Modeling and simulation of electric vehicles: The effect of different Li-ion battery technologies

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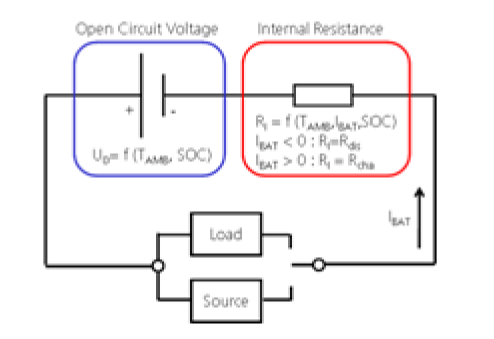
Fraunhofer ISE

Aim of the Paper

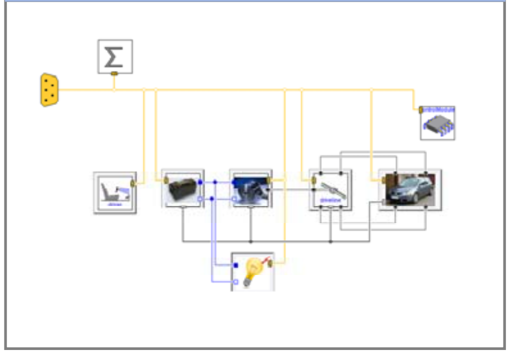
Which influence does the temperature have on different battery technologies? Eventually, how does it influence the range of battery electric vehicles?

Modeling of the battery



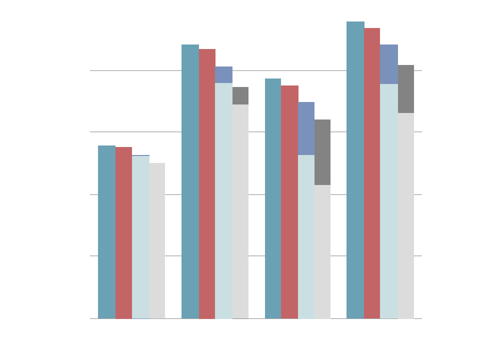
- 3 different technologies
- New developed model
- Battery behavior, depending on SOC[1], temperature, and current

Modeling of entire vehicle



- New developed model for the entire vehicle (AlternativeVehicles library)
- Incorporating different driving cycles
- Incorporating newly developed battery model

Results



- Electrical energy demand and range
- Overall efficiency
- Influence of temperature on the electrical range, w/ & w/o battery conditioning

1: SOC: State-of-charge (of the battery)
Source: DLR-FK, FhG-ISE

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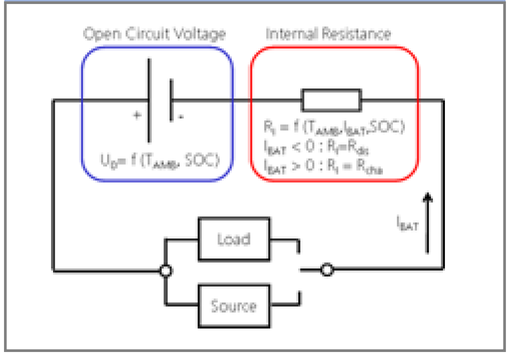

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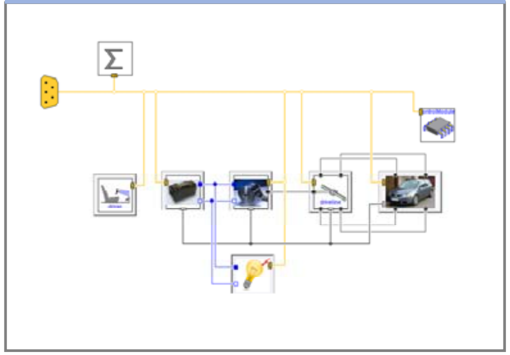

