CLEEN
Cluster for Energy and Environment

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Electric Vehicles and Energy Storages - Network Effects

sgem
Smart Grids and Energy Markets

Jukka Lassila, Juha Haakana,
Ville Tikka, Henri Makkonen
LUT Energy

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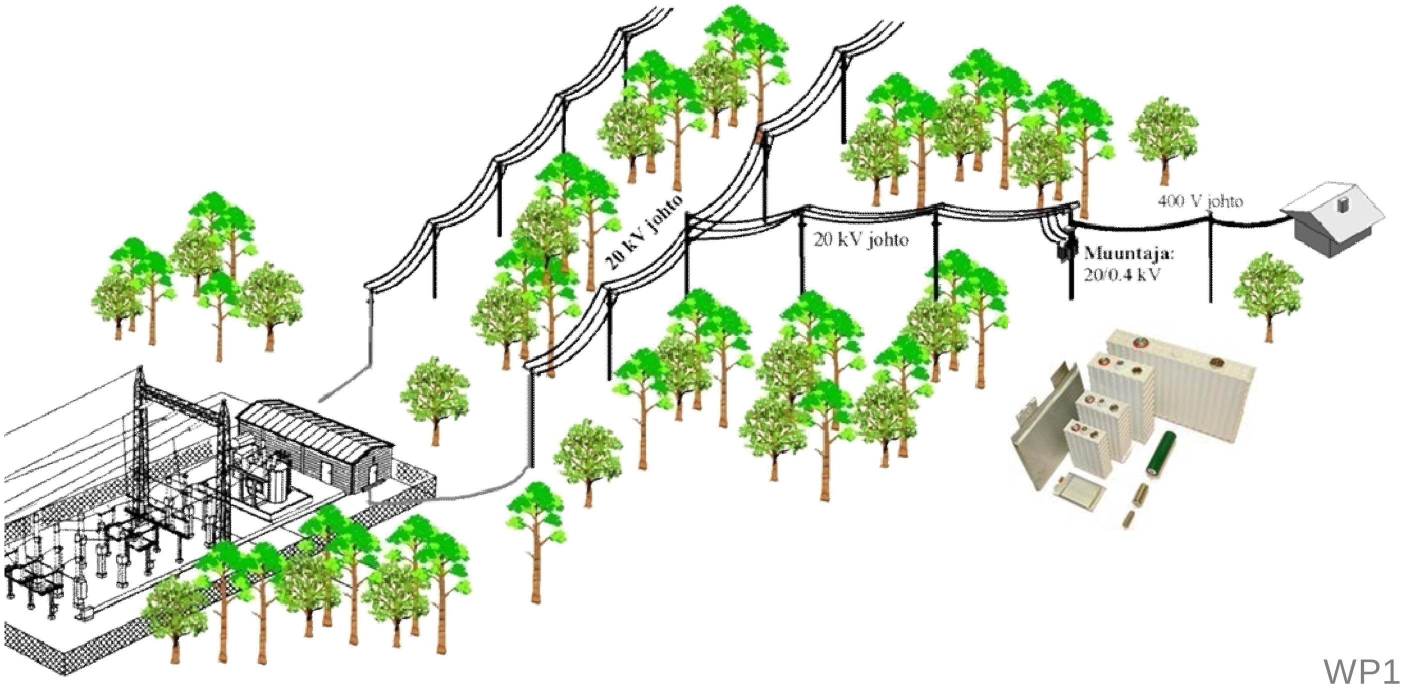
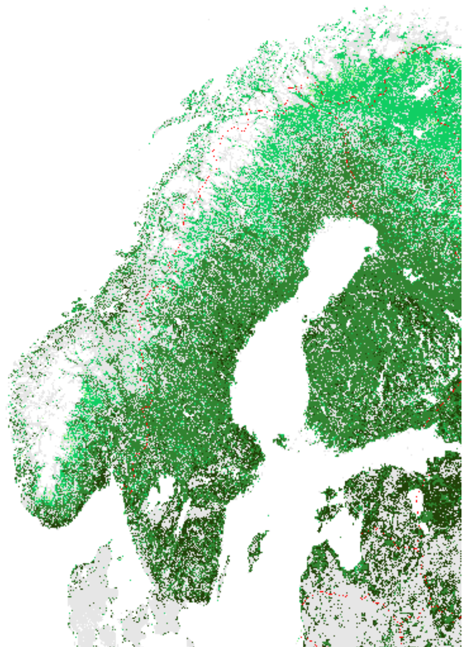
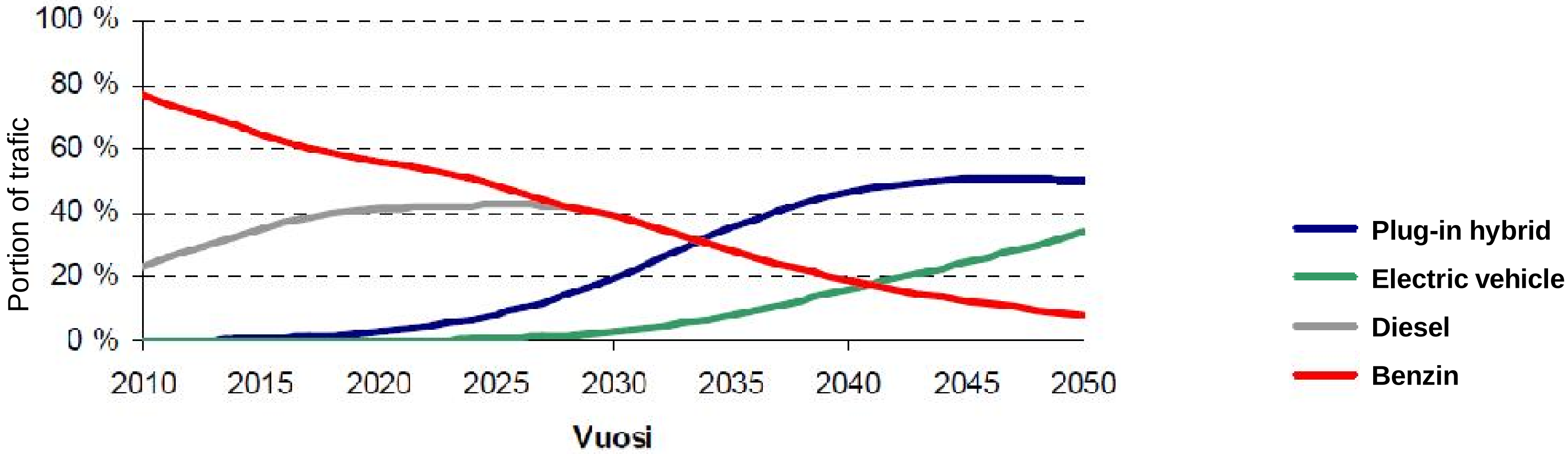


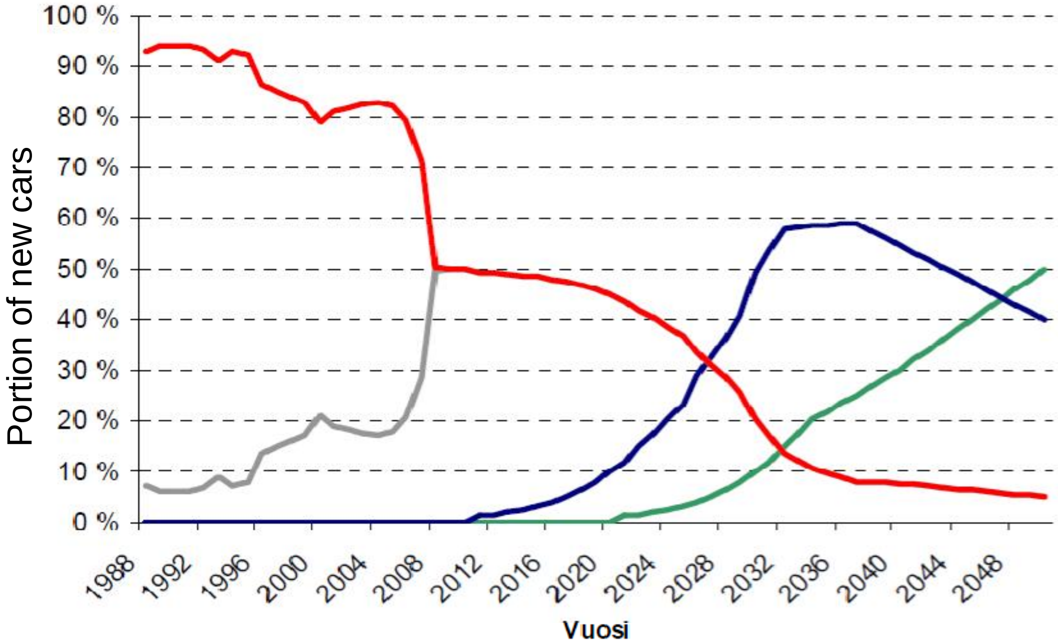
SGEM (Smart Grids and Energy Markets)
Theme 1 - Smart Grids architectures
WP1.1: Significance of electricity and Smart Grids

