Real-world energy demand determination within the ESMOBIL-RED project

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Motivation

Motor vehicle based mobility plays an important role in the economic and societal development of Switzerland. At the same time, it is also responsible for about one third of all end-user energy demand in the country and nearly 40% of all CO_2 emission. Possible paths for CO_2 reduction in mobility could be the optimization or substitution of drivetrains operated with fossil fuels. To assess the impact of such measures it is necessary to investigate the real world energy demand behavior of current drive train technologies and their impact on the national energy demand and energy supply system development.

Today there is no uniform approach to determine the real world energy demand of passenger cars. Therefore, energy experts stick mostly to the type approval consumption values. But these values only have a limited relation to reality and an energetically correct comparison of different power train concepts is also very limited.

On the basis of detailed analysis of the propulsion based and auxiliary based energy demand during real-world driving a validated energy demand model for several power train technologies will be developed. This model will be used to integrate new vehicle concepts in an energy-systemic approach to derive better substantiated scenarios for future mobility concepts within the Swiss energy system.

Methodology (Willans approach)

To determine reliable consumption data for different driving situations for a defined vehicle normally field measurements or appropriate chassis dyno examinations are necessary. These are very complex and costly. What is available for every registered vehicle, however, is the consumption data which is determined during the type approval procedure. Currently the NEDC is used as a standard cycle for these measurements. But this synthetic cycle only covers the low load range of the engine map, an extrapolation of the results to other driving conditions is only possible to a limited level.

In the next years the NEDC will be replaced by the more dynamic WLTC. The cycle consists of four sub-phases in its most dynamic form and the average engine load is higher due to the associated shift strategy. This broader range of the sub cycle results allows using them for calibration of a so-called Willans line. This line can then be used to determine different, WLTC independent consumption values.

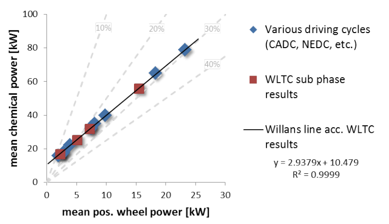

Figure 1: *Willans line; Gasoline EU6 vehicle*

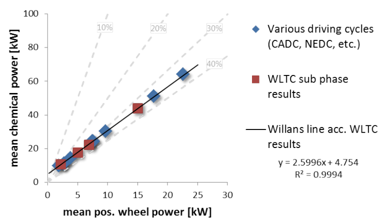

Figure 2: *Willans line; Diesel EU6 vehicle*

In order to take into account additional energy consumers, they can be added as additional positive power (e.g. heating, A/C, auxiliaries), "negative" energy demand (e.g. brake energy recovery) or additional energy loss (e.g. EV charging losses).

The advantage of the Willans approach compared to the type approval consumption is that it is based on a simple function (correlation) and not on an average value. It sets the average chemical/electrical power in relation to the average positive wheel power. Since the average wheel load for different vehicles and various driving profiles can be easily calculated, the Willans correlation is a very flexible energy demand model that is particularly attractive for the use in life cycle and / or energy-systemic studies.

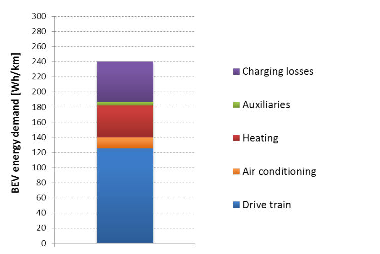

Figure 3: *Energy demand composition of a battery electric vehicle (annual average)*

$$\bar{\eta} = \frac{\text{mean pos. wheel power}}{\text{mean chemical power}} = \frac{\overline{P_w^+}}{\frac{NHV}{t_{sub-cycle}} \cdot \int_{sub-cycle} m_f^* \cdot dt}$$

- $\overline{P}_w^+$ is the mean positive wheel-power
- NHV is the lower fuel heating value of the used fuel
- m_f^* is the fuel flow.

