



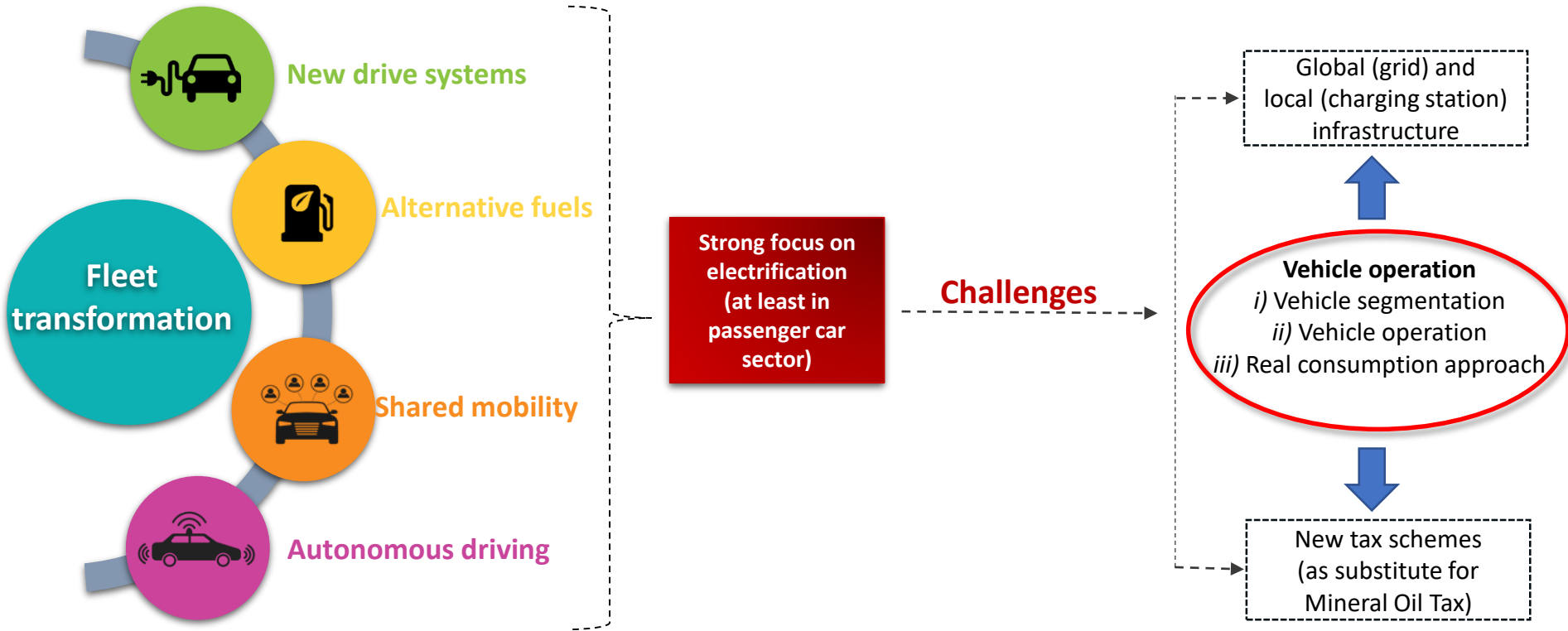
How are vehicles operated on the road?

CSFM Seminar: The transition to electric vehicles: Implications for public revenues

