Vehicle Targets Cascading for Battery Sizing

Energy Requirements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 875041

Trainings Scheme

solutions plus

Sizing 1	Sizing 2	Sizing 3	Follow-up :
Setting the vehicle targets	Vehicle targets cascading for battery sizing: traction requirements	Vehicle targets cascading for battery sizing: energy requirements	Q/A and results presentation
18th May	*19th May*	*20th May*	*25 May*

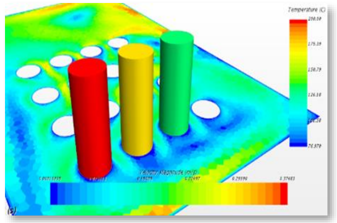
IDIADA Powertrain Virtual Development

Engineering

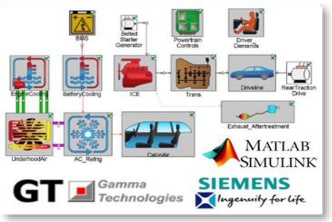
IDIADA offers continuous engineering & simulation support during all the phases of e-powertrain & vehicle development

VIRTUAL DEVELOPMENT PROCESS

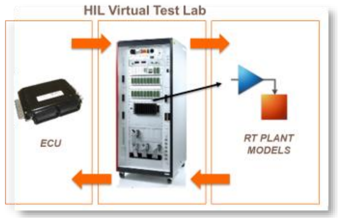
Concept Simulation



Detailed Design



System Integration



Virtual Validation

IDIADA Sizing projects examples

Concept → Development → Validation

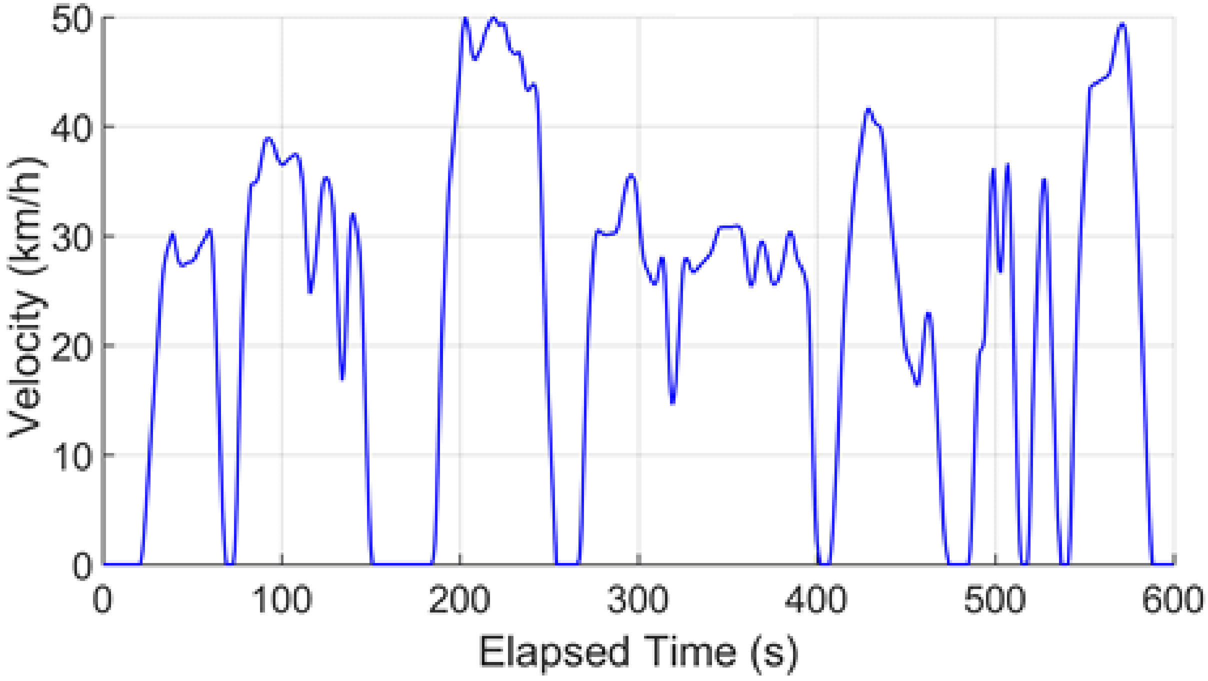
Agenda

1. Pre-process user cycles
2. Calculate tractive power demands from user cycle
3. Calculate electric traction power demands
4. Define battery target capacity
5. Energy requirements validation
6. References
7. Handout work

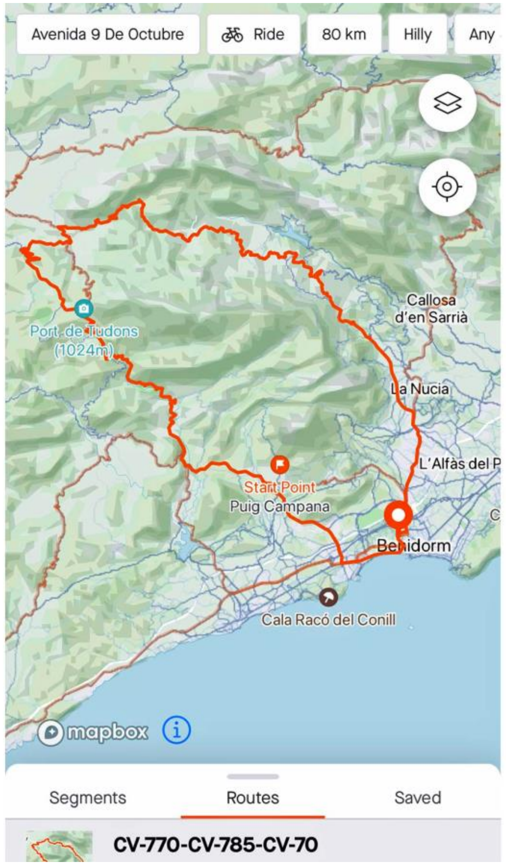
Pre-process user cycles

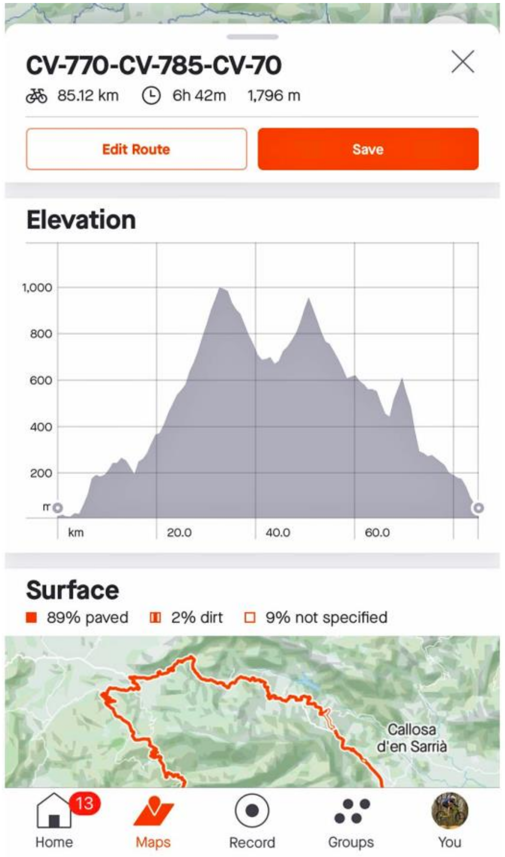
User cycle definition

- User cycle defined from:
  - Regulation cycles: WMTC



- Recording:

