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June 19-22, 2016 | du 19 au 22 juin 2016

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Design and prototyping of a rapid-charge electric bus for urban passenger transportation

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Some brief introductory notes

Modeling tool used

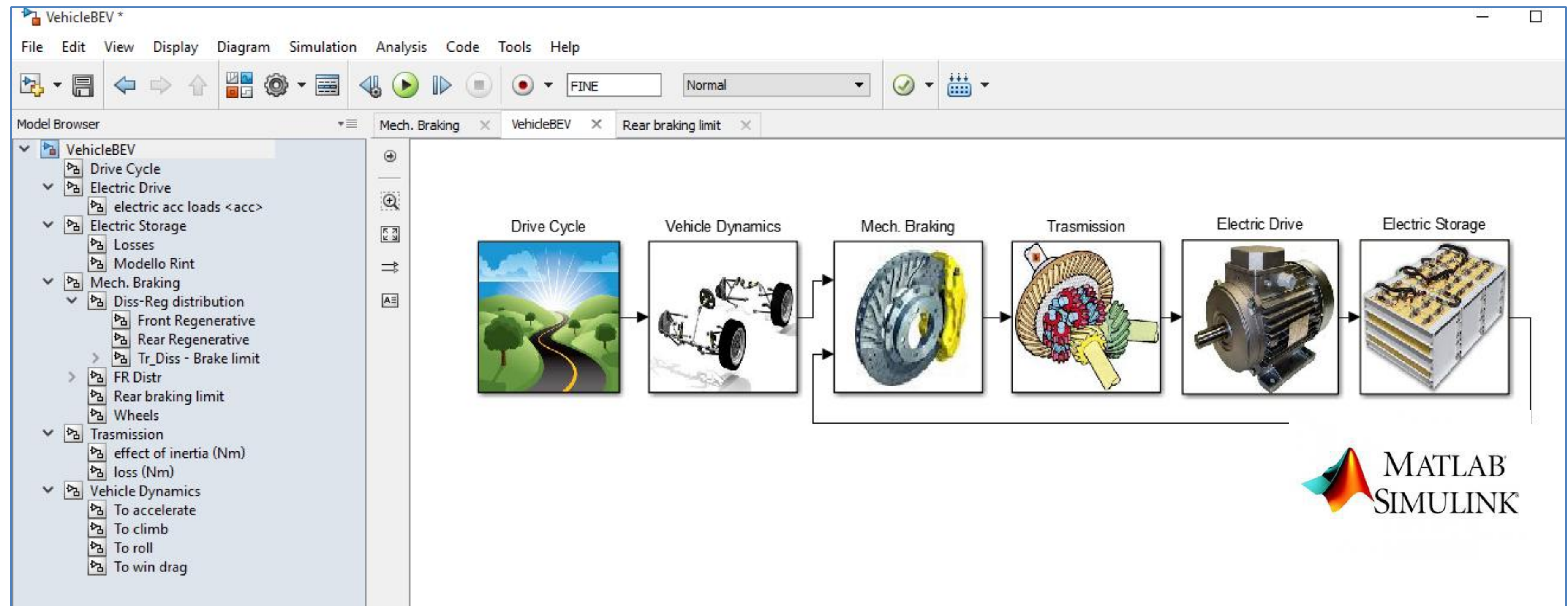
The activity carried out in this paper makes use of a modeling tool, completely derived and calibrated by the authors, for the energetic assessment of both conventional and alternative transport means to be used on a given route.

The tool starts from the definition of vehicle cycle and mission on a GPS web-based interface: it then automatically defines vehicle mission and calculates vehicles behavior on the given mission on a Tank-To-Wheels (TTW) basis.

Results are then also extended on a Well-To-Wheels (WTW) basis.

Some brief introductory notes

Modeling tool used

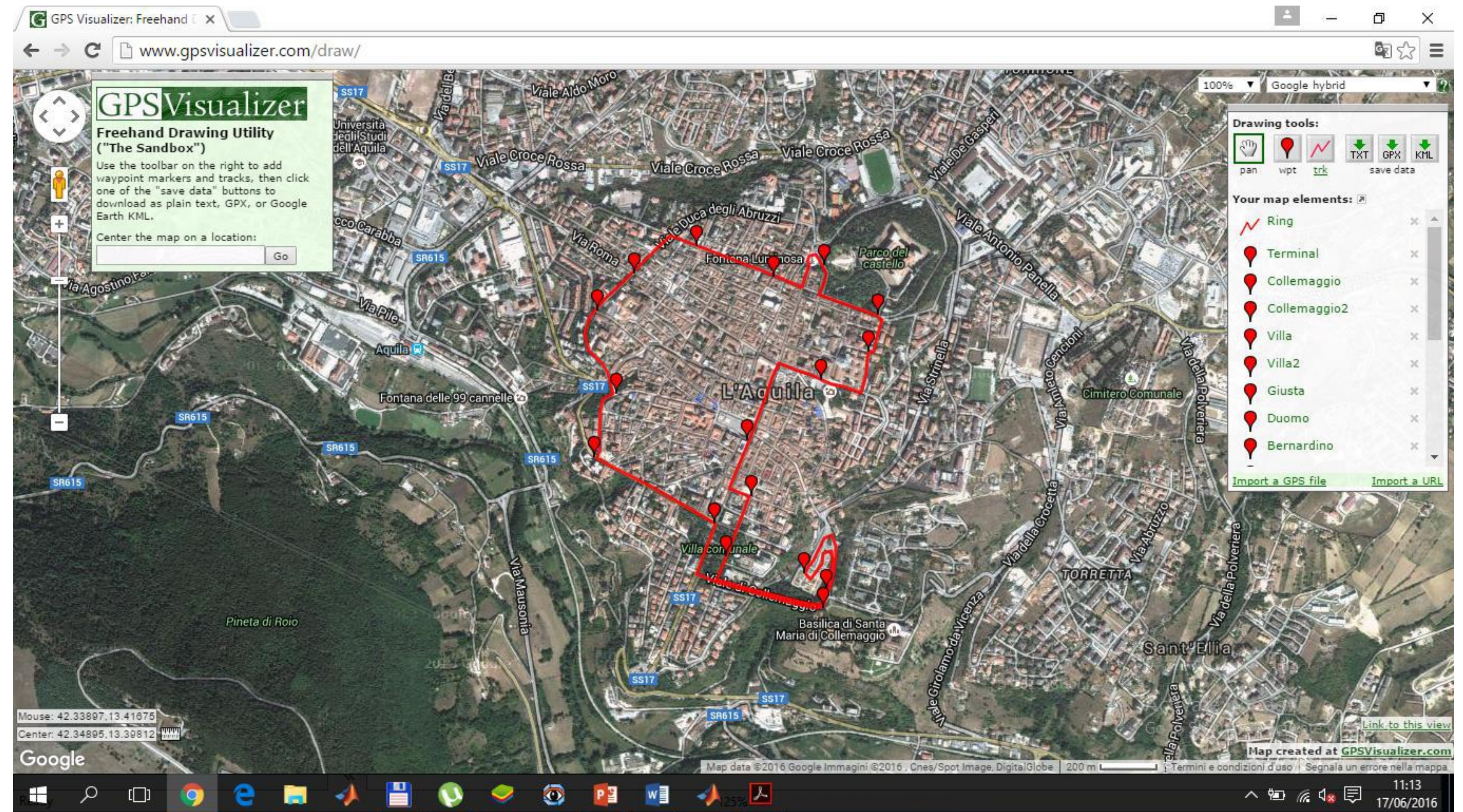


A sketch of the sub-model used for electric vehicles simulation

Some brief introductory notes

Modeling tool used

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GIS Web-based Path definition tool

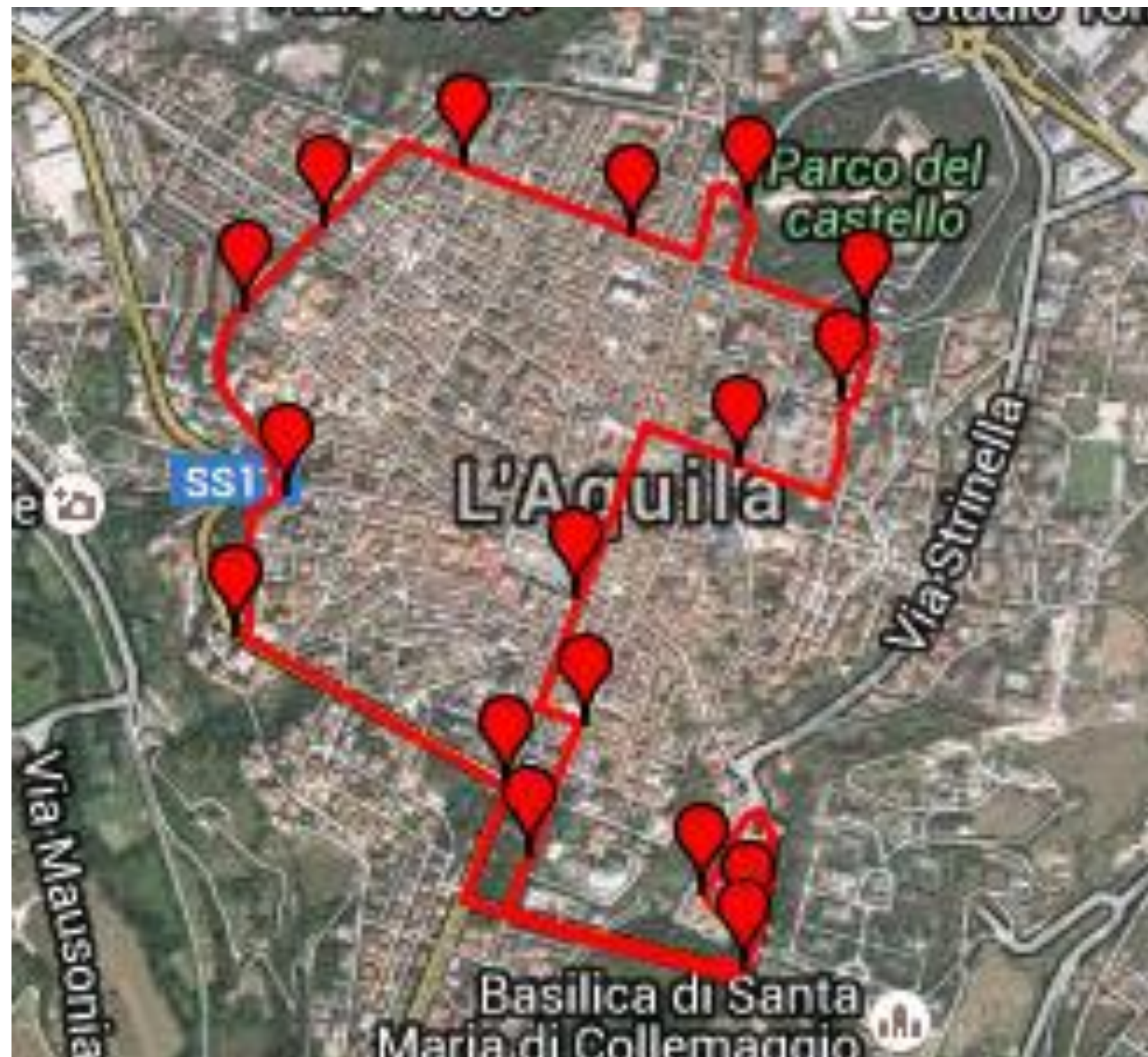
Design activity

The Model was here used for the design of the revamping of an hybrid vehicle which is in use in L'Aquila (ITALY) by Local Trasportation authorities