$\overline{P}_w^+$ is calculated as follows:

$$\overline{P}_w^+ = \frac{1}{t_{sub-cycle}} \cdot \int_{sub-cycle} \max(F_{wheel}, 0) \cdot v \cdot dt$$

- F_{wheel} is the wheel force
- v is the vehicle speed
- $t_{sub-cycle}$ is the time of the sub-cycle

Figure 4: *Calculations for Willans approach*

Data collection

The Willans approach is data based and requires measurements which are conducted in the ESMOBIL-RED project. Different power train technologies will be analyzed during laboratory investigations and a technical monitoring of the vehicles during a two year practical use as company and car-sharing vehicles at Empa. The small fleet is composed of the following vehicles:

- VW e-Golf, battery-electric vehicle
- VW Jetta Hybrid, full hybrid
- Audi A3 e-Tron , plug-in hybrid
- Audi A3 g-Tron, natural gas vehicle
- Hyundai iX35, fuel cell car

Figure 5: *Fleet vehicles with different drive train technologies*

The goal is to identify the energetic behavior of the vehicles in the laboratory at different environmental conditions (e.g. -10°C…+30°C), in different driving cycles (as NEDC, WLTP, real-world driving profiles) and with different auxiliary consumers (e.g. with/without air conditioning, heating). The resulting database includes actual consumption data applied at realistic but controlled conditions and is underpinned with field study data.

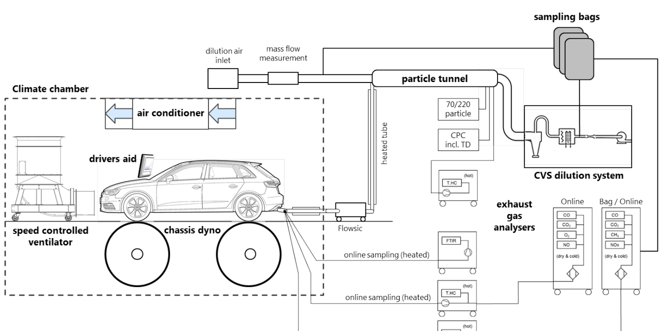

Figure 6: *Chassis dyno setup*

System integration

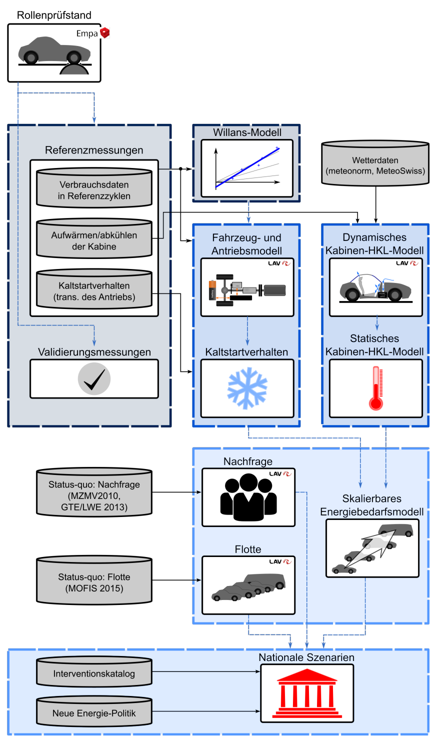

Figure 7: *ESMOBIL-RED project schematic*

The validated real-world energy demand model is used to assess disaggregated energy demand and flows of a vehicle fleet, i.e. all passenger cars in Switzerland for the national level. Investigated effects can base on:

- Fleet evolution / Change of composition (e.g. due to legislation)
- Technical improvement / Switch in power train technology
- Vehicle usage change (e.g. due to aging of population)

The benefit of such a modelling is that it accounts for different vehicle technologies (there is not one average vehicle) and different usage behavior.

Vehicle usage behavior as well as the infrastructure are constrains to the model and limit the possible solution space (i.e. not all vehicle or vehicle technology can supply every demand in mobility). The purpose is to identify "feasible" fleets in terms of given constrains and compare them with desirable national energy scenarios. The results are national fleets in agreement with national energy targets and paths for their realization.

Partners

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