Electrifying Commercial Vehicle Fleets – Energetic Simulation including Auxiliaries

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***Abstract*— In order to estimate real operational range of electric vehicles energetic simulation is used. To obtain realistic results also the energetic demand of auxiliary components is a highly relevant factor. The presented simulation model uses real usage profiles logged from individual, operational fleet vehicles and predicts total energy demand when replacing selected conventional with electric vehicles. In the current state a driving energy model and a heating energy model for the driver's compartment are implemented. The model is validated with real data from a long-term test of the light commercial battery electric vehicle Volkswagen E-Caddy.**

Keywords*— *E-Mobility, Auxiliary Consumers, Real Consumption, Naturalistic Driving Observation, Fleet Electrification, Energetic Simulation

I. Introduction

E-Mobility is identified as a key technology for the decarbonization of the transport sector.

Electric vehicles are economically feasible only if high initial investments can be compensated by low running costs. Numerous studies have shown that the correct sizing of the expensive propulsion battery system according to specific uses is crucial for economically successful implementation of electric vehicles [7], [2]. Prerequisites, including knowledge on actual daily and yearly kilometers traveled and a low variance in the needed daily range, are often met by vehicle fleets with focus in urban areas (i.e. courier/ express/ parcel services, repair trade/ services, delivery/ collect services, etc.). These fleets largely consist of commercial vehicles.

When it comes to electric vehicles additional to the driving energy all auxiliaries need to be supplied with electric energy from the propulsion battery. This includes common auxiliaries like the heating/ventilation/air conditioning system (HVAC), capable of consuming more than 50% of available energy in harsh conditions, as well as specific auxiliaries for commercial vehicles like lifting platforms or additional cooling systems. These auxiliaries are to be taken into account for an optimally sized battery.

Just like the energy demand for the driving task the energy demand of auxiliaries is highly dependent on individual usage of the vehicle and surrounding conditions (i.e. Temperatures, number of intraday stops, etc.). Employing driver observation methods [3], [6] and an energetic vehicle simulation [1], [4] of a battery electric vehicle (BEV) individual vehicle usage is analyzed in order to evaluate economic and ecologic aspects of substituting selected conventional vehicles with a BEV.

II. Targets of Research Intent

The main targets of the initiated research are

- Evaluation of electrification potential in commercial vehicle fleets with respect to economic and ecologic impact based on individual vehicle usage
- Implementation of a total vehicle energy simulation model taking into account drive train as well as all energetically relevant auxiliaries
- Providing a qualitative total cost of ownership based method to fleet managers to underpin decision-making in the process of investing in electric vehicles

III. Total Vehicle Energy Model

Total energy consumption of an electric vehicle adds up by energy demand from the propulsion system and from auxiliary consumers (cp. Fig. 1). In order to estimate an EV's total electric energy demand for fulfilling a certain task driver observation and energetic simulation are used. Through driver observation real vehicle usage is tracked for certain businesses and usage parameters are logged. These parameters are fed into a light duty commercial BEV simulation model to predict total energetic demand for the observed task, which may momentarily be carried out by a conventionally powered vehicle.

In the following the first two modules of the energy model are briefly introduced. Vehicle parameters are modeled to represent the Volkswagen E-Caddy. E-Caddy fleet data is used to validate the model. All simulation modules are implemented in Matlab/Simulink.