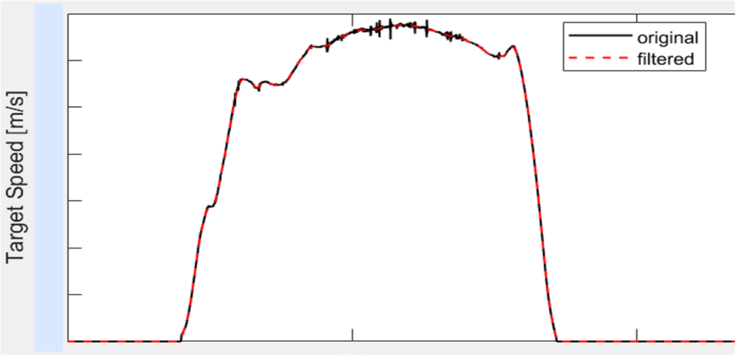




Pre-process user cycles

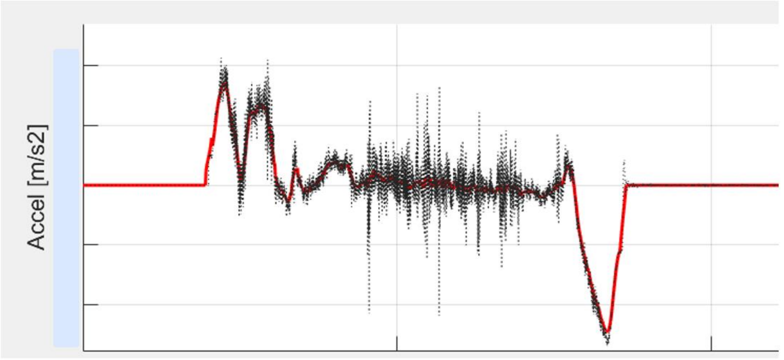
GPS possible errors: Vehicle Speed

Slightly noisy speed



Acceleration is calculated as the speed derivative

Extremely noisy acceleration



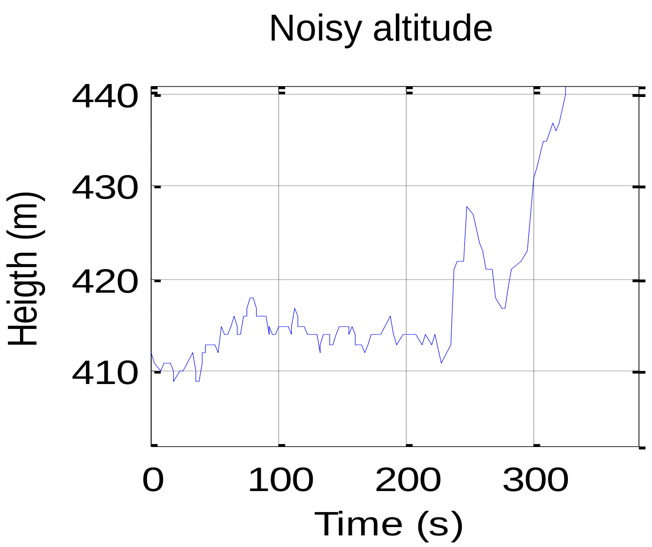
$$F_{Wheel} = F_{res}(v) + \boxed{m_k a} + mgsin\alpha$$

The GPS error related to the vehicle speed can lead into big errors in terms of power calculation (up to 30%)

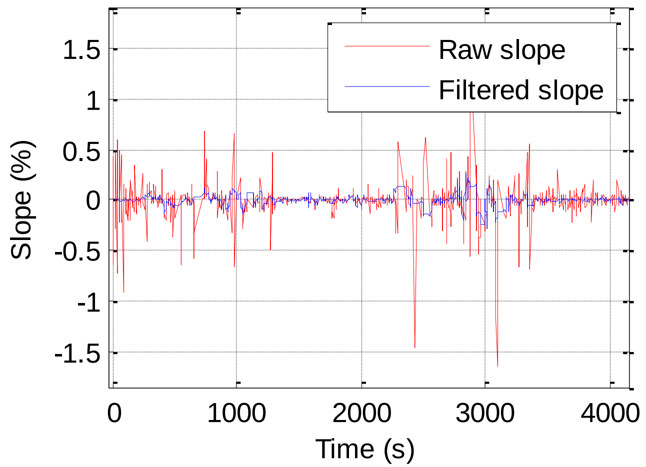
"VIRTUAL MODELLING OF REAL-DRIVING CONDITIONS FOR EARLY EVALUATION AND VALIDATION OF VEHICLE DESIGN" Sabria, Didac1; Diaz, Francisco Javier; Salat, Roger; Cano, Pablo; Roche, Marina; Bertoli, Xavier, *https://doi.org/10.46720/F2021-ADM-130*

Pre-process user cycles

GPS possible errors: Altitude



Slope is calculated from the derivative of the heigth



$$F_{Wheel} = F_{res}(v) + m_k a + \boxed{mgsin\alpha}$$

The GPS error related to the height can lead into big errors in terms of power calculation (up to 30%)

"VIRTUAL MODELLING OF REAL-DRIVING CONDITIONS FOR EARLY EVALUATION AND VALIDATION OF VEHICLE DESIGN" Sabria, Didac1; Diaz, Francisco Javier; Salat, Roger; Cano, Pablo; Roche, Marina; Bertoli, Xavier, https://doi.org/10.46720/F2021-ADM-130

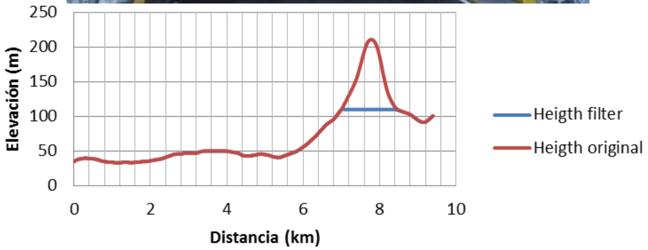
Pre-process user cycles

Topograhic databases possible errors: Altitude

- Cross-check the GPS altitude with altitude in topographic databases, but be careful with:

Poor latitude-logitude position in places with high buildings

In tunnels, the map may consider the elvation over the tunnel



In mountany roads, 2m error in position may imply 200 m error in height

→ **Best is to merge GPS with topographic database. Maybe the App you use is already making that merge**

Pre-process user cycles

GPS possible errors: Solutions

- The following soultions may help to obtain a representative cycle:
  - Increase the precision of the acquisition device
  - Post-processing with filters
  - Post-processing with average mean
  - Post-processing with Kalman filters
  - Matching the recorded resutls with topographic databases
  - …

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Calculate tractive power demands from user cycle

Force calculation

$$F_{res}(v) = f_0 + f_2 \cdot v^{2}$$

$$F_{Wheel} = F_{res}(v) + m_k a + mgsin\alpha$$

→ Take into account:

- The mass to be used for the force calculation should be the test mass for the vehicle, not the empty vehicle mass
- The acceleration should be calculate at the center of the time step we are calculating: $a(i) = \frac{v(i+1)-v(i-1)}{t(i+1)-t(i-1)}$
- Be careful with the units of f_2. International units would be $N/(m/s)^2$. But in most test and regulation documents f_2 is presented in $N/(km/h)^2$. In $F_{res}(v)$ always use the same speed units for speed and f_2 and double check. Review also the calculations of sizing 2 for the f_2 units.