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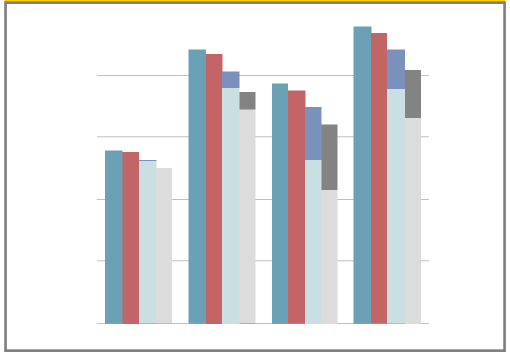

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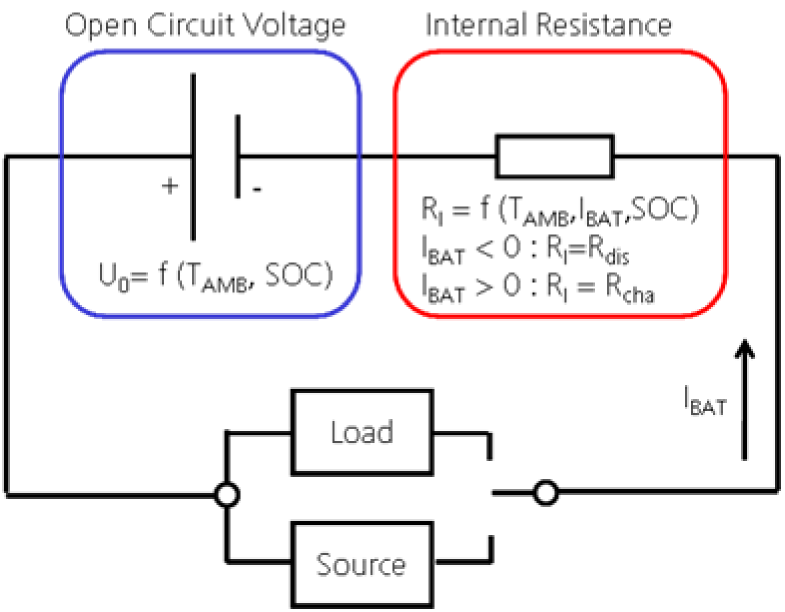
Modeling of the Battery

The batteries has been modeled by an equivalent circuit model, consisting of the open circuit voltage and the internal resistance

Types of cell-chemistries

1. **NMC**
   $LiNi_xMn_yCo_zO_2$ vs. graphite
2. **$LiFePO_4$**
   $LiFePO_4$ vs. graphite
3. **Titanate**
   $LiCoO_2$ vs. titanate

Model of the Battery



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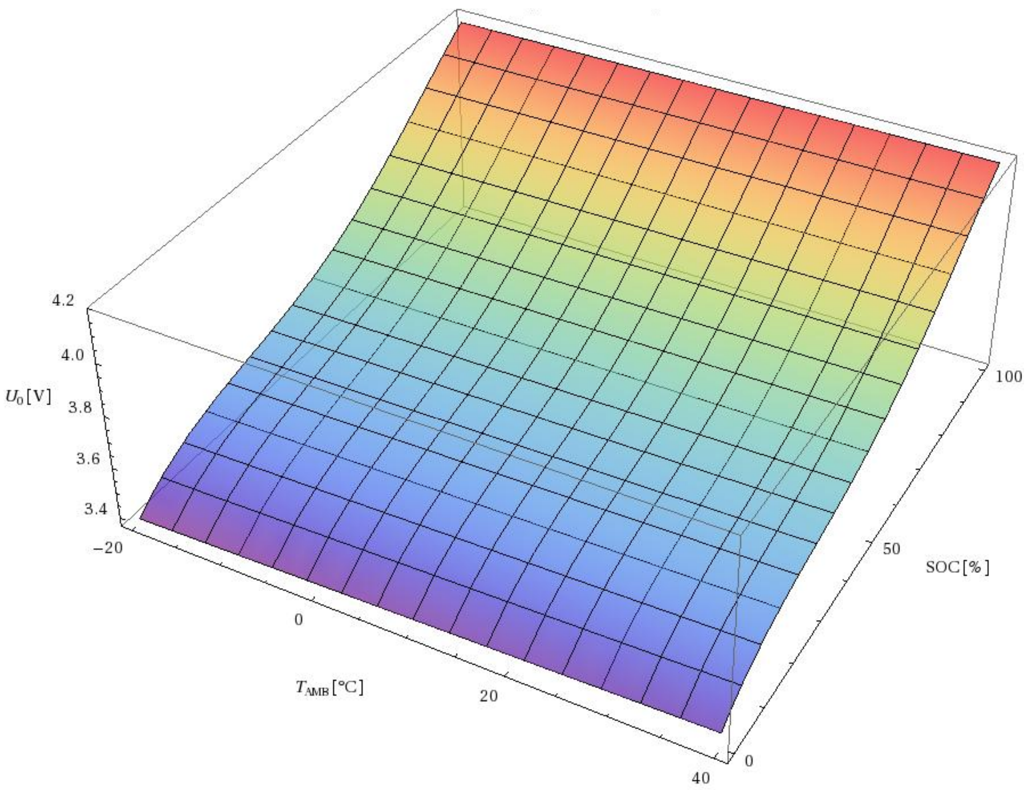
Results of the Battery Model – NMC U_0