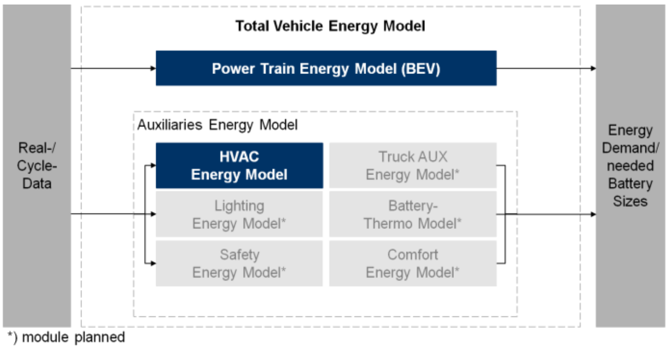

Fig. 1: Total vehicle energy model

A. *Drive train energy model*

For calculation of the energy needed to drive the vehicle a BEV-model as described in [5] is employed (Fig. 2). Applying a vehicle and driving resistance profile the vehicle's acceleration and deceleration are converted into rotational speed and torque of the electric machine. The resulting mechanical power demand allows calculation of the needed electric power input to the electric machine and via power electronics the power output of the high voltage battery. Incorporating multiple efficiency factors the integral represents the drive trains energy demand. Inputs are velocity-time profiles either from a driving cycle (i.e. New European Driving Cycle) or from real driving data. The model comprises a module for the high voltage battery as well.

B. *Auxiliaries energy model*

Successively modules are designed for all energetically relevant auxiliaries. Modules for HVAC, lighting, safety, battery tempering, truck auxiliaries, and additional comfort auxiliaries will be covered. Momentarily implemented and described in the following is a HVAC module.

HVAC

To derive needed heating and cooling powers a driver compartment temperature model based on [1],[4] is employed. Inputs are velocity, cabin and ambient temperature, status of vehicle ignition (on/off), and number of occupants in the vehicle. In the cooling case additionally the solar radiation is to be considered (cp. Fig. 3).

The temperature model describes heat transfer between the air in the driver's cabin, the solid elements of the driver's cabin, passengers, and the ambient air. Taken into account are convective heat flows as well as radiation and the air mass flow through the cabin.

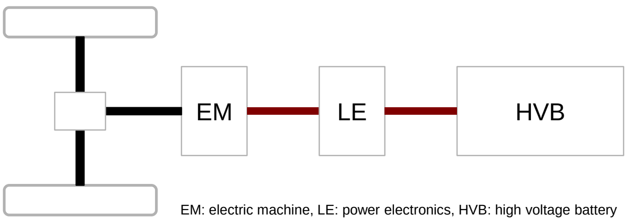

Fig. 2: Power train configuration BEV, cp. [5]

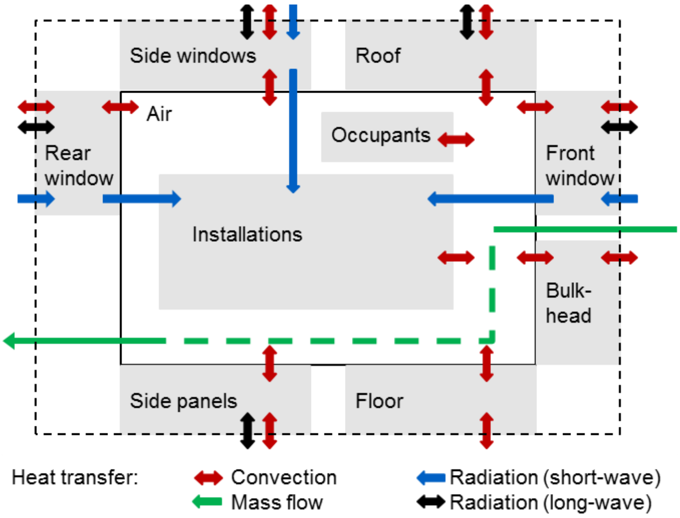

Fig. 3: Heat transfer in the driver's cabin model, cp. [4]

To deliver the needed heat a water PTC (positive temperature coefficient) heater system is modeled (cp. Fig. 4). Electric energy is consumed to heat a cooling agent to a desired temperature level. Via heat exchanger (HWT) the cooling agent heats the air flow into the driver's cabin.

In order to evaluate efficiency potential of different cabin tempering systems (i.e. PTC air heater, heat pump, infrared heating, etc.) the modular set-up of the model allows for implementation of different heating approaches. Thus different systems can be analyzed for performance in selected usage scenarios.

OTHER AUXILIARIES

Other auxiliaries' modules are being implemented currently. In the presented model these auxiliaries' energy demands are modeled as additional constant energy demand and accounted for in the battery module.

