Enhancing Synergy Effects Between The Electrification Of Agricultural Machines And Renewable Energy Deployment With Semi-Stationary Energy Storage In Rural Grids

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Motivation for electrifying agricultural machines

- higher working precision
  -> saves fertilizer and chemical plant protection products can even be done mechanically
- automation of agricultural production possible
- silent operation -> operations 24 hours per day
- higher efficiency, higher power
- abundant potential for renewable electric energy generation can be used on site
- synergy between PV generation and agricultural machine operation

Two ways of electrification

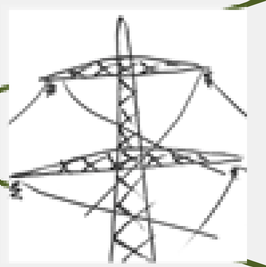
1. on-board battery

   -> only for small machines, mainly cattle breeding

2. connection to grid via 1-5 km long cable

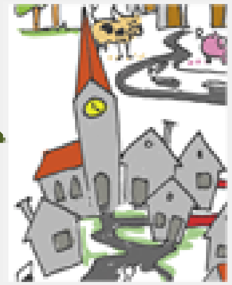
   -> even higher power possible than with diesel engines, for cultivation

Model topology „scenario 1“ of cable-powered agricultural machine



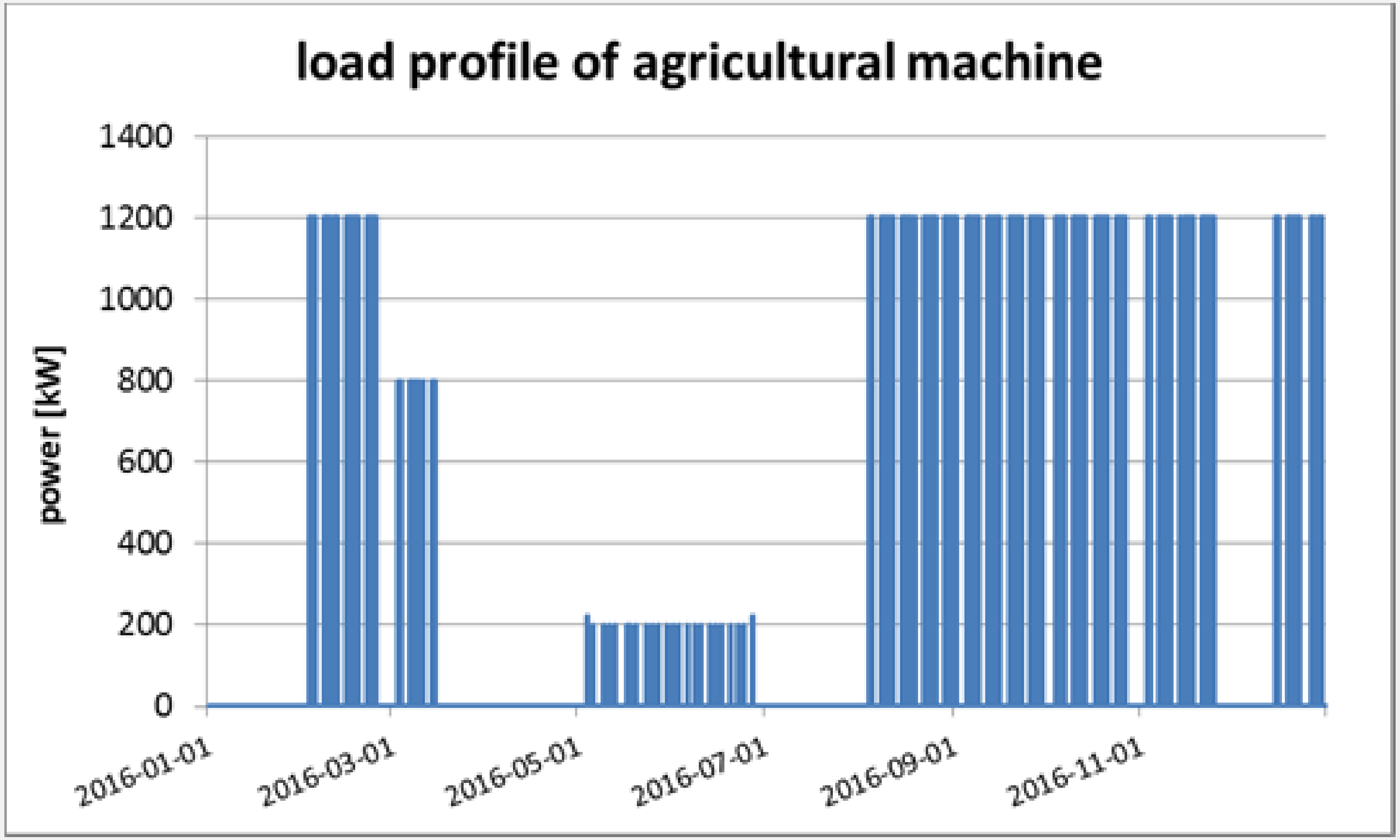
“unlimited“
residual
generator

curtailment



“unlimited“
residual
consumer

PV generation + base load
+ 1.2 MW agricultural machine
+ stationary energy storage


load profile of agricultural machine
power [kW]
1400
1200
1000
800
600
400