Design activity

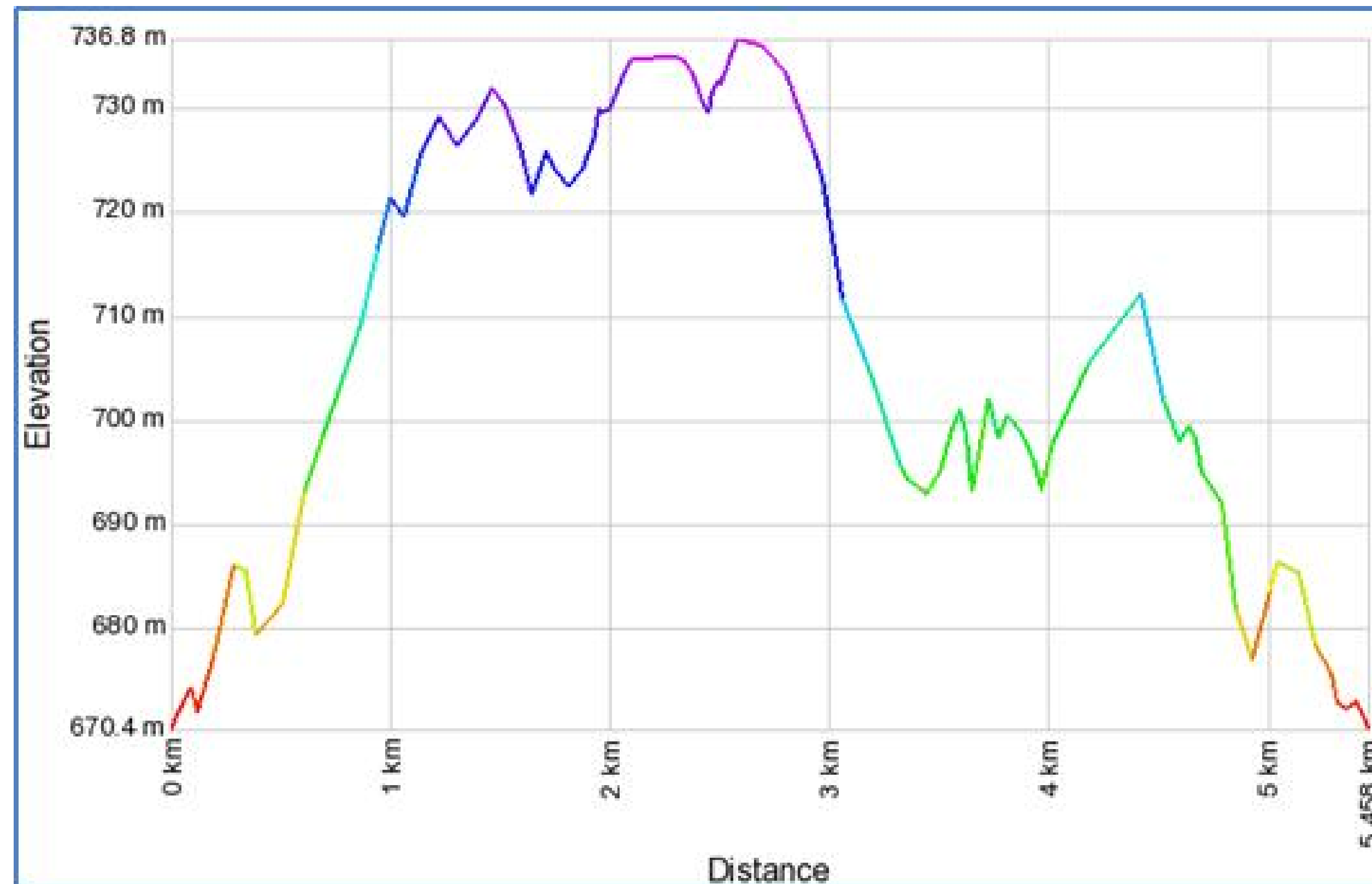
The revamped vehicle will be used in a new service to be setup within a Pedestrian Zone in the historical city center of L'Aquila. No real service data are available for this future application.



*Web-based Reconstruction
of the service path and stops*

Design activity

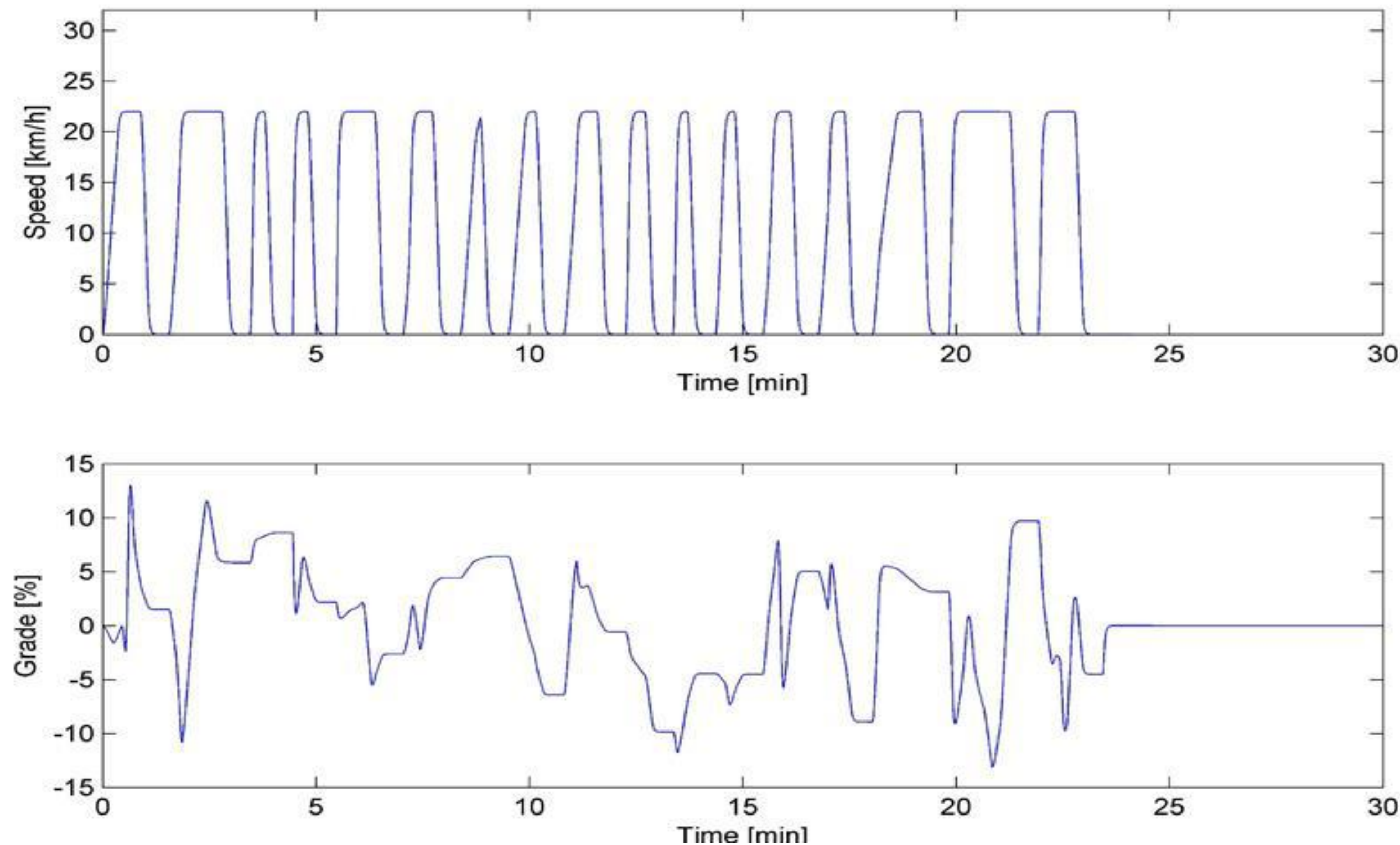
The revamped vehicle will be used in a new service to be setup within a Pedestrian Zone in the historical city center of L'Aquila. No real service data are available for this future application.



*Automatic
GIS-based Reconstruction
of the altitude profile
of the service path*

Design activity

The revamped vehicle will be used in a new service to be setup within a Pedestrian Zone in the historical city center of L'Aquila. No real service data are available for this future application.

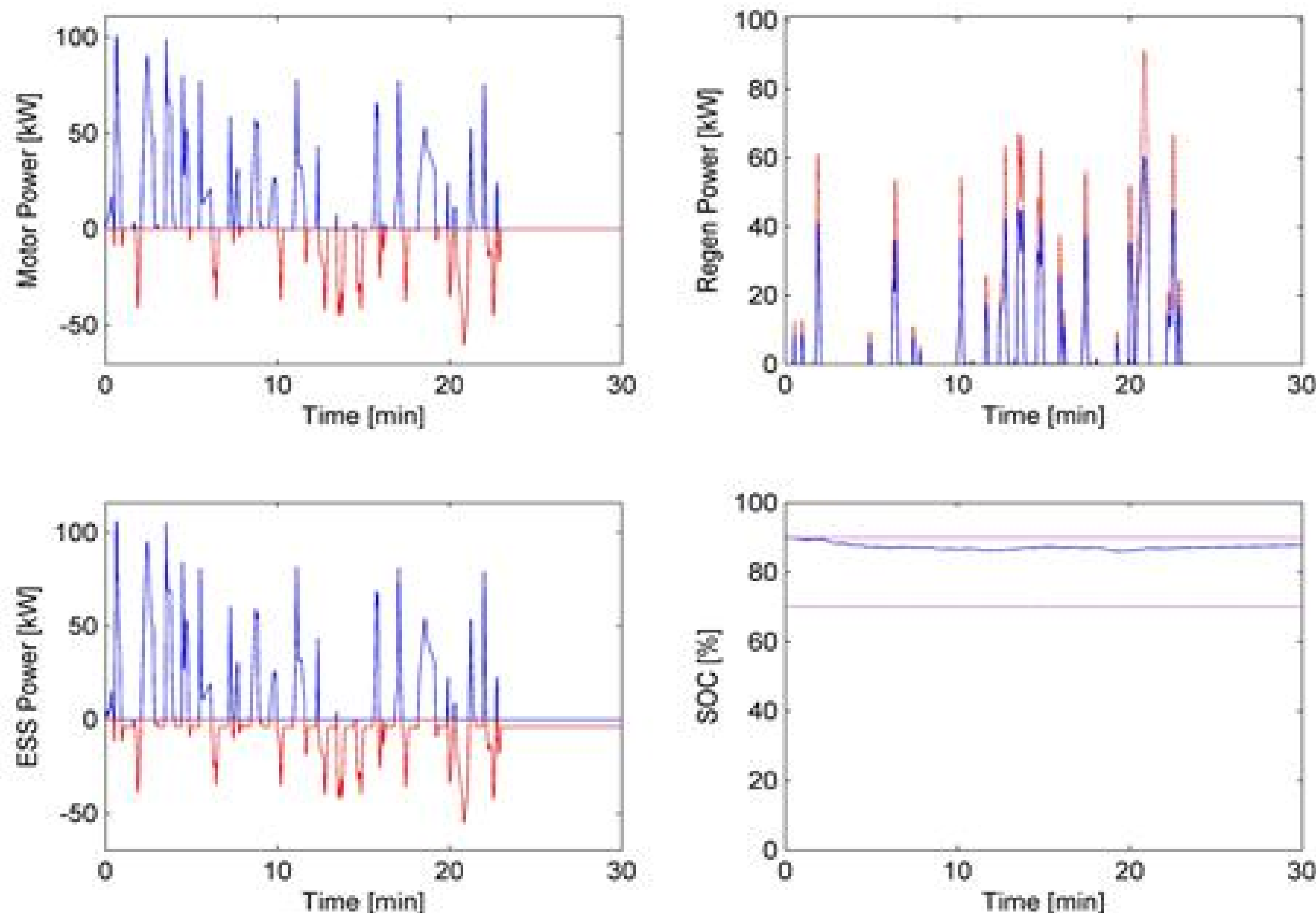


*Automatic Vehicle Cycle
Recostruction, based on:
expected acceleration time;
expected deceleration time;
Max cruise speed;
Stops duration*

Simulation Results – actual vehicle

Calculated performances of the Actual Hybrid vehicle on the new mission

SERIES HYBRID (Diesel): 100 kW DRIVE; 60 kWh ESS; 30 kW APU



The model of the actual hybrid vehicle was previously calibrated on a number of experimental results made available by the manufacturer.

