm{Charge}}$$

$$PI_{\mathrm{Road}} = 10\,\frac{l_{\mathrm{Road}}}{n_{\mathrm{Veh}}}$$ ⇨ Traffic congestion occurs at road supply of less than 5 m road per vehicle

$$PI_{\mathrm{PT}} = f(l_{\mathrm{Rail}}, I_{\mathrm{Rail}})$$ ⇨ Importance for rail systems (I_{Rail}) rises with density of population.

$$PI_{\mathrm{Charge}}$$ ⇨ Qualitative evaluation based on current and planned charging infrastructure and special treatments for BEV

Electromobility Potential Index - KPI_S

Socio-Demographic Conditions

KPI_S describes the living conditions of the population and the reliability of the government.

$$KPI_S = 0.5\ PI_{HDI} + 0.2\ PI_{QoL} + 0.3\ PI_{Cor}$$

$PI_{HDI} = f(HDI)$ ⇨ A high Human Development Index[1] (HDI) increases chances of user acceptance for BEV

$PI_{QoL} = f(QoL)$ ⇨ A high Quality of Living[2] (QoL) increases chances of user acceptance for BEV

$PI_{Cor} = f(Cor)$ ⇨ Corruption level[3] (Cor) forecast success and failure of major public projects

[1] United Nations, "Human Development Report," 2011
[2] Mercer, "Quality of Living Report," 2012
[3] International Transparency, "Corruption perceptions Index," 2011

Evaluation

EMPI determined for 46 cities, including 21 megacities

9 North-American cities

6 European cities

22 Asian cities

5 South-American cities

3 African cities

- What is the required range for EVs in these cities?

Evaluation
Derivation of required range

Approach

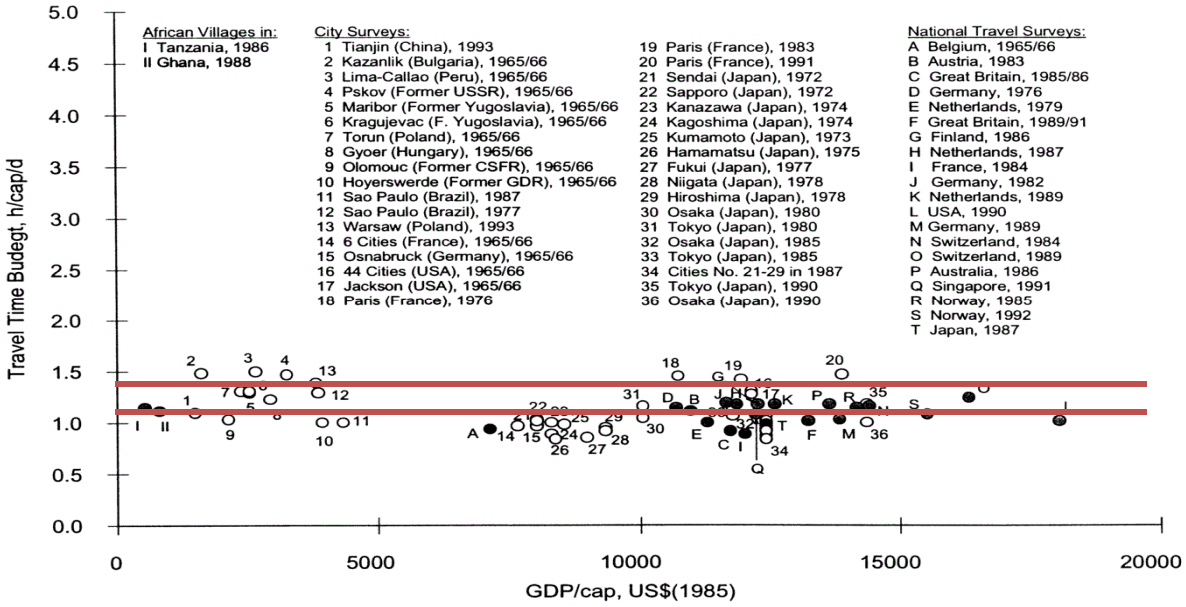
Country and city independent approach needed: concept of **Travel Time Budget (TTB)**