Calculate tractive power demands from user cycle

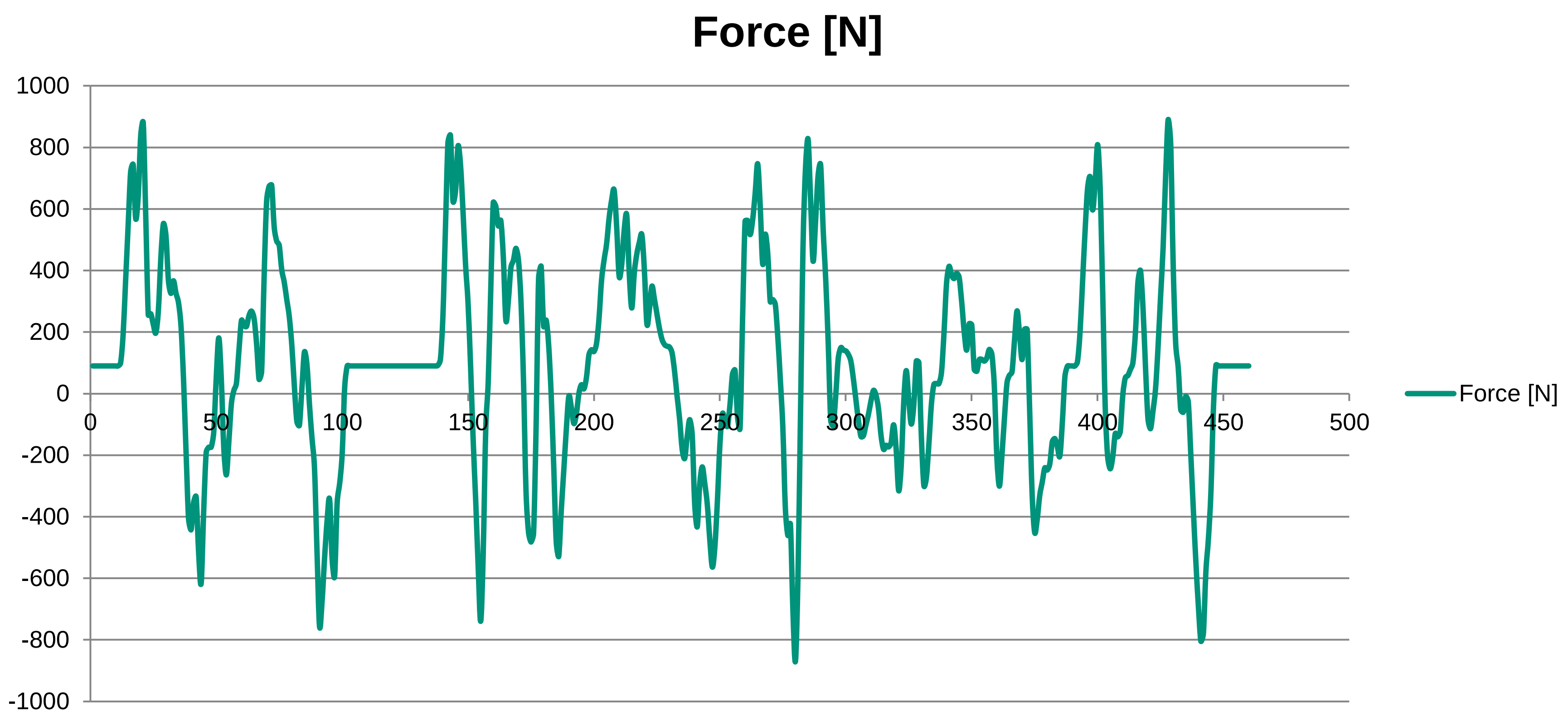
Force calculation

Example result for first 450 s of WLTP cycle and sample quadricycle data:

Vehicle Data		
Concept	Value	Units
Mass	650	[kg]
Inertia	5%	-
m_k	682.5	[kg]
f0	90	[N]
f1	0	[N/(km/h)]
f2	0.041	$[N/(km/h)^2]$

$$F_{res}(v) = f_0 + f_2 \cdot v^2$$

$$F_{Wheel} = F_{res}(v) + m_k a + mg sin\alpha$$



Calculate tractive power demands from user cycle

Total Power Demand

$$P_{elec} = F_{Wheel} \cdot v$$

Vehicle Data		
Concept	Value	Units
Mass	650	[kg]
Inertia	5%	-
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f0	90	[N]
f1	0	[N/(km/h)]
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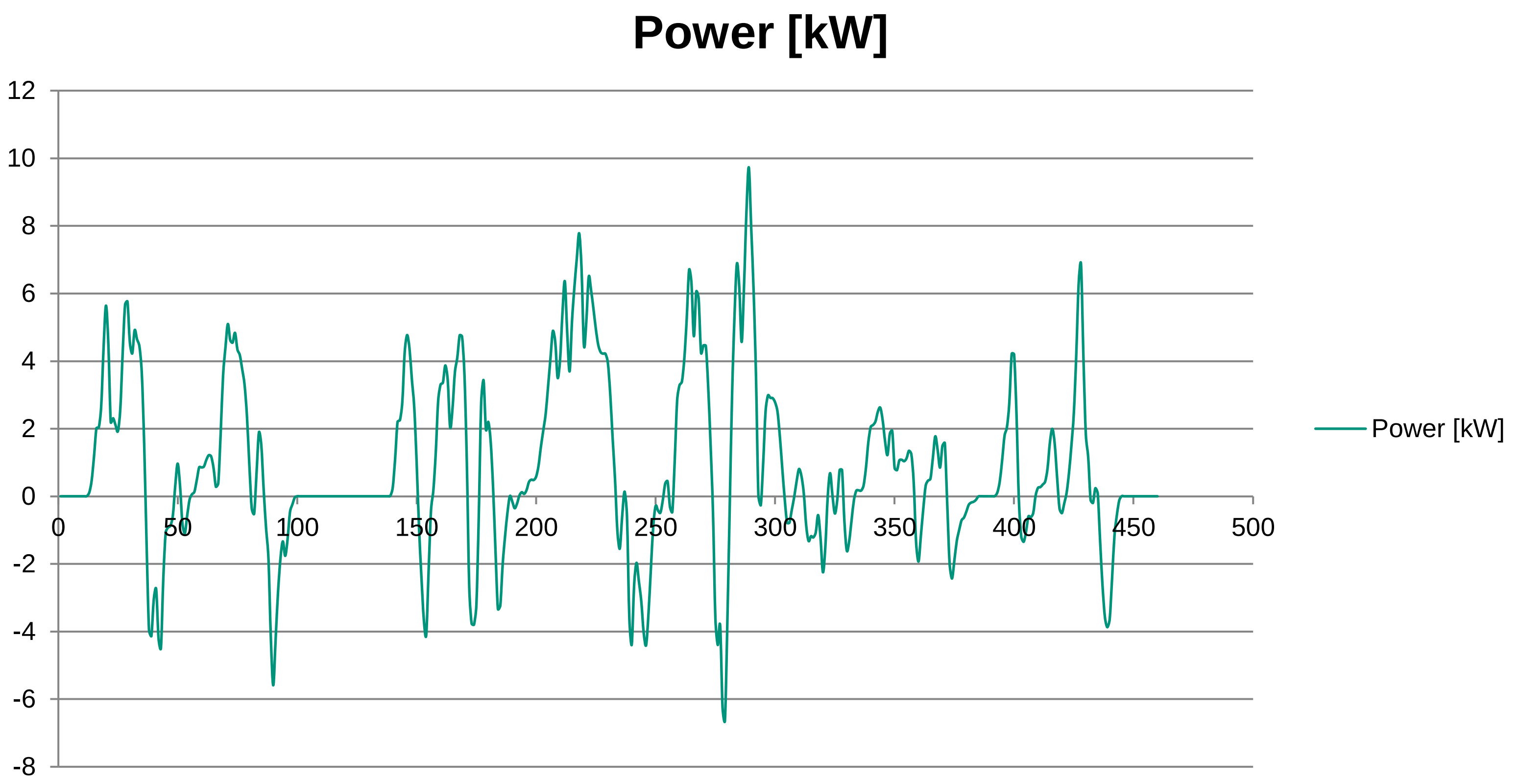

Calculate tractive power demands from user cycle

Motor Power at wheel

Calculate the part of the Wheel power that is executed by the electric motor (the rest is executed by the hydraulic brake).

For this we limit the total acceleration, to the acceleration that can be performed by the motor brake (up to 1-1,5 m/s2).

The rest of the acceleration will be performed by the hydraulic brake and the energy will be lost.