IV. VALIDATION OF ELECTRIC MACHINE AND HVAC ENERGY DEMAND USING VOLKSWAGEN E-CADDY-FLEET-DATA

In an extended on-road testing phase real users had the chance to test one of 40 Volkswagen E-Caddy (BEV) in their daily business surroundings over a period of multiple weeks to months each. During that period data to analyze the usage and the energetic behavior of the vehicle has been acquired by Volkswagen and is available for the verification of the energy model employed.

In the following a set of particular cold days is used to compare driving and heating behavior of the energy model with the real driving data. The results are used to evaluate the total energy

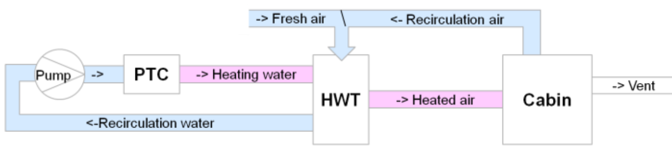

Fig. 4: Modeled heat flow in HVAC (heating mode), PTC: positive temperature coefficiant, HWT: heat exchanger

model's performance in predicting electric vehicles' real energy demand under real usage conditions.

A. *Model performance on exemplary cold day*

Table 1 summarizes the characteristics of a particular cold January day. The data is used for a first validation of the described energy model. Input variables for the energetic simulation are time dependent arrays of temperatures, speed, and operational mode.

TABLE 1: COLD DAY – VALIDATION PROFILE PARAMETERS

Ambient temperature	-4,5 - 3,0	°C
Temperature driver's cabin	-1,5 - 19,0	°C
Distance travelled	37,4	km
Max. speed	100,6	km/h
Operating time	1:46:21	hh:mm:ss

The following Figures provide an overview on energy demand profiles depending on their respective determining circumstances on an exemplary cold day. Cumulative parameters show their final (daily) value at the end of each plot. Fig. 5a shows the velocity and distance profile that determines energy demand of the electric machine.

Fig. 5b compares electric machine energy demand calculated in the simulation model to logged data. For reasons of comparability electric machine energy demand is used instead of consumption of electric energy from the battery. Similarly, Fig. 6a shows the temperature profile of the same day with ambient and driver's cabin temperatures and Fig. 6b compares the simulated PTC-heater energy demand with logged data. Noticeable is that the PTC-heater energy demand for heating the driver's cabin at an ambient temperature between -4,5°C and +3°C is already of similar magnitude as the vehicle's driving energy demand. Note that no temperature preconditioning has taken place.

Taking into account the energy demand for heating the driver's cabin the simulation shows an increase in consumption from 14,1 kWh/100km to 24,5 kWh/100km respectively by 74,1%. The mean power demand increases from 3,0 kW to 5,2 kW

B. *Overview model performance – cold days*

In the following the relation between simulated energy demand and energy demand calculated from the respective logged data (voltage and current) for the five coldest days available for the year 2014 and for two analyzed vehicles is discussed.