The open circuit voltage U_0 for the NMC-based battery shows a strong SOC-dependence and a weak temperature dependence

Modeled open circuit voltage U_0 for NMC based battery



Comments

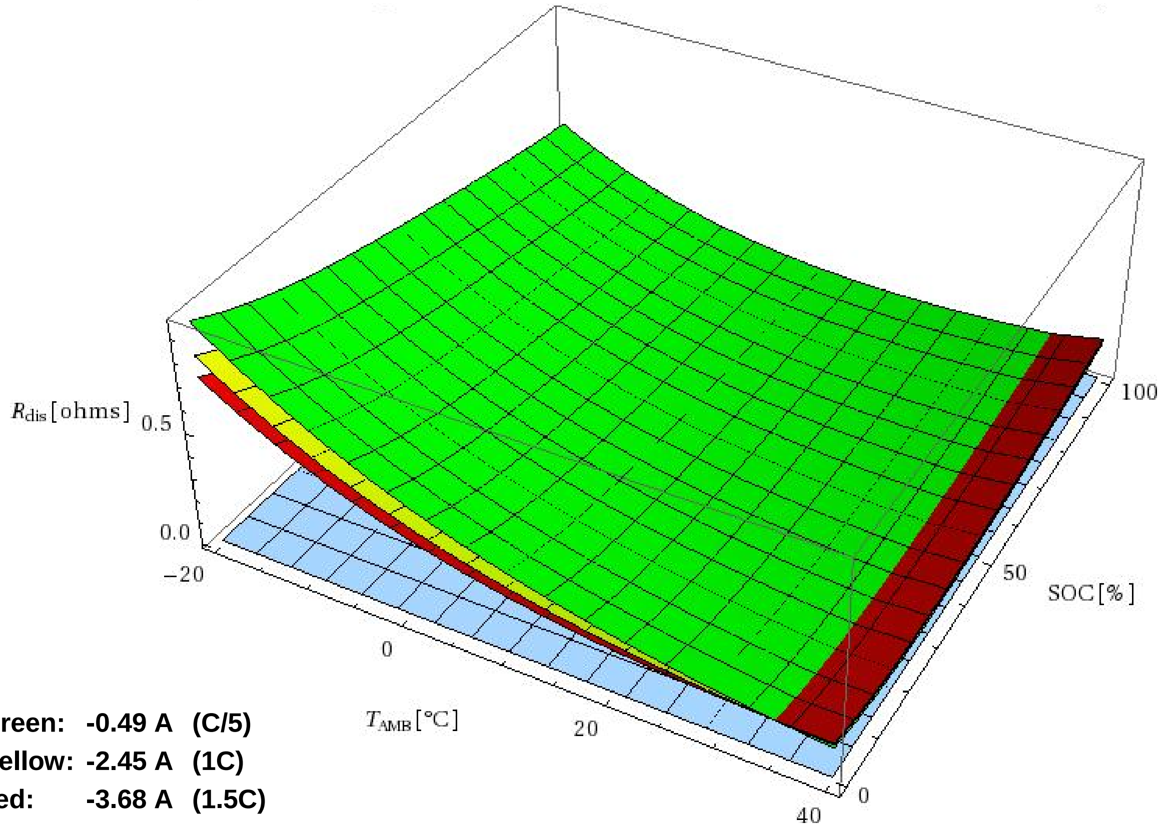
- The graph shows the results of the modeled open circuit voltage
- The function is a result based on the preceding measurements as well as the parameter estimation
- As expected, the open circuit voltage shows a strong SOC-dependence
- However, the temperature has only a weak influence