Vehicle Data		
Concept	Value	Units
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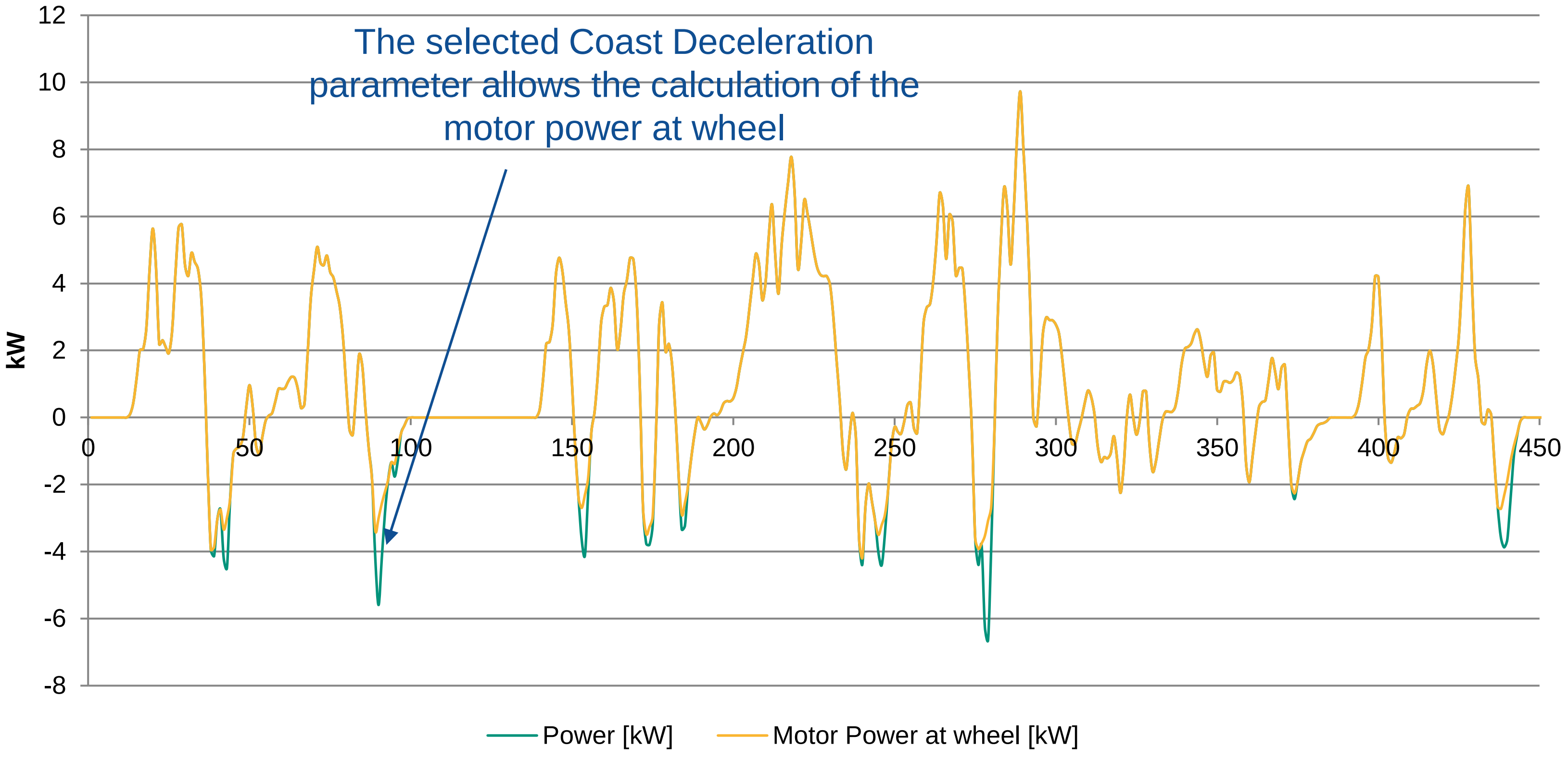
Inertia	5%	-
m_k	682.5	[kg]
f0	90	[N]
f1	0	[N/(km/h)]
f2	0.041	[N/(km/h)^2]
Coast Deceleration	-0.75	[m/s^2]



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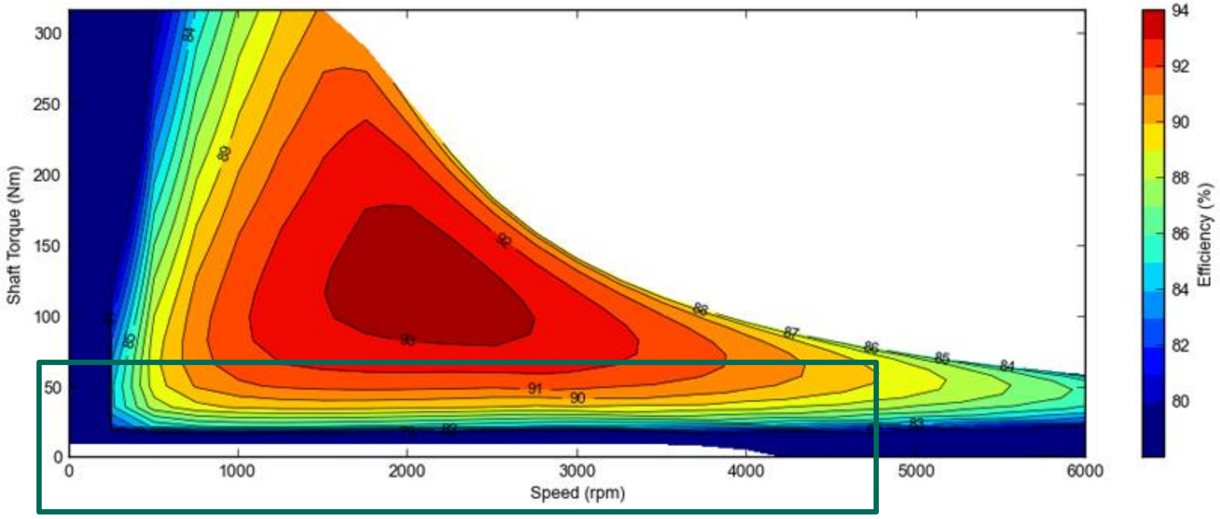
Calculate electric traction power demands

Motor efficiency:

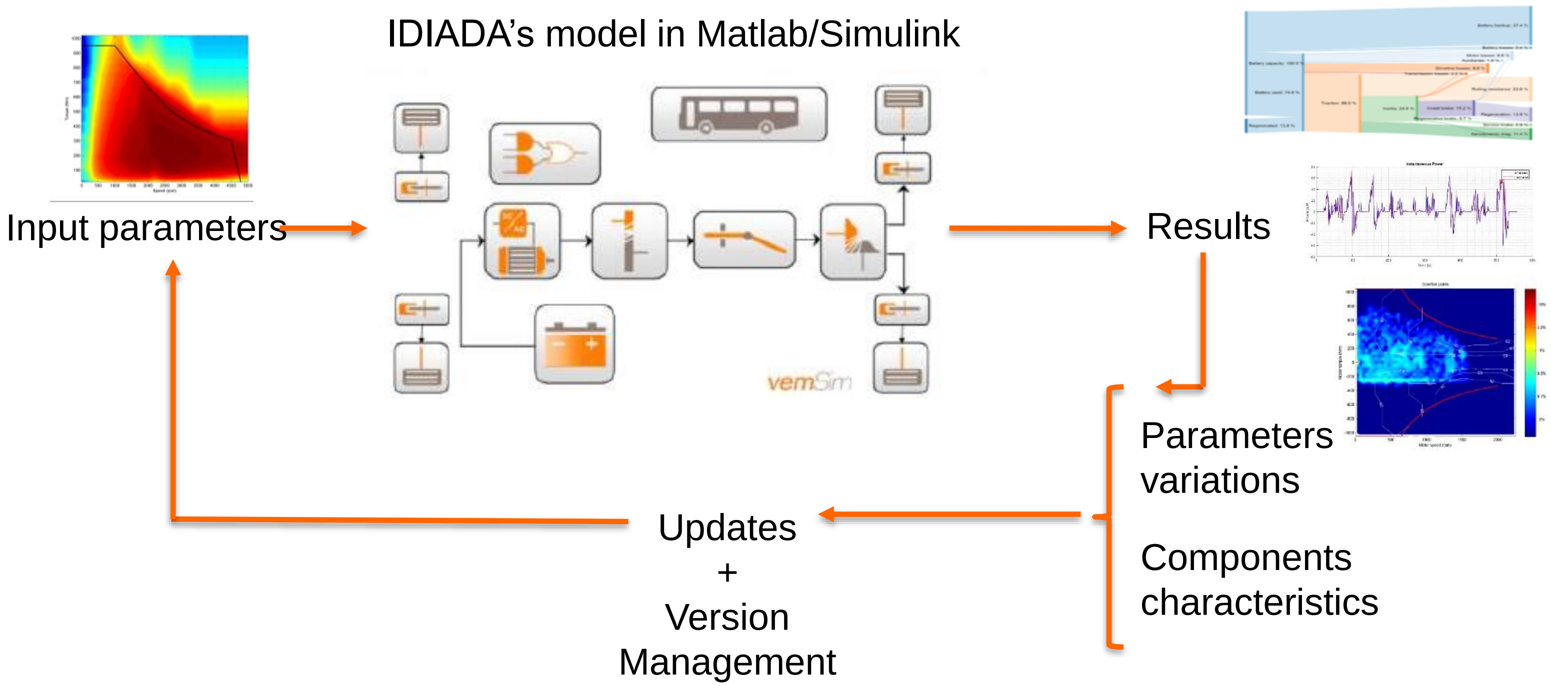
- Motor and transmission efficiency are not constant.
- It depends mostly on the instantaneous torque and speed, but also on temperature, voltage…
- The lower areas have lower efficiency because all the mechanical components have a drag, that we need to overcome in every revolution. At high torque that drag is very small in % so it does not affect the efficiency much. But at low torque the efficiency is very affected.
- For example: if the drag of an electric motor is 4 Nm, when working at 50 Nm it lowers the electric efficiency 4/50=8%, but at 400 Nm it only lowers the efficiency 4/400=1%
- Even though we observe very high efficiency areas, in practice in normal driving we work in the lower areas with lower efficiencies. The high torque areas are only used in specific high demanding situations.