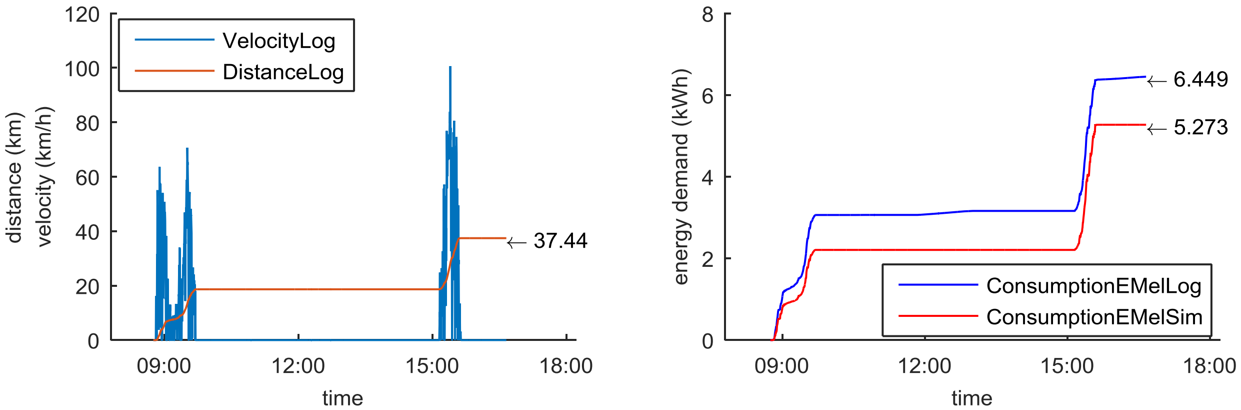

Fig. 5a) distance and velocity profile logged, b) Energy demand of electric machine logged and simulated

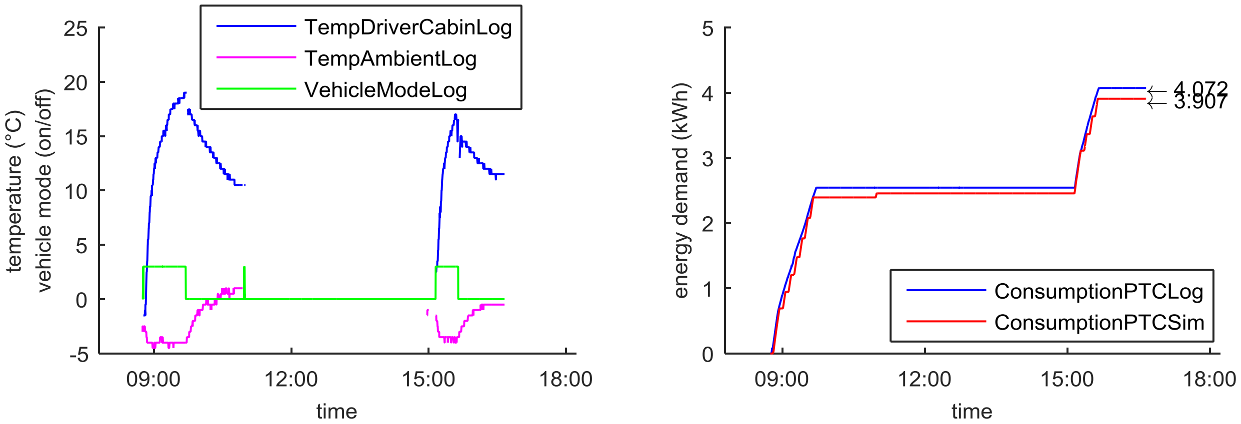

Fig. 6a) Temperature profile logged, b) Energy demand of PTC logged and simulated

DRIVE TRAIN ENERGY MODEL

Fig. 7 shows the drive train energy model performance. The ratios are calculated from simulated and logged energy demand of the electric machine during the operational time of a whole day. The green dashed line indicates a ratio of one where the simulated energy demand equals the logged data. The date is indicated on the x-axis.

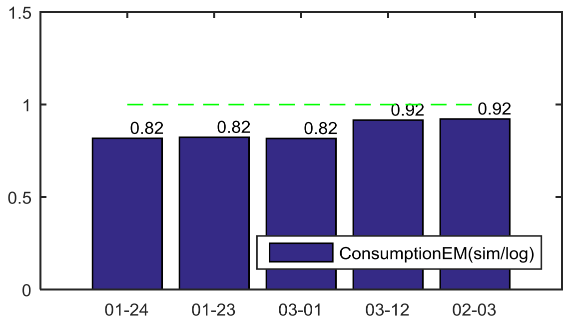

Fig. 7: Model performance - electric machine

HVAC ENERGY MODEL (HEATING)

Similarly, Fig. 8 shows the HVAC model performance for the heating case. On display are the relations between simulated and measured energy demand of the PTC heater.