24 October 2023- Doc. Betsy Sandoval Guzman
Vehicle System Group
Automotive Powertrain Technologies Lab

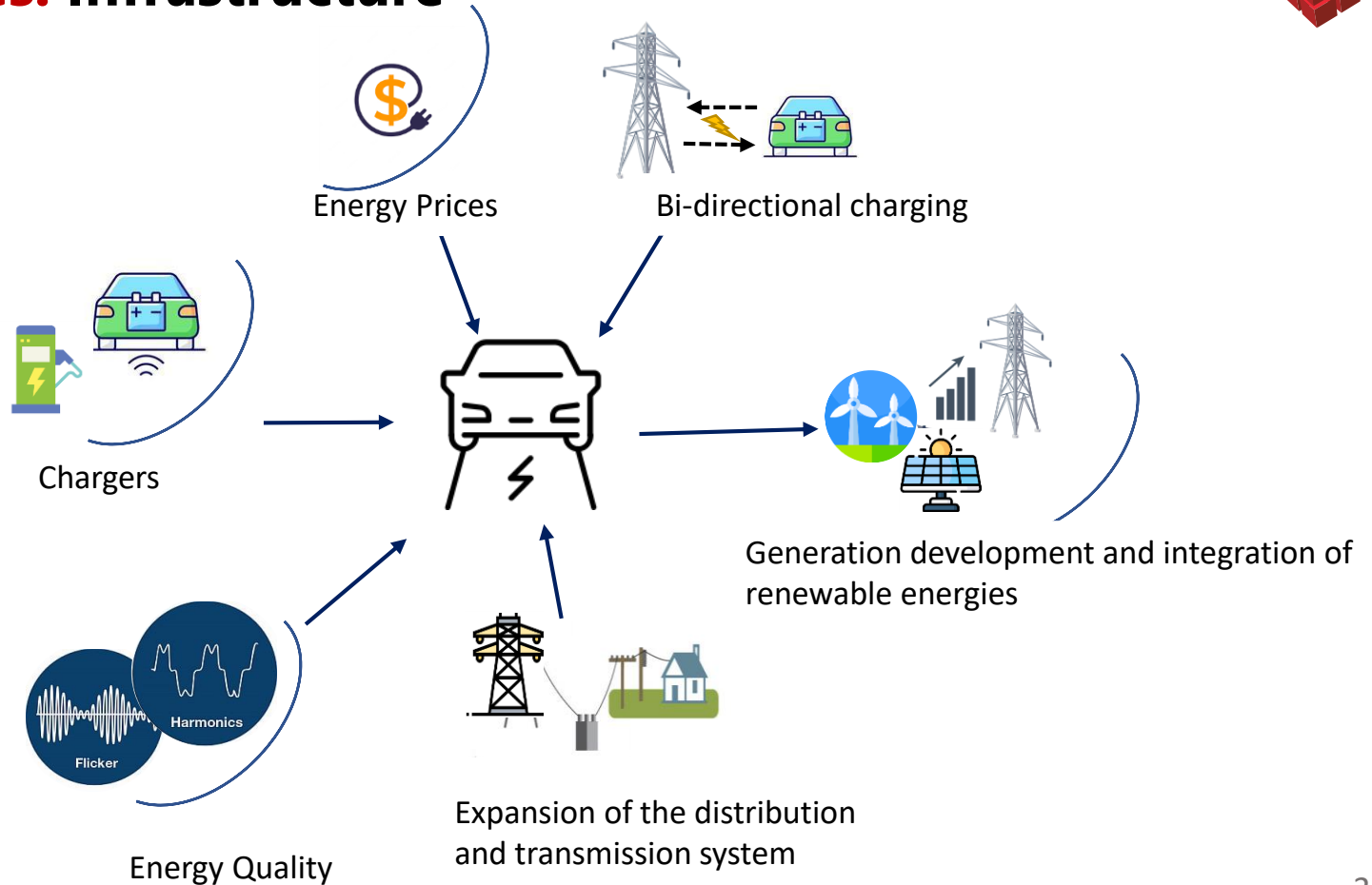


1. CO₂ reduction targets for 2050





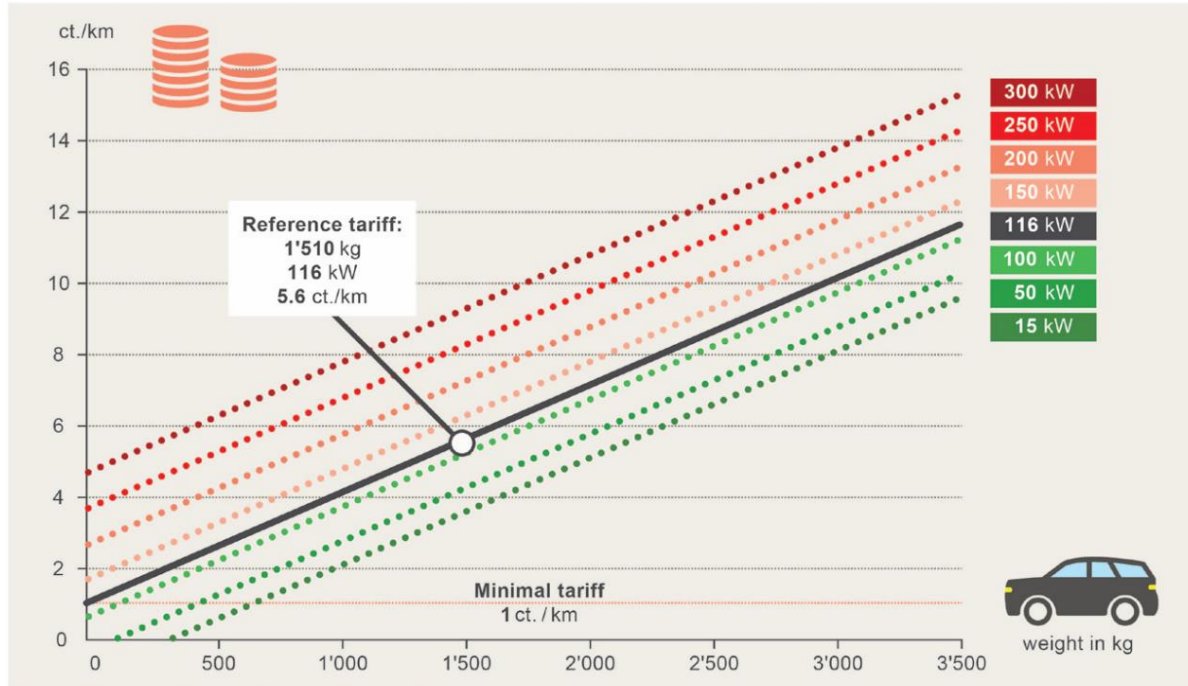
2. Challenges: Infrastructure





2. Challenges: Tax schemes

Tariff model for passenger cars according to unladen weight and engine power



The km-based taxation approach may have fixed or time-based rates



Real-world operational aspects not considered:

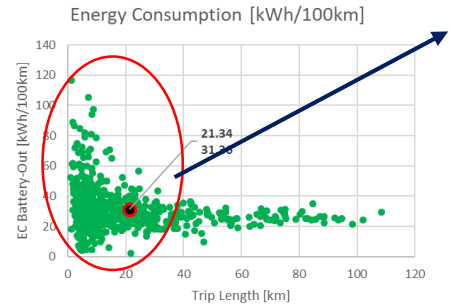
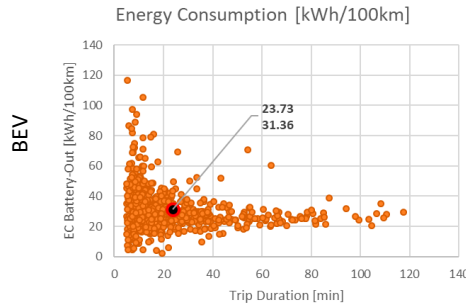
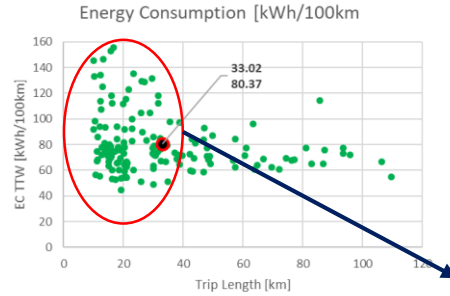
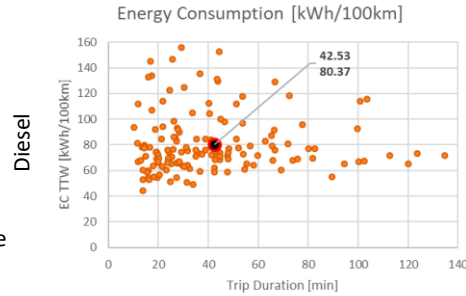
- Geographical-temporal information.
- Energy/Fuel consumption considering real-world conditions.

Source: Concept for the substitution of mineral oil taxes (alternative tax), Federal Department of the Environment, Transport, Energy and Communications DETEC



Example of Energy and Fuel consumption considering real-world conditions

Upper-middle class vehicle



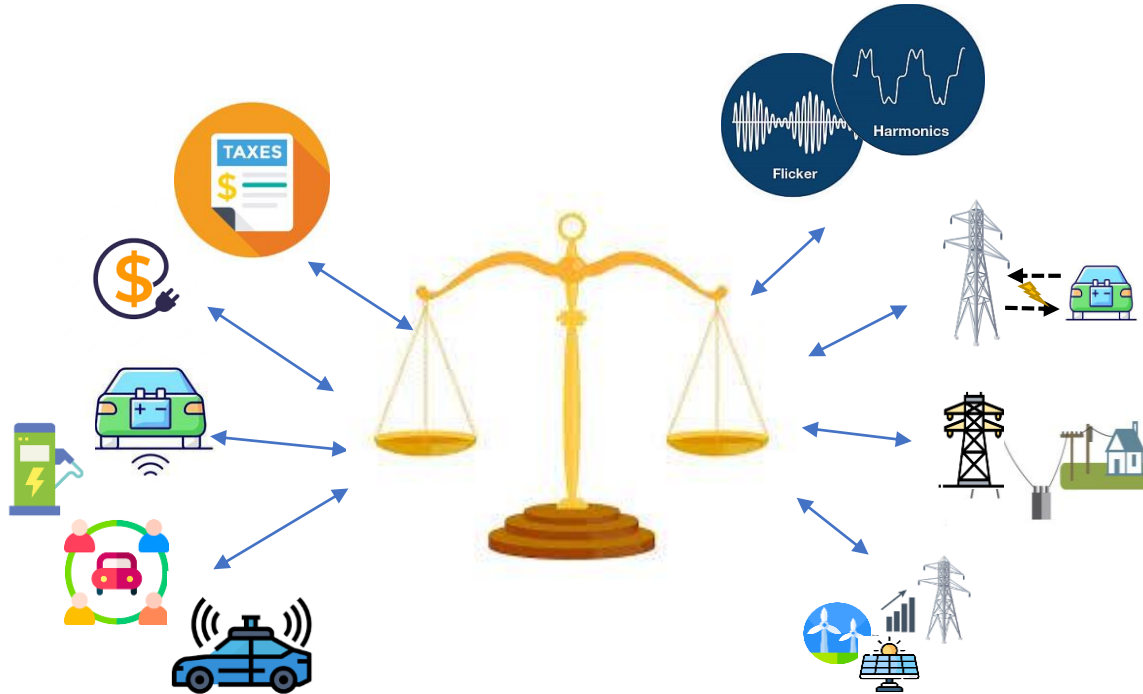
For trips < 40km the correlation between the energy/fuel consumption and the distance is not lineal

Importance of analyzing factors affecting real-world energy consumption (trip profile, driving style, usage of auxiliaries, road congestion level...)