Contents



EV scenarios





Source: *LUT, Sähkön ja kaukolämmön rooli energiatehokkuudessa ja energian säästössä, 2009*

EU: Major challenges in Electrification

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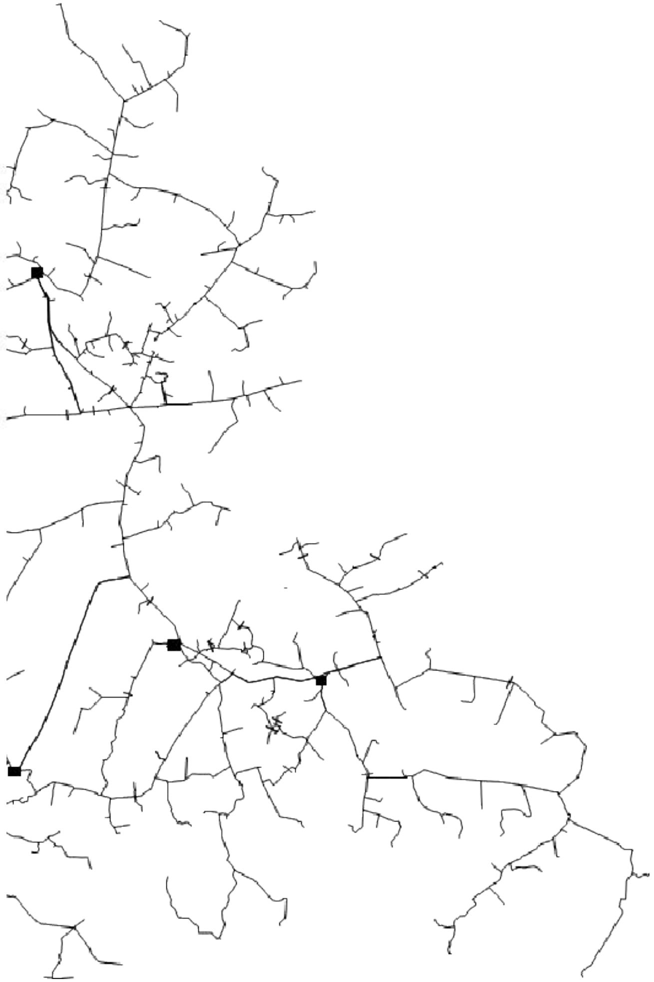
EPoSS
European Technology Platform
on Smart Systems Integration

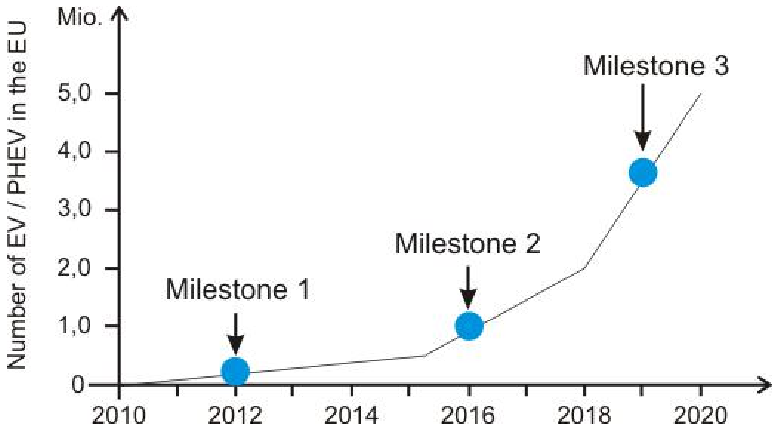
ERTRAC
European Road Transport
Research Advisory Council

Major Challenges Electrification

- **Energy Storage Systems**
  (cost, performance, lifetime, safety)
- **Drive Train Technologies**
  (energy recovery, range extenders)
- **System Integration**
  (energy efficient interplay of components)
- **Grid Integration**
  (charging, metering, renewables, V2G)
- **Safety**
  (crashworthiness, HV, emergency)
- **Transport System Integration**
  (road infrastructures, intermodal use)



EU: Major challenges in Electrification



ERTRAC

PPP European Green Cars Inititative

EPoSS European Technology Platform on Smart Systems Integration

SMARTGRIDS

www.green-cars-initiative.eu

	Milestone 1	Milestone 2	Milestone 3
Energy Storage Systems	Full understanding and proper management of all relevant parameters for safety, performance, lifetime	Manufacturing of long life, safe, and cheap energy storage systems with advanced energy and power density	Availability of batteries providing tripled energy density, tripled lifetime at 20-30% of 2009 cost and matching V2G.
Drive Train Technologies	Availability of drive train components optimized for efficient use and recovery of energy	Manufacturing of range extenders & update of electric motors for optimized use of materials and functionality	Implementation of power train systems providing unlimited range at sharply reduced emissions
System Integration	Solutions for safe, robust and energy efficient interplay of power train and energy storage systems.	Optimized control of energy flows based on hard- and software for the electrical architecture	Novel platform based in overall improved system integration
Grid Integration	Charging adaptive to both user and grid needs.	Charging at enhanced speed	Quick, convenient, smart and bi-directional capabilities
Safety	Electric vehicles providing same safety levels as conventional cars	Implementation of solutions for all safety issues specific to mass use of the electric vehicle and road transport based on it	Maximum exploitation of active safety measures for electric vehicles
Transport System	Road Infrastructures and communication tools encouraging the use of EV	Full integration of electric vehicles with other modes of transport	Autonomous driving based on active safety systems and car-to-x communication

Electric Vehicles
Classification

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- EV **(Electric Vehicle)**
  - Only electric power to produce propulsion
  - Th!nk City, Testa, Nissan Leaf
- HEV **(Hybrid Electric Vehicle)**
  - Propulsion with ICE or electric motor
  - Classification by propulsion type
    - **Parallel**, ICE and electric motor are connected parallel to produce propulsion (Honda Insight)
    - **Series**, ICE is connected to generator and propulsion is made with electric motor (aka Range-Extented EV, Chevrolet Volt)
    - **Series-Parallel**, ICE and electric motor connected parallel via a power splitter(Planetary gear). The ration between ICE and electric motor can be chanced and electric motor can also work as generator. (Prius)

Th!nk City EV

Electric Vehicles
Classification

- PHEV **(Plug-in Hybrid Electric Vehicle)**
  - HEV with possibility to charge battery
  - Battery capacity is higher than in similar HEV to ensure longer distances using EV mode (car can be driven using only electric power)
  - About terminology:
    - PHEV-10, PHEV-[*miles*] car witch can do10 miles in EV mode
    - PHEV16km, PHEV[*kilometres*]km car witch can do16 kilometres in EV mode
- Conversion
  - Conversion EV can be made by using ICE car
  - HEV can be also converted to PHEV by adding larger battery an replacing some electronics
  - Commercial conversion kits are also available for some car models

Chevrolet Volt, Plug-in Hybrid Electric Vehicle (Series Hybrid)

