Electrification of agricultural tractors

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Contents

Research objectives

Larger context

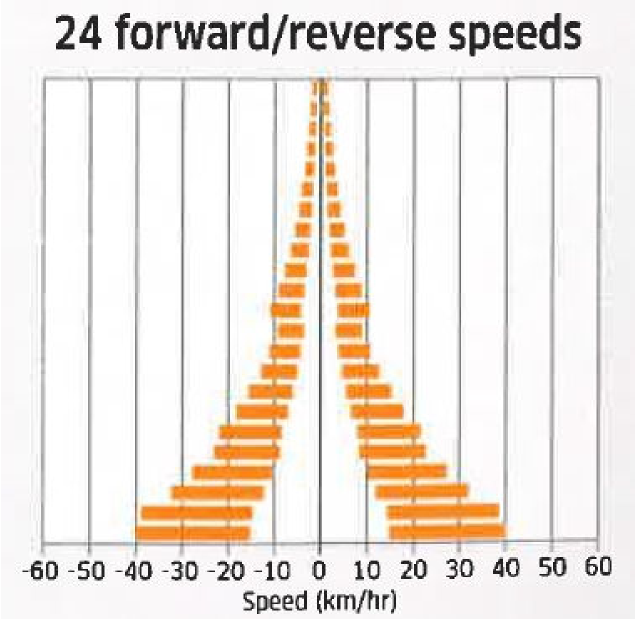
- Investigation of the opportunities and limitations of using electric power in agricultural tractors and implements

This research (EVS32)

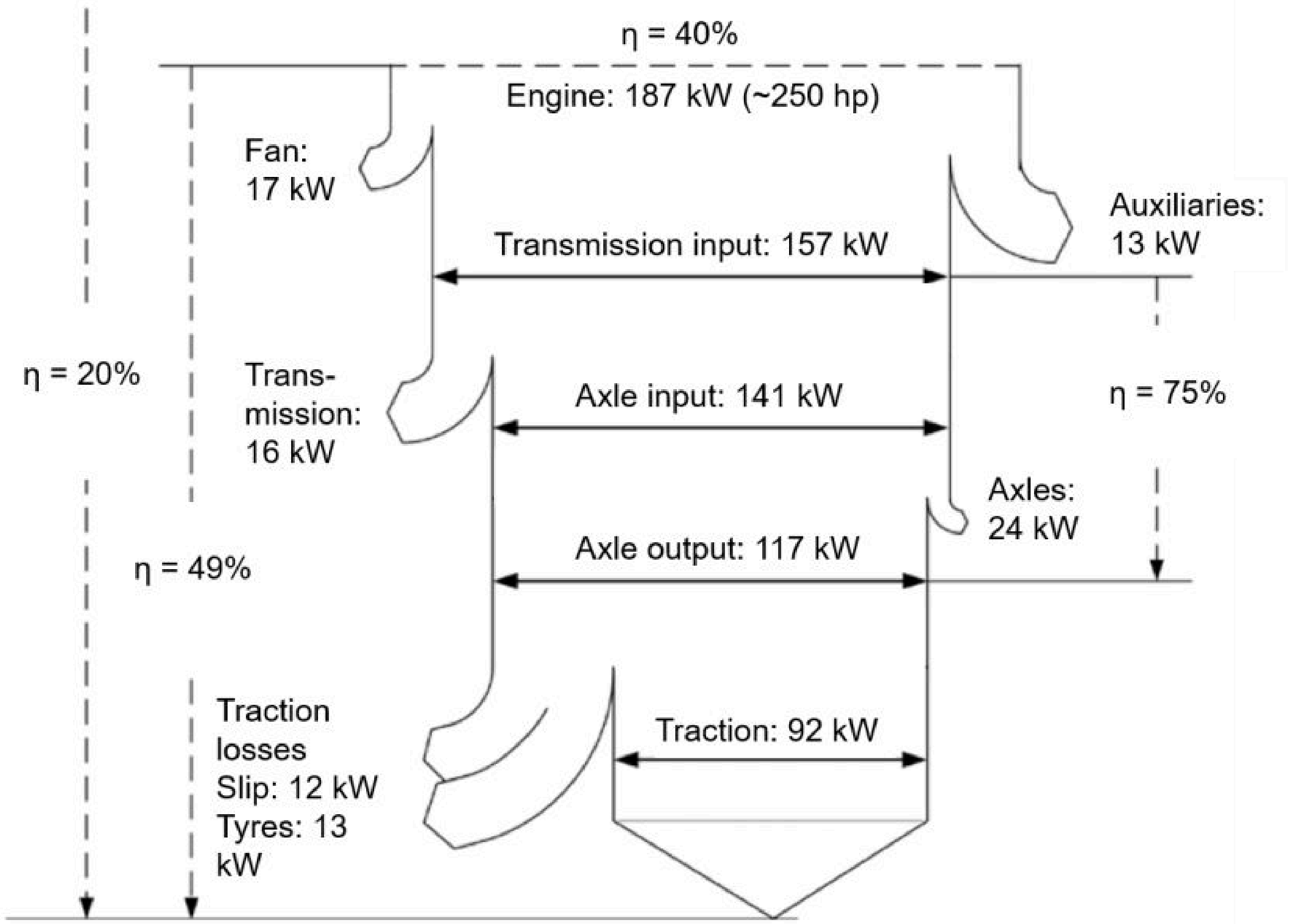
- Modeling of conventional and alternative powertrains
- Comparison of conventional, hybrid and electric powertrain technologies

Description of agricultural tractors

- A multipurpose mobile machine in modern farming and tillage operations
- The driving power is transferred through a specific transmission to the tires
- The working power is delivered via the power take-off (PTO) to the implements
- The transmission needs to have multiple gear reductions and speed ranges