200
0
2016-01-01
2016-03-01
2016-05-01
2016-07-01
2016-09-01
2016-11-01

Parameters characterising different situations

1. Base electric energy demand in rural local grid (MWh/yr)
2. PV saturation rate: factor by which a grid connection just meeting the peak base load needs to be reinforced to allow for complete feed-in of PV electricity not consumed locally (e.g. 234% corresponds to 100% net PV supply of local base load)

Specific annual fixed grid and storage costs

grid		
specific investment costs	500	€/kW
annual cost decrease	-	-
financial life time	50	a
financial period considered	50	a
number of investments	1	
weighted average cost of capital	5.0%	
annuity	27.39	€/kW
fixed operational costs	10.00	€/kW
fixed annual costs	37.39	€/kW

energy storage		
specific investment costs	300	€/kWh
annual cost decrease	10%	1/a
financial life time	5	a
financial period considered	50	a
number of investments	10	
weighted average cost of capital	5.0%	
annuity	30.57	€/kWh
fixed operational costs	6.00	€/kWh
fixed annual costs	36.57	€/kWh

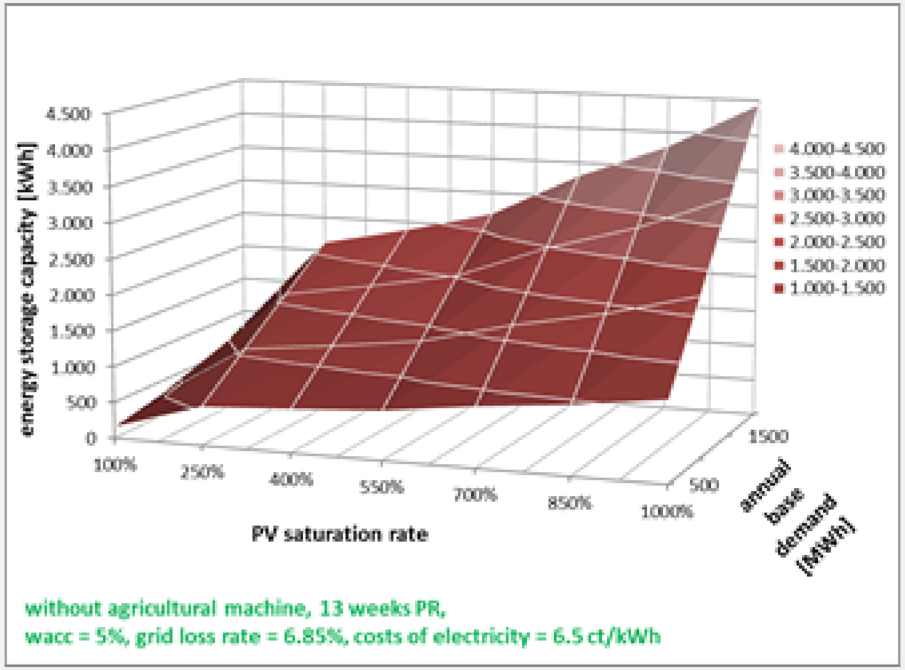
Further parameters

- income from primary balancing power provision:
  13 weeks * 3,000 €/week/MW -> 31.2 €/kWh
- rate of electric energy lost in the grid: 6.85 %
- cost of electricity lost in the grid, storage or by curtailment:
  65 €/MWh