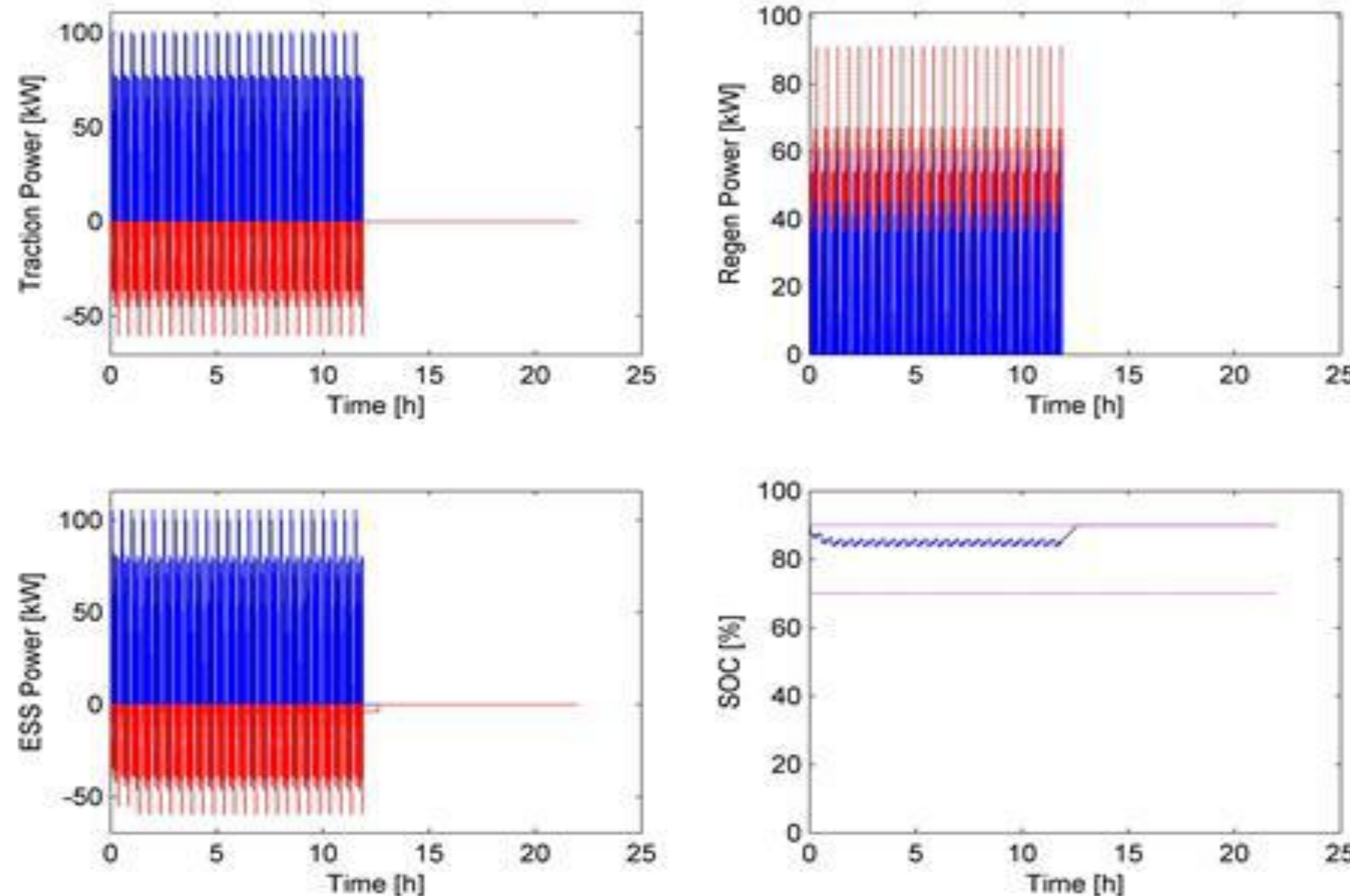
The Vehicle has a series hybrid configuration and makes use of a 30 kW Gas Turbine APU by Capstone (USA) and a 100 kW Electric Drive by ENOVA (USA)

← Single service cycle

Simulation Results – actual vehicle

Calculated performances of the Actual Hybrid vehicle on the new mission

SERIES HYBRID (Diesel): 100 kW DRIVE; 60 kWh ESS; 30 kW APU



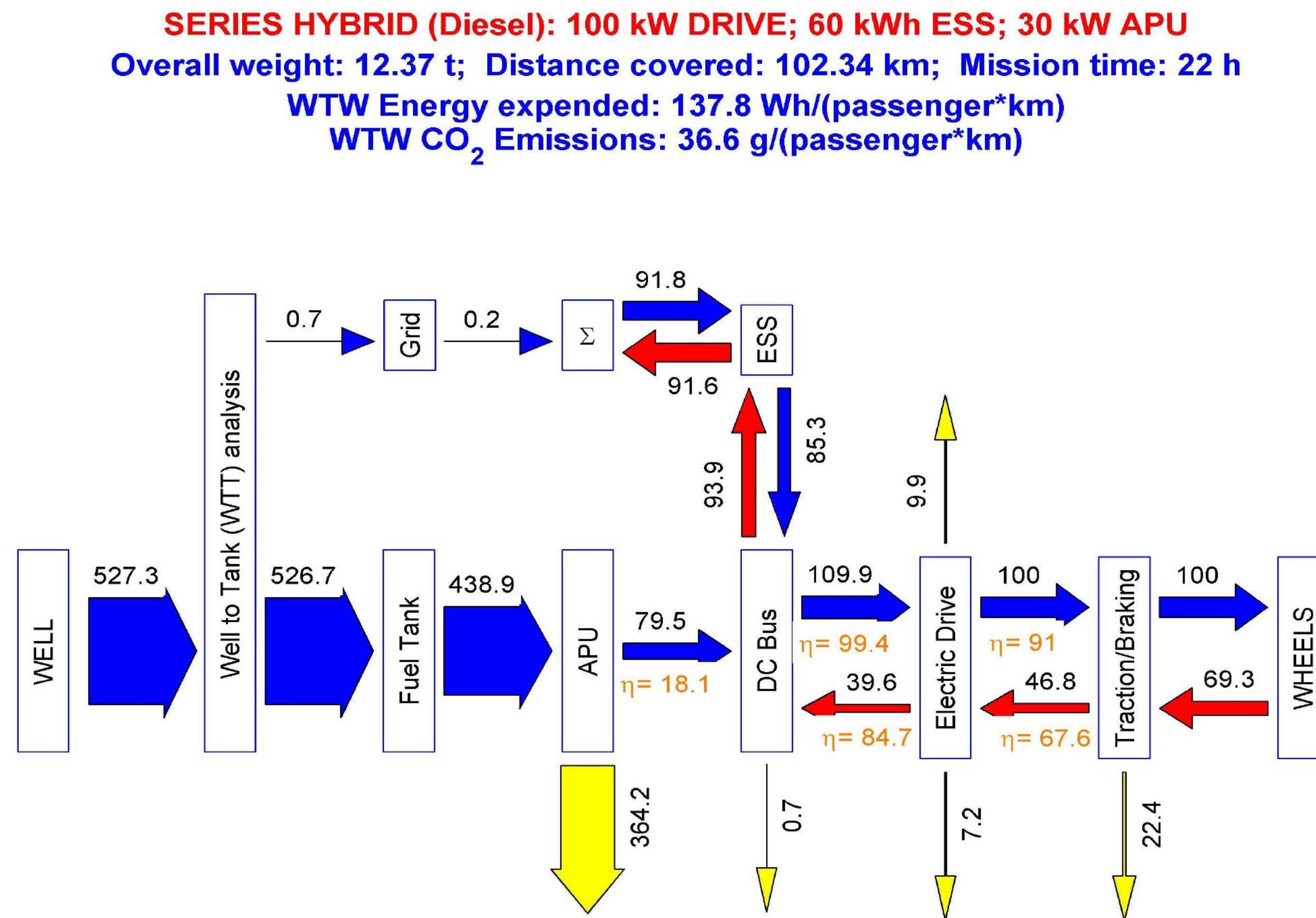
The model of the actual hybrid vehicle was previously calibrated on a number of experimental results made available by the manufacturer.

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← Daily vehicle Mission

Simulation Results – actual vehicle

Calculated performances of the Actual Hybrid vehicle on the new mission



SANKEY referred to 100 road out corresponding to: 26.1 Wh/(pass*km)

The model of the actual hybrid vehicle was previously calibrated on a number of experimental results made available by the manufacturer.

The Vehicle has a series hybrid configuration and makes use of a 30 kW Gas Turbine APU by Capstone (USA) and a 100 kW Electric Drive by ENOVA (USA)