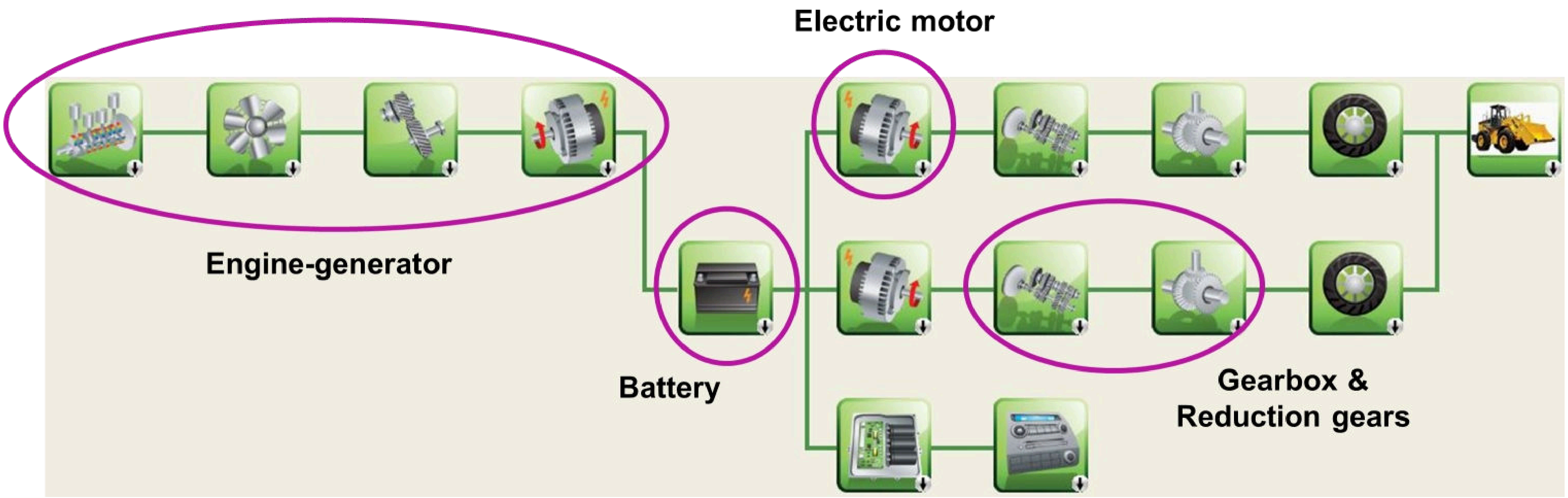
Breakdown of tractor energy losses



Benefits and drivers of electrification

- Improvement of energy efficiency
- Increase of performance
- Reduction of emissions
- New functionalities
- More flexible architectures
- Enhanced controllability and drivability
- Less maintenance and noise pollution
- No idling losses
- Comfort enhancement for the driver
- Autonomous operation

Powertrain electrification – key components



Challenges

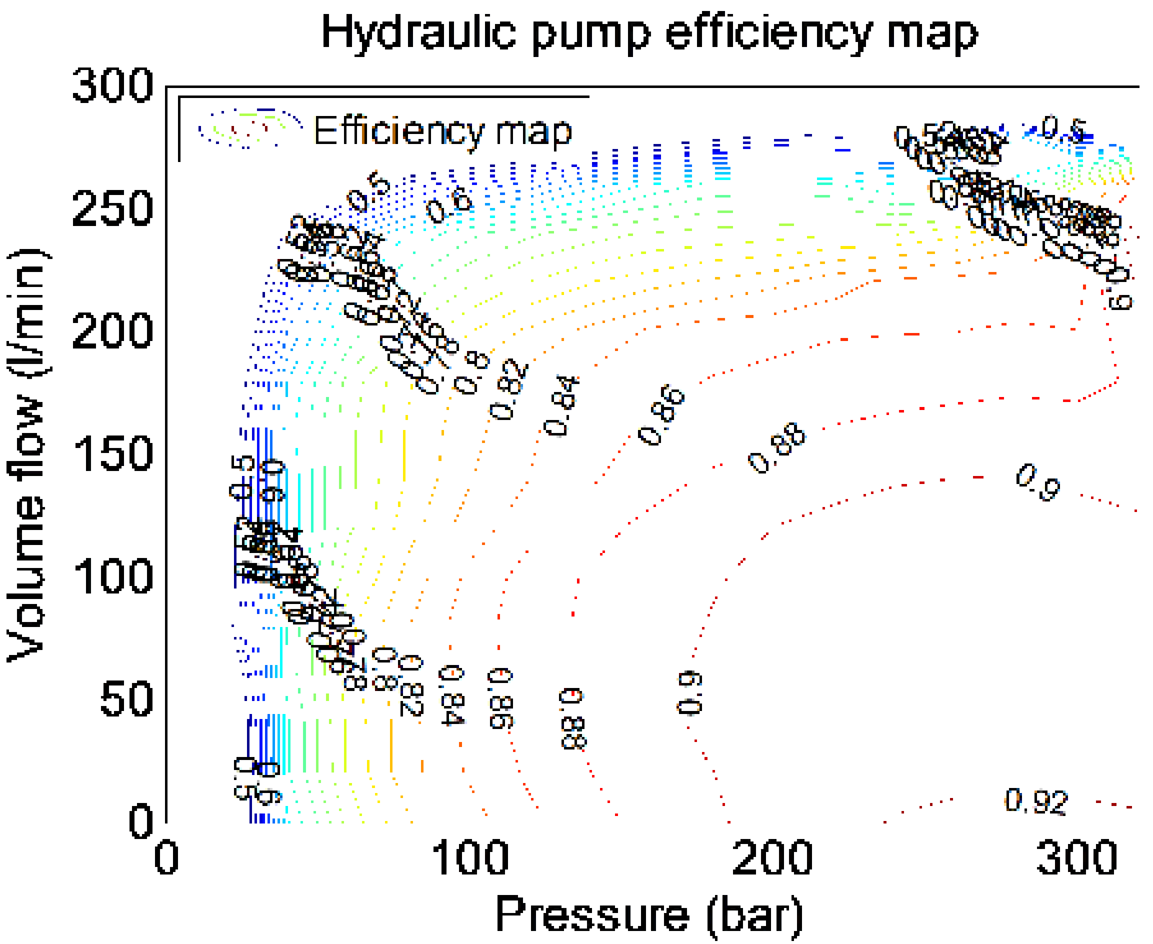
- Thermal management → Many electrical components need liquid cooling
- Safety
  - High voltage systems can cause serious danger → monitoring/diagnostics
  - Requires well trained personnel for service and maintenance
- System level costs
  - Key electrical components (batteries, motors, converters) are still quite expensive
- Availability of charging, from grid to energy storages
- Lack of harmonization e.g. charging interface and charging communication
- Product lifecycle management, e.g. appropriate management of software updates, obsolescence of components and code