Source: DLR-FK, FhG-ISE

Results of the Battery Model – NMC R_{dis}

In contrast to the open circuit voltage, the internal resistance shows a strong temperature dependence whilst discharging

Modeled internal resistance R_{dis} for NMC based battery (discharging)



green: -0.49 A (C/5)
yellow: -2.45 A (1C)
red: -3.68 A (1.5C)

Comments

- The graph shows the results of the modeled internal resistance, depending on the SOC, the temperature, and the charging current
- Again, the function is a result based on the preceding measurements as well as the parameter estimation
- In contrast to the open circuit voltage, the internal resistance shows a strong temperature dependence and a relatively weak SOC-dependence
- The internal resistance decreases with increasing current

Source: DLR-FK, FhG-ISE

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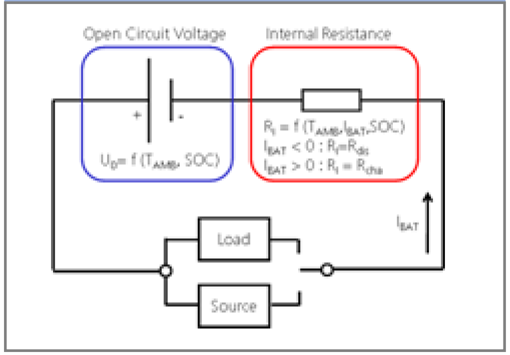

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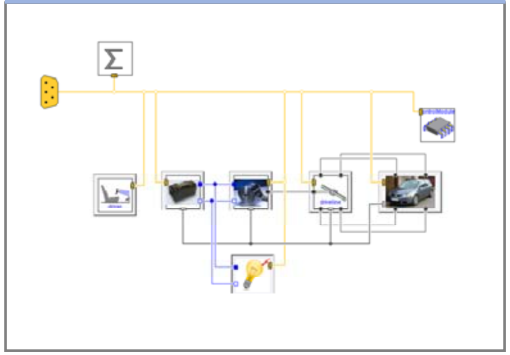

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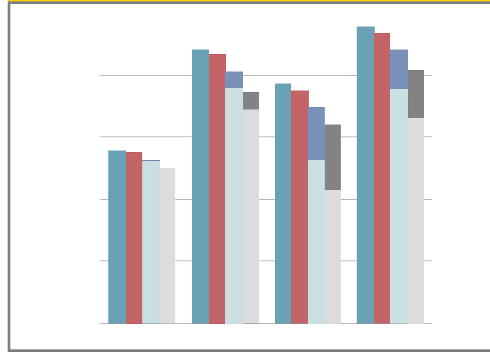