← Energy performances

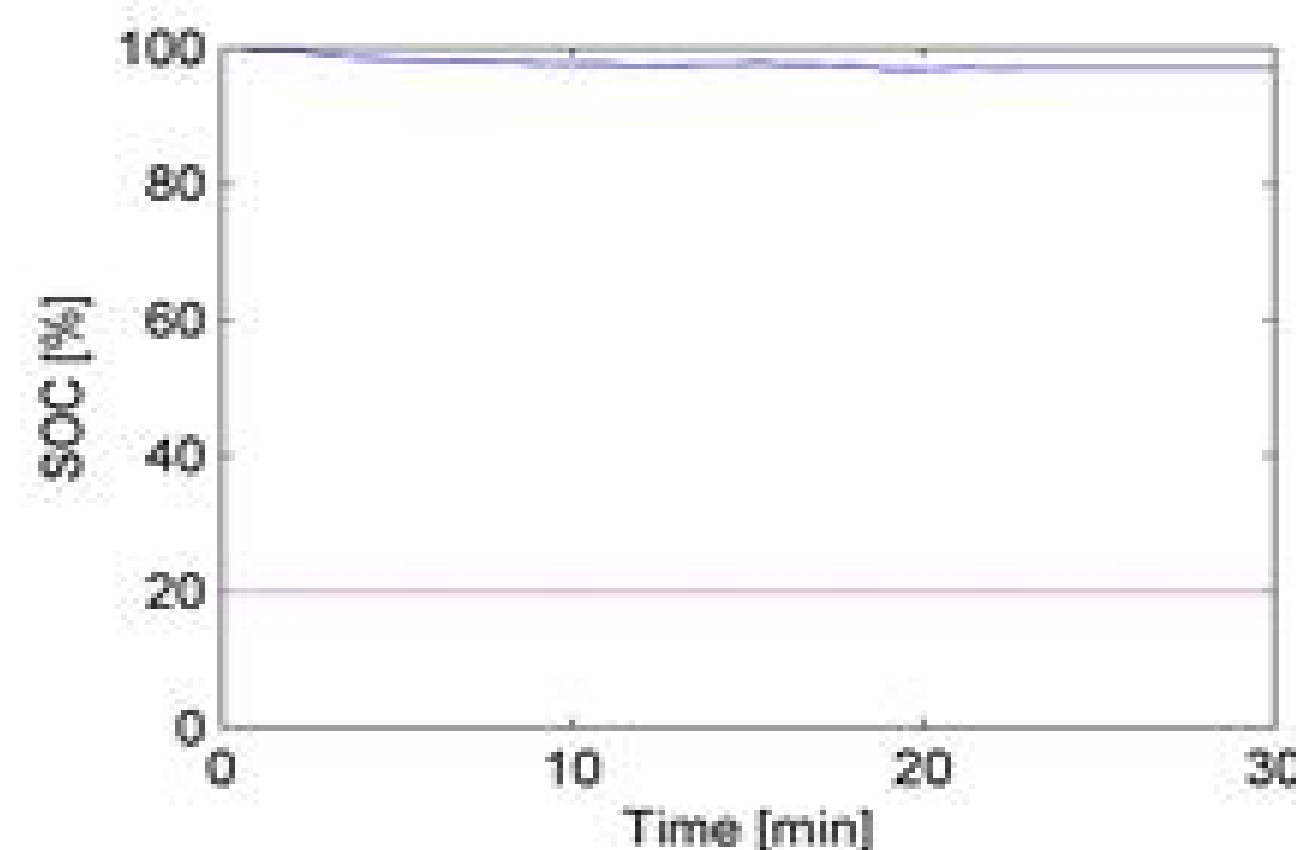
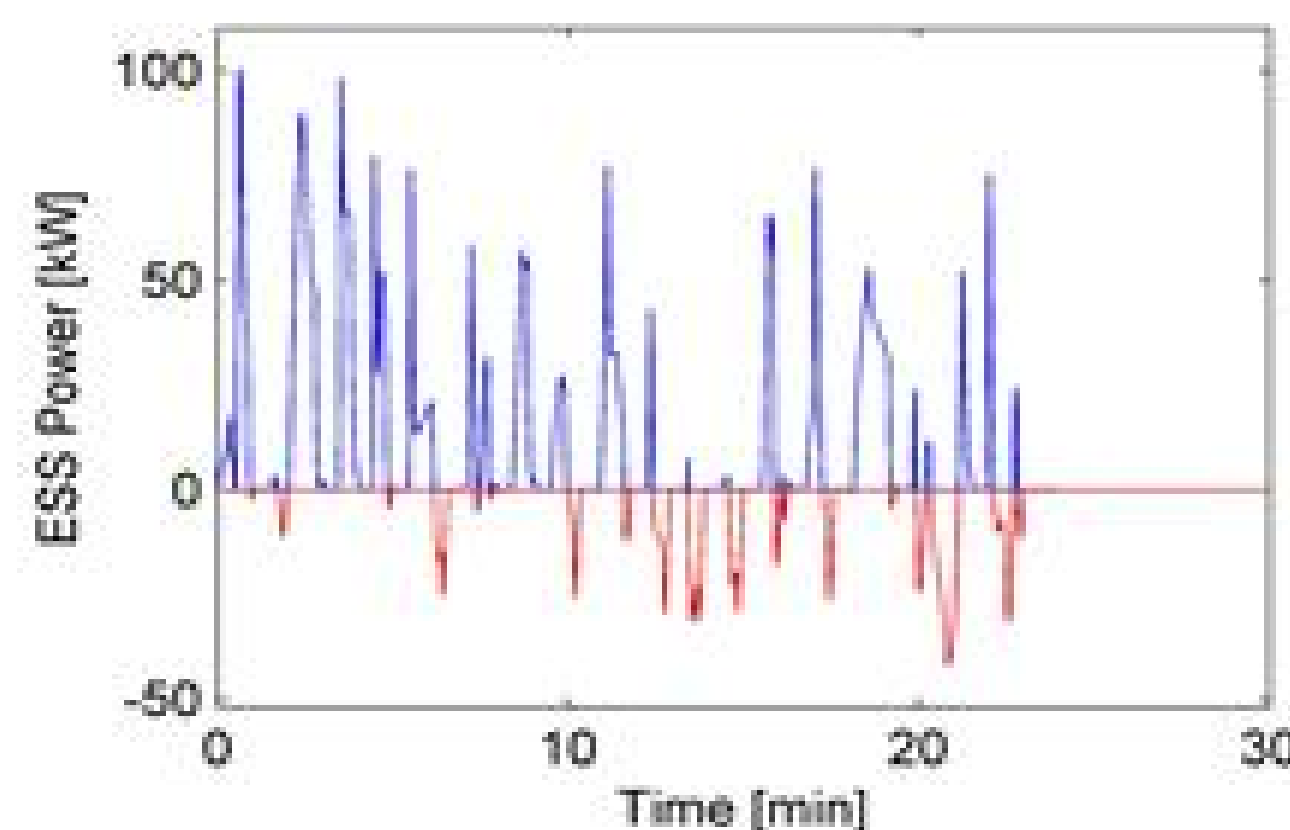
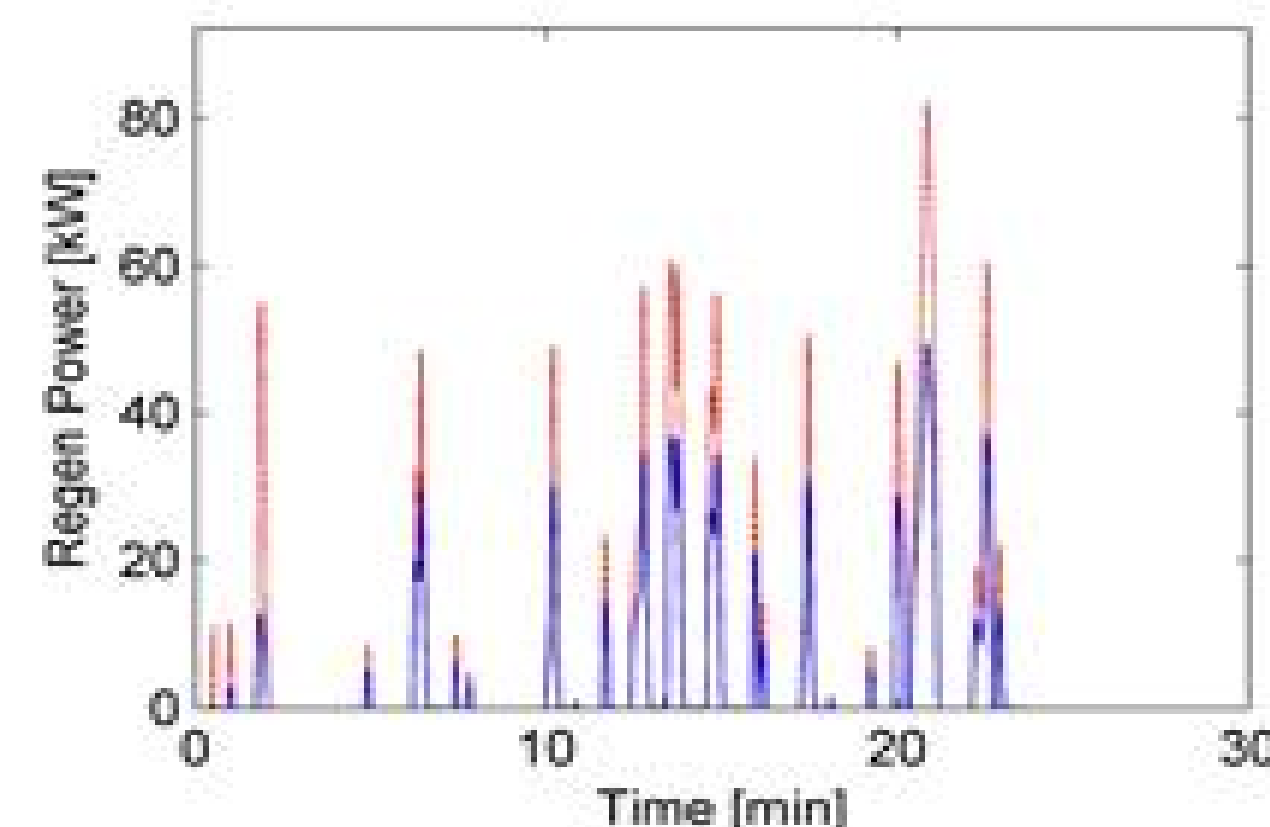
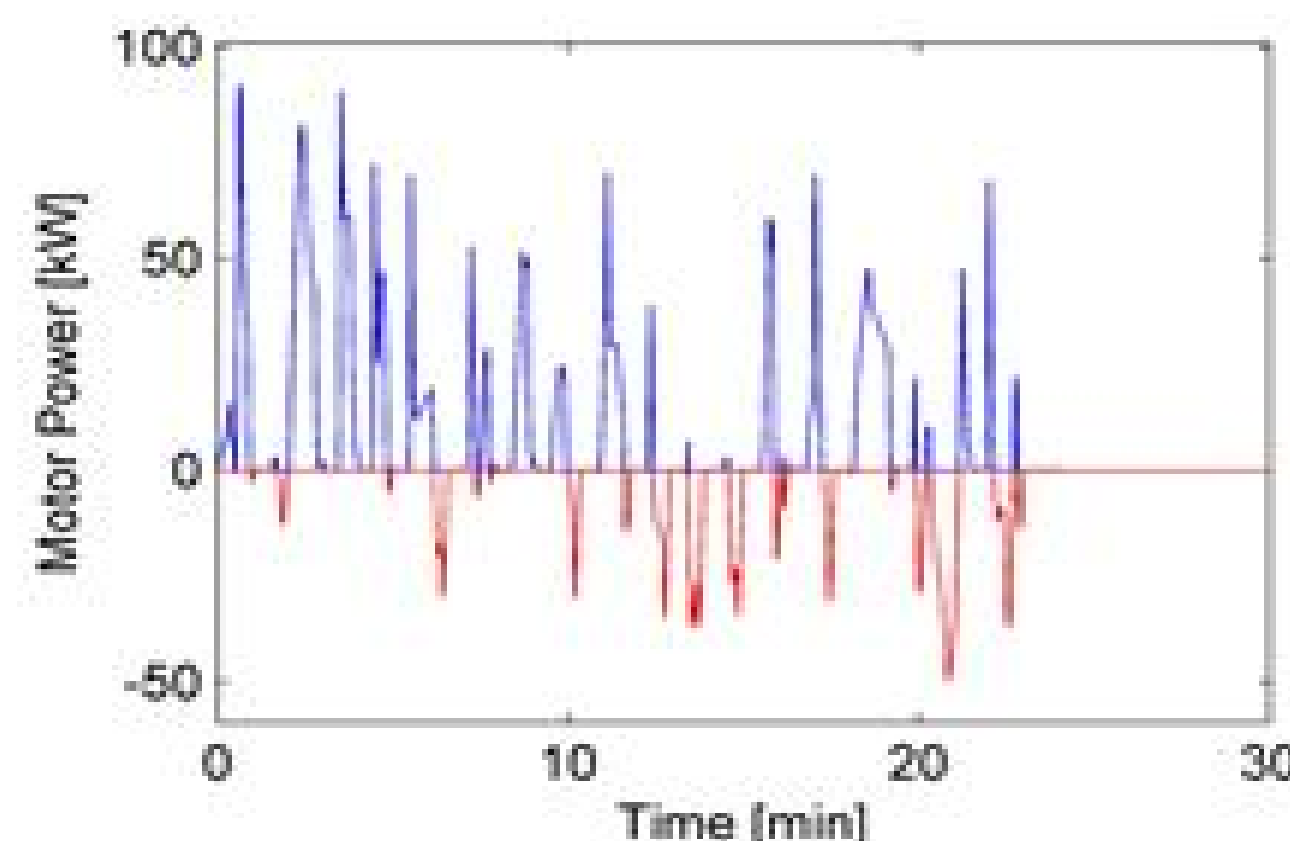
Design and prototyping of a
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Simulation Results – Normal BEV

Calculated performances for a newly designed slowly charged vehicle

BEV (SLOW CHARGE): 100 kW DRIVE; 102 kWh ESS



The lead-acid batteries actually equipping the vehicle were substituted with high energy Li-ion batteries tested by ENEA.