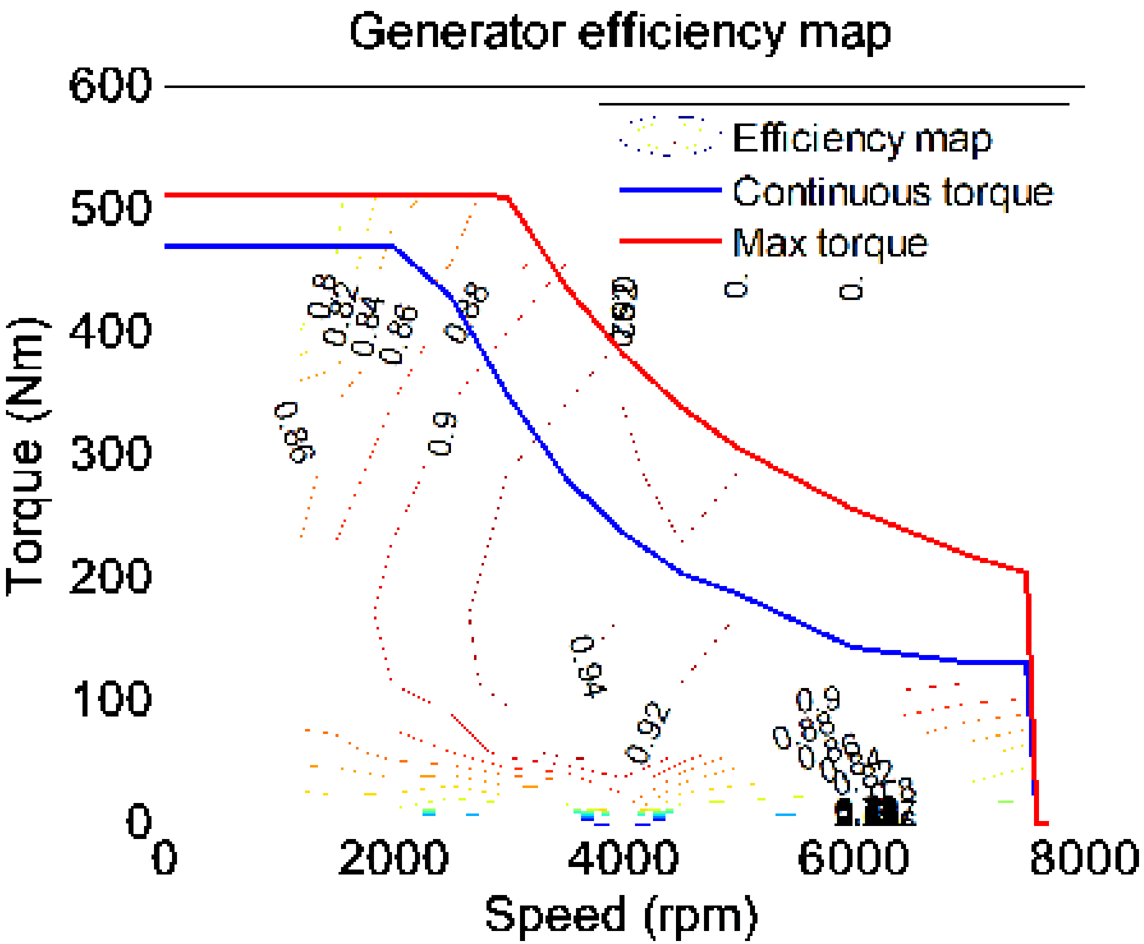
Comparison of technologies

	Electric	Mechanic	Hydraulic
Power to weight ratio	low	good	best
Power to density ratio	low	good	best
Energy transmission	best	good	good
Energy storage	good	low	good
Controllability	best	low	good
Efficiency	best	good	low
Design flexibility	best	good	best
Cost	partially high	low	high