Source: Automotive Powertrain Technologies, Empa



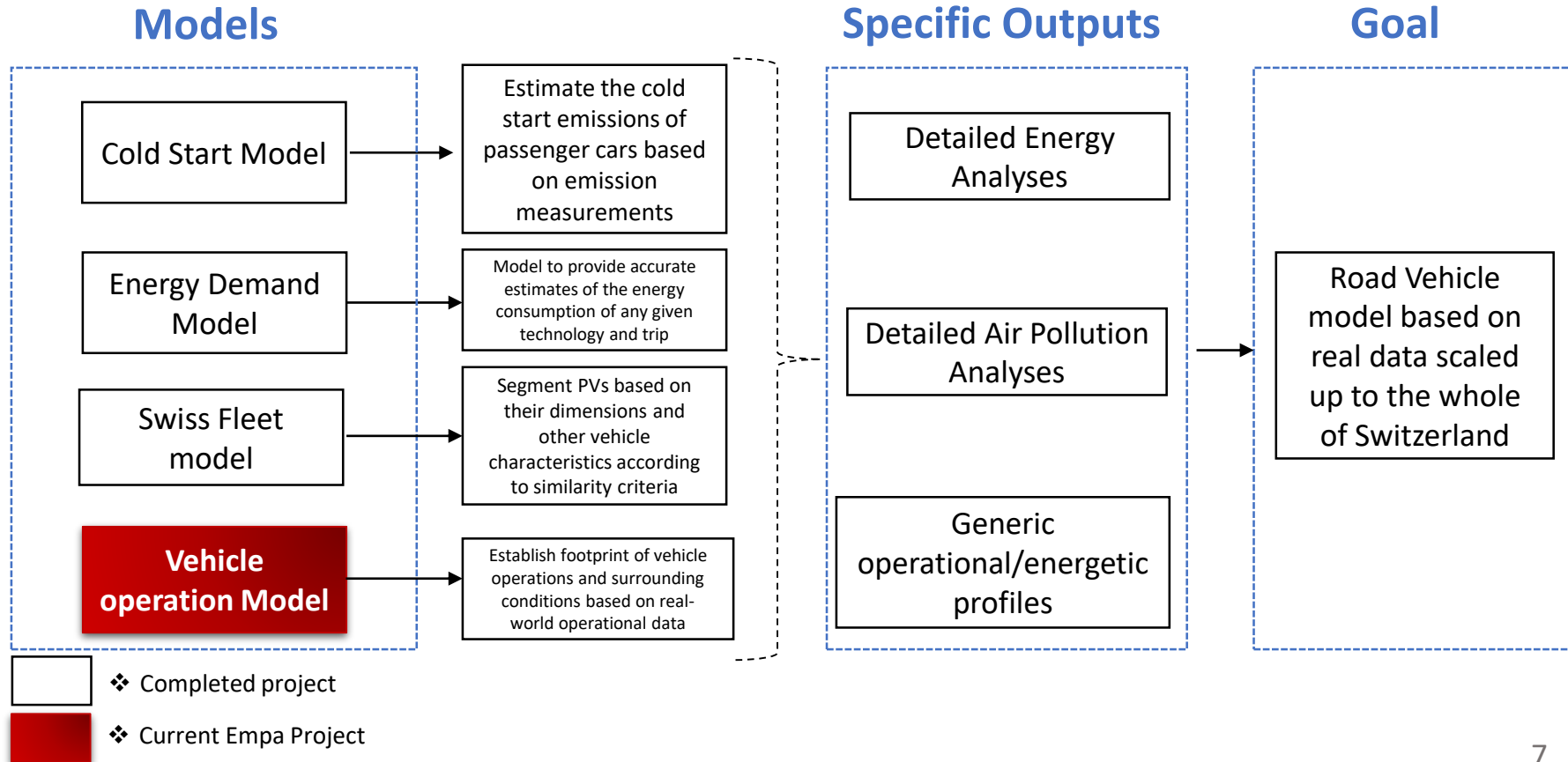
3. Making the transition more efficient



“A deep understanding of the current vehicle fleet and its operations is required to make the transition more efficient in a science-based approach”



4. Related projects at Empa





Energy demand model

(1) Vehicle-tracking in daily operations:

Natural gas Vehicle

NGV



Fuel cell vehicle

FCV



Hybrid electric vehicle

HEV



Plug-in hybrid electric vehicle

PHEV

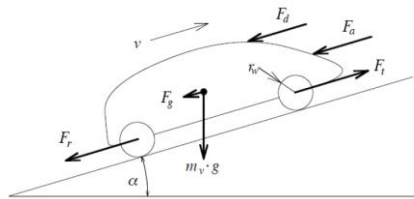


Battery electric vehicle

BEV



(2) Willans approach to model real energy consumption:

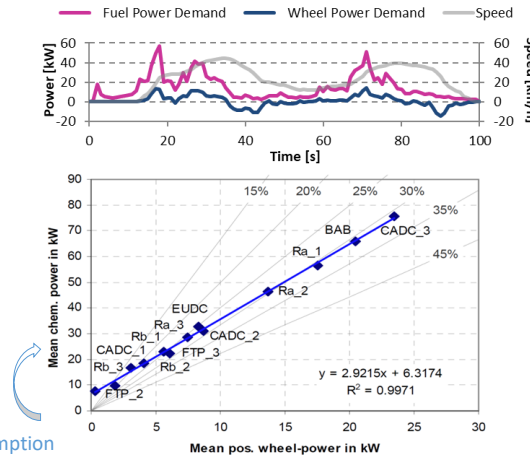


$$m_v \frac{d}{dt} v(t) = F_t(t) - (F_a(t) + F_r(t) + F_g(t) + F_d(t))$$

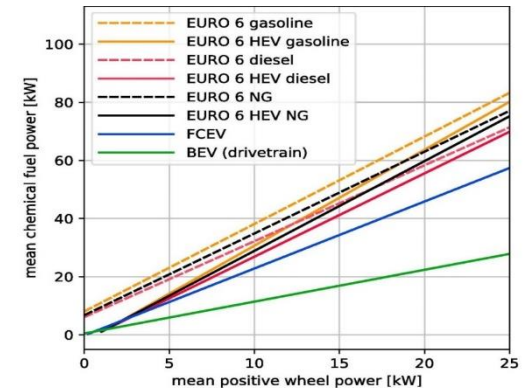
Traction/Wheel power
Rolling resistance
Drag resistance

Aerodynamic resistance
Grade/slope resistance

Positive wheel power correlates with the energy consumption (Willans Approach)



Willans-Lines for the different powertrain systems → Basis for the modelling of the tank-to-wheel energy consumption



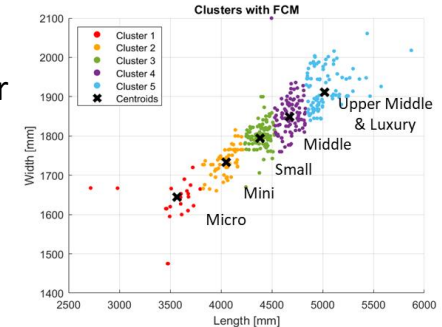
Source: C. Bach and R. Deutschmann, «Welcher Antrieb ist richtig?» – Analysetool klärt, TIR transNews, 2021



Swiss Fleet model

- Machine learning based segmentation of passenger cars of the data based from Motor Vehicle Information System (MOFIS database-all new passenger vehicles registered in Switzerland in 2018).

Classification of passenger cars in 7 main classes (micro, mini, small, middle, upper-middle & luxury, sport, van) and 2 sub-classes (SUV/non-SUV) based on vehicle dimensions and other technical attributes using Principal Component Analyses (PCA) and Fuzzy C-Means (FCM).



Source: N. Niroomand, Et al., "Vehicle Dimensions Based Passenger Car Classification using Fuzzy and Non-Fuzzy Clustering Methods," *Transportation Research Record*, 2021.

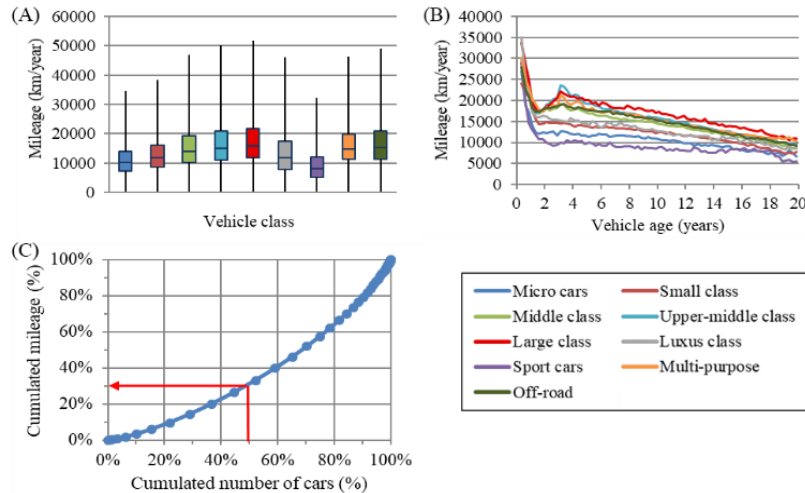
- Swiss fleet characterization and changes over time