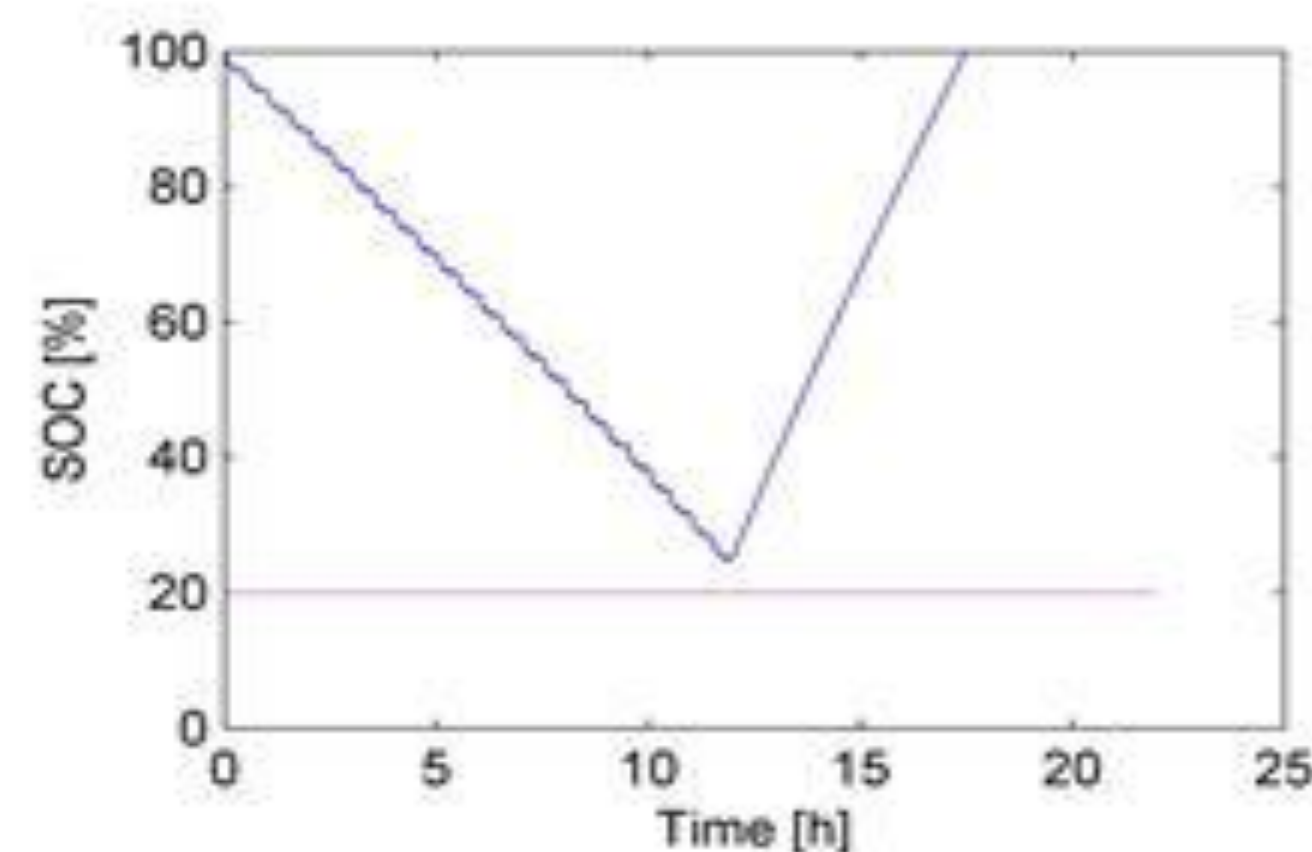
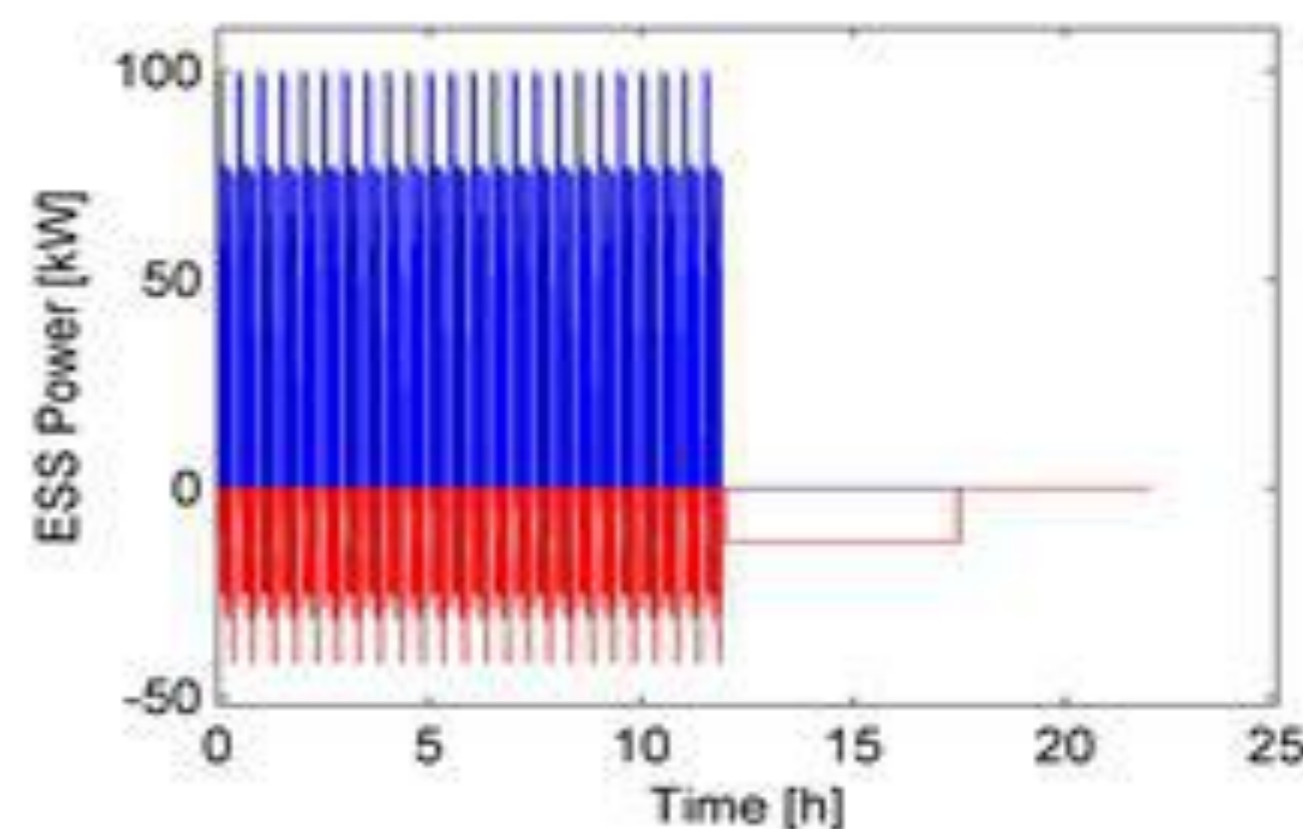
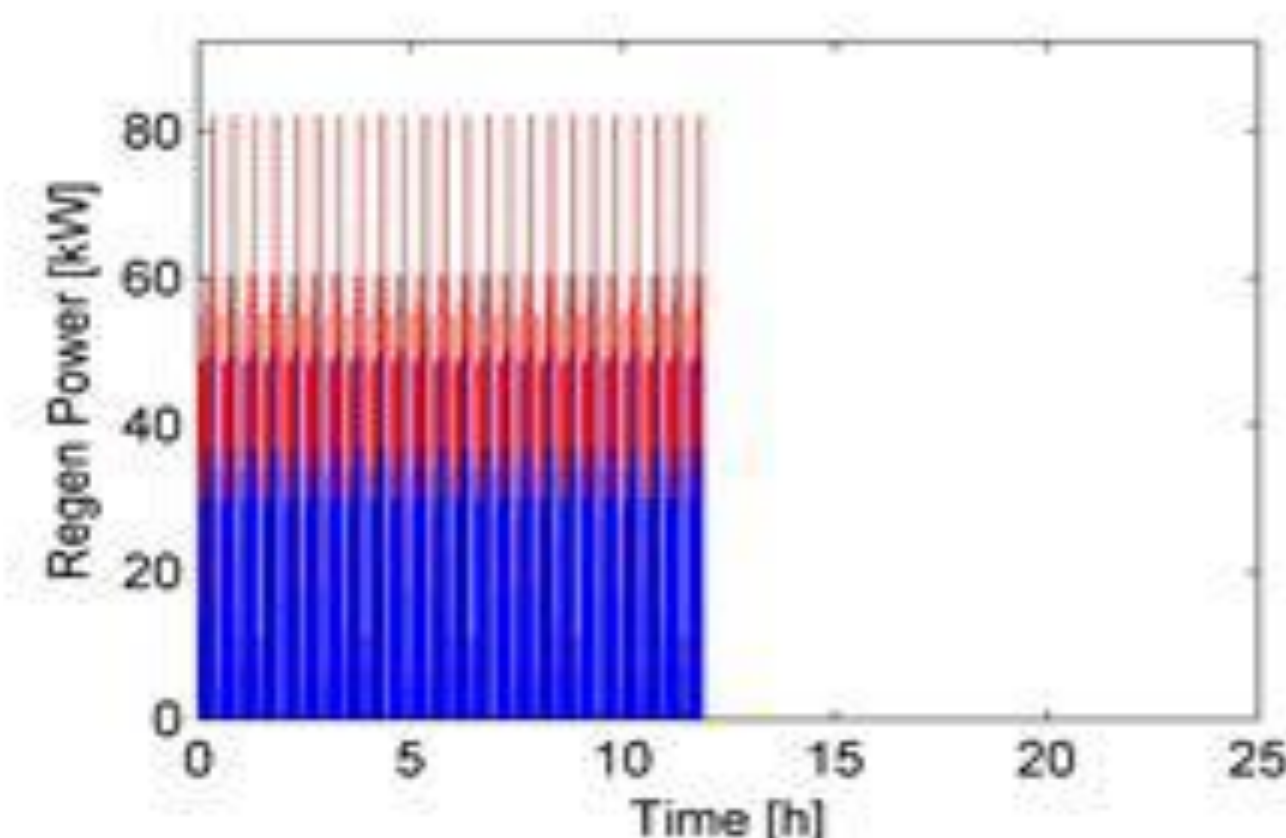
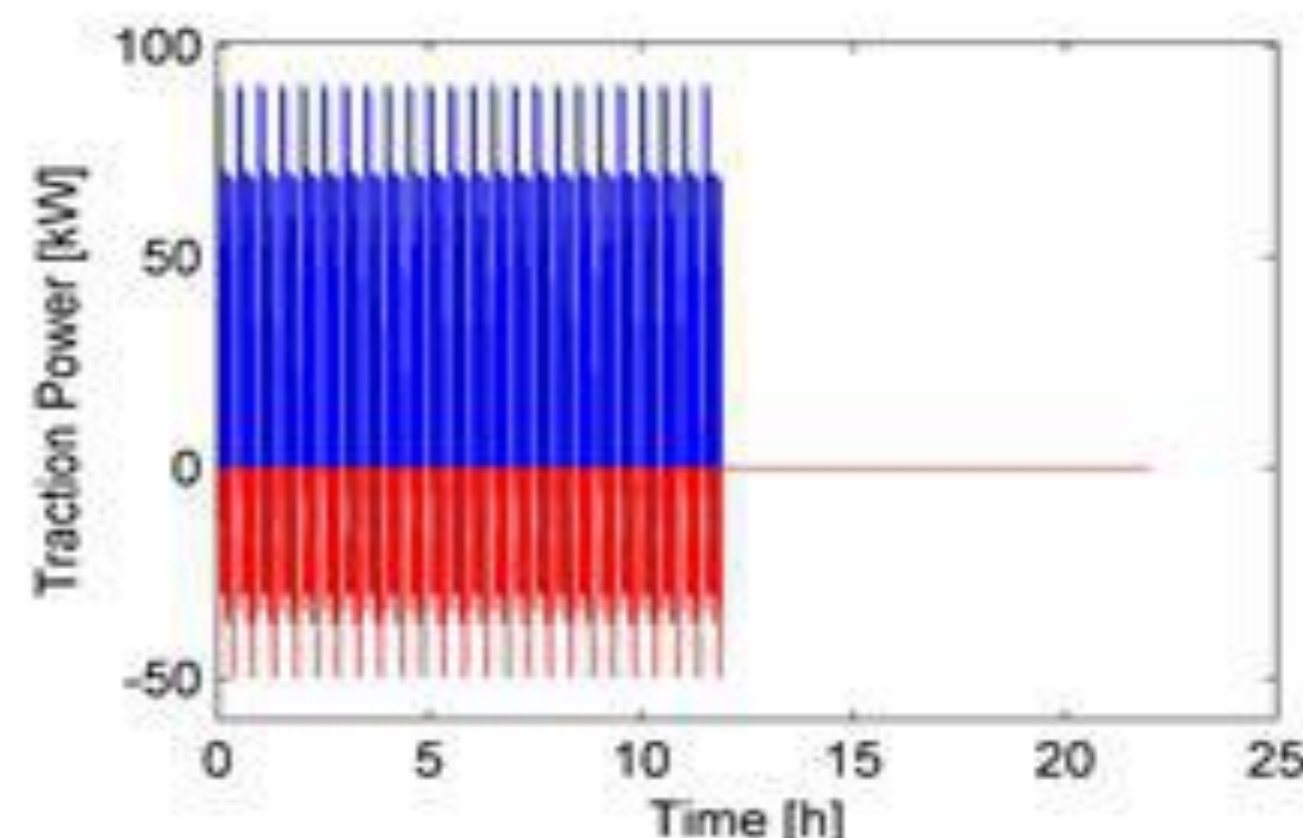
*The size fo the battery pack was designed to fullfill complete daily mission energy requirements: **102 kWh***

← Single service cycle

Simulation Results – Normal BEV

Calculated performances for a newly designed slowly charged vehicle

BEV (SLOW CHARGE): 100 kW DRIVE; 102 kWh ESS



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*The size fo the battery pack was designed to fullfill complete daily mission energy requirements: **102 kWh***

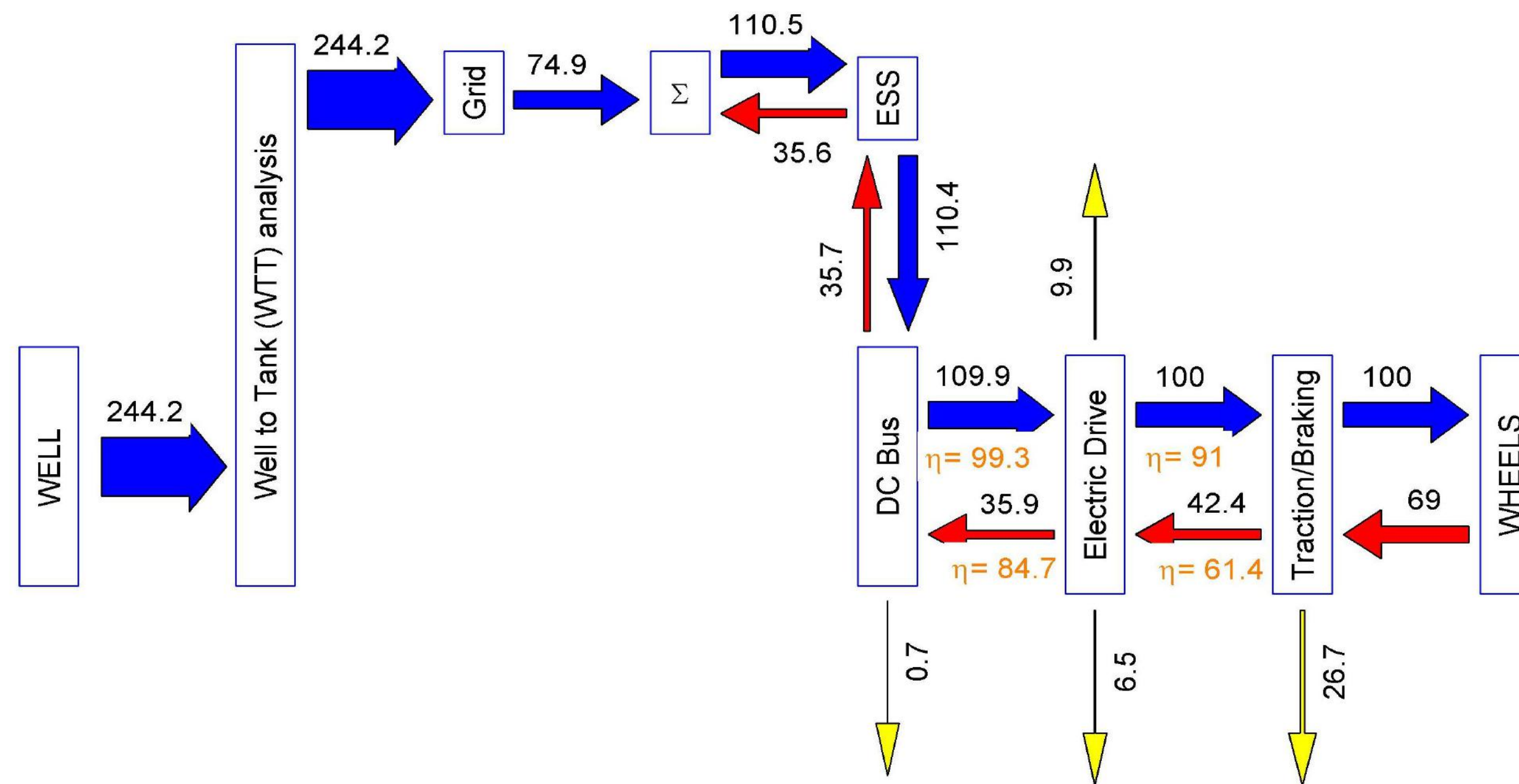
← Daily vehicle Mission

Simulation Results – Normal BEV

Calculated performances for a newly designed slowly charged vehicle

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BEV (SLOW CHARGE): 100 kW DRIVE; 102 kWh ESS
 Overall weight: 11.17 t; Distance covered: 102.34 km; Mission time: 22 h
 WTW Energy expended (Electric Energy by EU mix): 64 Wh/(pass*km)
 WTW CO₂ Emissions (Electric Energy by EU mix): 10.6 g/(pass*km)



SANKEY referred to 100 road out corresponding to: 23.6 Wh/(pass*km)

The lead-acid batteries actually equipping the vehicle were substituted with high energy Li-ion batteries tested by ENEA.