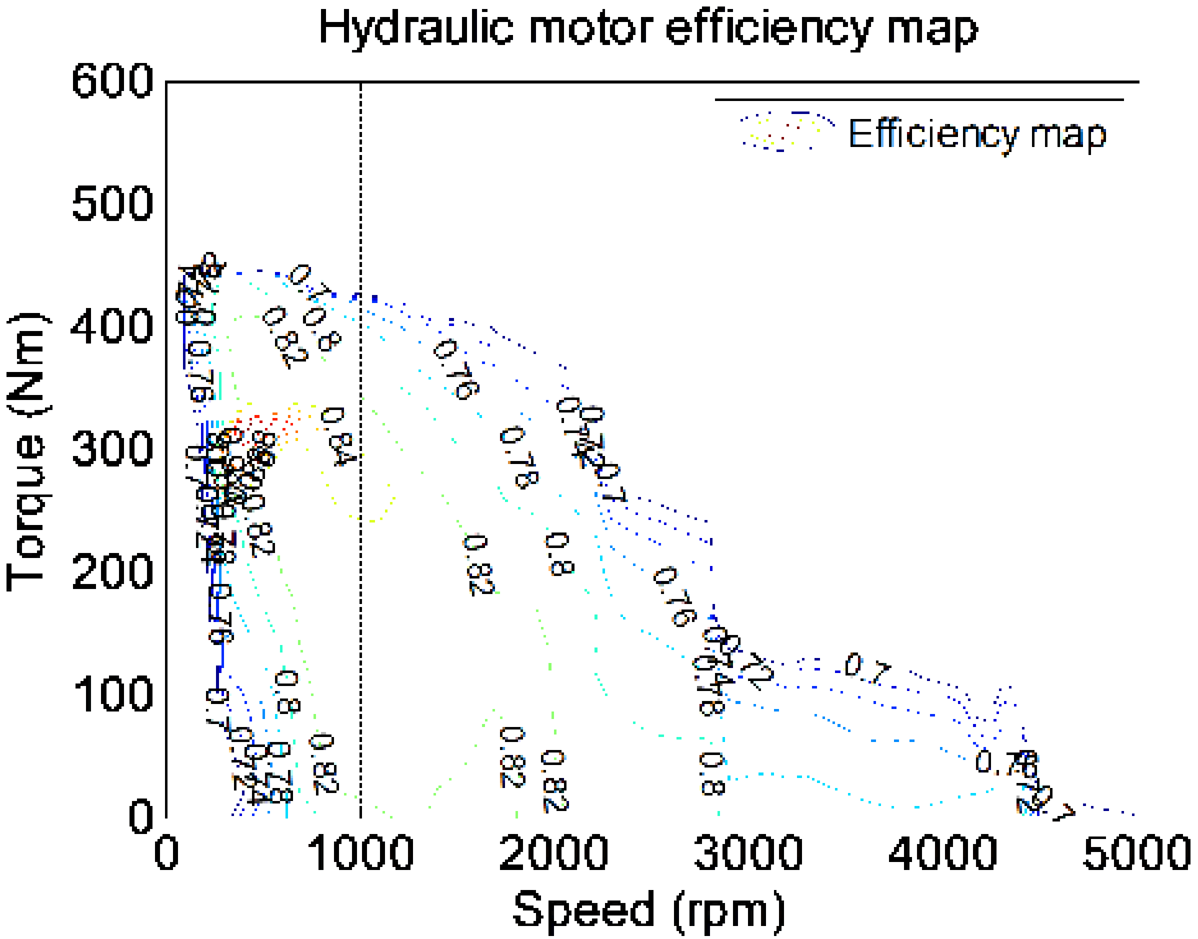
Source: ATZ Off-Highway, "Alternative Drives", October 2009