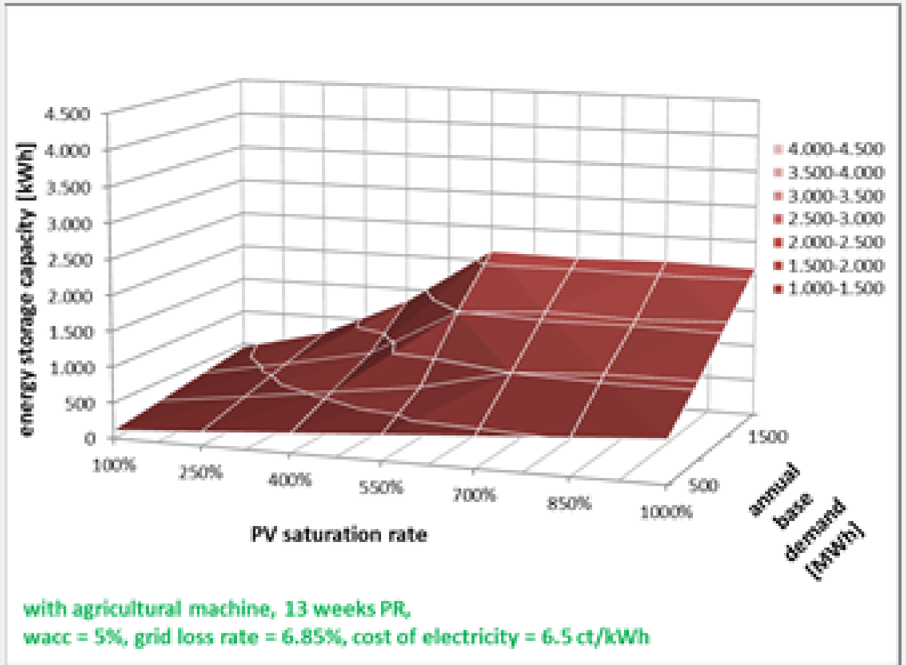
Optimisation

- Minimizing total annual costs of electricity needed by the system
  - annuity of grid and energy storage system;
  - fixed annual costs (2 % of initial investment costs);
  - variable annual costs (energy lost by grid transmission, storage or curtailment of PV generation.
- Implementation in Open Energy System Modelling Framework
  - OEMOF, https://oemof.org/; free ware; python;
  - collection of modules for modelling energy systems.