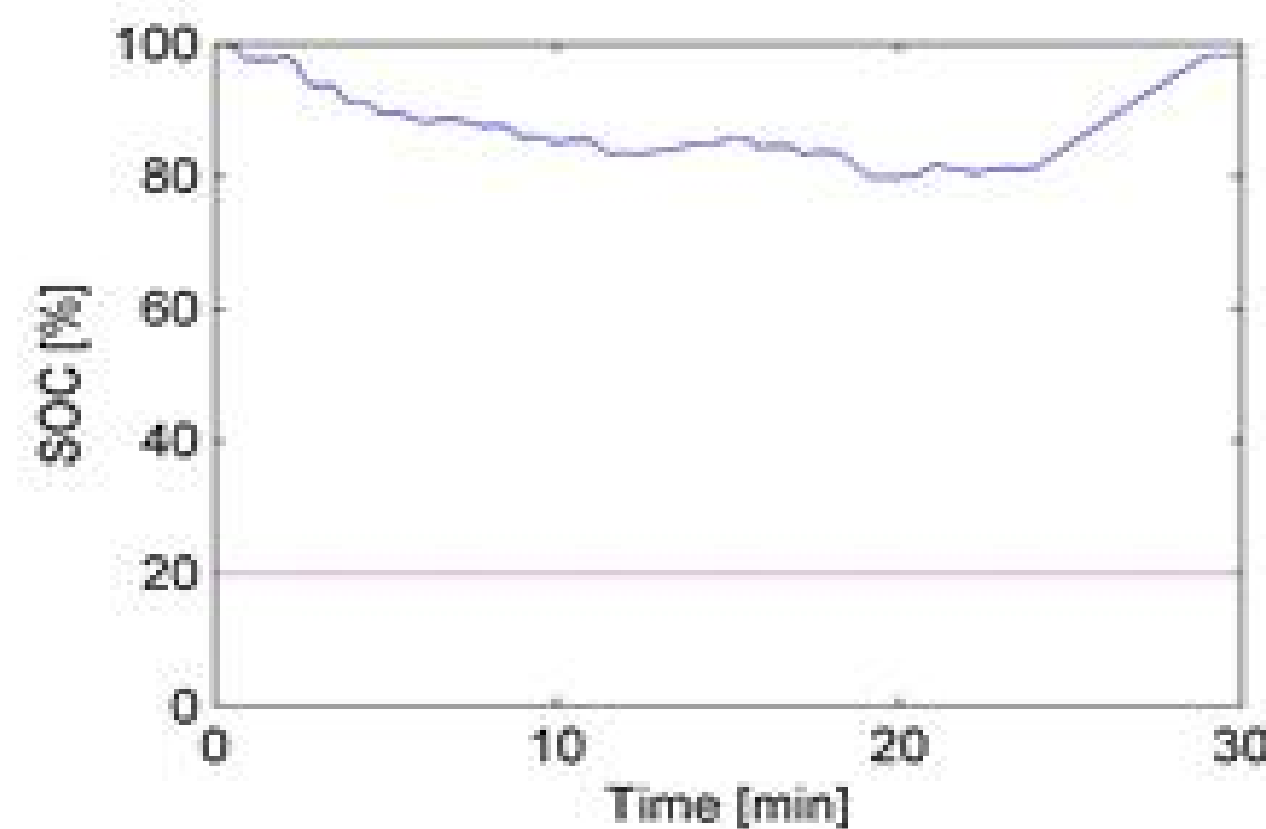
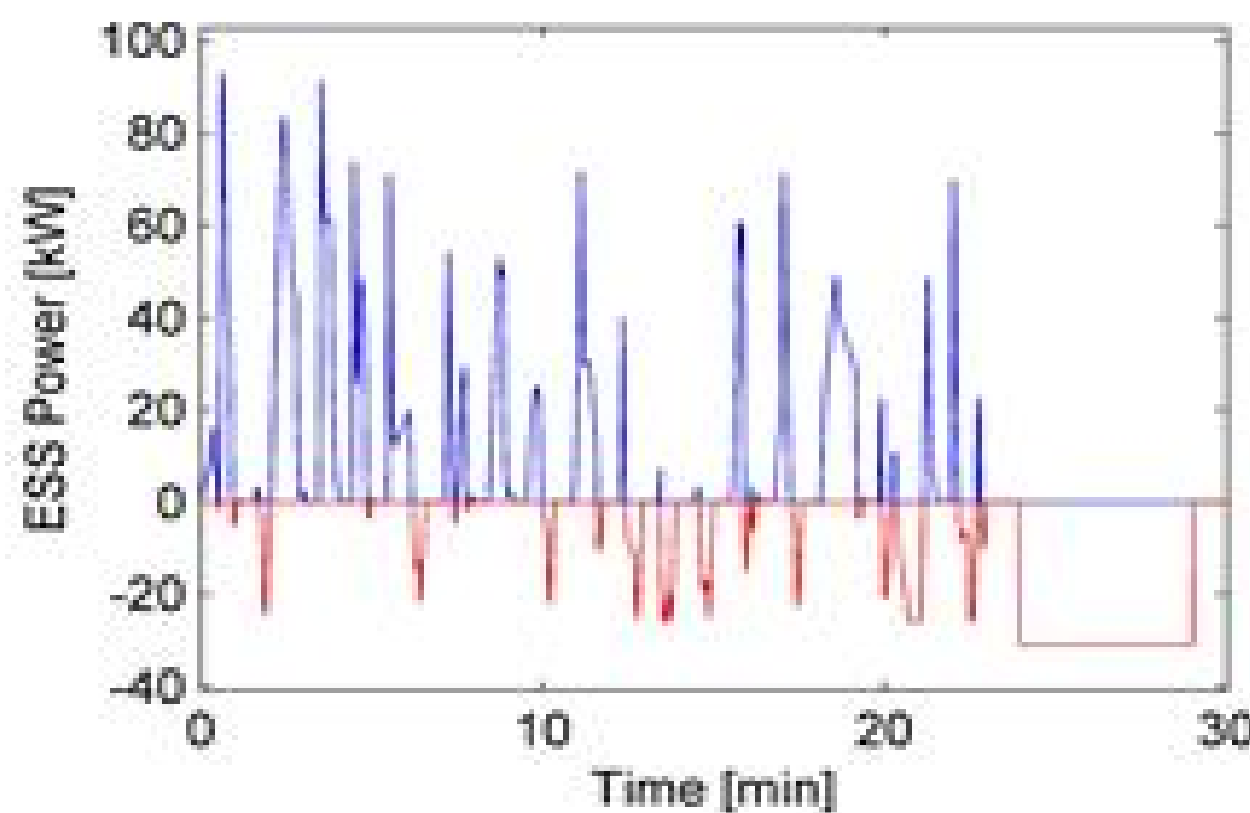
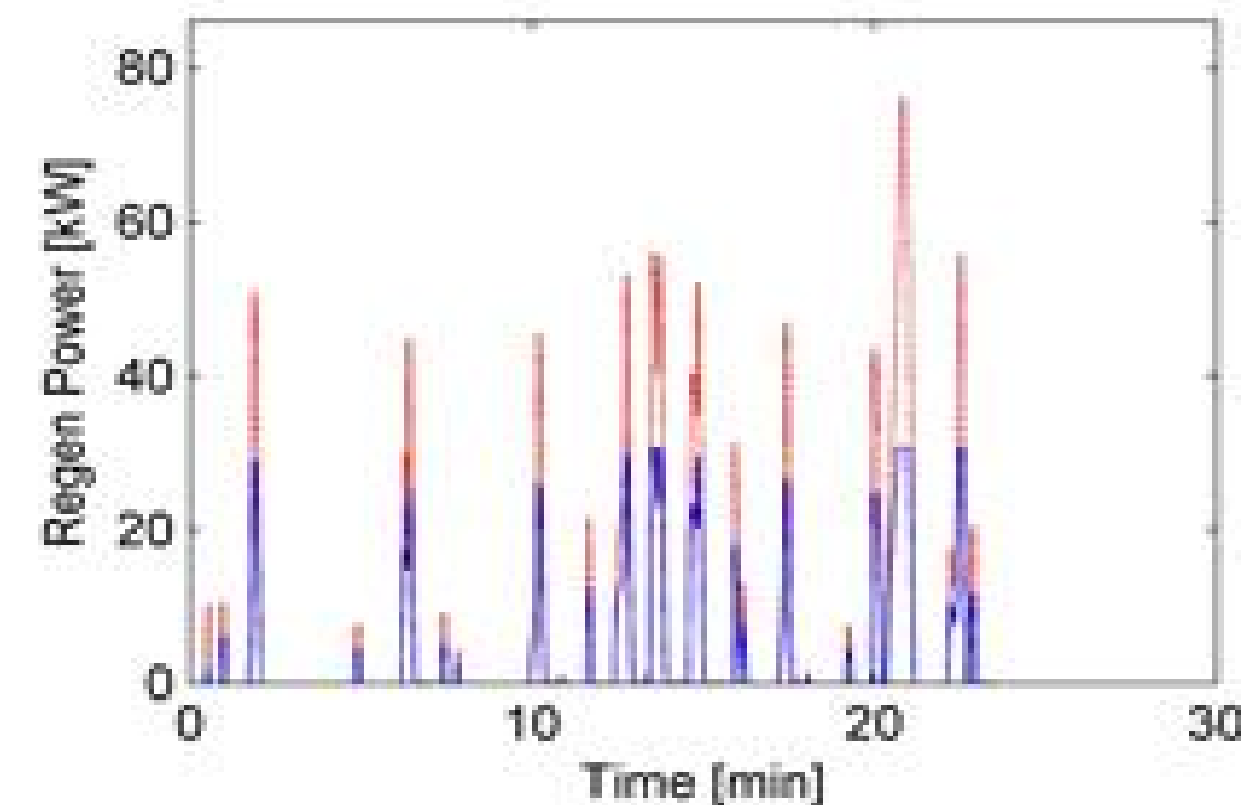
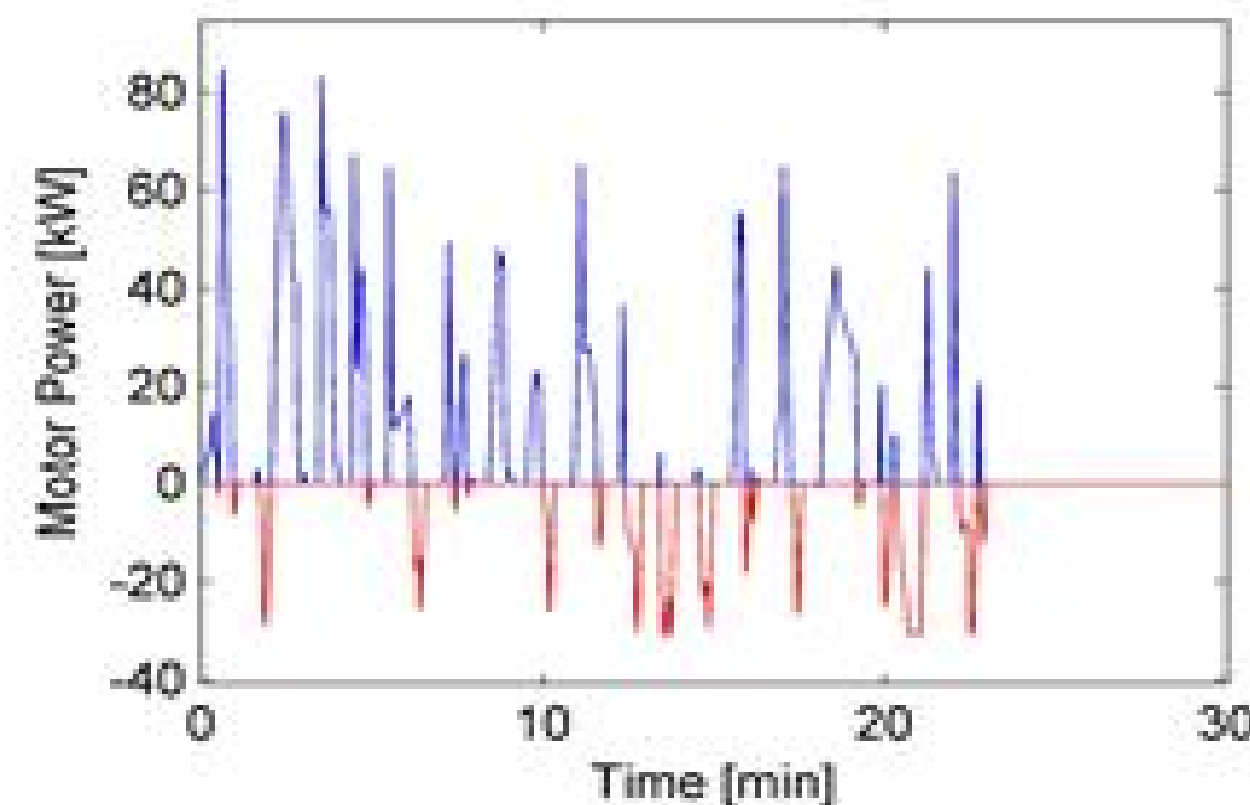
The size for the battery pack was designed to fulfill complete daily mission energy requirements: **102 kWh**

← Energy performances

Simulation Results – Rapid-charge BEV

Calculated performances for a newly designed rapid-charge vehicle

BEV (RAPID CHARGE): 100 kW DRIVE; 15 kWh ESS



High Power Li-ion batteries (developed by ENEA) were used to equip the vehicle.