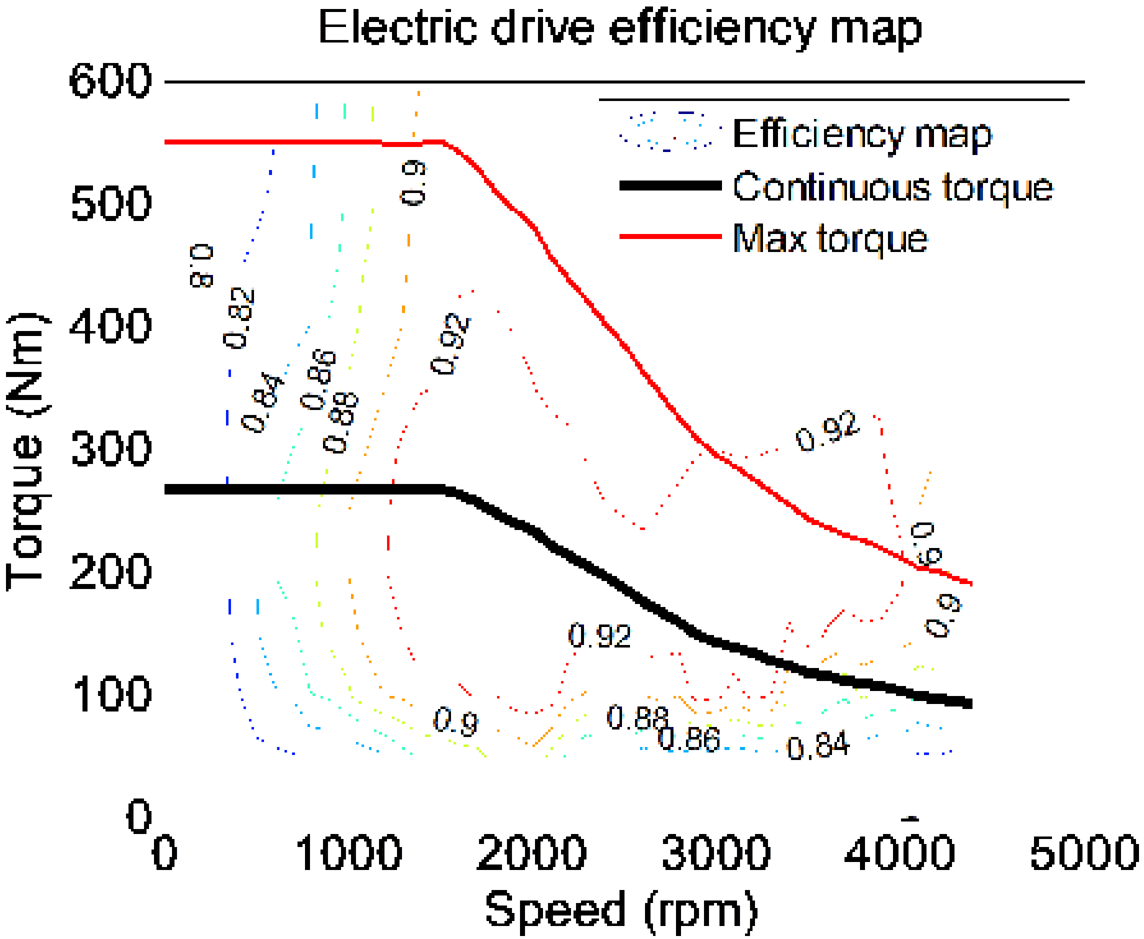
Electric generator vs. hydraulic pump



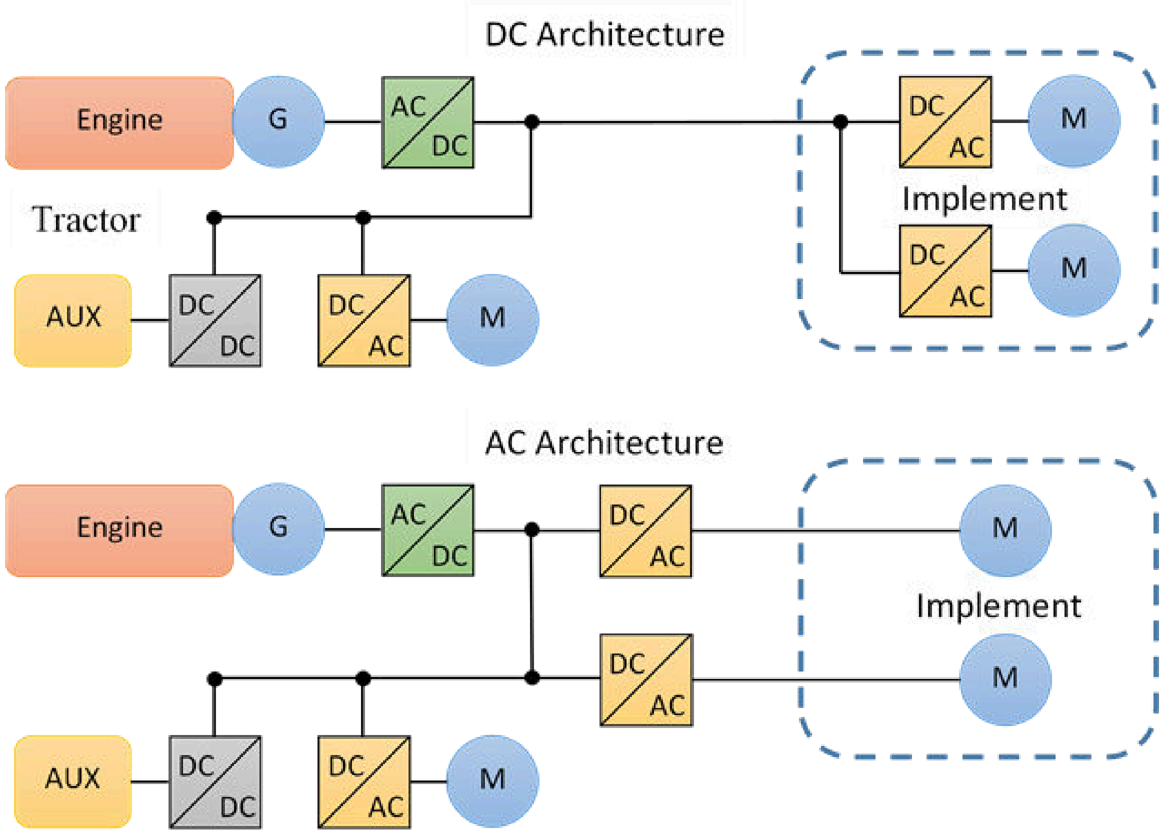


Electric drive vs. hydraulic motor





Electrification - DC and AC architecture



Type	Implement	Example
AC open loop	Simple implements with one or two electric motors	Spreader, Seeder (Fan)
AC closed loop	Simple implement with requirements for controlled speed/torque	Torque axle
DC	Implement with large number of electric motors, or complex control functionality	Fully electrified harvesting machines
DC and AC	Complex implements	Round baler wrapper

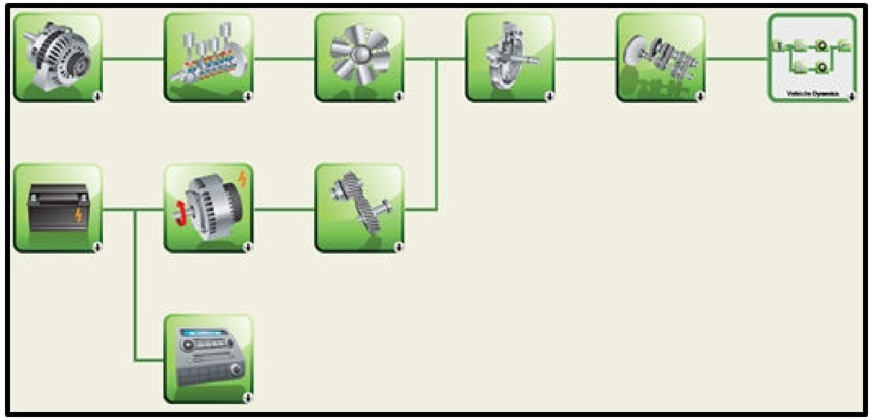
Comparison of architectures

DC Architecture	AC Architecture
❑ Cost effective system for tractor ❑ Higher costs for implements ❑ Control intelligence resides on implement ❑ Complex systems are possible to develop ❑ Cooling of inverters might be needed on implement	❖ More complex system for tractor ❖ Cost effective for implements ❖ Intelligence of control can be distributed ❖ Complex systems harder to realize ❖ Cooling on implement is not necessary