Calculate electric traction power demands

Motor efficiency:

- It is complex to calculate the consumption considering the instantaneous components efficiency. For that purpose, a simulation software is required to interpolate in each time step the instantaneous efficiency. For example:

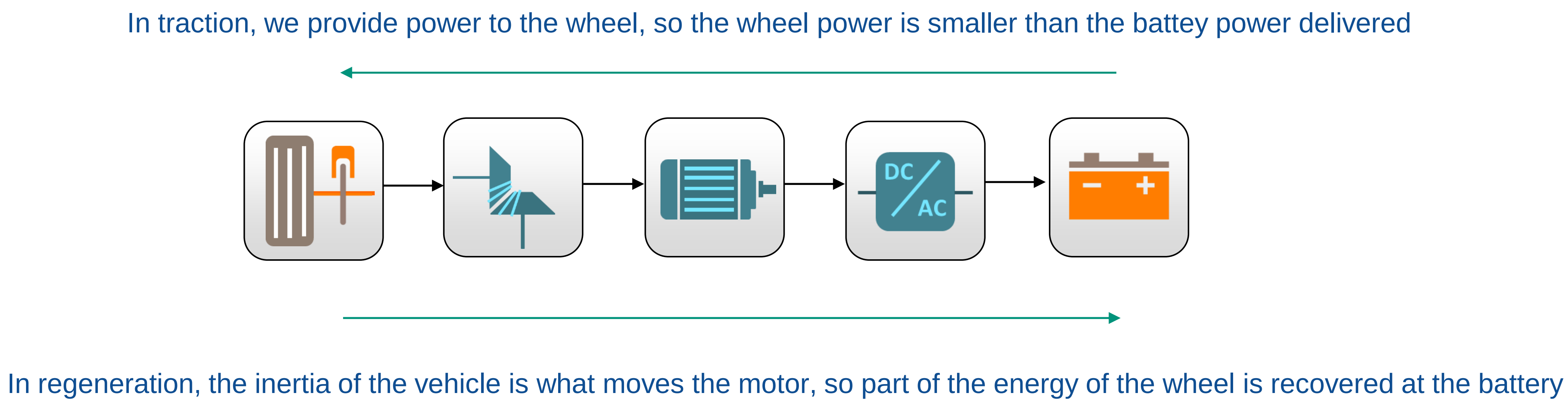


However, consumption can be approximated by considering an average efficiency of all the drivetrain components (transmission+motor+inverter). For very specific and optimized automotive motors consider 70-85% average efficiency. If the motor is not optimized for the application consider 60-70% average efficiency.

Calculate electric traction power demands

Electric demand for traction

- The power demand is a flow energy between the battery and the wheels.
- Due to the components efficiency, the energy at the beginning of the flow is always higher that the energy obtained at the end of the flow.

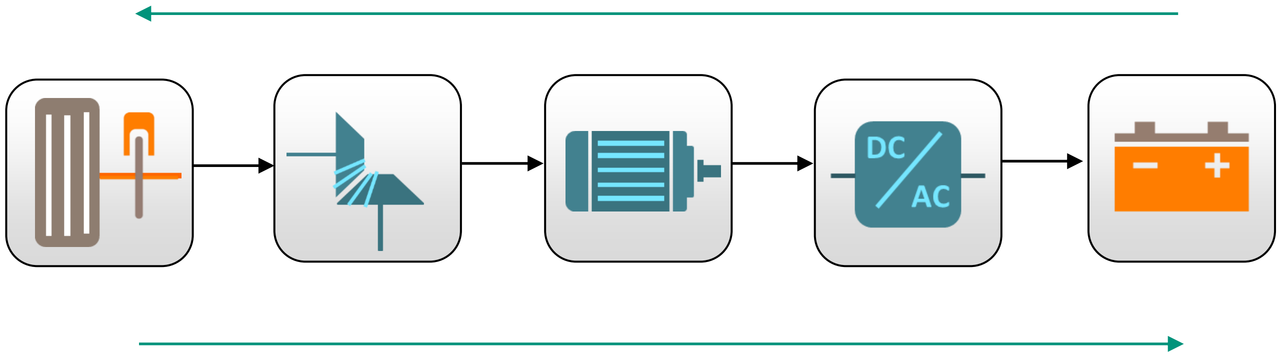


Calculate electric traction power demands

Electric demand for traction

- The power demand is a flow energy between the battery and the wheels.
- Due to the components efficiency, the energy at the beginning of the flow is always higher that the energy obtained at the end of the flow.

$$In\ traction \Rightarrow\ P_{elec} = \frac{P_{Wheel}}{\eta_{trans} \cdot \eta_{motor} \cdot \eta_{inverter}}$$



$$In\ regeneration \Rightarrow\ P_{elec} = P_{Wheel} \cdot \eta_{trans} \cdot \eta_{motor} \cdot \eta_{inverter}$$

$$P_{elec} = \frac{P_{Wheel}(P_{Wheel} > 0)}{\eta_{trans} \cdot \eta_{motor} \cdot \eta_{inverter}} + P_{Wheel}(P_{Wheel} < 0) \cdot \eta_{trans} \cdot \eta_{motor} \cdot \eta_{inverter}$$

Calculate electric traction power demands

Electric demand for traction

Vehicle Data		
Concept	Value	Units
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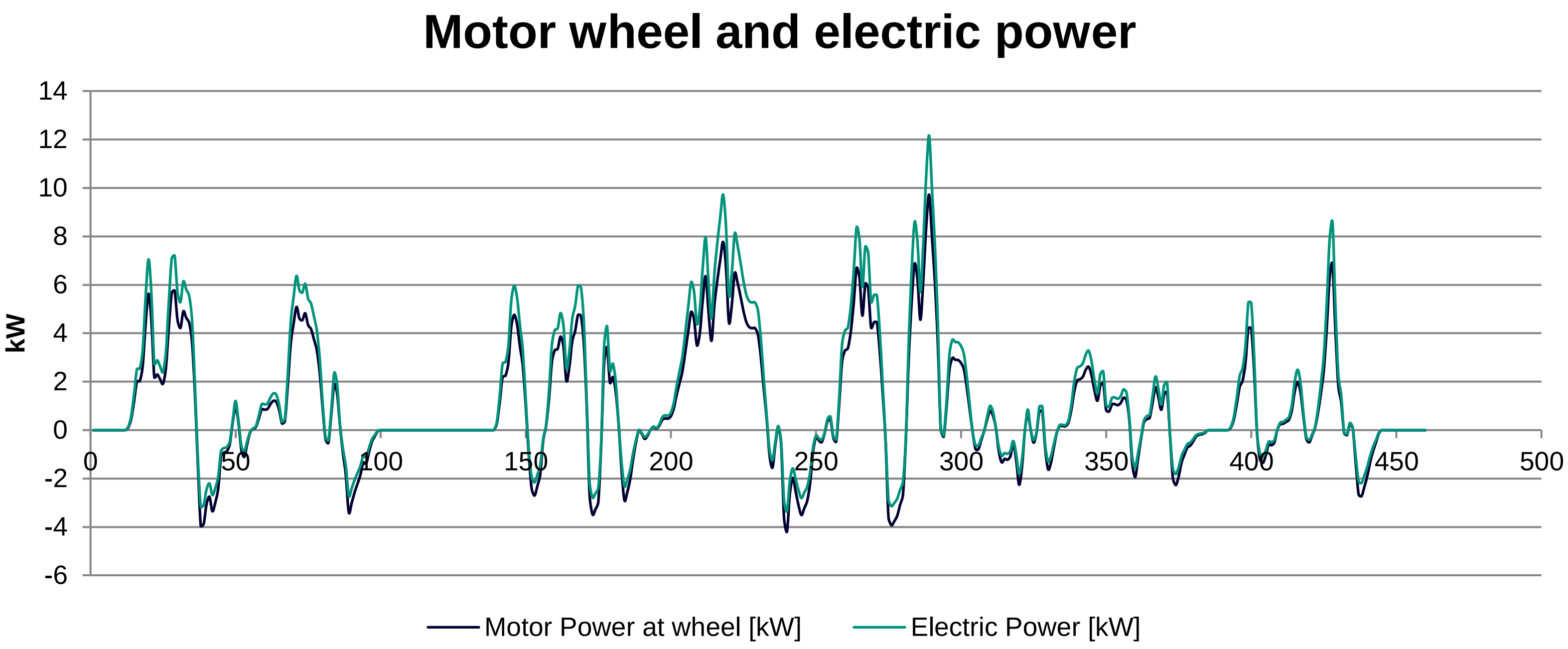
Inertia	5%	-
m_k	682.5	[kg]
f0	90	[N]
f1	0	[N/(km/h)]
f2	0.041	$[N/(km/h)^2]$
Coast Deceleration	-0.75	$[m/s^2]$
Average efficiency	0.8	-