Energy storage capacity

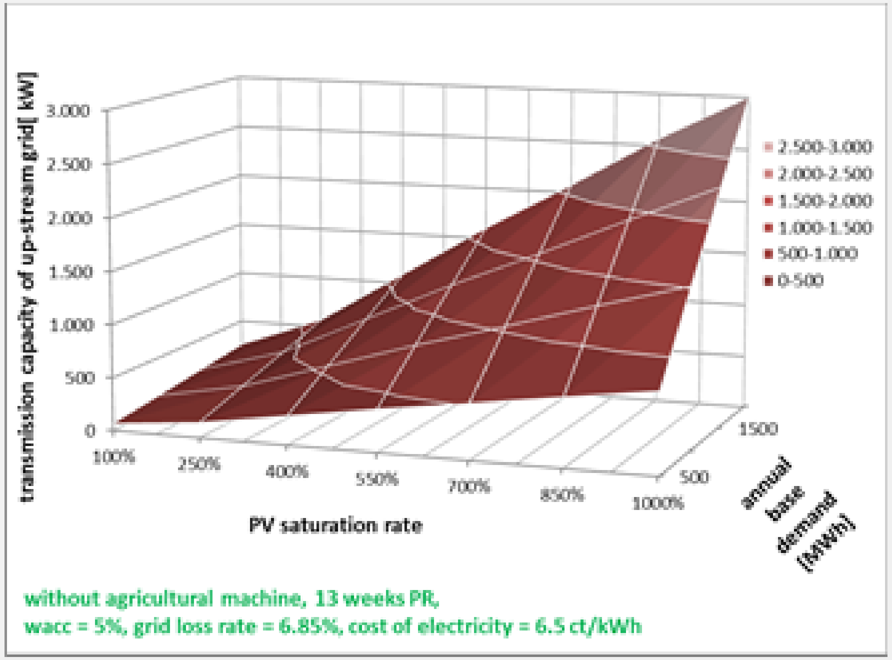


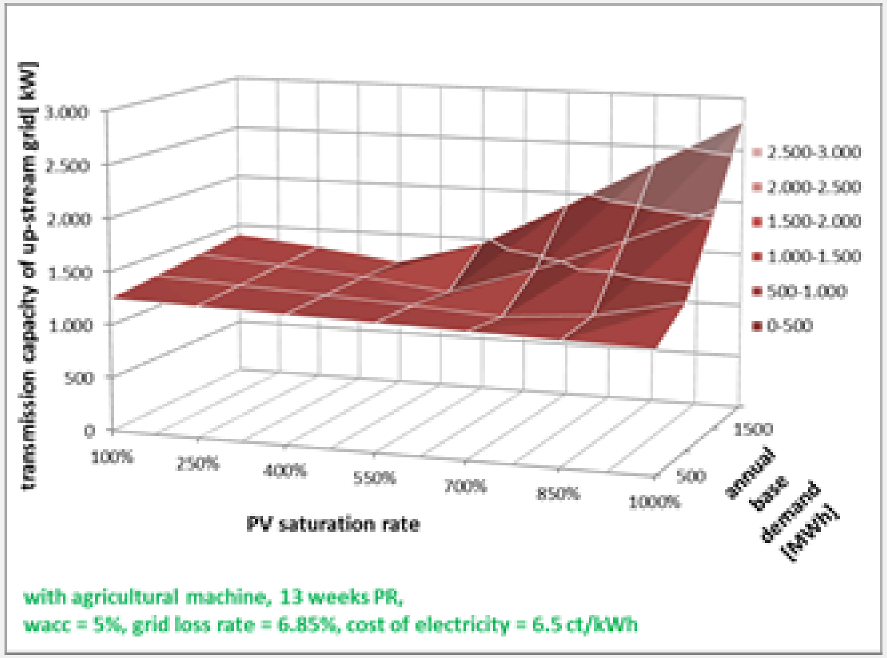
without agricultural machine



with agricultural machine

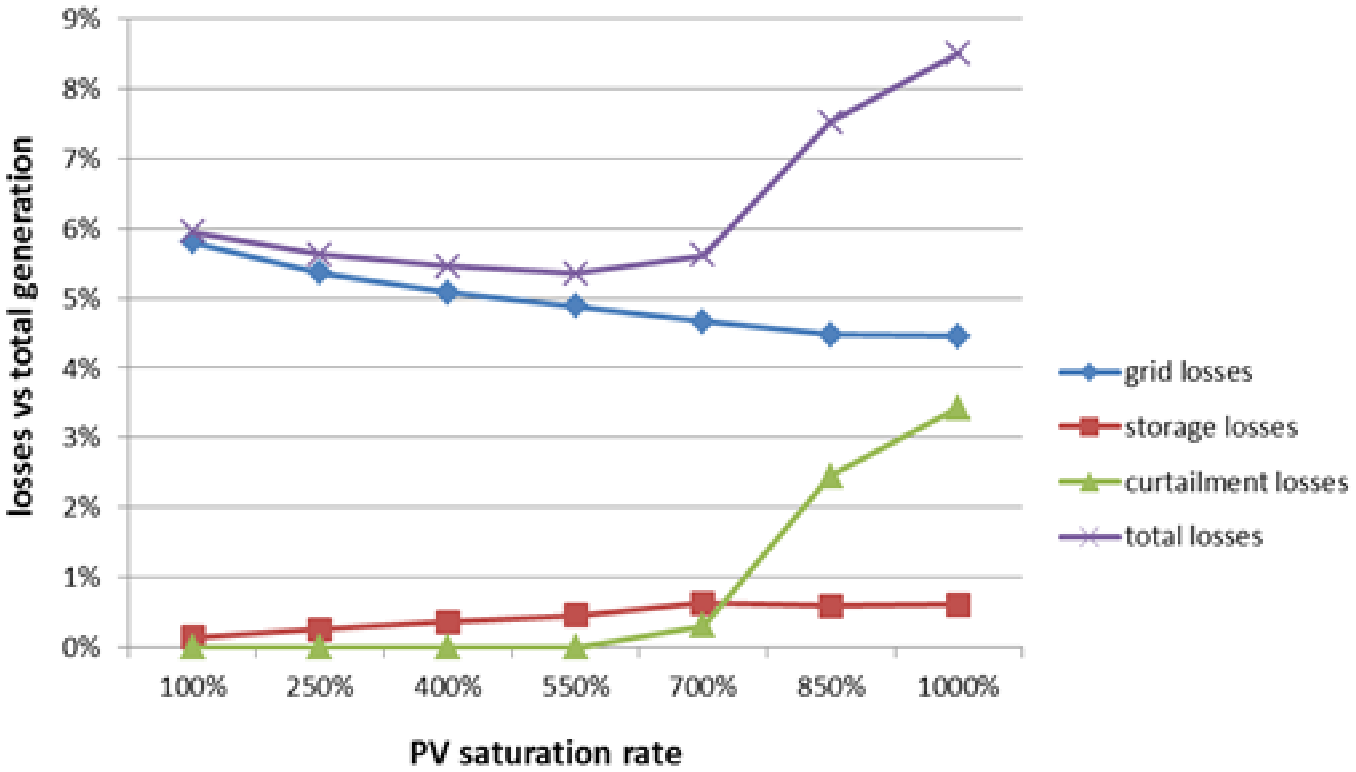
Transmission capacity of up-stream grid



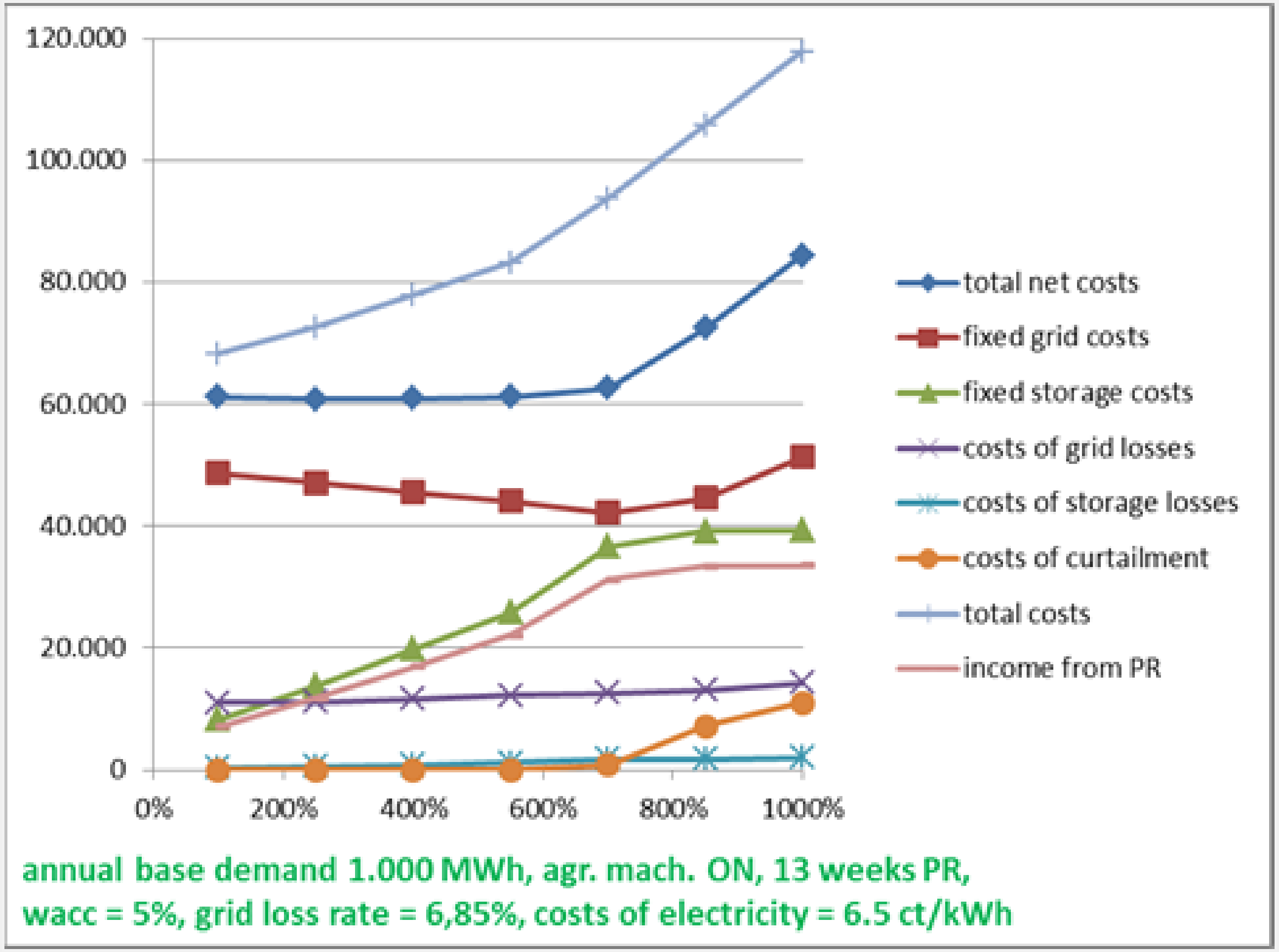


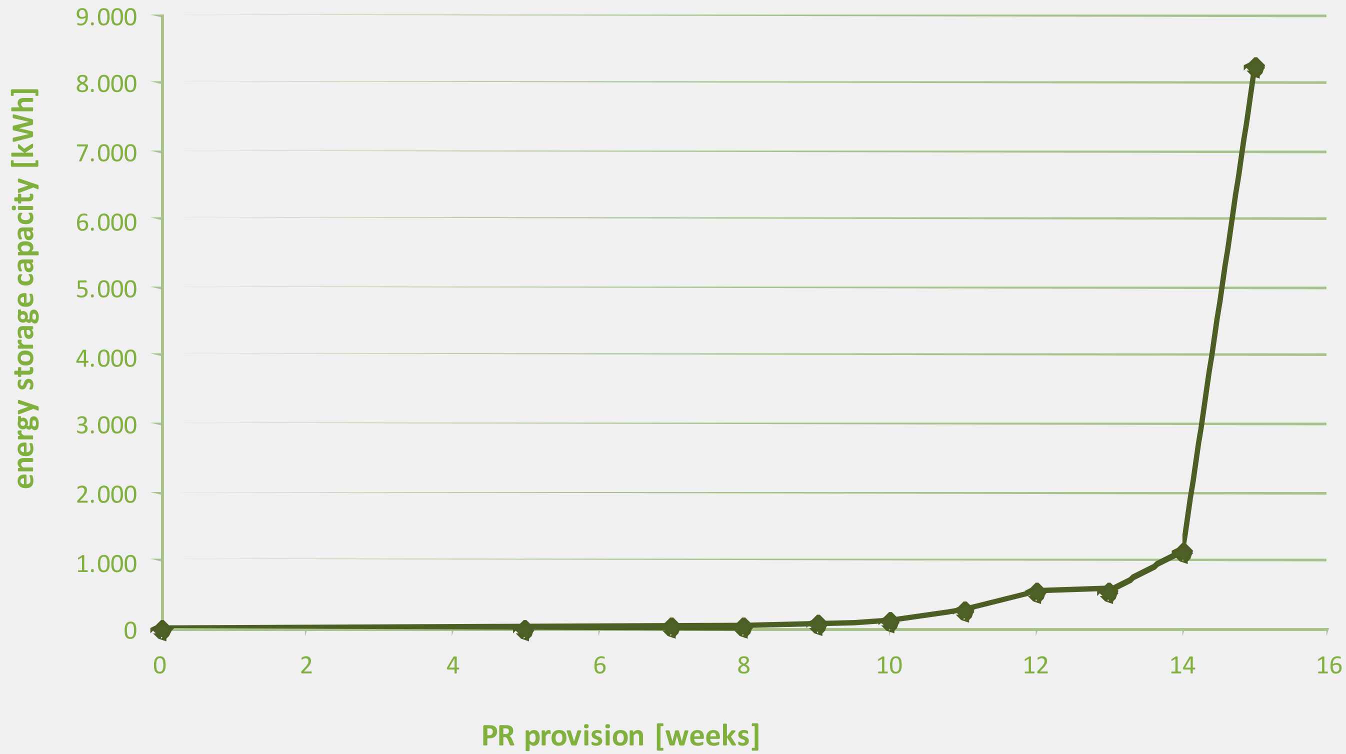
without agricultural machine

with agricultural machine

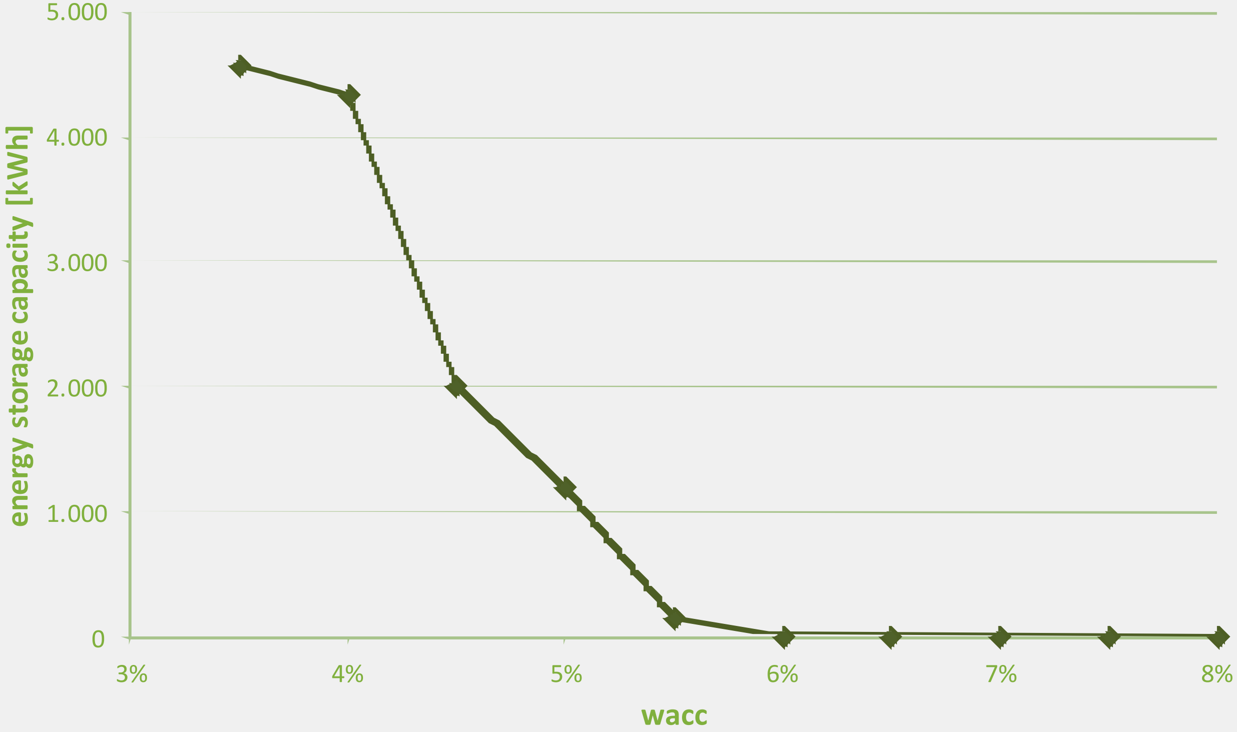