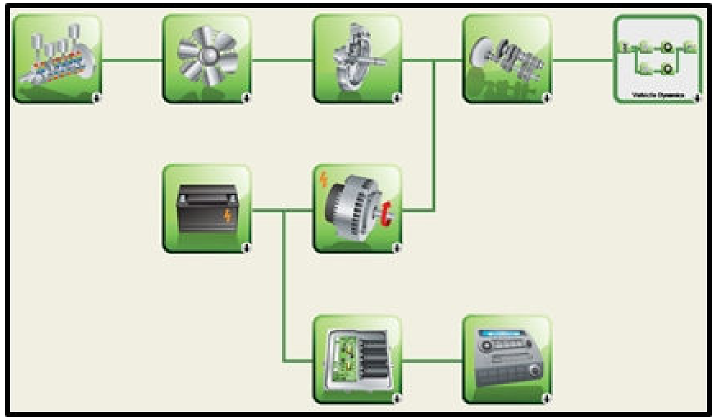
Powertrain modeling

- Simulation models of agricultural tractors were developed in the Autonomie
- Conventional, parallel hybrid electric, and battery electric tractors were modeled
  - Conventional tractor: diesel engine with a dual-clutch transmission
  - Parallel hybrid tractor: pre-transmission hybrid with a dual-clutch transmission
  - Electric tractor: full electric powertrain with a battery and three-speed gearbox

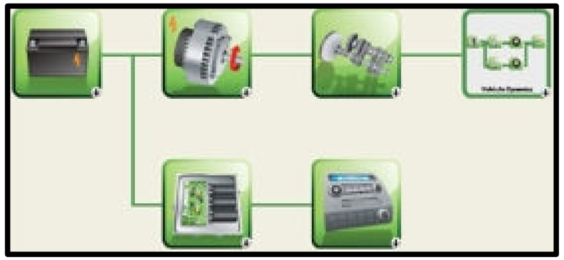
Conventional



Parallel hybrid



Electric



Simulation parameters

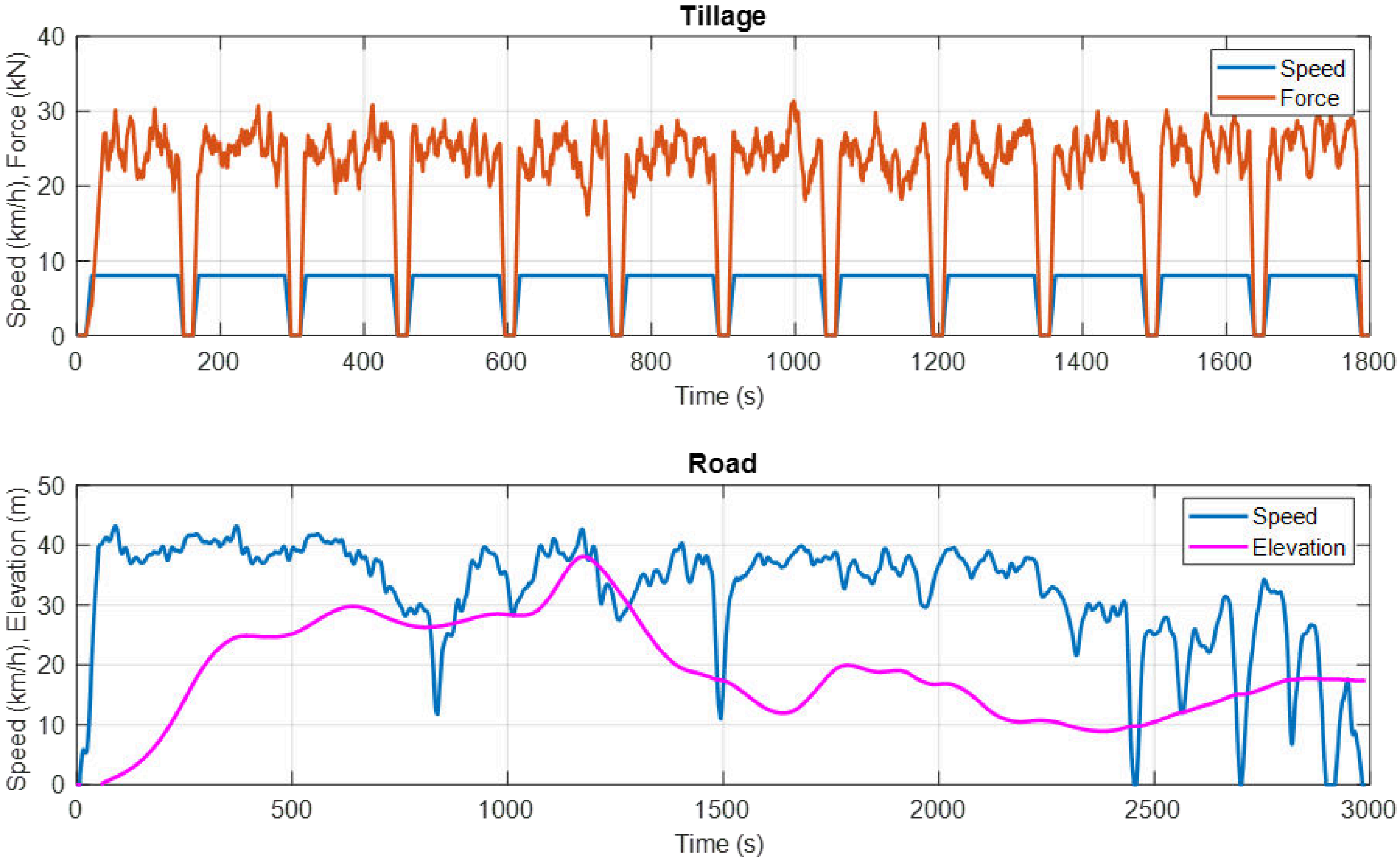
The simulation models correspond to typical agricultural tractors of power range around 200 kW.
The models were parameterized by using the Autonomie libraries.