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Define battery target capacity

Additional consumers

Appart from the traction demand, we should consider other consumers:

- Electronic control units
- LV systems
- Radio
- Lights
- Display screen
- Comfort consumption
- Cargo refrigeration
- Special devices: eg: refuse collection
- …

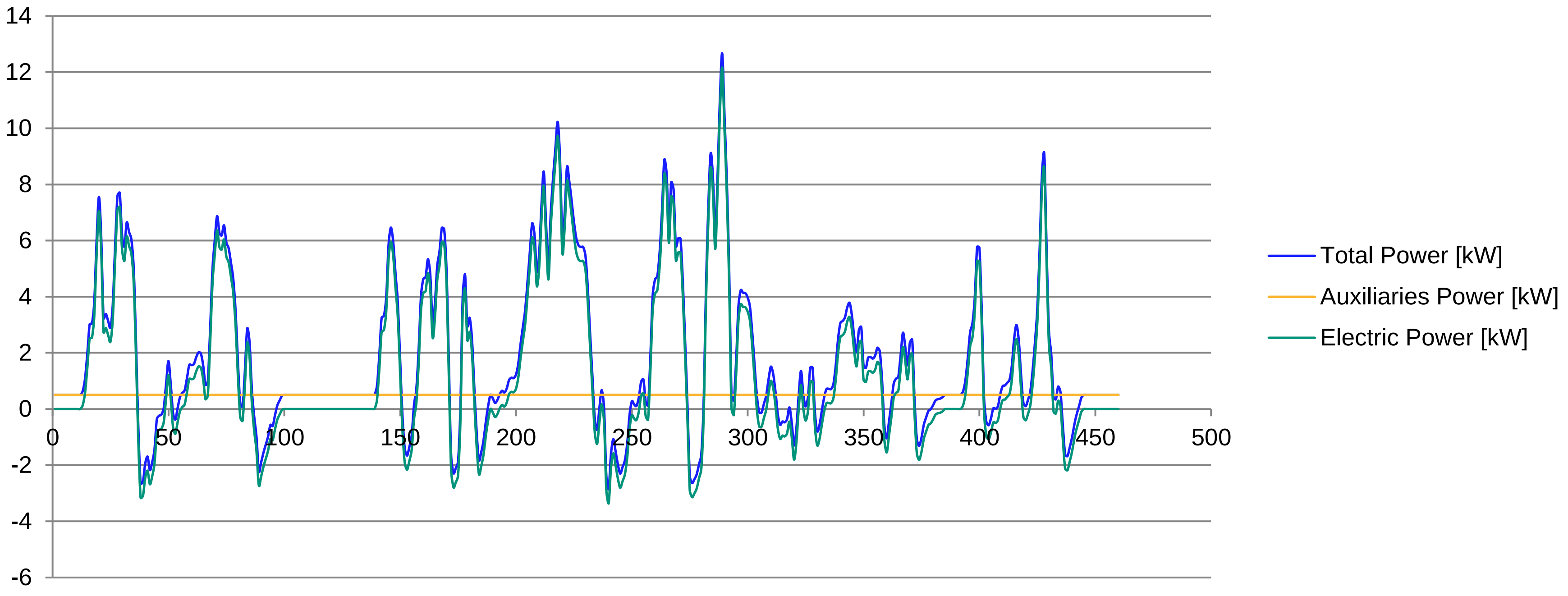
To consider the additional demand, consider the specification kW consumption of your devices and consider which ones, and to which load demand, will be using in the use case

Define battery target capacity

Additional consumers

Vehicle Data		
Concept	Value	Units
Mass	650	[kg]
Inertia	5%	-
m_k	682.5	[kg]
f0	90	[N]
f1	0	[N/(km/h)]
f2	0.041	$[N/(km/h)^2]$
Coast Deceleration	-0.75	$[m/s^2]$
Average efficiency	0.8	-
Additional Consumers	0.5	[kW]

$$P_{bat,out} = P_{elec} + P_{consumers}$$



Define battery target capacity

Energy requirements for the range:

Total Energy for the cycle: $E_{bat,out} = \frac{\int P_{bat,out} \cdot dt}{3600}$

Total Distance for the cycle: $D = \int v \cdot dt$

Kilometric consumption $Cons_{bat,out} = \frac{E_{bat,out}}{D}$

Total energy for the range: $Erange_{bat,out} = Range \cdot Cons_{bat,out}$

Define battery target capacity

Additional margins

- Appart from this energy, you also need to consider additional margins due to:

Internal resistance:

The resistance is small, but it disipates part of the power when charging and discharging. The energy loss depends on the cell technology, battery architecture, current, SOC, charge/discharge, temperature…

Remaining SOC:

You should not size the battery to comply the target range at 0% SOCs for various reasons:

- When charging, most of the time charge does not reach 100%
- Depleting to 0% strongly damages the battery and reduces its life
- When the vehicle communicates that there is no energy remaining, there should be some additional energy at least for a safety stop
- When the vehicle ages, the range is reduced. If we want the vehicle to comply with the range target after X years we need to oversize the battery considering that degradation

Define battery target capacity

Battery capacity

Calculate the battery capacity:

$$E_{bat} = E_{bat,out} \cdot k_{resistance} \cdot k_{margin}$$

Knowing this capacity, you can design your battery combining cells or modules to reacht the target capacity, power and voltage

You can check for different cells at: https://www.batemo.de/products/batemo-cell-library/

Please consider that the weight and the volume of the battery is not negligible when making a vehicle:

- If the battery volume is too high, you may analyze where to integrate it or lower your range targets
- After you know your battery weight, maybe you should re-consider the final weight of the vehicle and rerun the power and range calculations with that higher weight

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Energy requirements validation

Benchmarking

- It is always useful to validate your analysis and calculations with the competitors in order to validate the sizing of the electric motor and battery.
- To validate the power calculation, compare the power you obtained for the emotor with the power declared by the competitor.
- Differences can be due to different use case targets. But are useful to validate our calculation and target setting