- 'Throughout the world the **average** time people devote on travel is **constant** over a wide range of geographical and cultural settings'

$$TTB = 1.1h$$

$$TTB_{\text{city}} = 1.3TTB$$

$$R_{\emptyset} = TTB_{\text{city}} v_{\emptyset}$$



[1] Schafer & Victor – The future mobility of the world population (2000), Crozet – Time and Passenger Transport (2005)

Evaluation
Derivation of required range

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$$TTB = 1.1h$$

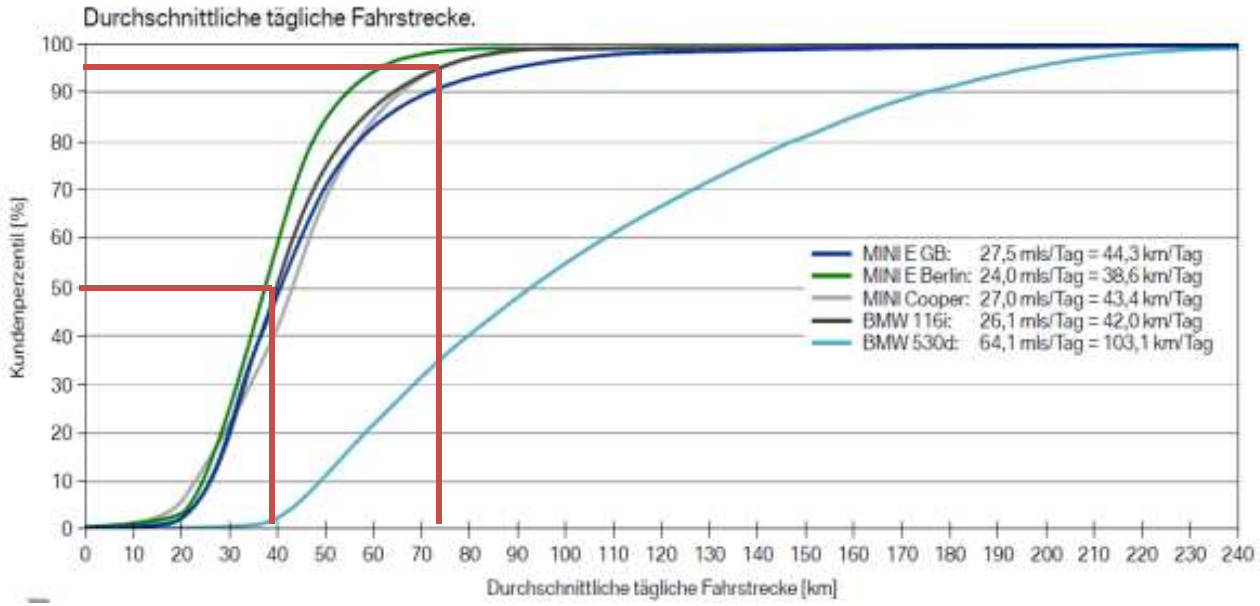
$$TTB_{\text{city}} = 1.3TTB$$

$$R_{\emptyset} = TTB_{\text{city}} v_{\emptyset}$$

$$R_{95} = 2R_{\emptyset}$$

$$R = R_{95} + 15\text{km}$$

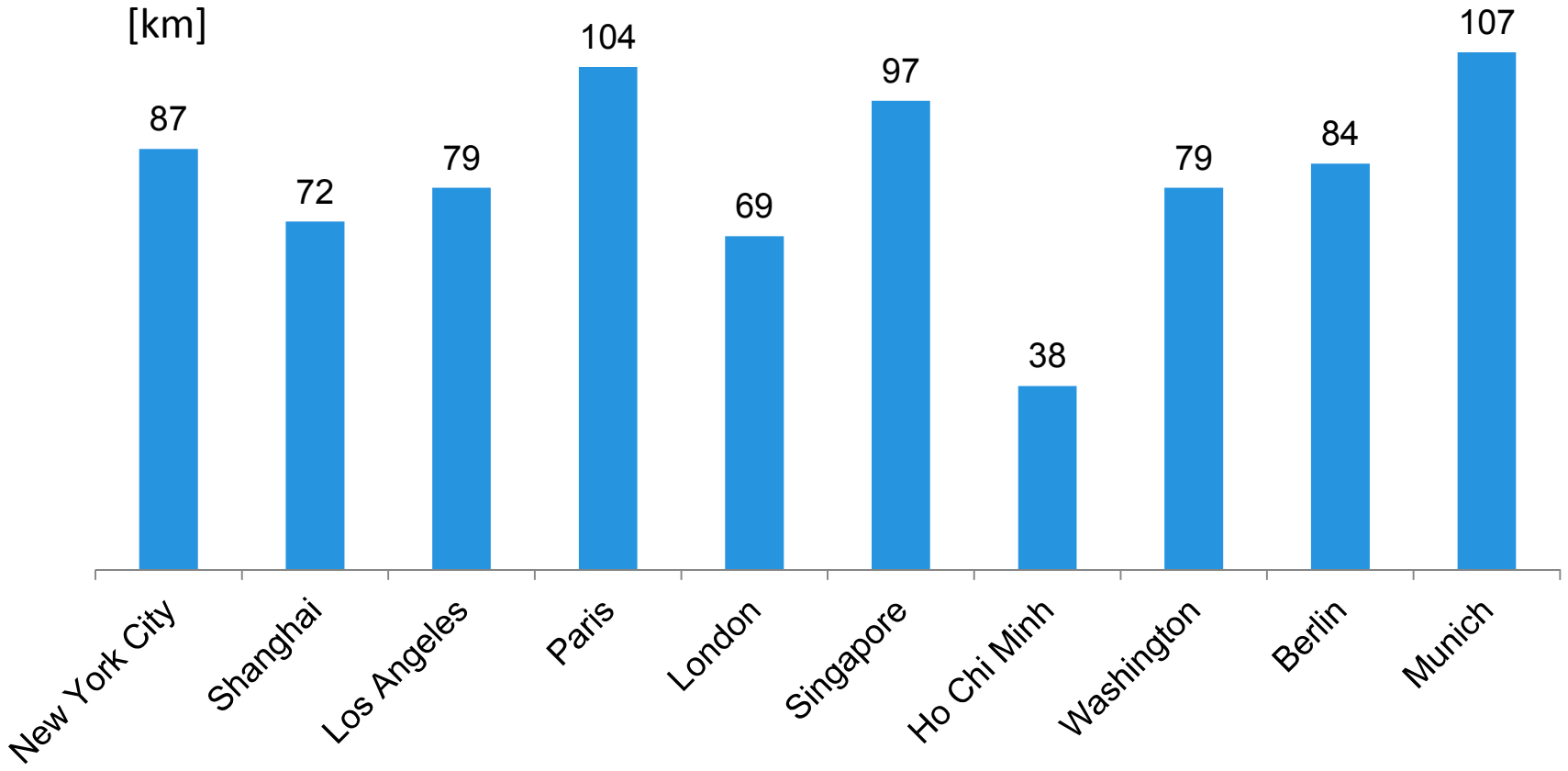
$$= 2.86v_{\emptyset} + 15\text{km}$$