Charging speed for the application was prudentially limited to C1

The size fo the battery pack was designed to fullfill both the single service cycle, and the complete daily mission:
15 kWh

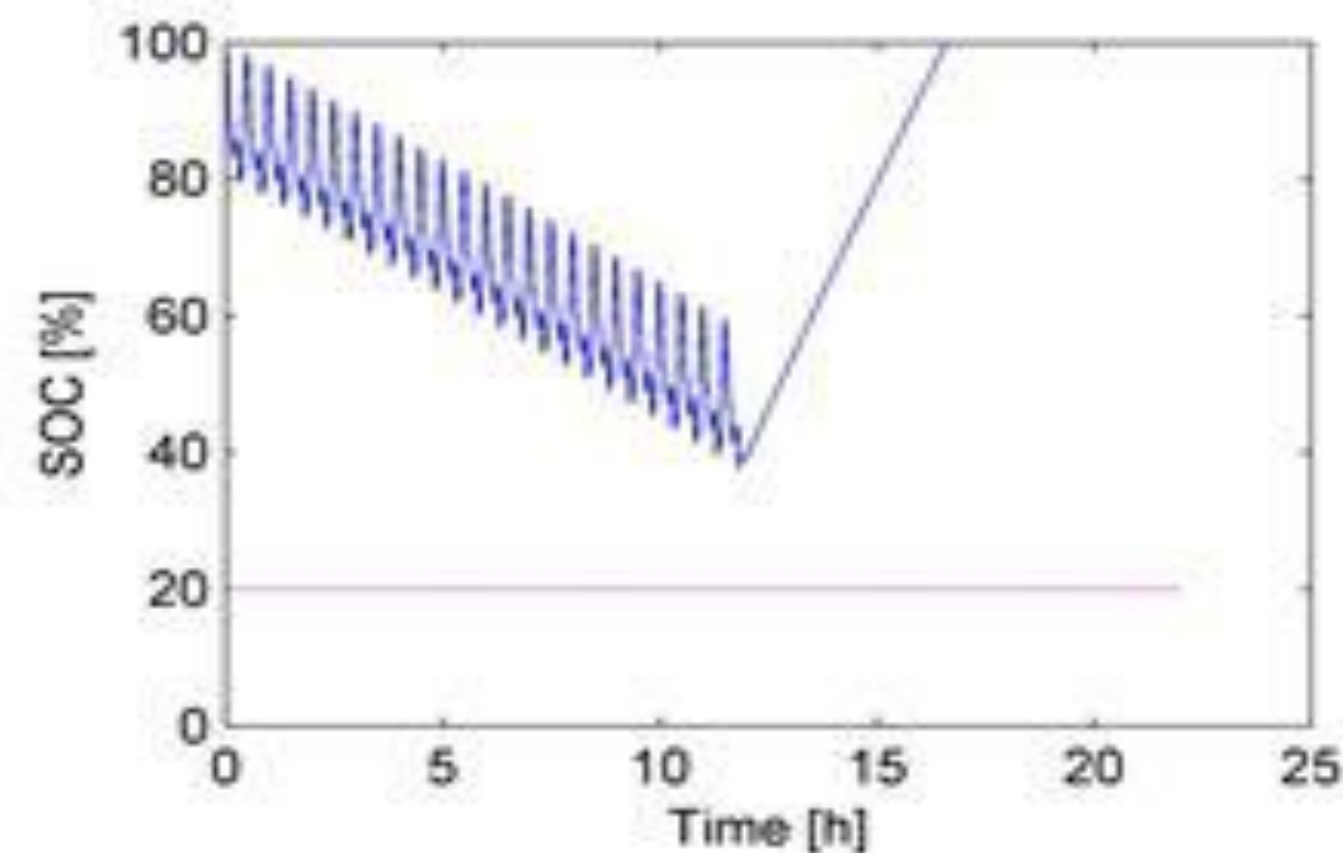
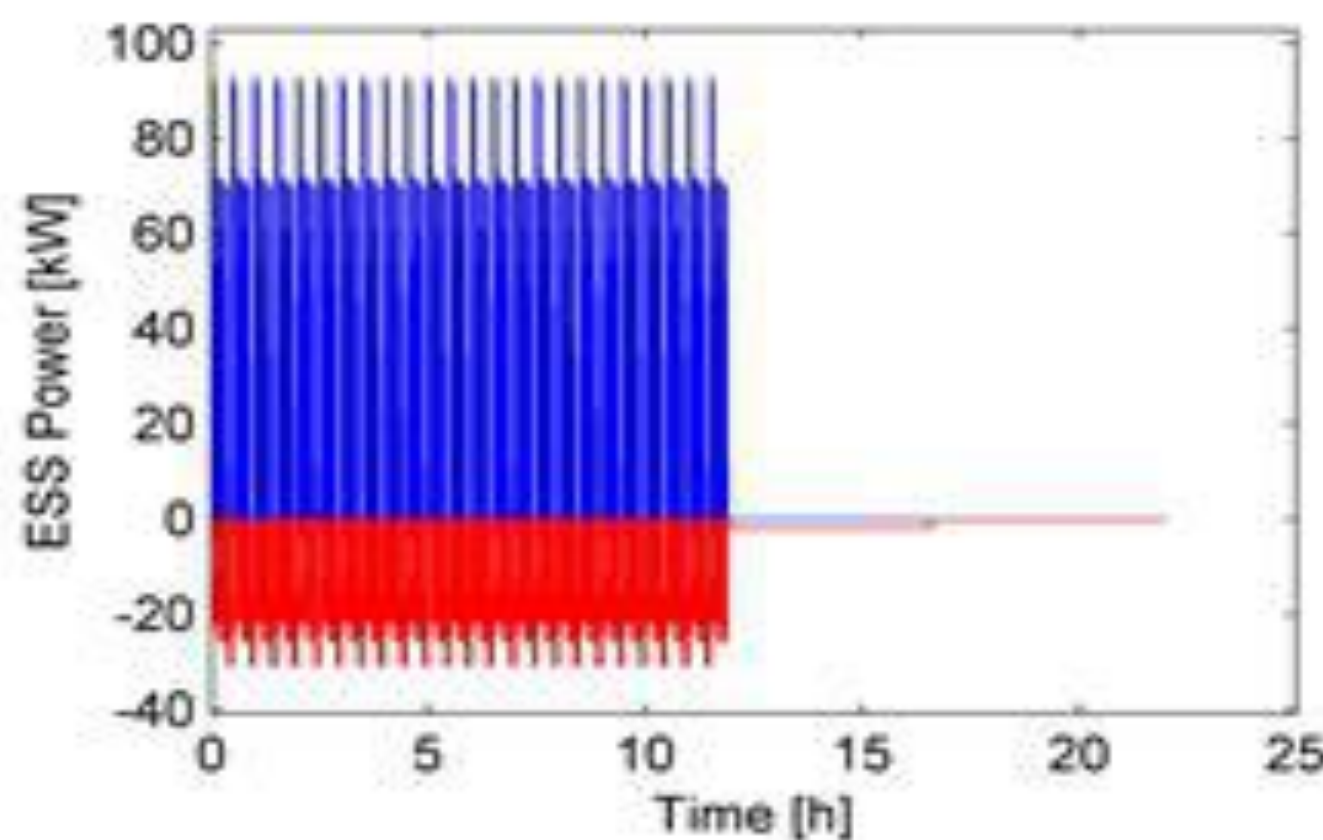
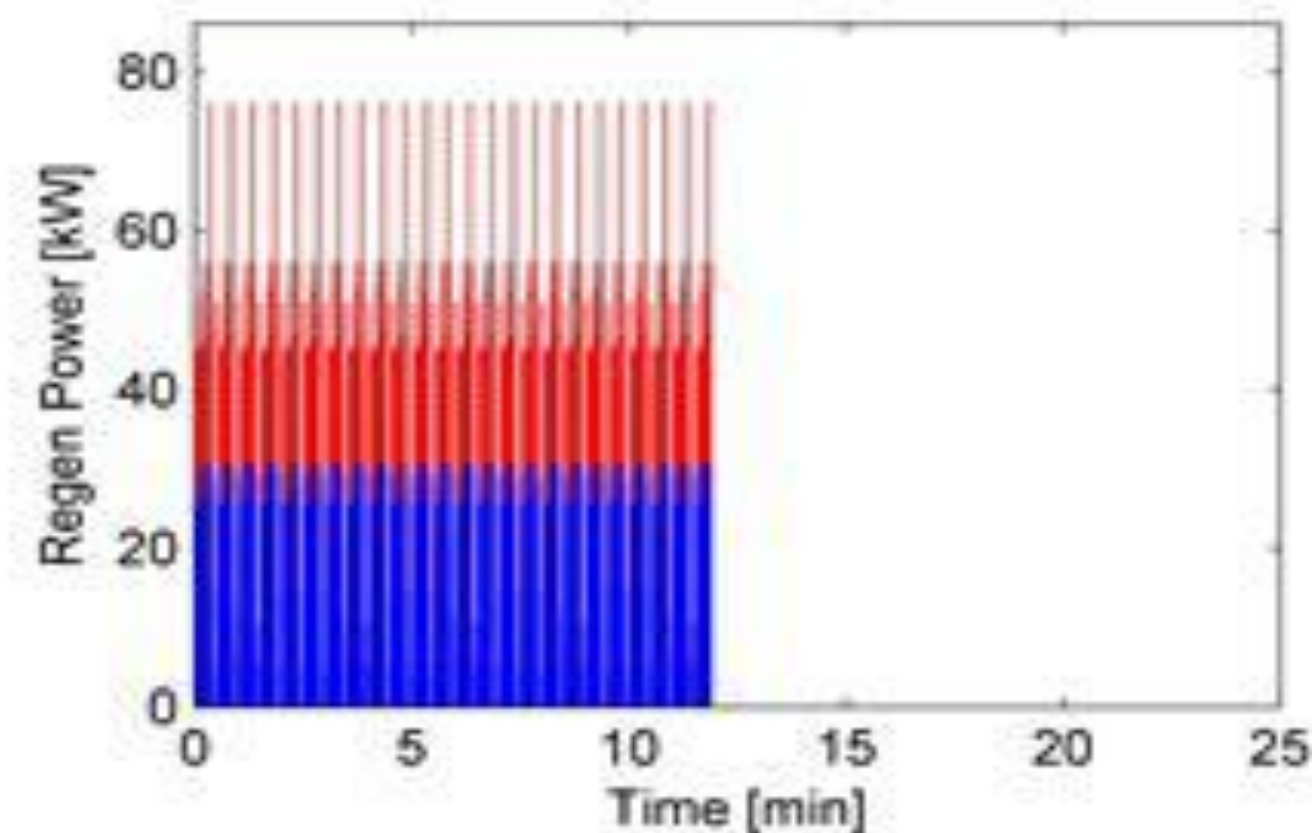
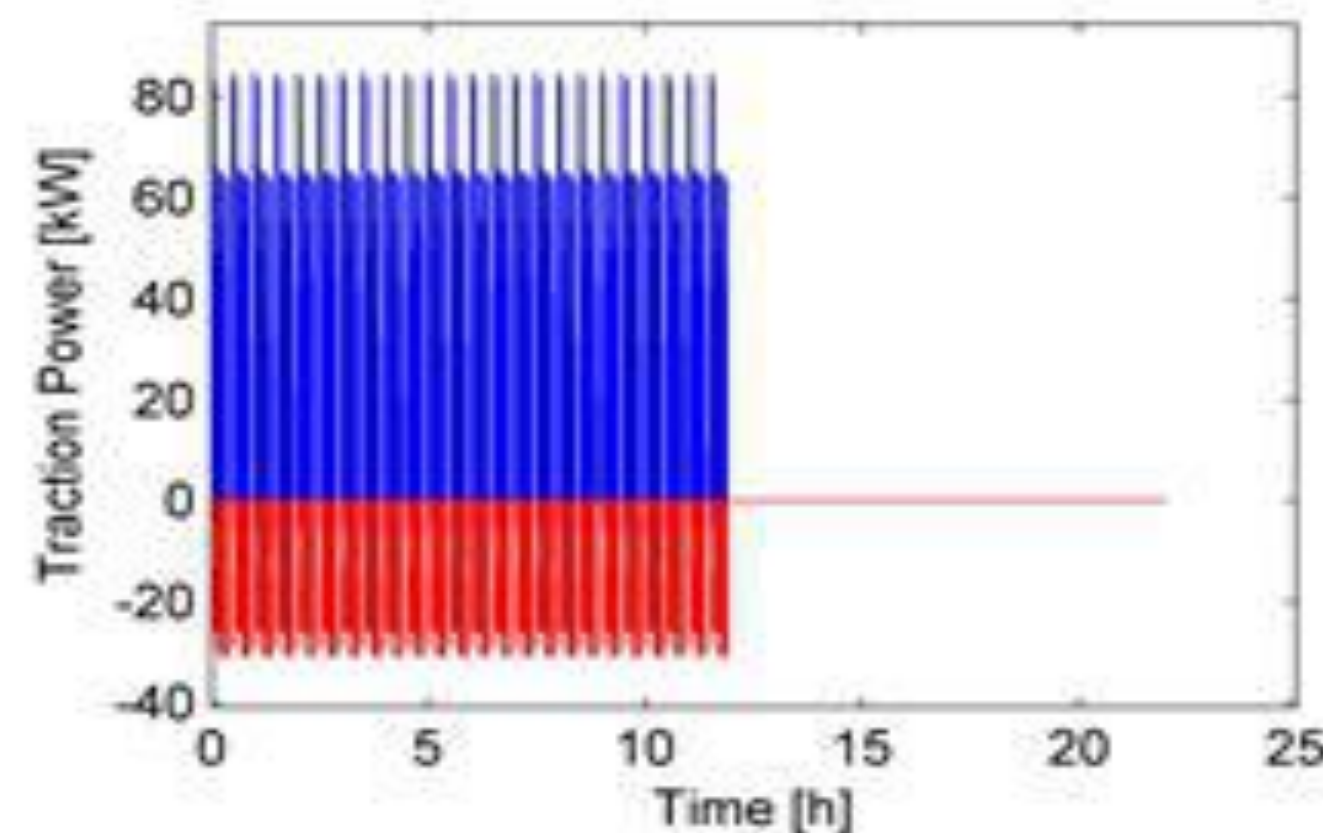
← Single service cycle