Fiat 500, conversion EV

Electric Vehicles
Charging interfaces

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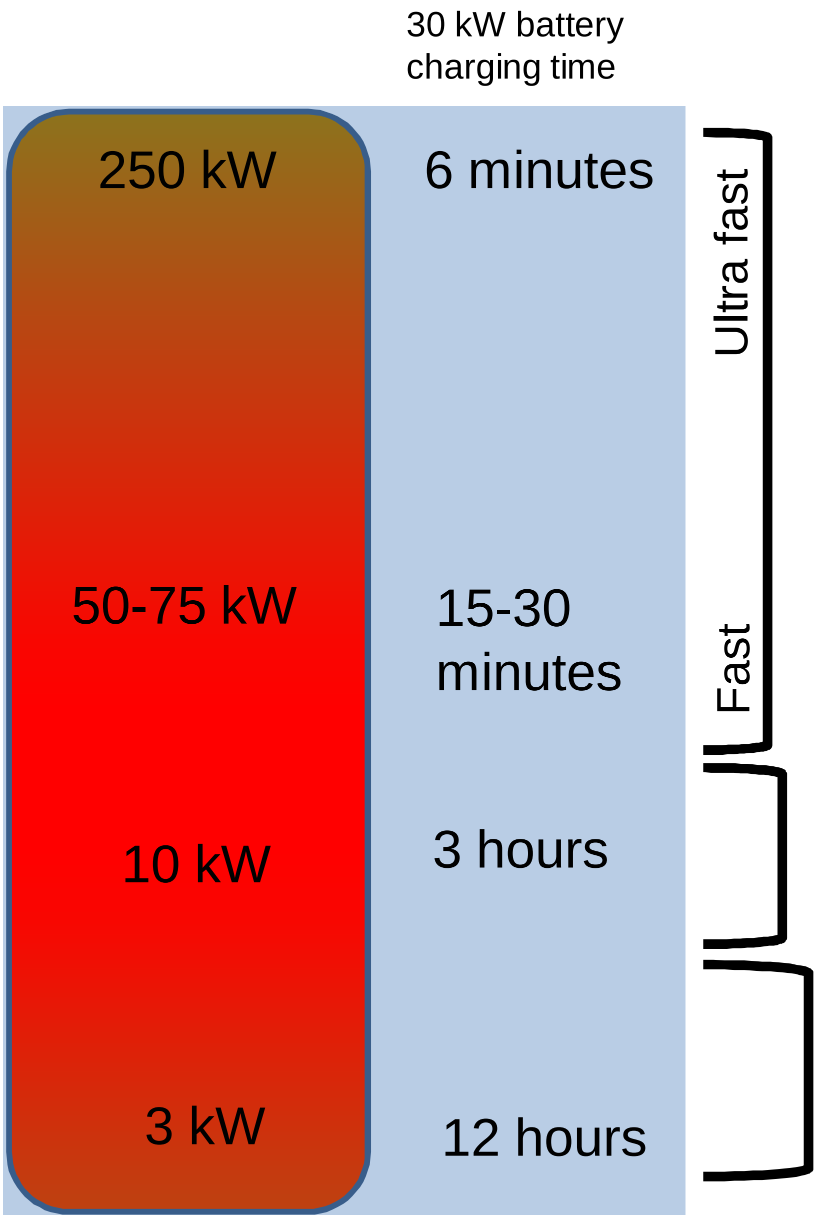

Classification by charging power or time
(SESKO)

- Mode 4 DC charging using off-board charger

- Mode 2/3 charging
- 400 V, AC, 3 phase
- **Mode 2 plug/interface: IEC 60884-1 + CEE7**

- Mode 1 charging
- 230 V, AC , 1 phase
- **Mode 1 plug/interface: IEC 60884-1 + CEE7**

Electric Vehicles
Charging interfaces

- Plugs and charging interfaces under preparation
  - **Mode 3**
    - IEC 62196-1 general interface standard during first half of 2011
    - IEC 62196-2 standard about dimensional compability, plug socket, etc. during 2011/2012
  - **Mode 4**
    - IEC 62196-1
    - IEC 62196-3 standard about mode 4 dimensional compability, plug socket, etc during 2013-2014

Mennekes Plug (Germany), 3 phase

Scame Plug (Italy), 3 phase

SAE J1772 (US-Japan), 1 phase

Electric Vehicles
Charging interfaces

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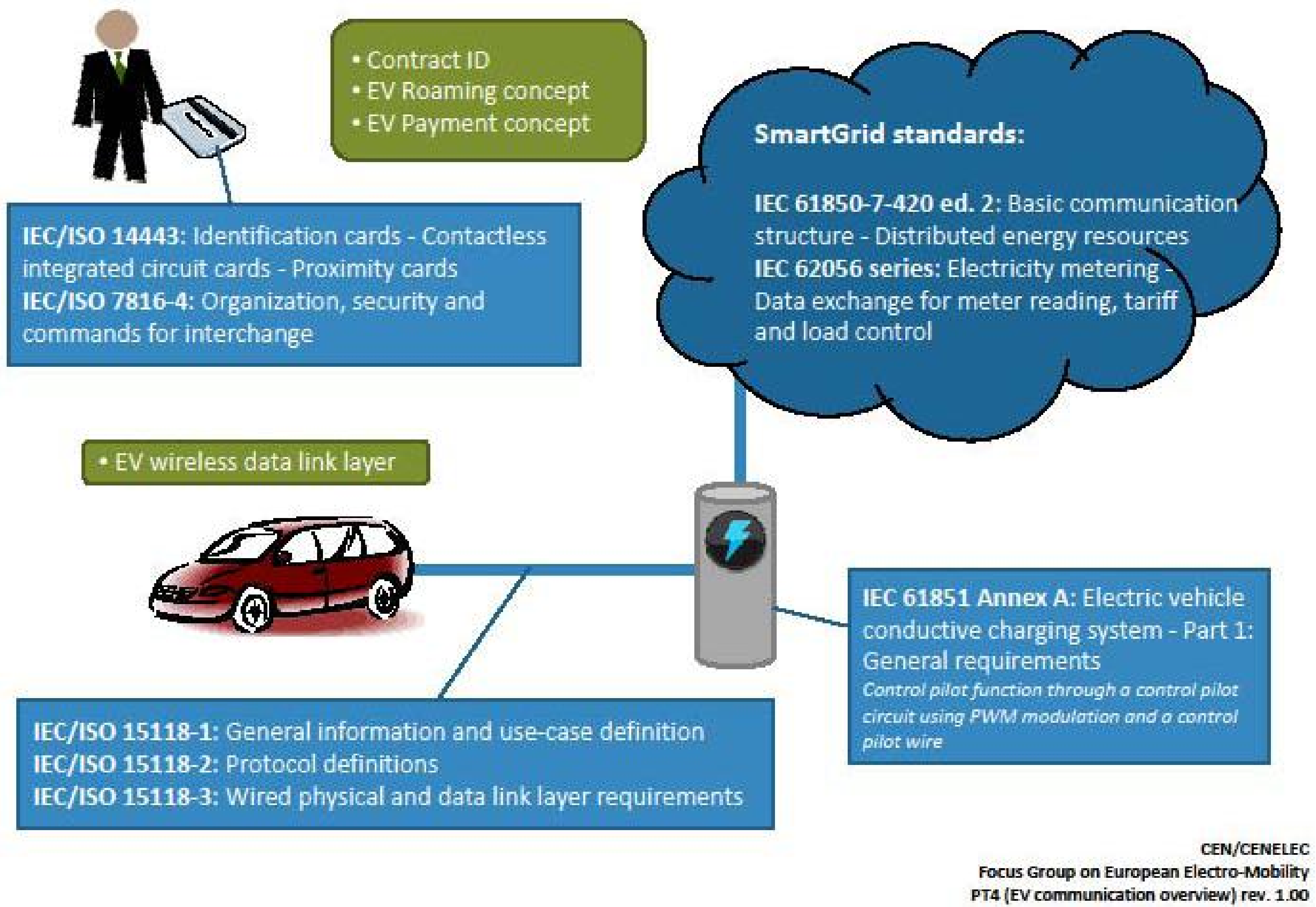
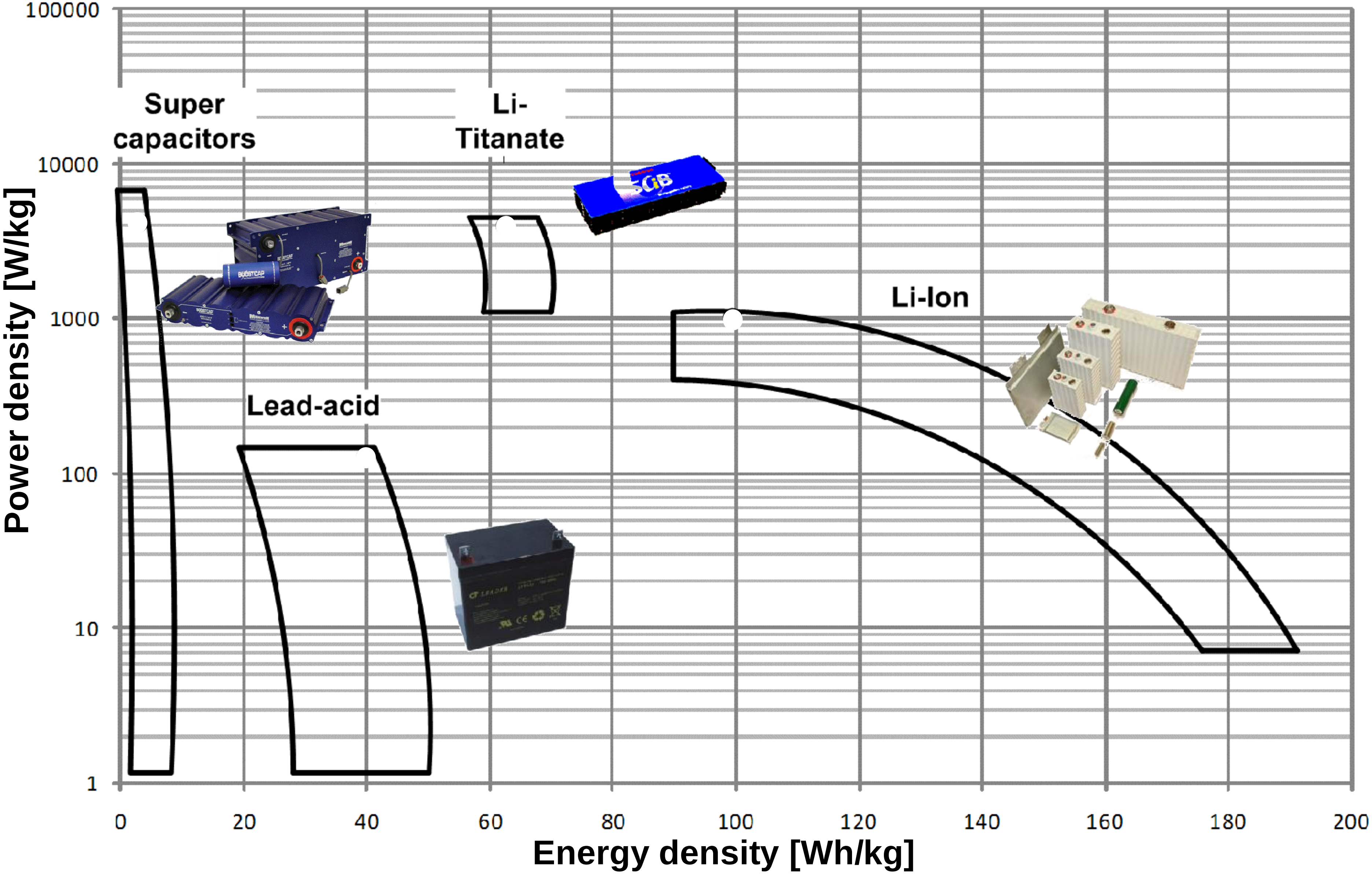
Overview diagram for EV communication standards