BMW Group, Ergebnisse MINI E Berlin powered by Vattenfall 1.0

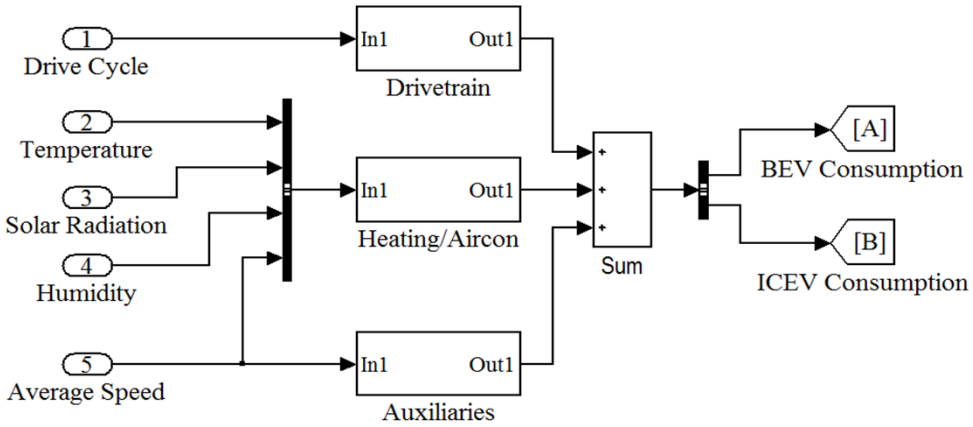
Evaluation
Derivation of required range

Range requirements for 95 % average use case in selected cities



Evaluation Simulation

Simulation of BEV energy consumption



Description	Constants	Values
Curbweight ICEV	$m_{curb,ICEV}$	1100 kg
Baseweight BEV (excl. Battery and Drivetrain)	$m_{base,BEV}$	650 kg
Additional Weight (Driver)	m_{add}	75 kg
Energy Density Battery Cell (LiMn)		118 Wh/kg
Regenerative Braking Rate		55 %
Power Auxiliaries	P_{aux}	700 W

$$m_{BEV} = m_{base,BEV} + m_{bat} + m_{drive} + m_{sec}$$

For the calculation of the energy consumption, a lumped-parameter simulation from [1] is chosen and slightly modified to compensate for some known overestimations.