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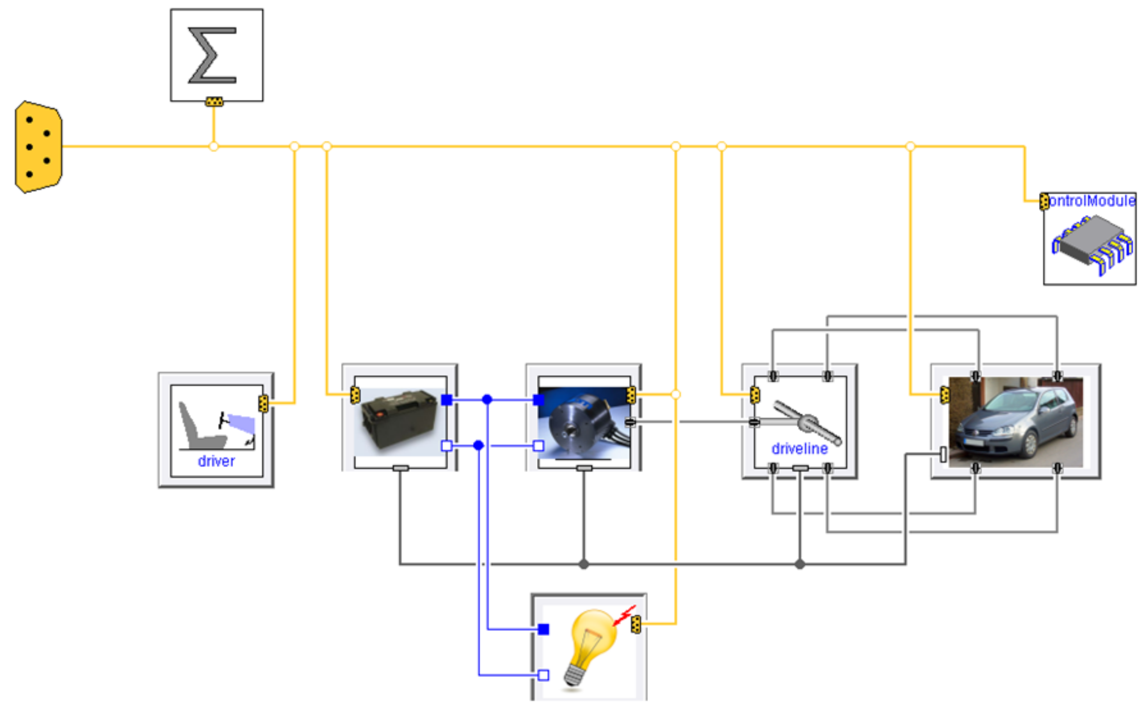
Source: DLR-FK, FhG-ISE

Modeling of the Vehicle

The vehicle has been modeled using the AlternativeVehicles library[1], incorporating a variety of input parameters

Input

- **Vehicle characteristics**
- **Battery characteristics**
- **Temperature levels**
- **Driving cycles**
- **Auxiliary-systems characteristics**



1: The AlternativeVehicles library has been developed by the DLR Institute of Vehicle Concepts and is based on the object-oriented modeling language Modelica.
Source: DLR-FK, FhG-ISE

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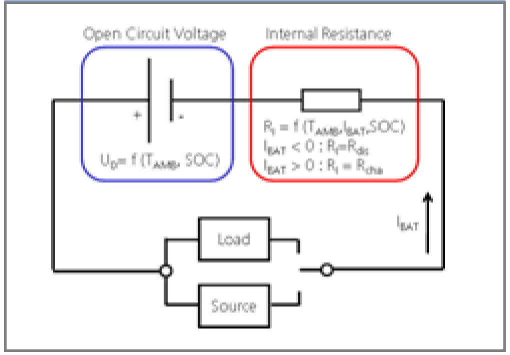

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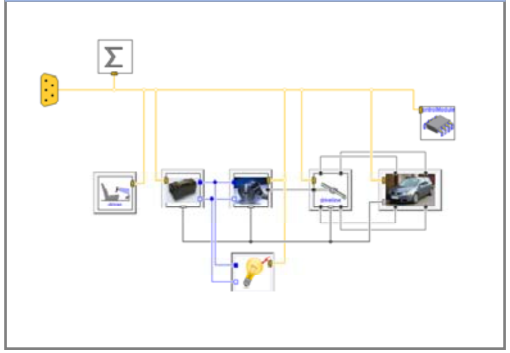