Batteries

Power and energy densities



Batteries
Life-time

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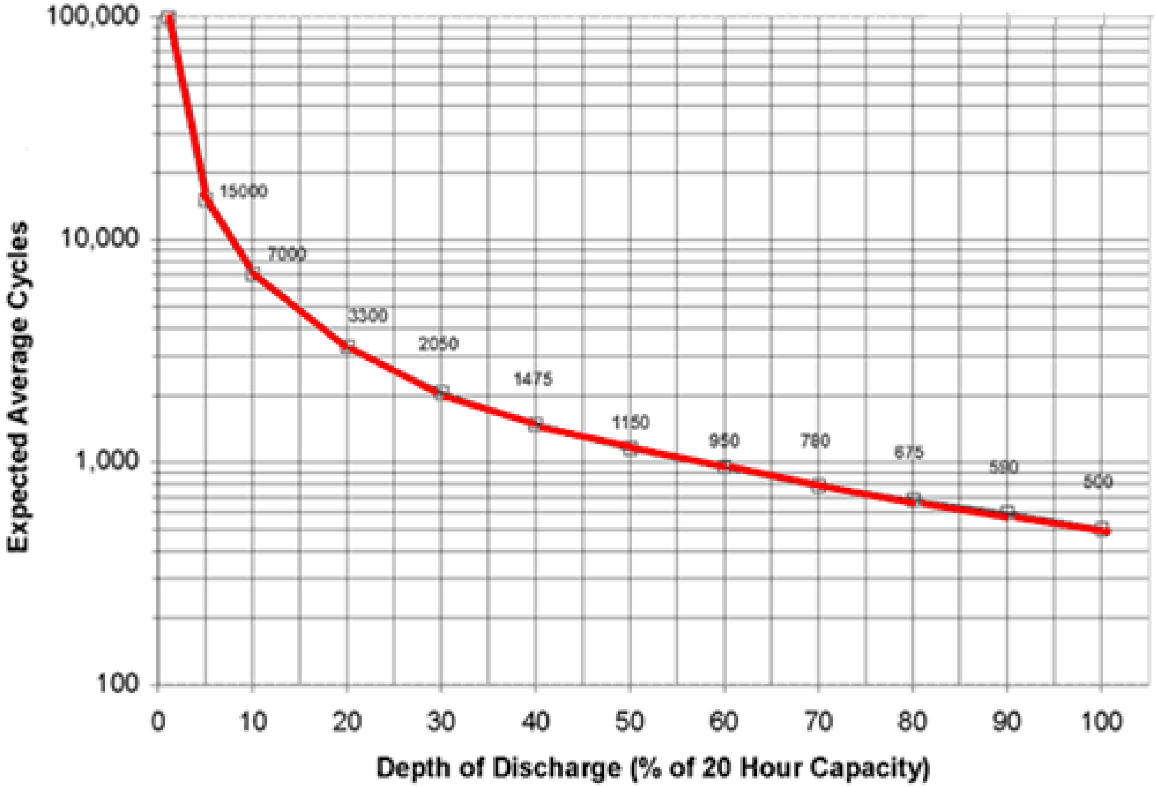
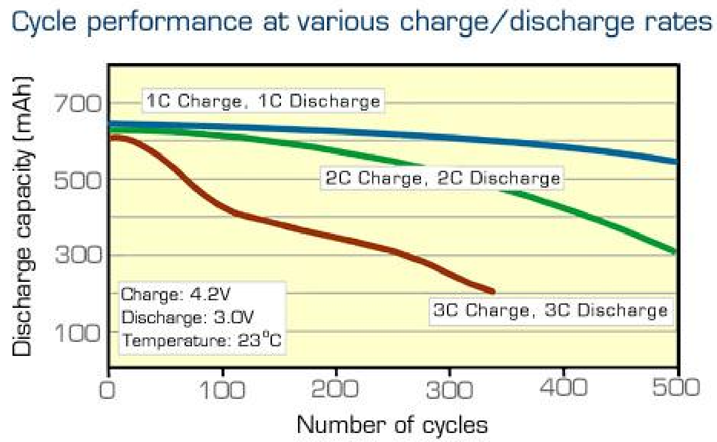
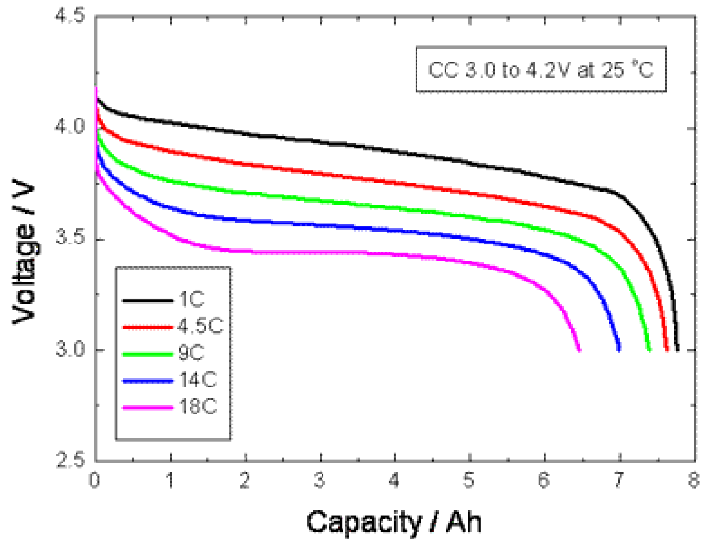
DOD (Depth Of Discharge) effects strongly on life-time of the battery