Energy requirements validation

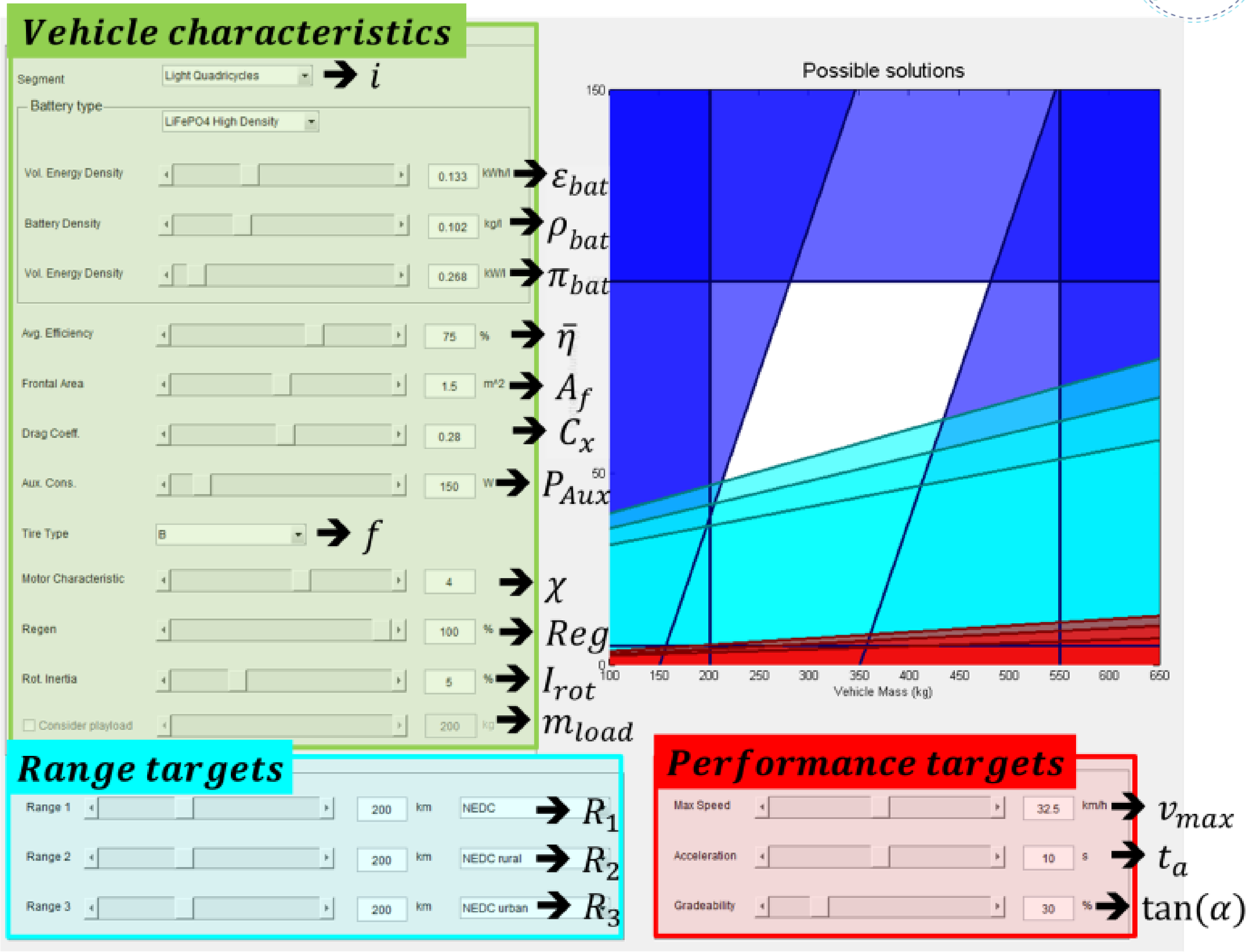
IDIADA's Pre-sizing tool

- Constraints are interrelated through vehicle weight and battery volume
- Market practices, structural feasibility, regulation restrictions, battery density, packaging…
- Linear programming → Inequations

Feasible solutions

Critical restrictions

- Represents deterministic restrictions
→ It helps decision-making



Energy requirements validation

IDIADA‘s Pre-sizing tool

Vehicle segment constraints:

❶ **Max. battery volume** ~ available space

❷ **Min. battery volume** ~ feasibility

❸ **Max. battery mass**

→ guarantee consistent structural weight

❹ **Max. vehicle mass**

** Light duty → Max. GVM = 3500 kg → Playload considered*

❺ **Min. vehicle mass** ~ feasibility

❻ **Quadricycle mass limit** without battery

Power constraints:

❼ **Max. speed**

❽ **Gradeability**

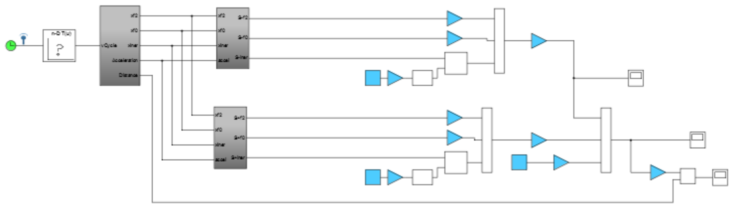
❾ **Acceleration**

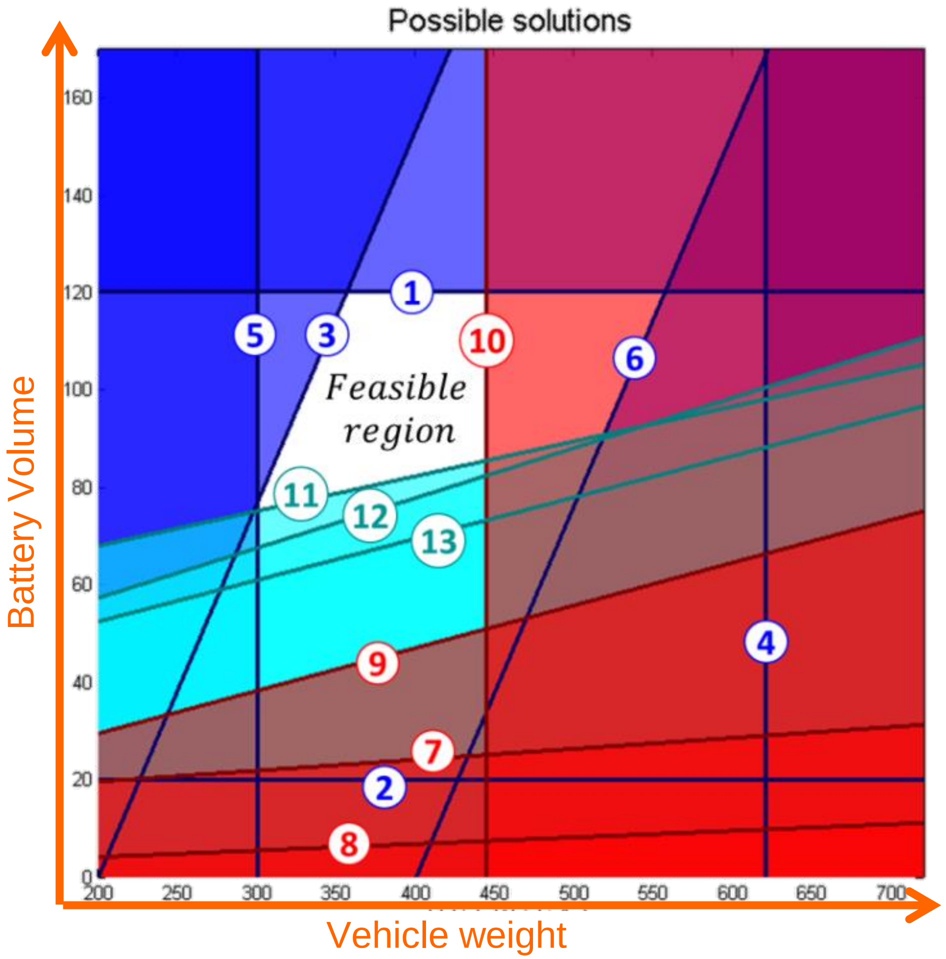
❿ **Quadricycle power limitation**

→ delimits a mass m

Energy constraints:

⓫ ⓬ ⓭ **Range in 3 user-defined cycles**

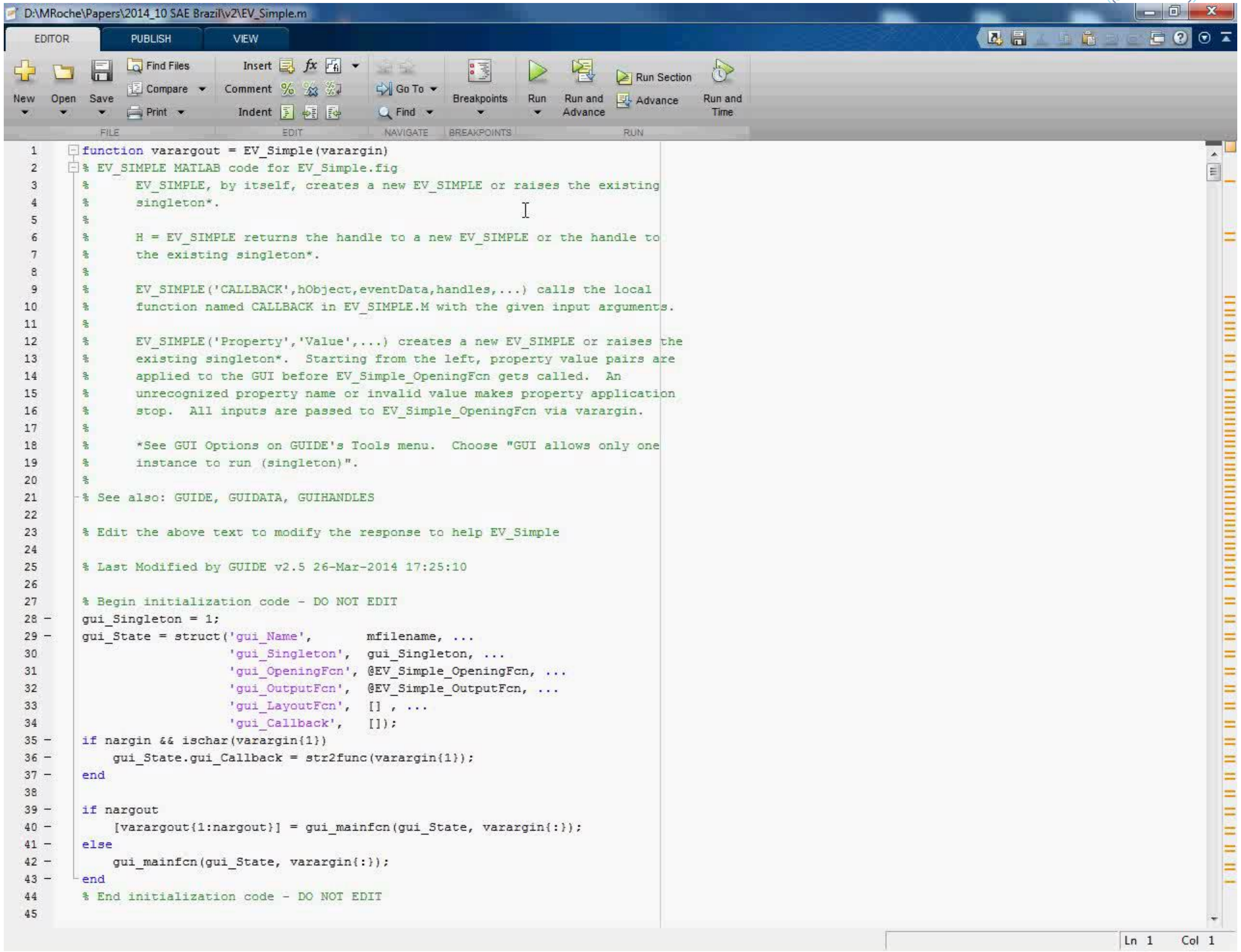




Energy requirements validation

IDIADA‘s Pre-sizing tool

Demo video:



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References

References list:

- **Sizing of some IDIADA’s prototypes:** *Mammetti, M., Roche, M., "The Development of the Online Tool For the Definition of the Powertrain’s Components Requirements for Electric Vehicles within the ELVA Project", SAE Brazil 2014 Technical Paper 2014-36-0233.*
- **Development of the Minibus prototype:** *Roche, M., Maroto, P., Mammetti, M. et al, “Development of an advanced and sustainable vehicle for optimal transportation of people in urban environments”, NuGen 2019*
- **Regulation cycles for quadricyles:** *Commission Delegated Regulation (EU) Nº 134/2014: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02014R0134-20161016&from=DA*
- **Need of postprocessing or route recordings:** *Sabria, D; Diaz, F. J.; Cano, P; Roche, M, et al “Virtual Modelling or Real-Driving Conditions for Early Evaluation and Validation of Vehicle Design”, FISITA 2021 doi:10.46720/F2021-ADM-130*
- **IDIADA’s pre-design tool:** *Roche, M., Sabrià, D., Mammetti, M., “An Accesible Predesign Calculation Tool to Support the definition of EV Component”, International Journal of Automotive Technology, Vol. 17, No. 3, pp. 509−521 (2016). DOI 10.1007/s12239−016−0052−7.*

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Handout work

Handout work tasks:

- Select vehicle data parameters: Mass, f0, f1, f2, Coast Deceleration, auxiliaries…etc
- Calculate force requirements
- Calculate power requirements
- Calculate motor force at wheel
- Calculate electric traction power & total power
- Calculate battery requirements
- Validation: competitors benchmarking,

example…

Vehicle Data		
Concept	Value	Units
Mass	650	[kg]
Inertia	5%	-
m_k	682.5	[kg]
f0	90	[N]
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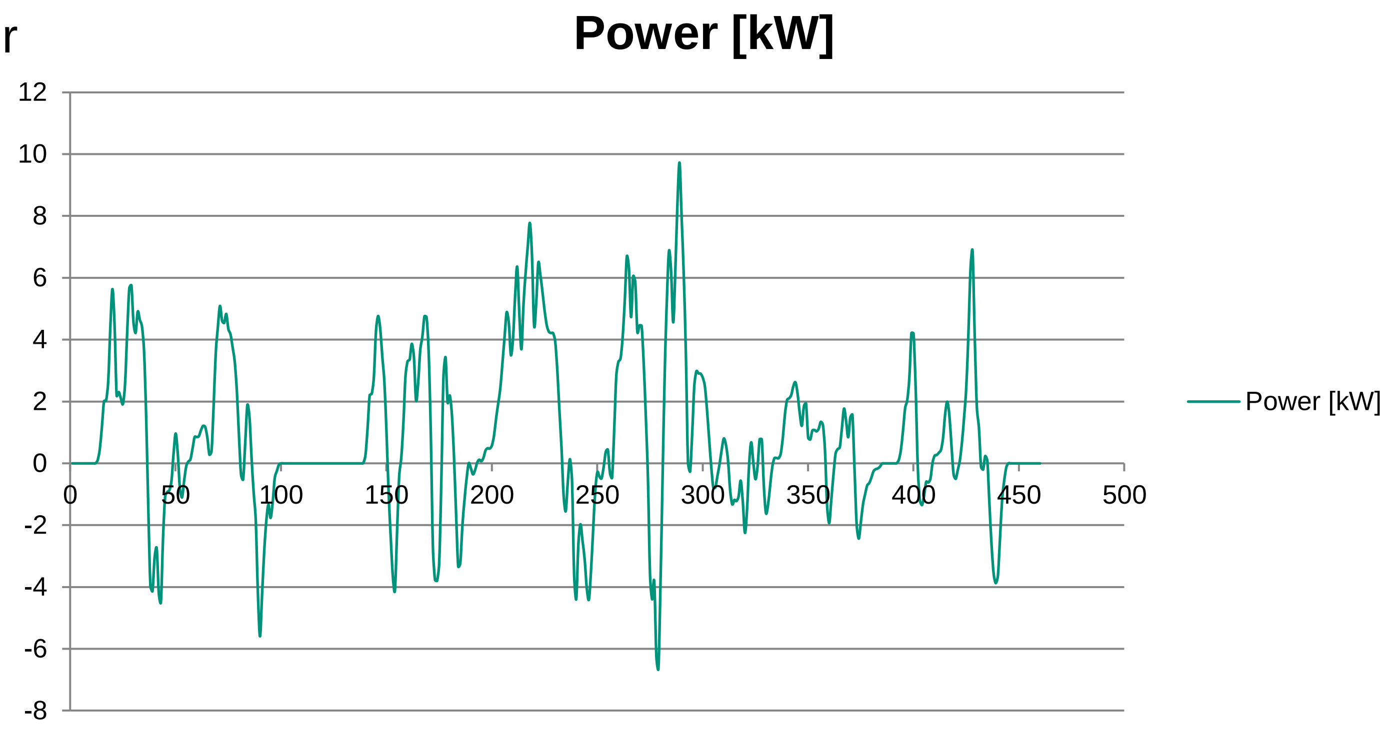
Additional Consumers	0.5	[kW]



Thanks for your kind attention