Vehicle segmentation can be combined with vehicle specifications (power, fuel, consumption) and GIS data (vehicles, fuel stations, dealers) to investigate geographical and temporal changes in the vehicle fleet



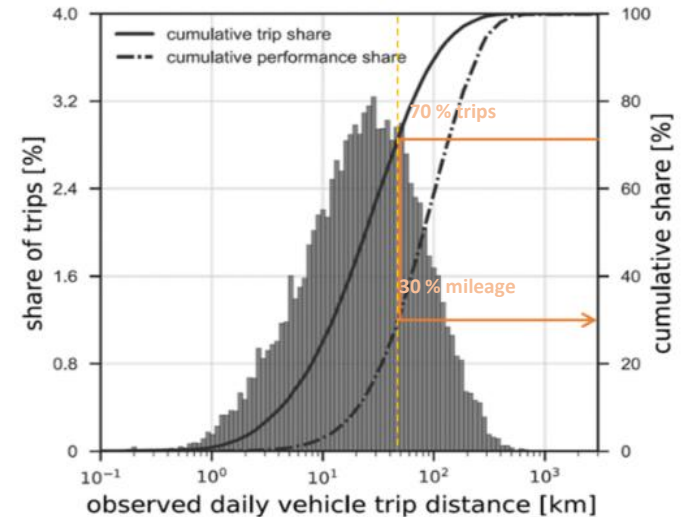
Operations of Swiss passenger cars

- Analyses of Autoscout listings
(1.4 million second hand vehicle listings)



Source: S. L. Teske, M. Rüdösli, C. Bach and T. Schildhauer, "Potentialanalyse Power-to-Gas in der Schweiz," 09 05 2019

- Analyses of microcensus data



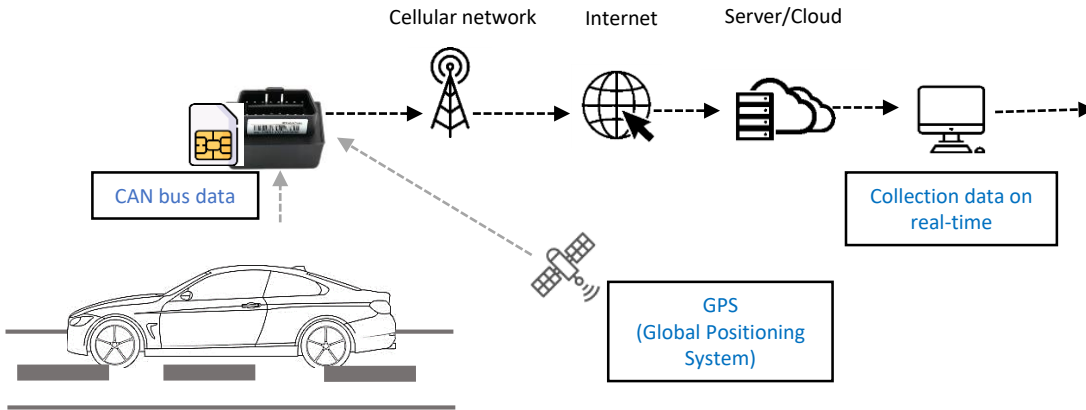
Source: L. Küng, T. Bütler, G. Georges and K. Boulouchos, "Decarbonizing passenger cars using different powertrain technologies: Optimal fleet composition under evolving electricity supply,"

But no statistically relevant data sets available for individual journeys!



Operational model of the Swiss passenger vehicle fleet based on real data:

Current Empa Project within the SWEET Lantern project



- ❖ Up to 1000 passenger vehicles
- ❖ Considering Combustion, Electrical and plug-in Hybrid vehicles.
- ❖ 1 years

Data

- ❖ **Trajectory data:**
 - Location (longitude, latitude, altitude)
- ❖ **CAN bus Data**
 - Vehicle speed,
 - Engine speed (RPMs)
 - Engine load
 - Coolant temperature
 - Intake air temperature
 - Odometer,
 - Fuel consumption (Fuel percentage tank, fuel consumption)
 - State of Charge-SoC (EV).
 - Energy In During AC Charging (EV).
 - Speed
 - Among others.