Charging speed effects on life-time and capacity of the battery





Networks
Real estate networks and EVs

- **Residential (3x25 A tai 3x35 A) and agriculture houses** have good precoditions for EV charging
  - Need for intelligent load control and load alternation
- **Apartment houses:** Parking areas dimensioned traditionally for instance 1.5 kW/car (VVO 2009)
  - Major challenges in big cities (downtowns)
    - **Preheating possibility of cars does not necessarily exist**
    - **Parking houses may have preheating possibility, but dimensioning of power supply may be insufficient**
  - Reinforcement costs (level 1x16 A + kWh –meter)?
- **Row houses:** Various practices in preheating networks
  - Often parking place for the car with preheating possibility (for instance 1.5 kW/car)

Challenge: Lack of information of present situation of real estate networks

VVO VUSU 2009, available in Finnish: http://www.vvo.fi/attachements/2009-09-29T15-48-2938.pdf

Network simulations
Input Parameters

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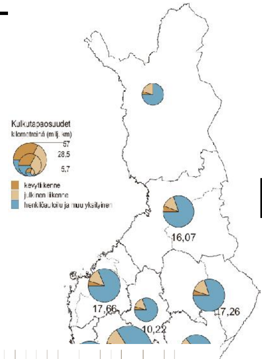
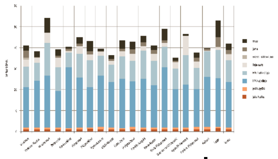
National passenger transport survey
- Spatial and temporal variations in passenger trips
- Length of daily trips
- Annual length of driving (region dependent)
- Length of daily trips according to housing type
- Length of daily trips according to residential area
- Length of daily trips according to the month of year
- Length of trips according to the time of day
- Number of cars in households





Properties of electric cars
- Energy consumption, kWh/km
- Capacity of the batteries, kWh
- Charging power, kW
- Required charging time, h/day (battery properties)

Town planning statistics
- Workplaces according to the area and time of day
- Residential areas (detached houses, terraced houses, apartment houses)

Penetration of electric cars
- Development of electric car markets

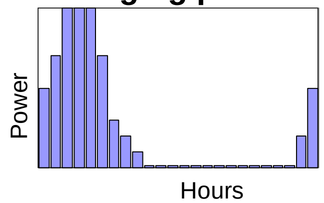
Tariffs and supplier
- Distribution fee

Area-specific additional energy

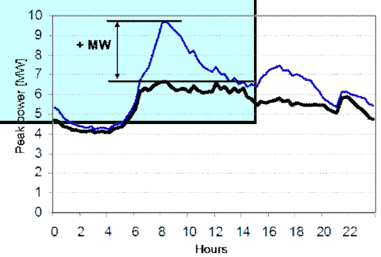
__ kWh/day

(working hours/ leisure time)

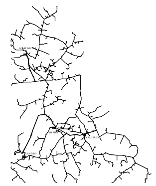
Charging profile

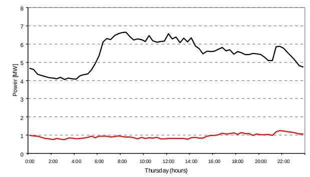


Network simulations and analysis results
- Load flow and loss calculations
- Estimation of reinforcements required



Electricity distribution network
- Network topology and customer information
- Feeder and hourly-specific actual load curves
- Network volume
- Replacement value
- Parameters: loss costs, load growth, lifetime, price of network components





Case Network
Background data

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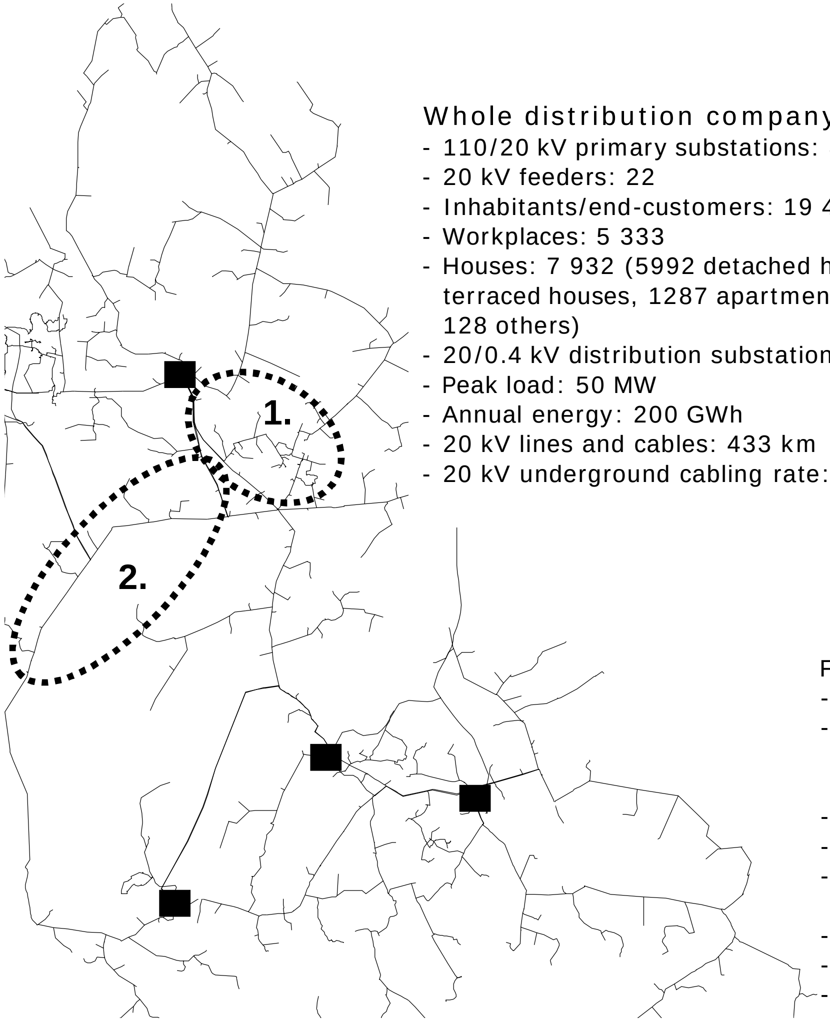
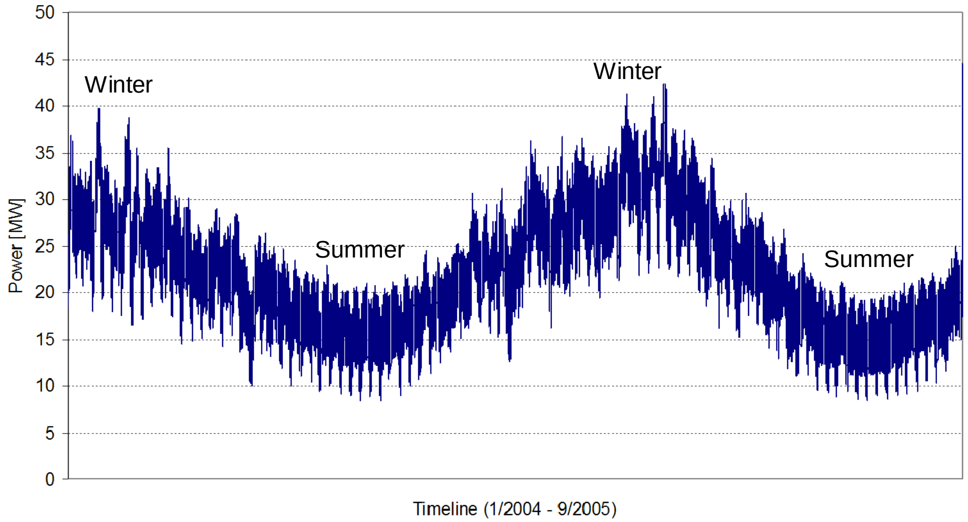