[1] A. Simpson, *Parametric modelling of energy consumption in road vehicles*, University of Queensland, 2005

Evaluation Simulation

Evaluation Parameters & Simulation

Indicator value	Indicator ability
100	perfect
90	excellent
80	excellent
70	good
60	good
50	acceptable
40	improvements needed
30	poor
20	poor
10	very poor
0	extremely poor

- EMPI, all KPIs and PIs are all quantified on a scale from 0 – 100 with 50 defined as acceptable value
- Simulation tool is implemented in Matlab/Simulink
- Evaluation focusses on BEV only

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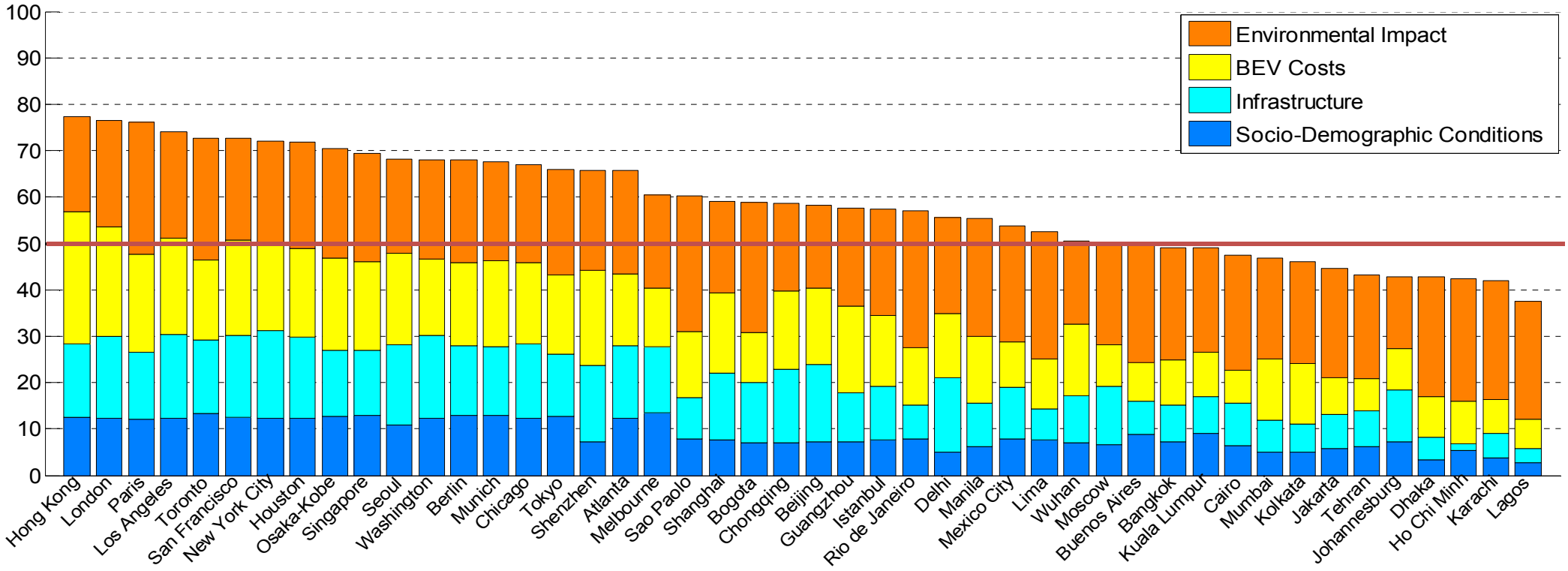
Evaluation Results