annual base demand 1.000 MWh, agr. mach. ON, 13 weeks PR,
wacc = 5%, grid loss rate = 6,85%, costs of electricity = 6.5 ct/kWh


120.000
100.000
80.000
60.000
40.000
20.000
0
0%
200%
400%
600%
800%
1000%
total net costs
fixed grid costs
fixed storage costs
costs of grid losses
costs of storage losses
costs of curtailment
total costs
income from PR
annual base demand 1.000 MWh, agr. mach. ON, 13 weeks PR,
wacc = 5%, grid loss rate = 6,85%, costs of electricity = 6.5 ct/kWh



with agricultural machine, PR provision variable, wacc = 5%,
grid loss rate = 6,85%, costs of electricity = 6.5 ct/kWh



with agricultural machine, 13 weeks PR,
wacc = variabel, grid loss rate = 6,85%, costs of electricity = 6.5 ct/kWh

Summary

1) If the stationary energy storage is used for primary reserve (PR) provision for at least 10 weeks per year, its use is always cost-effective, with and without a cable-led agricultural machine.
2) Operating a cable-led agricultural machine in small and medium-size local grids usually requires a grid reinforcement.
3) The optimum size of the optimum stationary energy storage very sensibly depends on the income from secondary use such as PR, and on the weighted average cost of capital (wacc).

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