Whole distribution company
- 110/20 kV primary substations: 4
- 20 kV feeders: 22
- Inhabitants/end-customers: 19 470 / 11 000
- Workplaces: 5 333
- Houses: 7 932 (5992 detached houses, 525 terraced houses, 1287 apartment houses, 128 others)
- 20/0.4 kV distribution substations: 470
- Peak load: 50 MW
- Annual energy: 200 GWh
- 20 kV lines and cables: 433 km
- 20 kV underground cabling rate: 16 %



Feeder 1. (Densely populated area), 20 kV
- Peak load: 8 MW
- Annual energy: 36 GWh
  - Residential 58 %, industry 22 %, public 13 % and service 7 %
- Inhabitants/end-customers: 4171 / 2278
- Workplaces: 1 577
- Houses: 1 840 (659 detached houses, 266 terraced houses, 888 apartment houses)
- 20/0.4 kV distribution substations: 39
- 20 kV lines and cables: 21 km
- 20 kV underground cabling rate: 33 %

Feeder 2. (Rural area), 20 kV
- Peak load: 2 MW
- Annual energy: 6 GWh
  - Residential 95 %, agriculture 2 %, industry 3 %
- Inhabitants/end-customers: 1037 / 444
- Workplaces: 84
- Houses: 372 (all detached houses)
- 20/0.4 kV distribution substations: 27
- 20 kV lines and cables: 31 km
- 20 kV underground cabling rate: 6 %

Case Network
Present load curves (without EVs)

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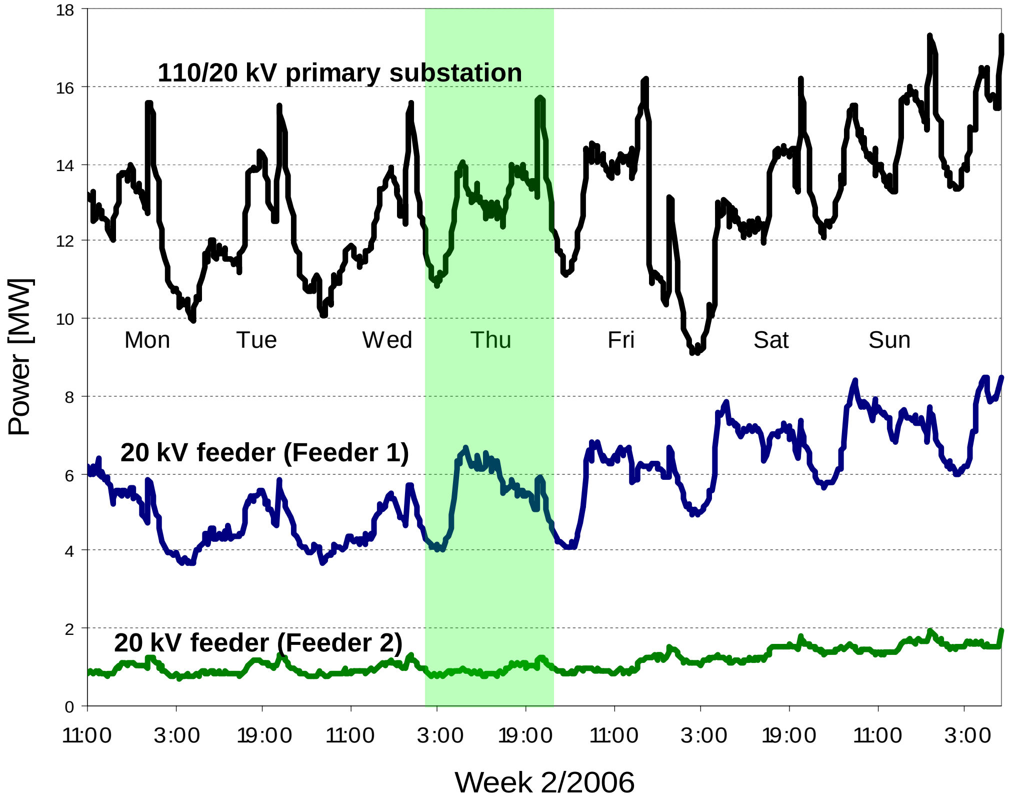
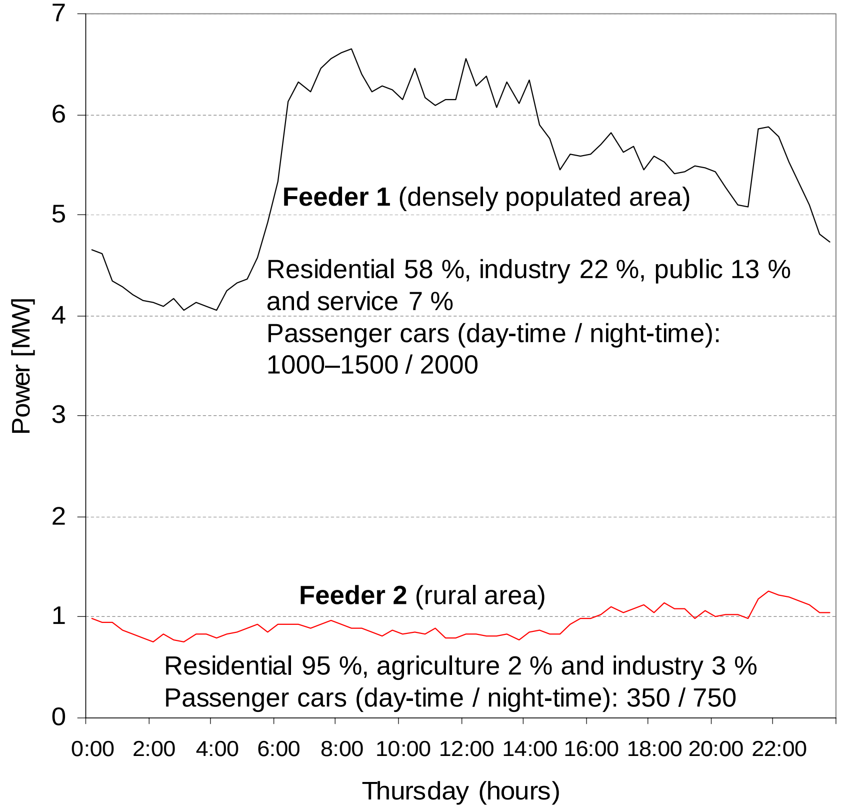


a)



b)

Case Network
Case area

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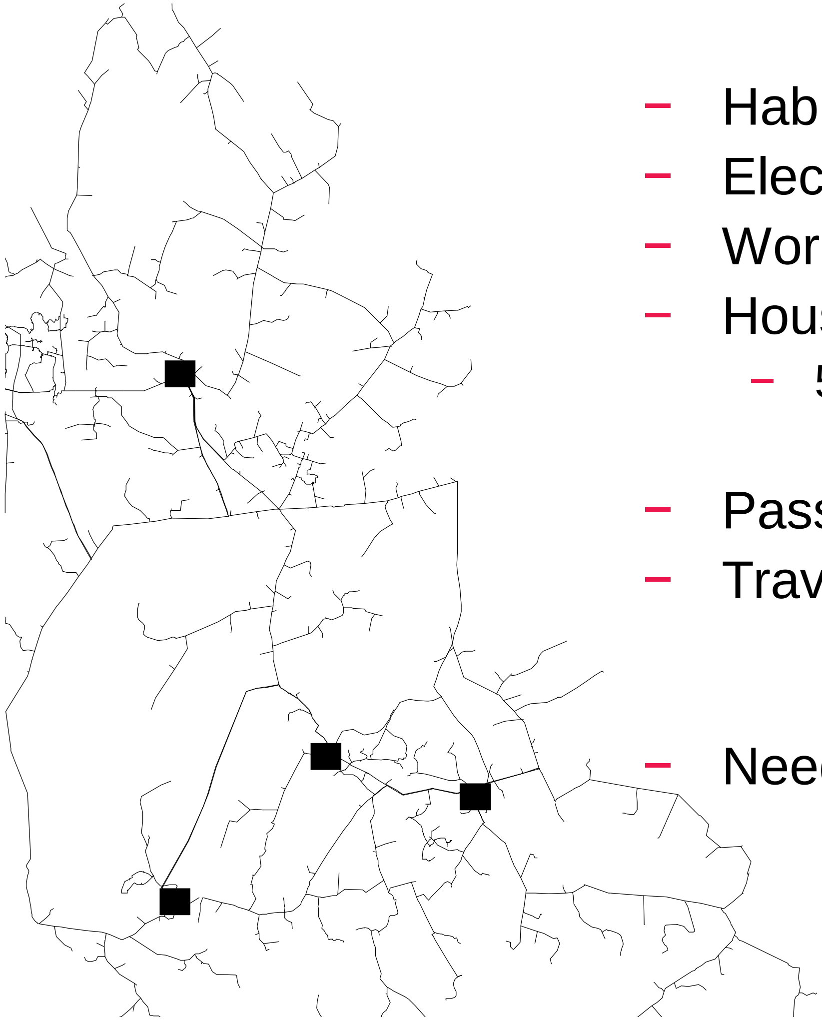
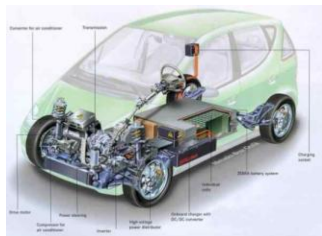