Component	Description
Diesel engine	maximum power 225 kW, maximum torque 924 Nm
Transmission	8-speed dual clutch transmission (DCT) with 3 ranges
Rear axle	bevel set ratio of 3.28:1 and planetary gear ratio of 6:1
Front axle	bevel set ratio of 2.48:1 and planetary gear ratio of 6:1
Tires	front: 540/65R30, rear: 650/65R42
Weights	kerb weight: 8600 kg, payload: 3900 kg

Component	Parallel hybrid	Electric
Diesel engine	maximum power 175 kW, maximum torque 719 Nm	---
Transmission	8-speed (DCT) with 2 ranges	3-speed gearbox
Battery configuration	Saft 6 Ah cell, 2 packs in parallel, 180 cells in series in a pack, 648 V, 7.8 kWh	33 Ah cell, four packs in parallel, 192 cells in series in a pack, 720 V, 95 kWh
Electric motor	max power 100 kW, max torque 542 Nm, max speed 4400 rpm	max power 225 kW, max torque 611 Nm, max speed 8000 rpm

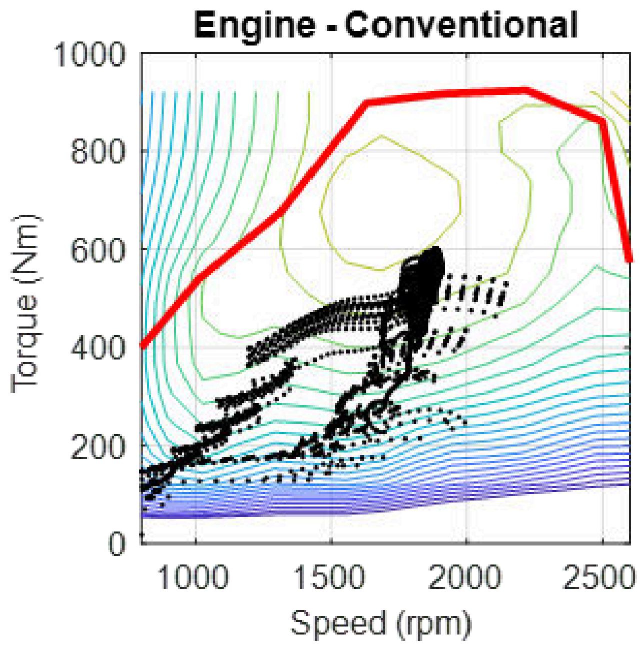
Simulation cycles

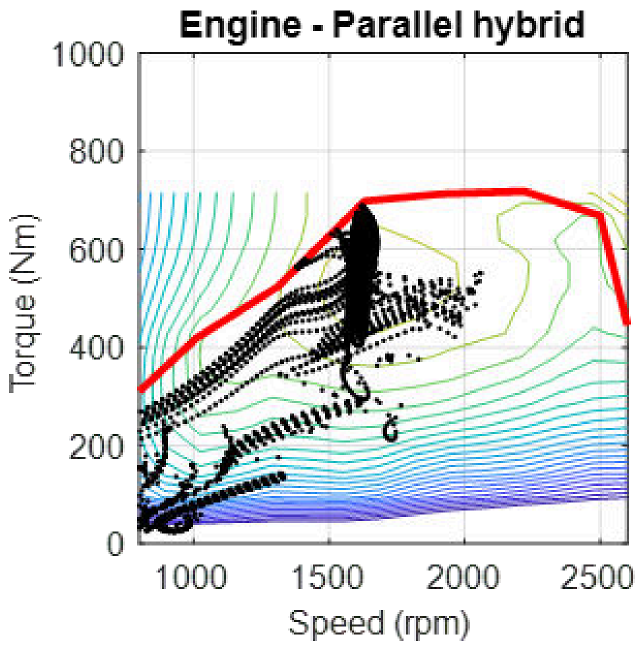
- The developed tractor models were simulated in dedicated test cycles that correspond a tillage operation and road cycle driving.
- The tillage cycle: the workload is on average 25 kN and target speed is 8 km/h.
- The road cycle represent a speed profile on a road route with elevation. The road cycle was simulated with a trailer having a load of 15000 kg.

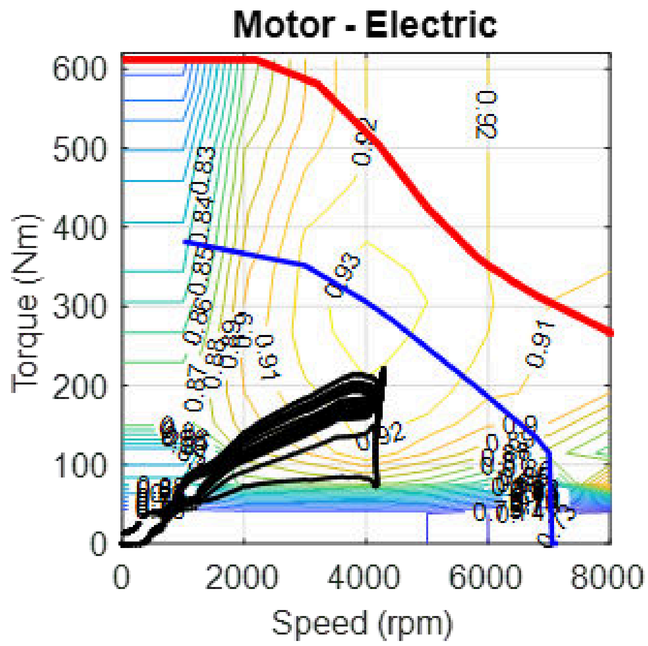


Simulation results – tillage operation

- The parallel hybrid: engine operation point very close to the best efficiency area.
- The electric tractor: no gears changes → better speed control, high efficiency