Simulation Results – Rapid-charge BEV

Calculated performances for a newly designed rapid-charg vehicle

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BEV (RAPID CHARGE): 100 kW DRIVE; 15 kWh ESS



High Power Li-ion batteries (developed by ENEA) were used to equip the vehicle.

Charging speed for the application was prudentially limited to C1

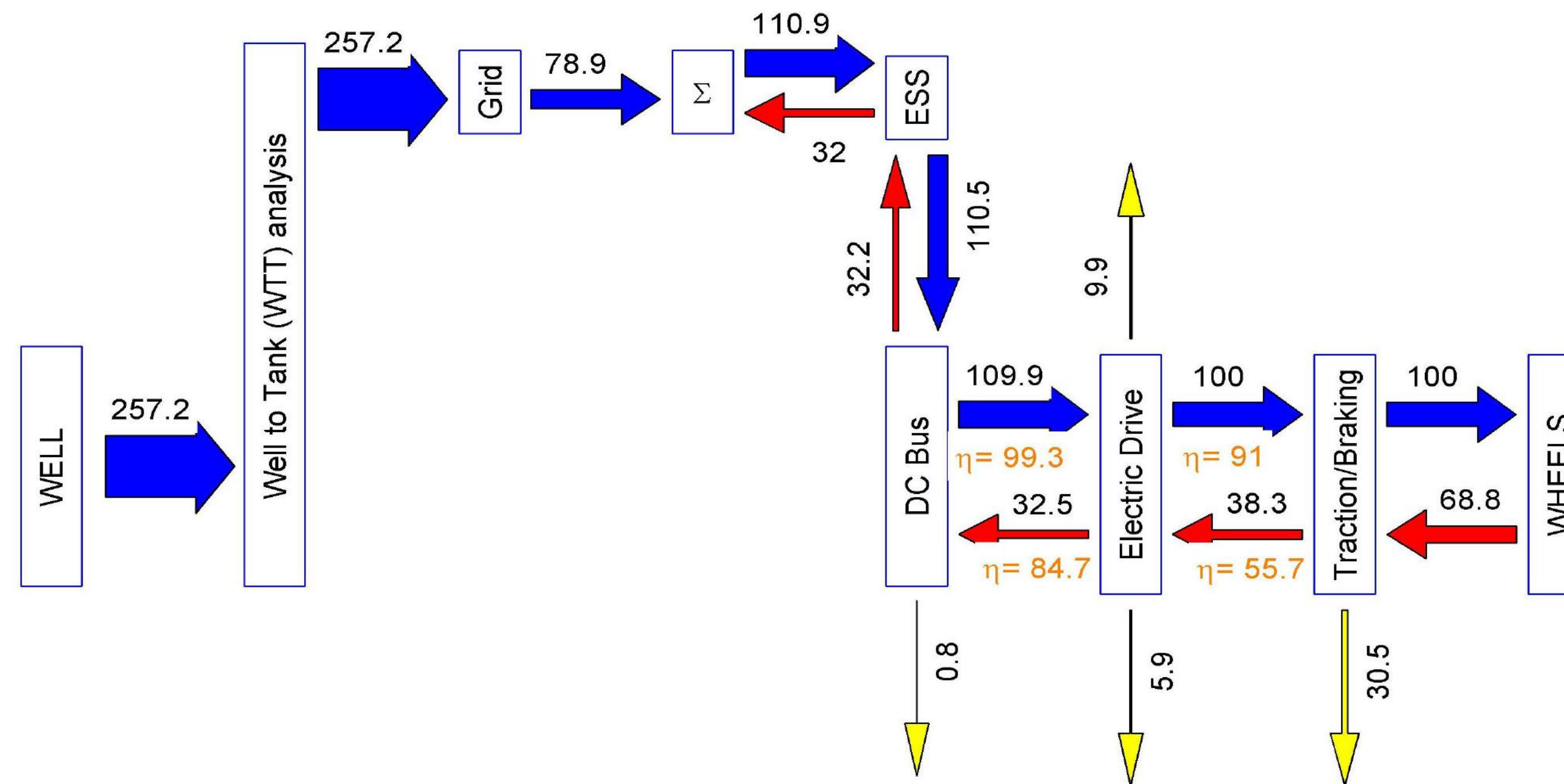
The size fo the battery pack was designed to fullfill both the single service cycle, and the complete daily mission:
15 kWh

← Daily vehicle Mission

Simulation Results – Rapid-charge BEV

Calculated performances for a newly designed rapid-charge vehicle

BEV (RAPID CHARGE): 100 kW DRIVE; 15 kWh ESS
Overall weight: 10.35 t; Distance covered: 102.34 km; Mission time: 22 h
WTW Energy expended (Electric Energy by EU mix): 65.8 Wh/(pass*km)
WTW CO₂ Emissions (Electric Energy by EU mix): 10.9 g/(pass*km)



SANKEY referred to 100 road out corresponding to: 21.9 Wh/(pass*km)

High Power Li-ion batteries (developed by ENEA) were used to equip the vehicle.

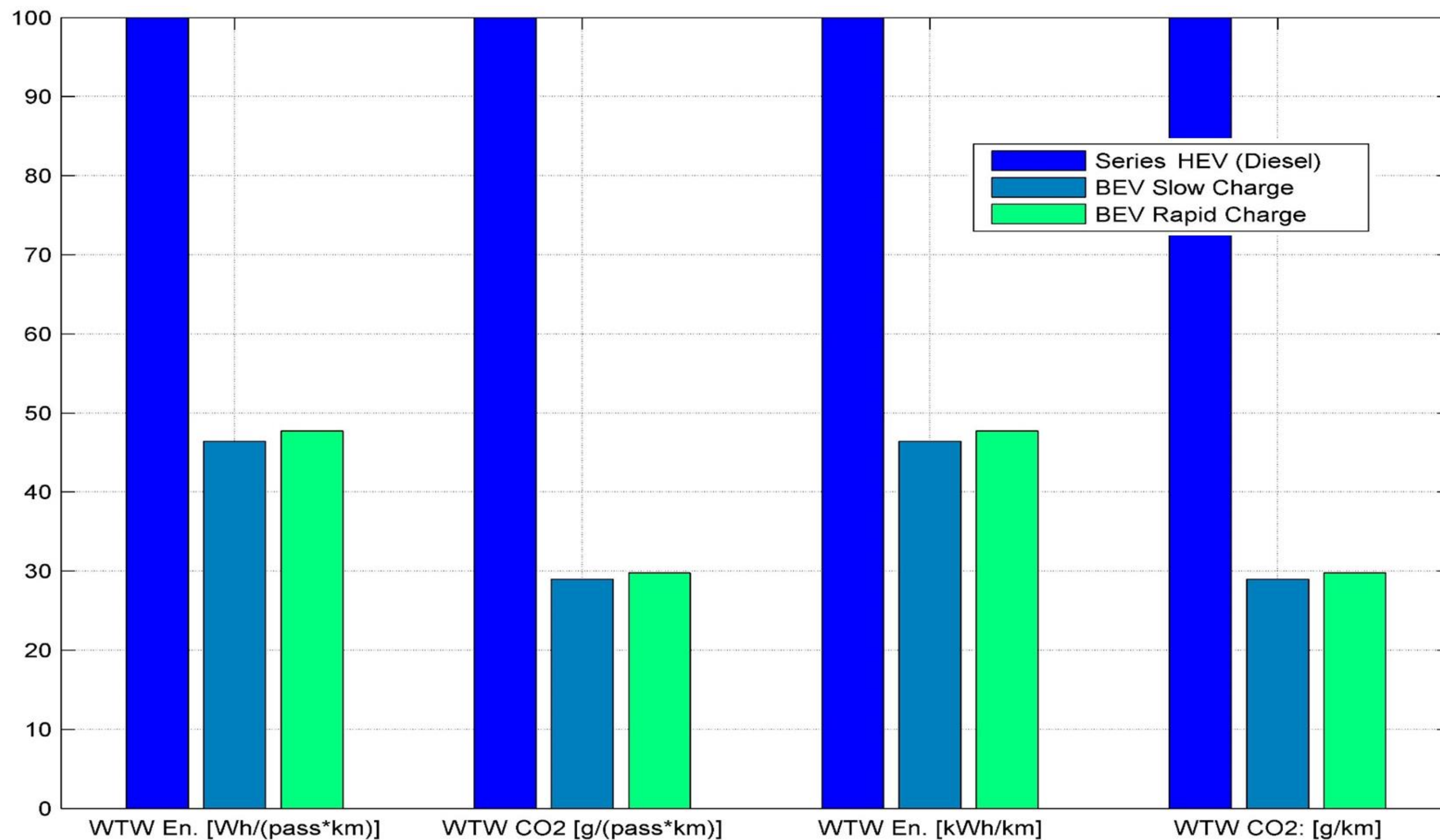
Charging speed for the application was prudentially limited to C1

The size fo the battery pack was designed to fullfill both the single service cycle, and the complete daily mission:
15 kWh

← Energy performances

Configurations comparison

Design and prototyping of a
rapid-charge electric bus for
urban passenger transportation





Conclusions

- A clear convenience in using a fully electric vehicle instead of a hybrid one for this urban application was demonstrated (-50% Energy; -70% Co2 emissions).
- Rapid charging Battery electric vehicle demonstrate to be fully successful in limiting the size of the battery pack to **approximately 1/6** of the energy needed for its overall daily mission. **Energy losses due to rapid charging are substantially balanced by the saving due to the lower vehicle weight.**
- Advantages are clear, on the other end, with respect to the **limited costs of the rapid charging solution**. Cost saved for the battery pack are not balanced by the additional costs of the rapid charging infrastructure, which is certainly compatible with those built for cars' application, not requiring significant power output (like those needed for high capacity Electric buses).
- The costs of the additional infrastructure may be divided by the number of buses using it and may be depreciated in a much longer period (20 years) with respect to battery packs (2-3 years for heavy duty transportation applications).



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Thanks for the attention

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