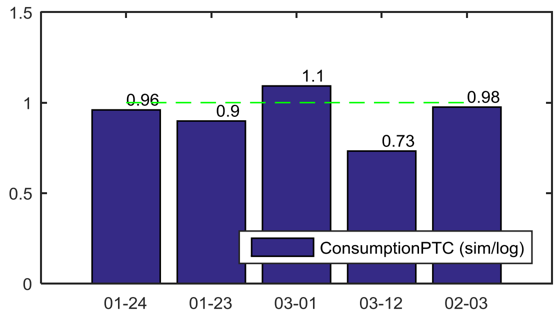

Fig. 8: Model performance - HVAC (heating case)

CONCLUSION OF VALIDATION

Concluding from these results it is necessary to further optimize the regarded models in order to obtain a more reliable energy demand prediction for specific usages.

The analysis of the drive train model suggests that the model systematically underestimates the actual energy demand. It is planned to improve the model's accuracy by additionally taking into account the slope of the track. Due to lack of data this has so far not been implemented.

Regarding the HVAC model no general conclusion of under- or overestimation can be drawn. First analyses show that the control of the PTC needs further improvement in order to meet real behavior.

In general the comparison of the simulated and the logged data already shows a qualitatively satisfying accordance. It is expected that an enhanced simulative consumption prediction for BEV including additional auxiliaries' energy models will generate a good prediction on real energy demand and needed battery size for specific vehicle usages.

V. SIMULATION WITH DATA ACQUIRED IN FIELD TEST

In a Berlin based electrician company the usage profiles of four conventional light commercial vehicles have been logged during February 2015. An exemplary day of the acquired data is applied to show the intended usage of the developed total vehicle energy model. The aim is to predict energy demand of the implemented electric vehicle (Volkswagen E-Caddy) used to fulfill the observed tasks. In the following an example on energy demands is given in a similar manner as in paragraph IV.A. Table 2 summarizes the characterizing parameters of the day analyzed. Due to difficulties in logging ambient temperature during the field test data from German Meteorological Service (DWD) [8] is used. The model identifies the next available weather station and assigns an average temperature from the relevant data to the logged data set.

Fig. 9a exhibits the input parameter velocity for the drive train model. Fig. 10a shows the input parameters temperature driver's cabin, temperature ambient air, and vehicle mode (on/off) for the HVAC model.

The results of the simulation are shown on in Fig. 9b and Fig. 10b. The comparison of simulated energy demand for electric machine and PTC-heater shows that already on a regular cold day the heating energy demand is of great significance. Taking into account the heating energy demand leads to an increase in energy demand of 68,0% compared to the demand of the electric machine only. In this example the PTC's mean power demand amounts to 2,2 kW, the mean power demand of the electric machine is 3,3 kW. This results in a total mean consumption of 23,3 kWh/100km compared to a demand of the electric machine only of 13,9kWh/100km.

VI. CONCLUSION AND PROSPECT

It was shown that through data logging and simulation total energy demand of an electric vehicle for a specific case of application can be predicted. In this first approach energy models for drive train as well as HVAC were presented and evaluated. Although further improvements to make energetic prediction more reliable are needed the model already calculates energetic demand of the implemented models with a satisfying accuracy. At a future stage the model will be used to calculate optimal battery size needed to fulfill certain tasks, taking into account additional auxiliary energy demand as well as economic restrictions (i.e. battery and energy prices).

TABLE 2: COLD DAY – ELECTRICIAN PROFILE PARAMETERS

Ambient temperature	2,0	°C
Temperature driver's cabin	2,0 - 27,5	°C
Distance travelled	41,1	km
Max. speed	75,1	km/h
Operating time	01:45:05	hh:mm:ss