Electromobility Potential Index for 46 cities



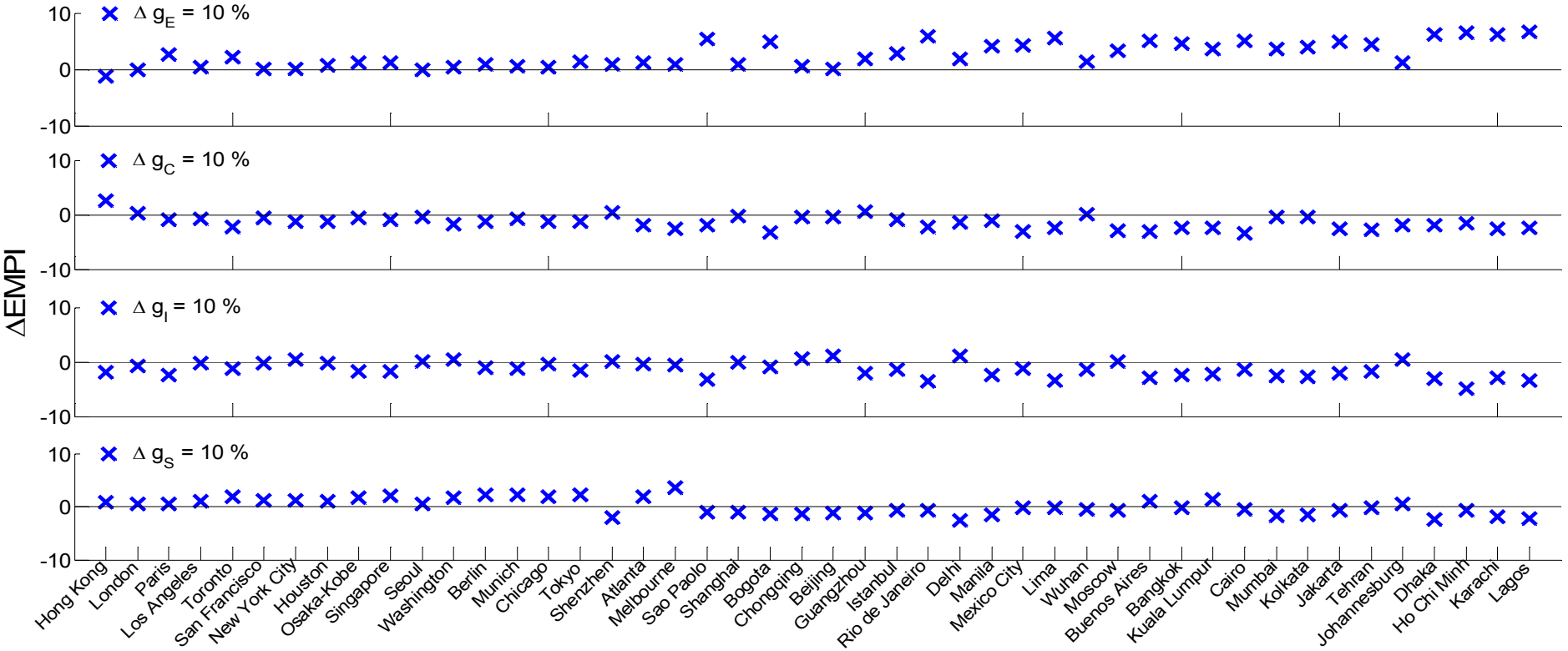
Cities show large differences in score results due to local conditions

Discussion
Key Insights

- Highest scoring cities are widely distributed between North America, Europe and Asia
- Some of biggest cities in developing countries currently do not show favorable conditions
- Wealthy cities with good traffic flow and mild climate conditions show the best boundary conditions.
- Most cities show favorable CO2 emissions balance
- One key success factor is to adapt the range requirement to local markets.