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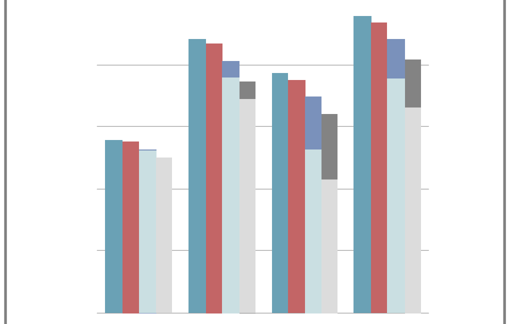

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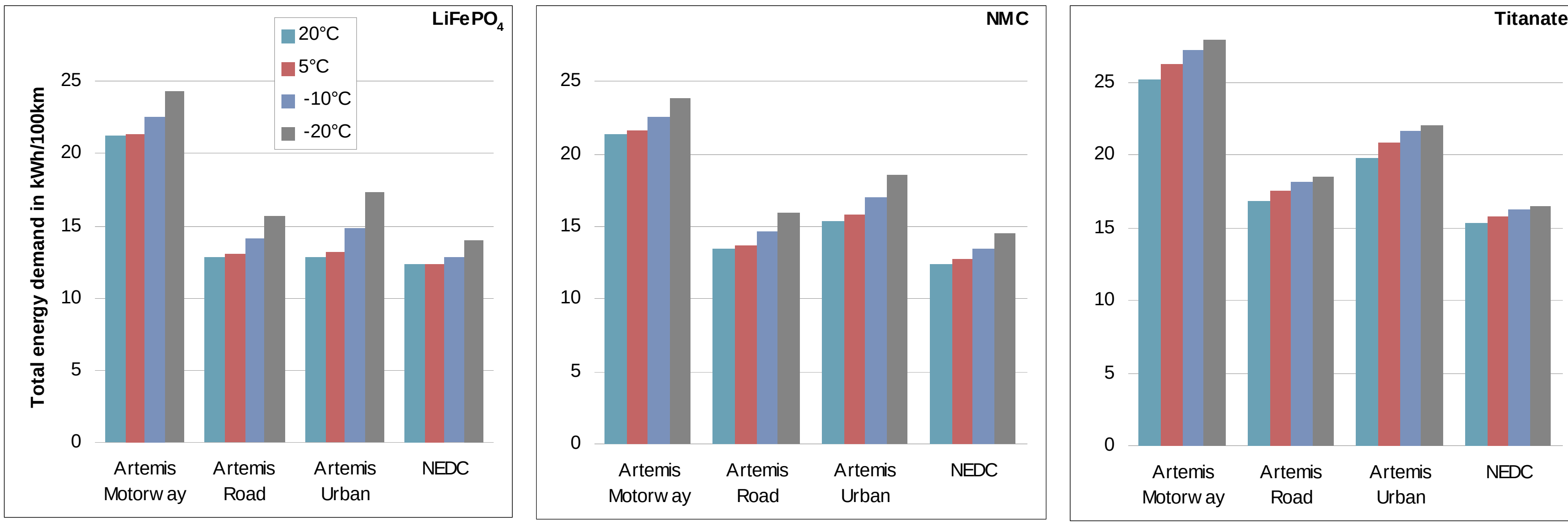
Results: Total Energy Demand

The energy demand rises significantly with dropping temperatures

Simulation results of the total energy demand using large sized batteries[1]