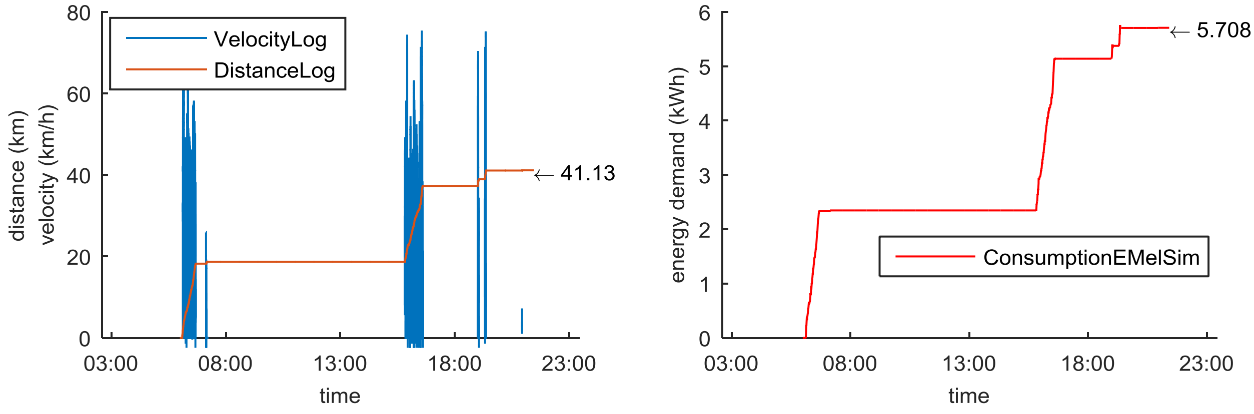

Fig. 9: a) distance and velocity profile logged, b) Energy demand of electric machine simulated

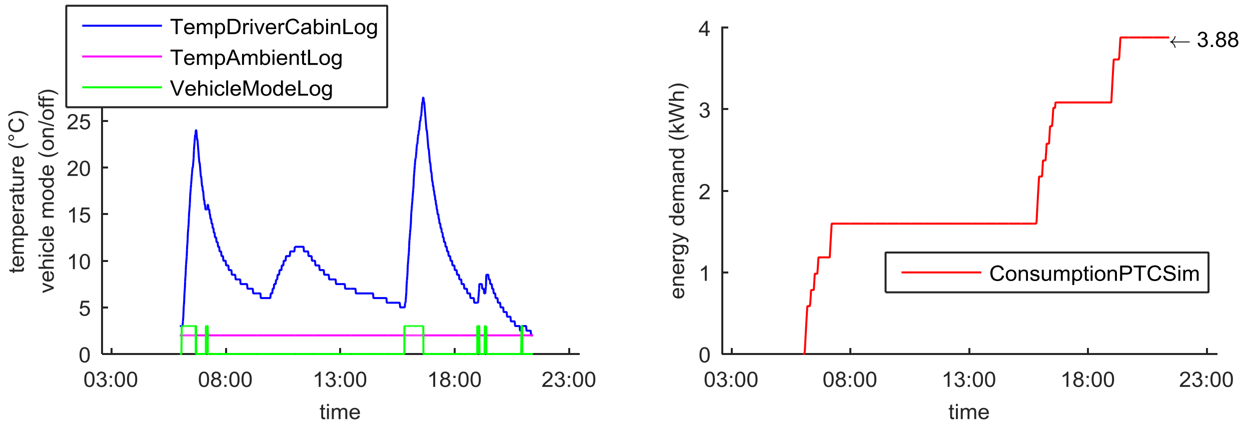

Fig. 10: a) Temperature profile logged, b) Energy demand of PTC simulated

Implying the implemented vehicle parameters and PTC-water-heated HVAC system the model shows that on colder days the heating can account for a significant energetic demand compared to the electric machine. This stresses the need for further improved methods to take auxiliary energy demand into account in order to predict real consumption in realistic environments. As a contribution further research is planned including:

- Improve performance of the presented models
- Enhance the presented HVAC model to cover cooling cases
- Implement models for other auxiliaries (including lighting, safety features, truck specific equipment)
- Combine the energy demand simulation results with established approaches to determine total cost of ownership of electric vehicles in comparison to conventional vehicles
- Grow the chair's fleet database of real driving profiles and knowledge on available electric vehicle parameters

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