Validation
Weighting Factors

Effects on variations in weighting factors on EMPI



▶ Varying the weighting factors by Δg_i = 10% for KPI_i, i={E,C,I,S} hardly shows any impact

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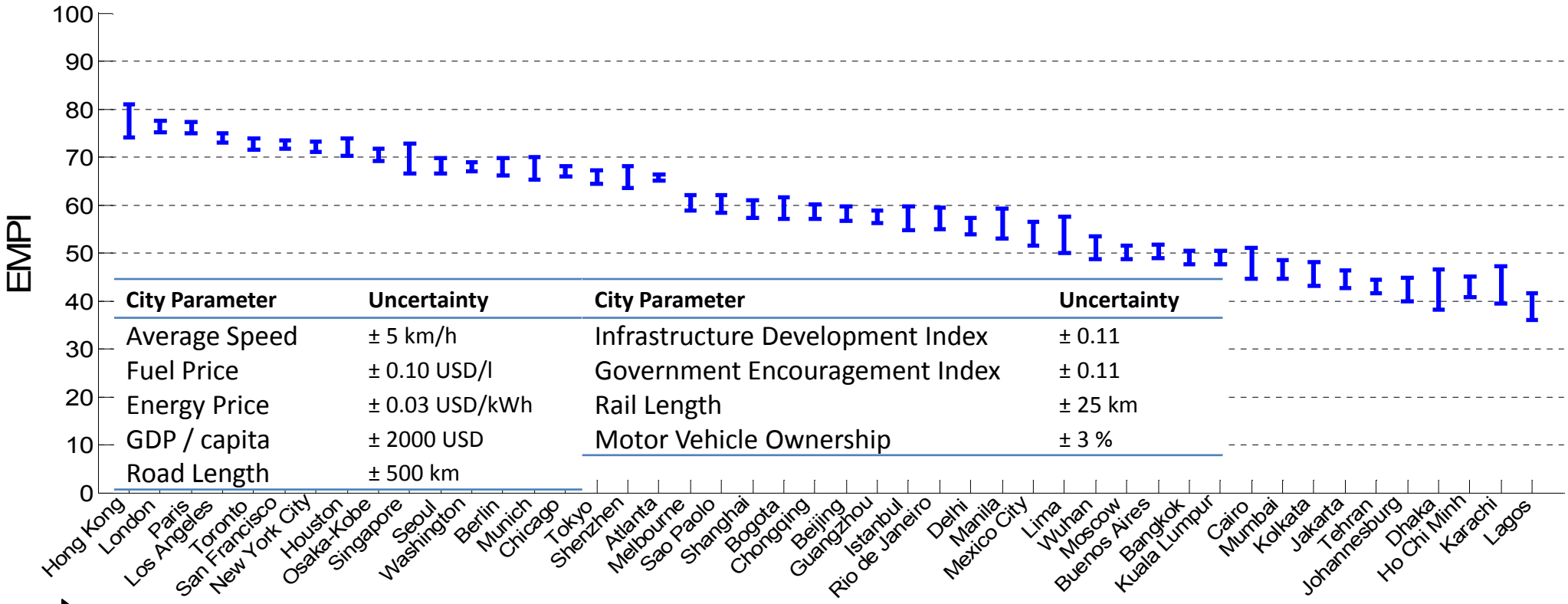
Validation
City Parameters

EMPI results considering uncertainties in city parameters



City Parameter	Uncertainty	City Parameter	Uncertainty
Average Speed	± 5 km/h	Infrastructure Development Index	± 0.11
Fuel Price	± 0.10 USD/l	Government Encouragement Index	± 0.11
Energy Price	± 0.03 USD/kWh	Rail Length	± 25 km
GDP / capita	± 2000 USD	Motor Vehicle Ownership	± 3 %
Road Length	± 500 km		

▶ EMPI is robust even against smaller data uncertainties

Conclusion

Summary

- EMPI provides a functional and robust tool to quickly evaluate the local potential for the sustainable introduction of BEV making use of city-specific data.
- Not all cities are “ready” for BEVs yet
- Wealthy cities with good traffic flow and mild climate conditions show the best boundary conditions.
- One key success factor is to adapt the range requirement to local markets.

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Thank you!

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