Models

Cold Start Model

Energy Demand Model

Swiss Fleet model

Vehicle operation Model (V-Drive)

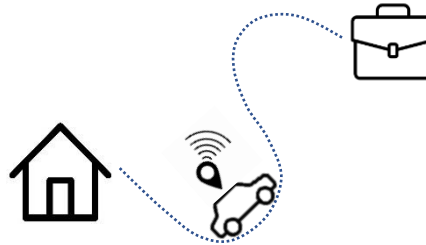
❖ Completed project

❖ Current Empa Project

OBD II port: On-Board Diagnostics port used to access the vehicle Electronic Control Unit (ECU)
CAN bus data: Data read from the vehicle's Electronic Control Unit



Challenges of vehicle tracking



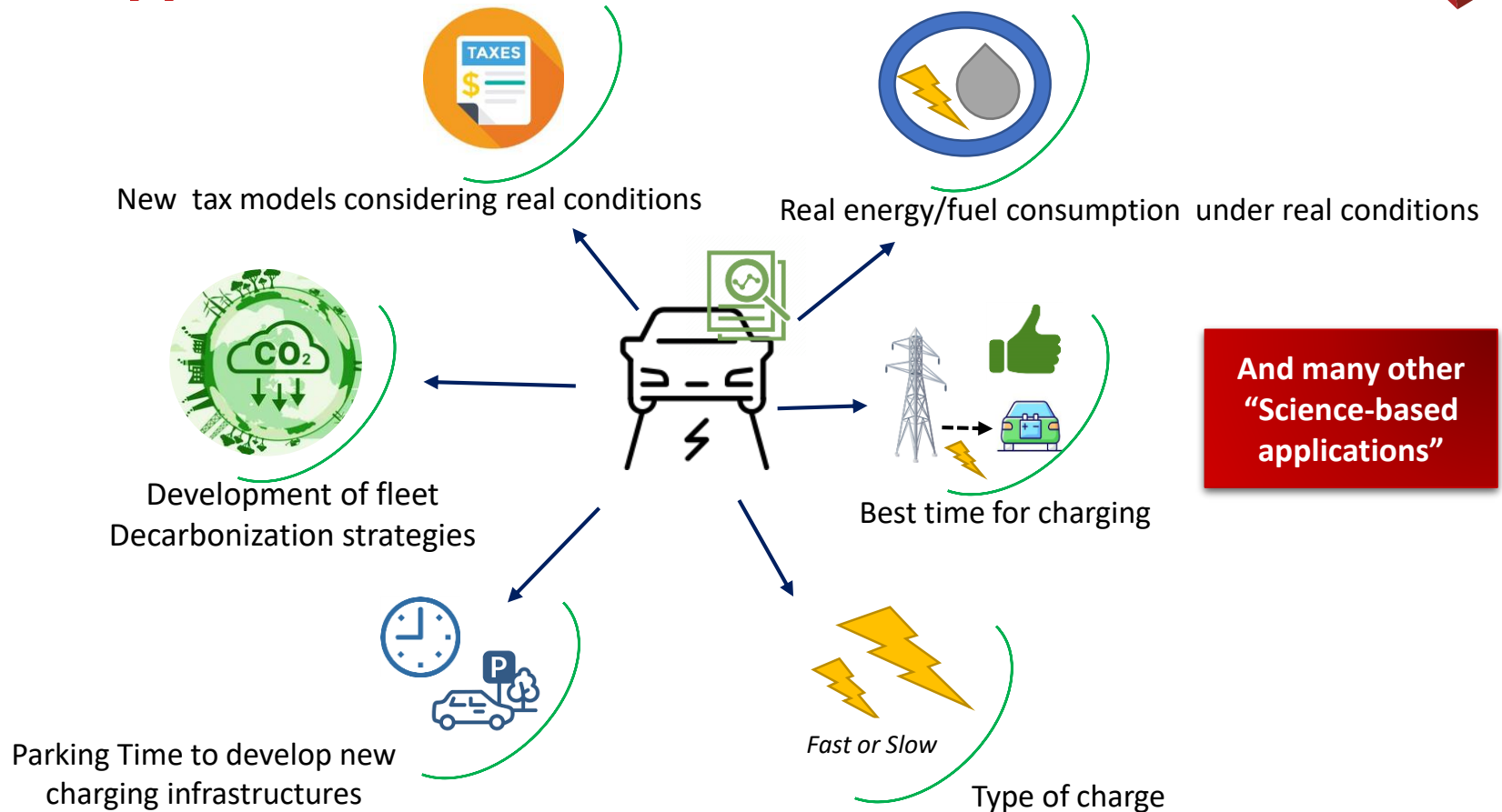
- Sample selection
- Access to participants
- Creation of statistically relevant data sets

- Protection of personal data
- Risk assessment
- Data anonymization

- Pre-processing: cleaning, resampling, compression...
- Big Data analyses with machine learning methods
- Upscaling of the results (e.g. to national level)



5. Main application fields





Example of development of Decarbonization strategies

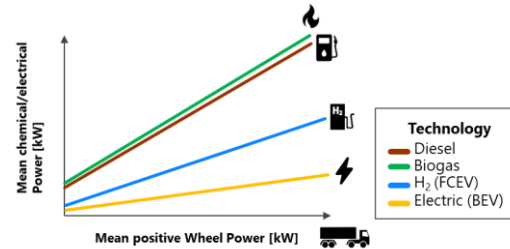
Innovation partnership Migros-Empa

(1) Tracking of trucks in daily operations



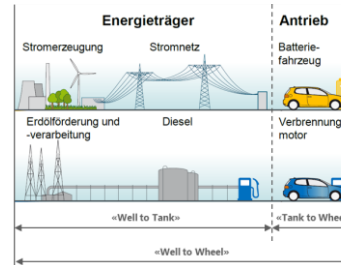
Verification and validation of the real-world energy consumption through CAN-Bus-Logging