- Habitants: 19 470
- Electricity end-customers: 11 000
- Workplaces: 5 333
- Houses: 7 932
  - 5992 detached, 525 terraced, 1287 apartment, 128 others

- Passenger cars: 11 000
- Travelling distances: 20 900 km/car,a
  = 57 km/car,day

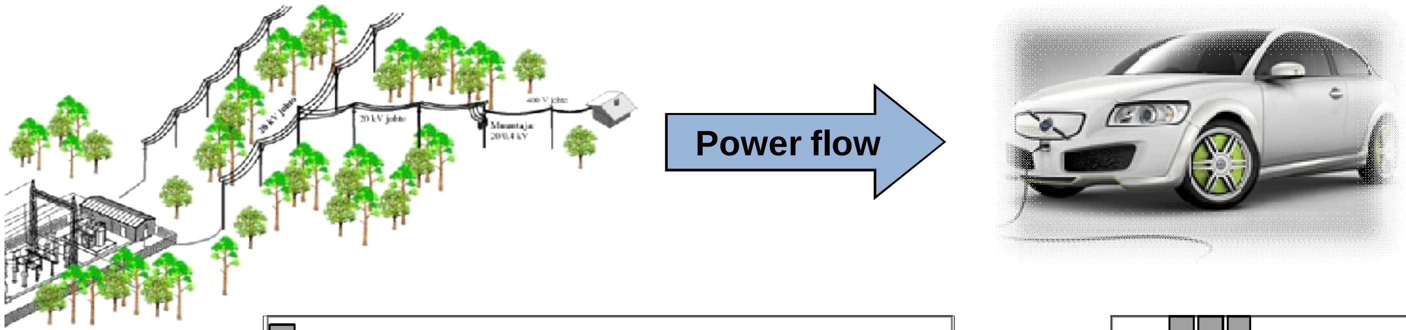
- Needed charging energy: 11.5 kWh/car,day
  46 GWh/a (all cars)

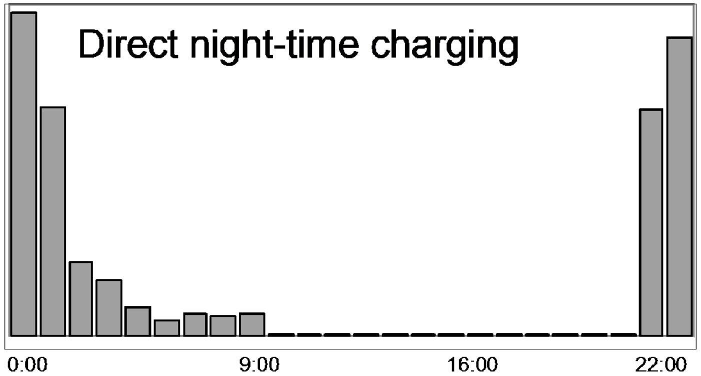
- Needed energy: 0.1 – 0.2 kWh/km
- Capasity: 30 kWh/car
- Charging power: 3.6 kW/car