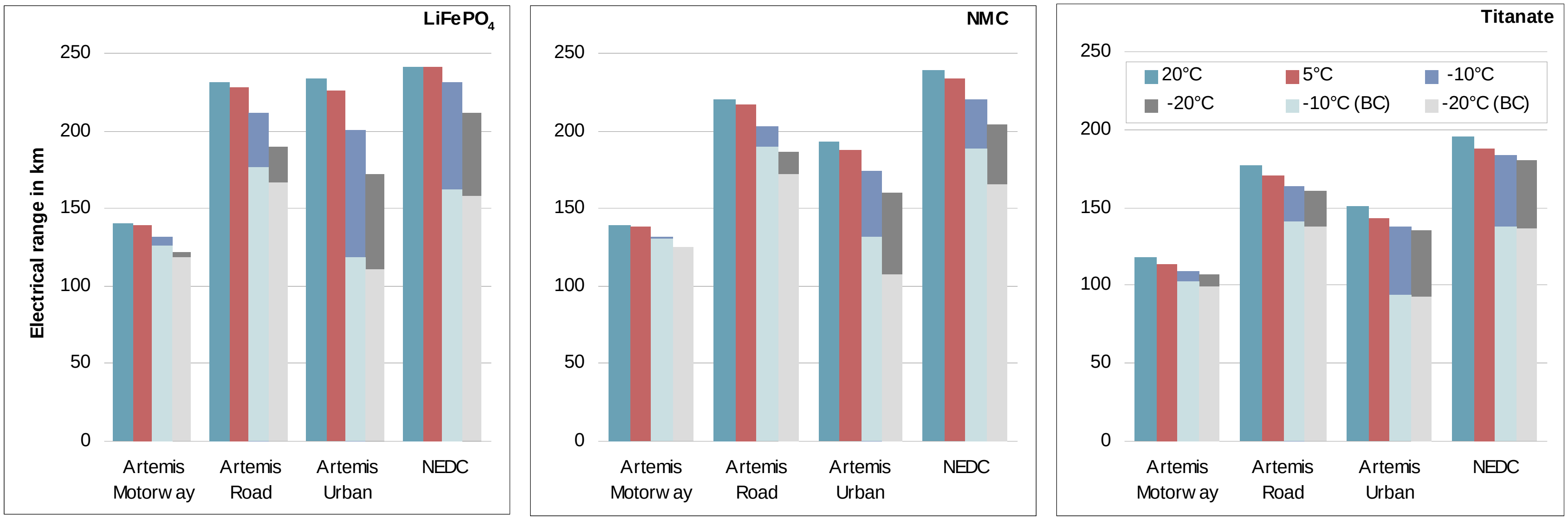
- Batteries based on **Titanate** show **highest energy demand**, due to higher inner resistance of battery
- Energy demand **rises significantly** when temperature falls **below 5°C**
- The increase in energy demand is comparably **higher in the Artemis Urban cycle**, due to a higher amount of energy conversion losses

1: Vehicle characteristics: Capacity 35 kWh, e-motor power 65 kW, battery mass 232 kg, max. velocity 150 km/h
Source: DLR-FK, FhG-ISE

Results: Electrical Range w/ & w/o Battery Conditioning

Preliminary heating of the battery becomes more advantageous the longer the driving cycle is

Simulation results of electrical range w/ and w/o battery temperature conditioning using large sized batteries[1]



- **Batteries have been heated** until their temperature reached **5°C** by battery conditioning system
- Motorway driving cycle shows the **lowest reductions** in range: due to higher velocities, the energy demand for heating per km is lower. In the Urban (very shot) Urban cylce the range is decreased by **around 30%**
- However, if the vehicle is **plugged-in**, the required energy could be provided by the **grid**
- This comparison does not show any possible advantages of heated batteries regarding **life-cycle increases**

1: Vehicle characteristics: Capacity 35 kWh, e-motor power 65 kW, battery mass 232 kg, max. velocity 150 km/h
Source: DLR-FK, FhG-ISE

Lessons Learned

The negative effects of low temperatures on the electrical range might very well be compensated by using energy provided by the electrical grid

1	**The three analyzed batteries show strong SOC- and temperature dependence**
2	**Low temperatures significantly decrease the electrical range of battery electric vehicles**
3	**A battery conditioning system is highly advantageous when the energy for heating is provided by the electrical grid**

We would like to thank the ***German Federal Ministry of Economics and Technology*** *for the funding of the research project* ***"Perspectives of Electric Vehicles with high share of distributed and renewable energy sources"*** *for which the work presented in this paper will be used.*

Source: DLR-FK, FhG-ISE

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