(2) Modelling of the energy consumption of individual trips through Willans-approach for all powertrains



Willans lines derived using logged real-world energy consumption data

(3) CO₂-Emissions on the well-to-wheel basis



"Well-to-Tank " : CO₂-Emissions of the supply chain, i.e. energy production and transport

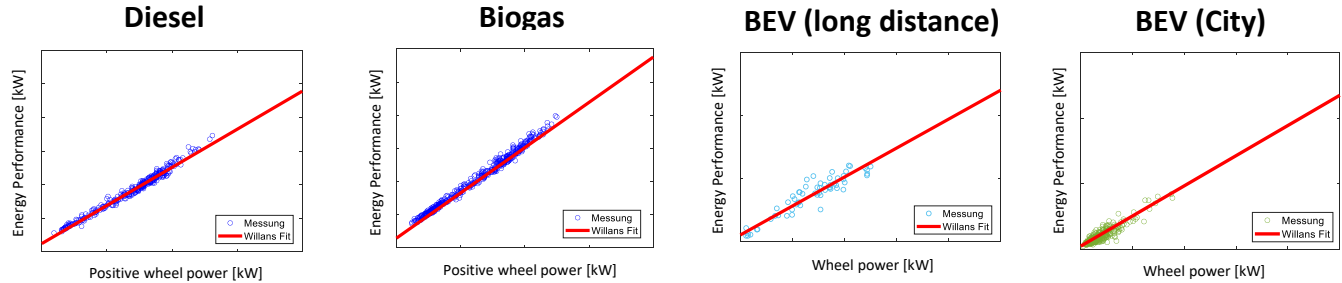
"Tank-to-Wheel": CO₂-Emissions from the vehicle operations (calculated based on the carbon content of the fuel)

Validation of real-world energy consumption approach

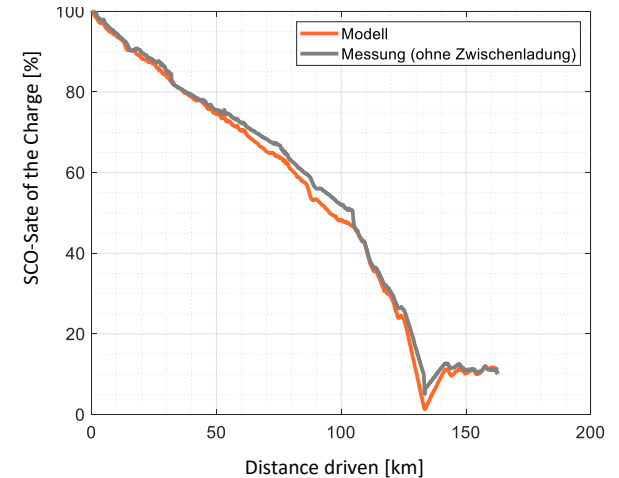
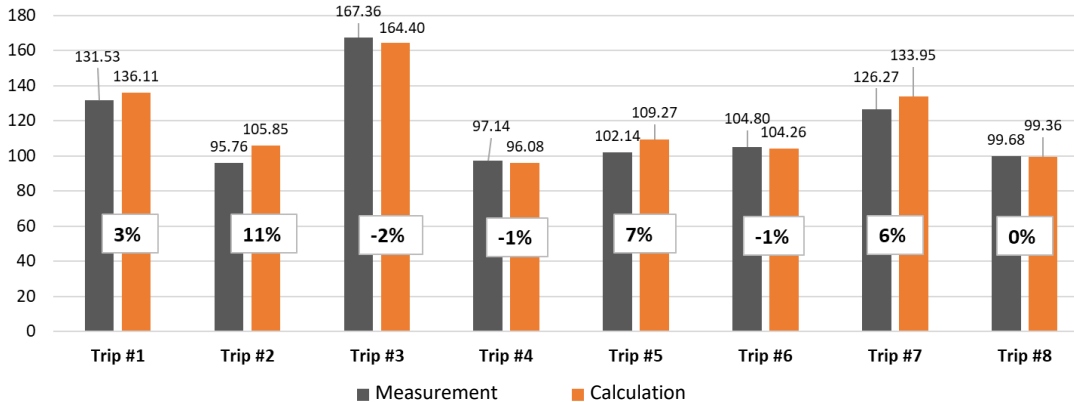
Innovation partnership Migros-Empa



Powertrain:



Consumption measurement and calculation of an e-truck on different routes





Thanks