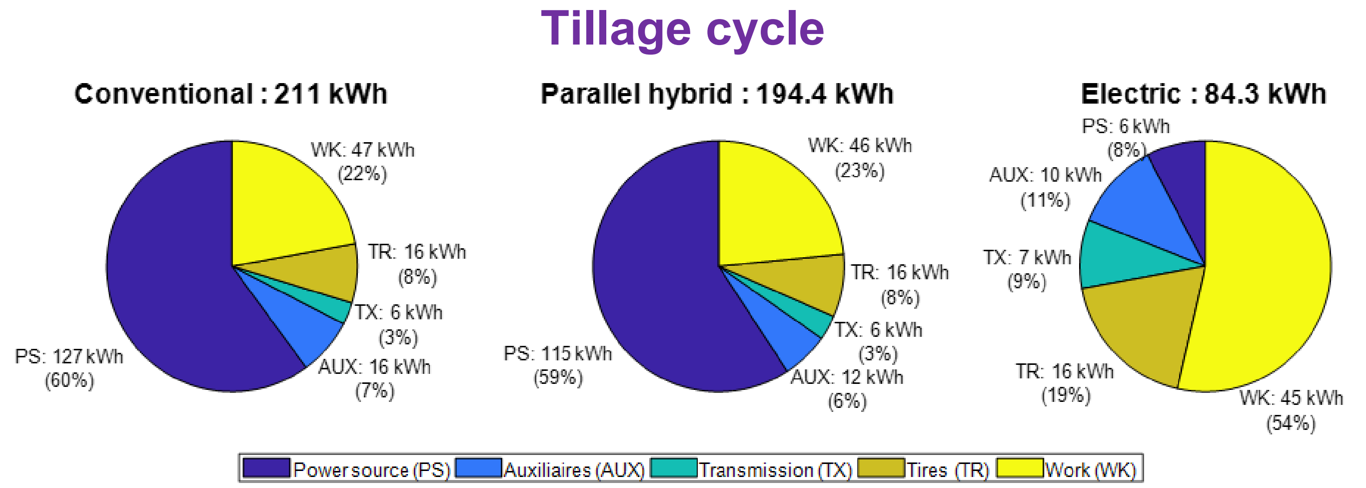


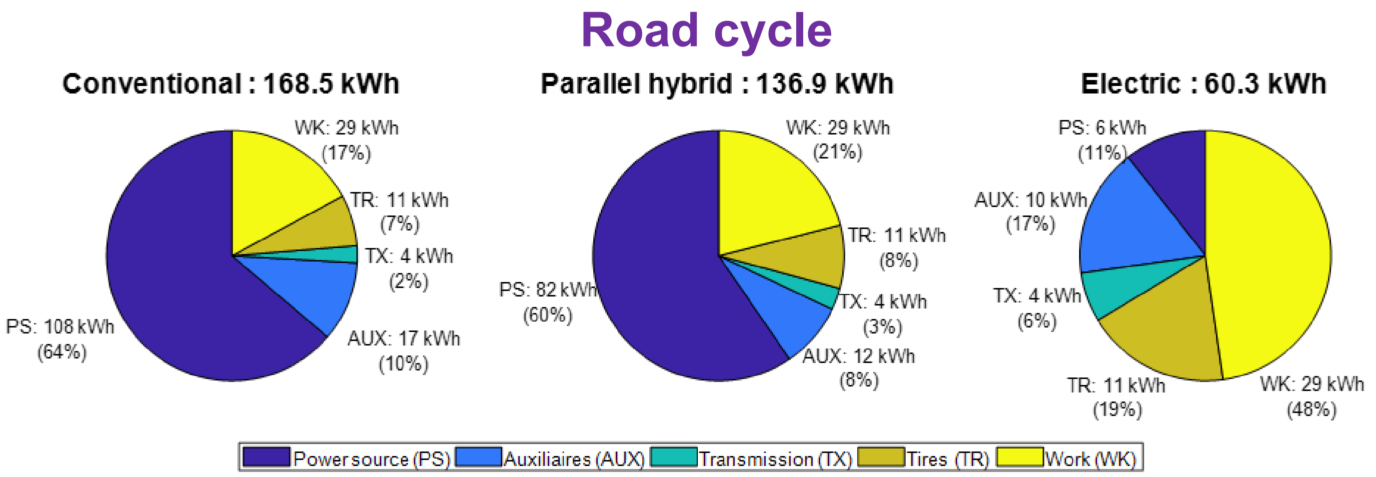




Simulation results – Energy consumption

- The energy savings of powertrain hybridization is from 8% to 20% being higher on the road cycle.
- The battery electric tractor illustrates a significant energy saving potential in both cycles being around 60% when compared to the conventional tractor.
- The driving on the road provides more potential for energy savings for the hybrid system due to the speed variations and changes in road load





Summary

- Agricultural tractors and vehicles have often dedicated transmissions that nowadays offer continuously variable speed control from the engine to wheels
- Many power functions in agricultural tractors and implements are based on using hydraulic systems
- Electrical systems provides several benefits over the traditional mechanical and hydraulic systems
- Electrification requires a well-design system structure which depends on the intended use
- Modelling and virtual simulation are important tools especially when designing complex systems having different technologies
- 48 Volts DC could be a (intermediate) solution for implements
- Full electric tractor with high power charging?

Thank you for your attention

Electrification is not a necessity but a great opportunity!

Any questions?