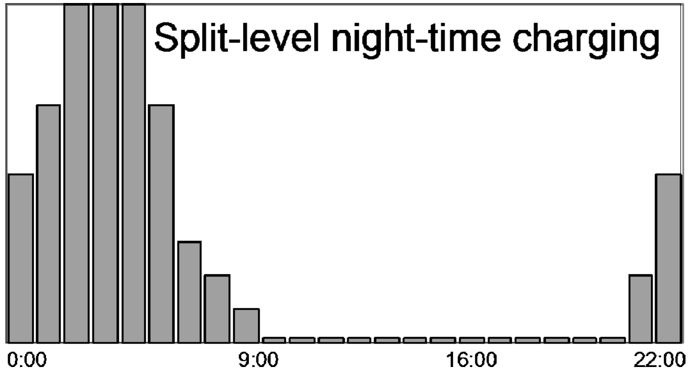


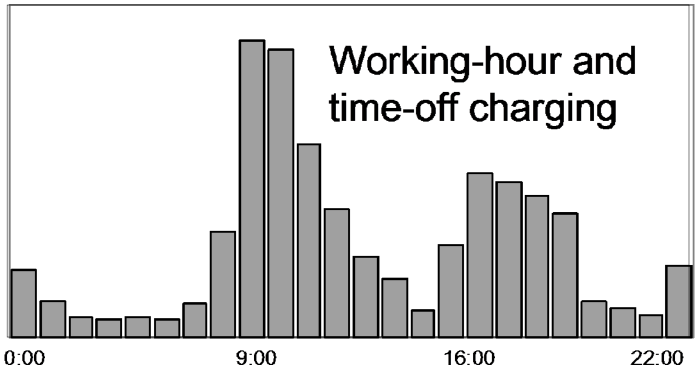
Case Network

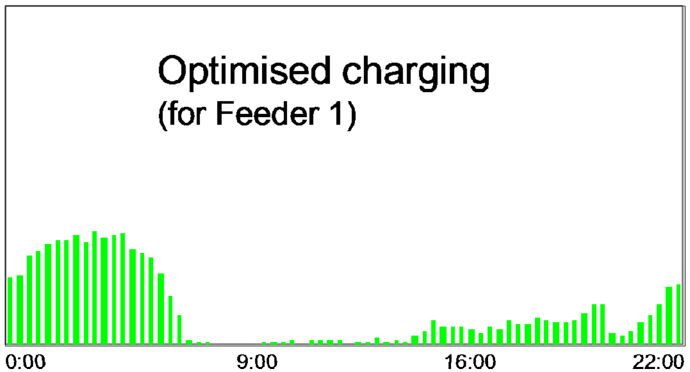
Electric car charging profiles









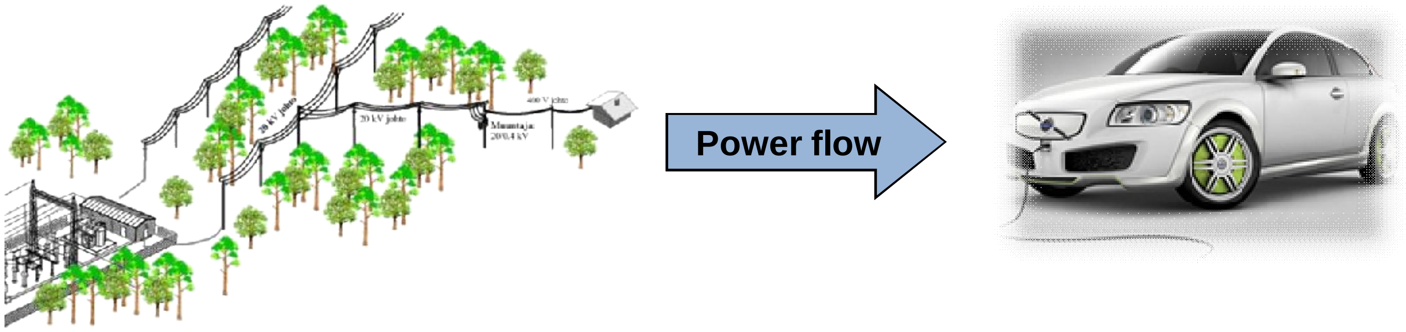


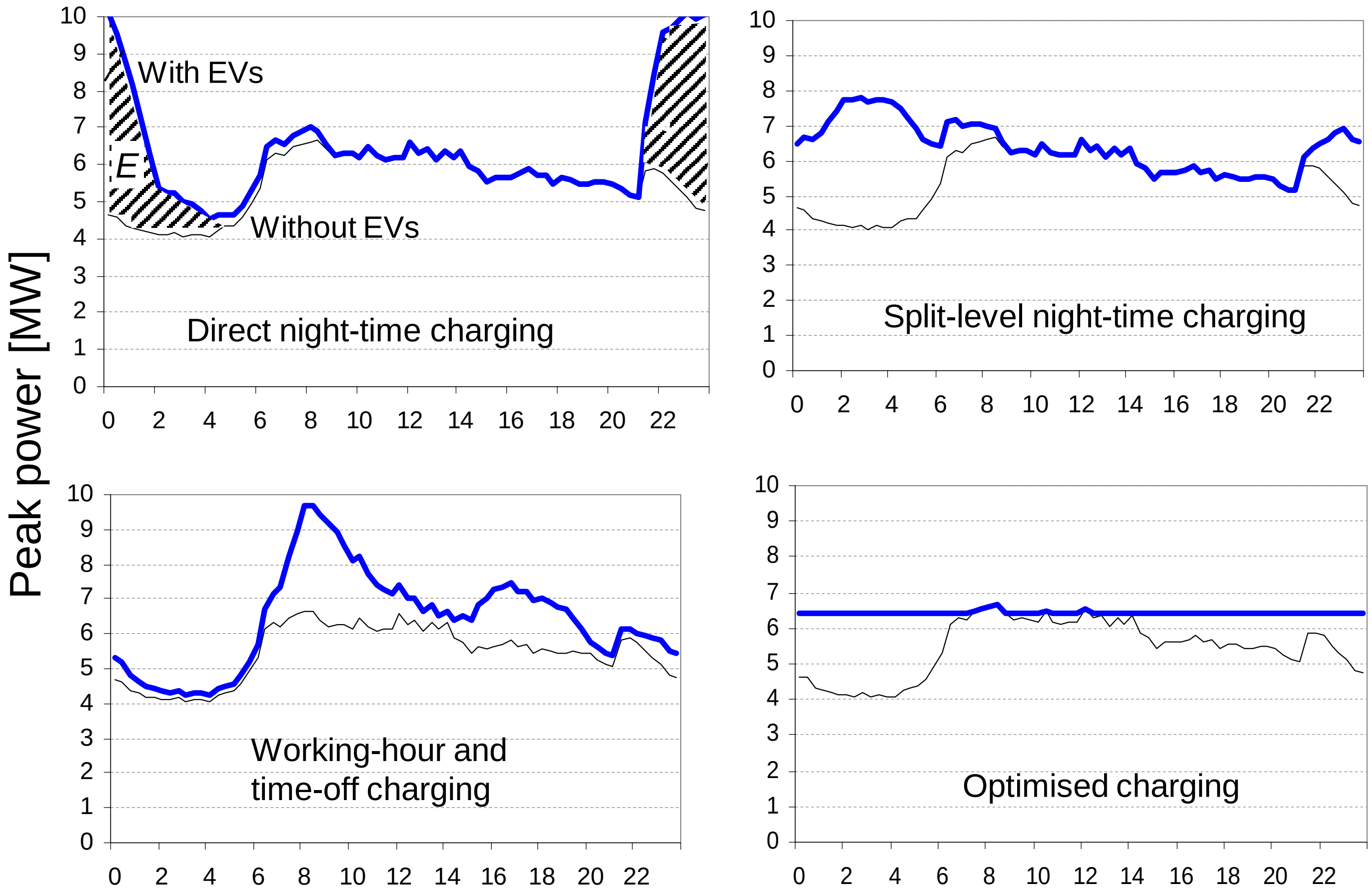
The same amount of charging energy in each profile!

→ Transmission capacity in the network?

→ Losses and loss costs?

Case Network
Load curves with charging





City area feeder:
- Peak load of the day: 6.6 MW
- Minimum load of the day: 4.0 MW

- Number of electric cars: 2000
- Driving distance: 57 km/car,day
- Energy consumption: 0.2 kWh/km
- Charging energy: 11.5 kWh/car,day → 22.9 MWh/day for all cars

- Charging power: 3.6 kW/car
- Additional power: 0 – 3.5 MW (depending on charging method)

- Charging energy (E) is equal in each charging alternative

Case Network
Reinforcement costs

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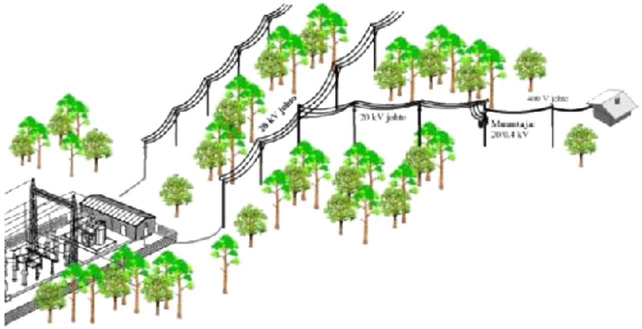
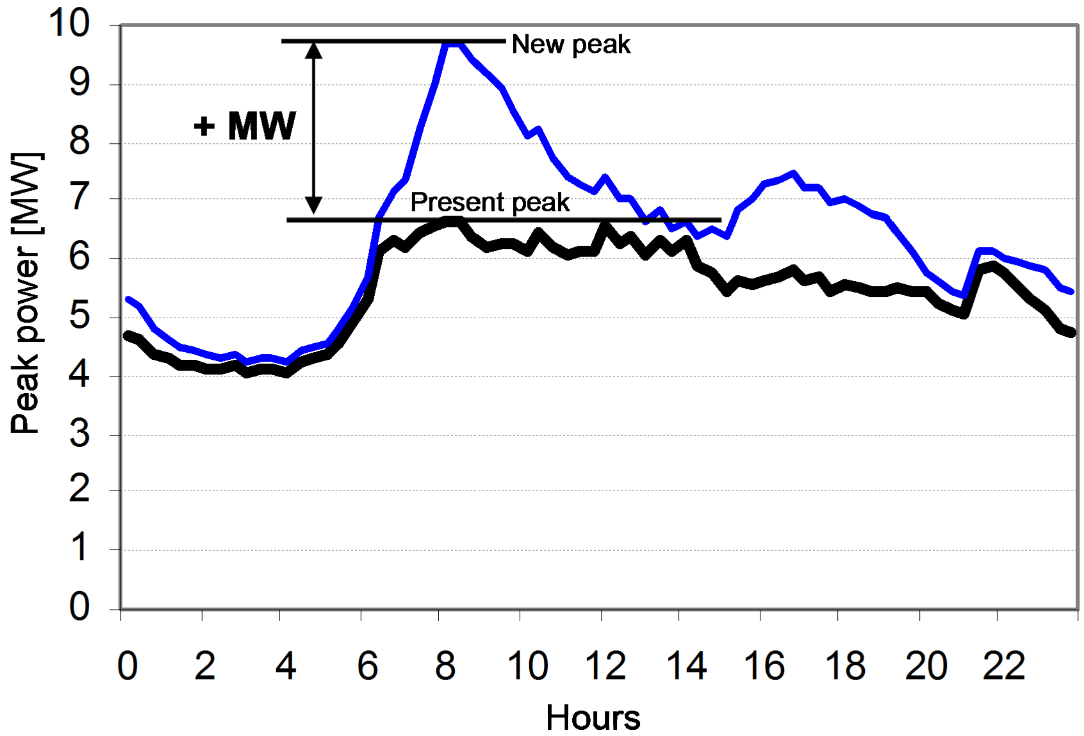


Power flow



An example of defining required reinforcement investments on the medium voltage feeder

20 kV feeder 1. (densely populated area)

-Peak load of the day: 6.6 MW

-Additional power: + 3.0 MW

- Average marginal cost: 300 €/kW

→ **Estimated need for reinforcement:**

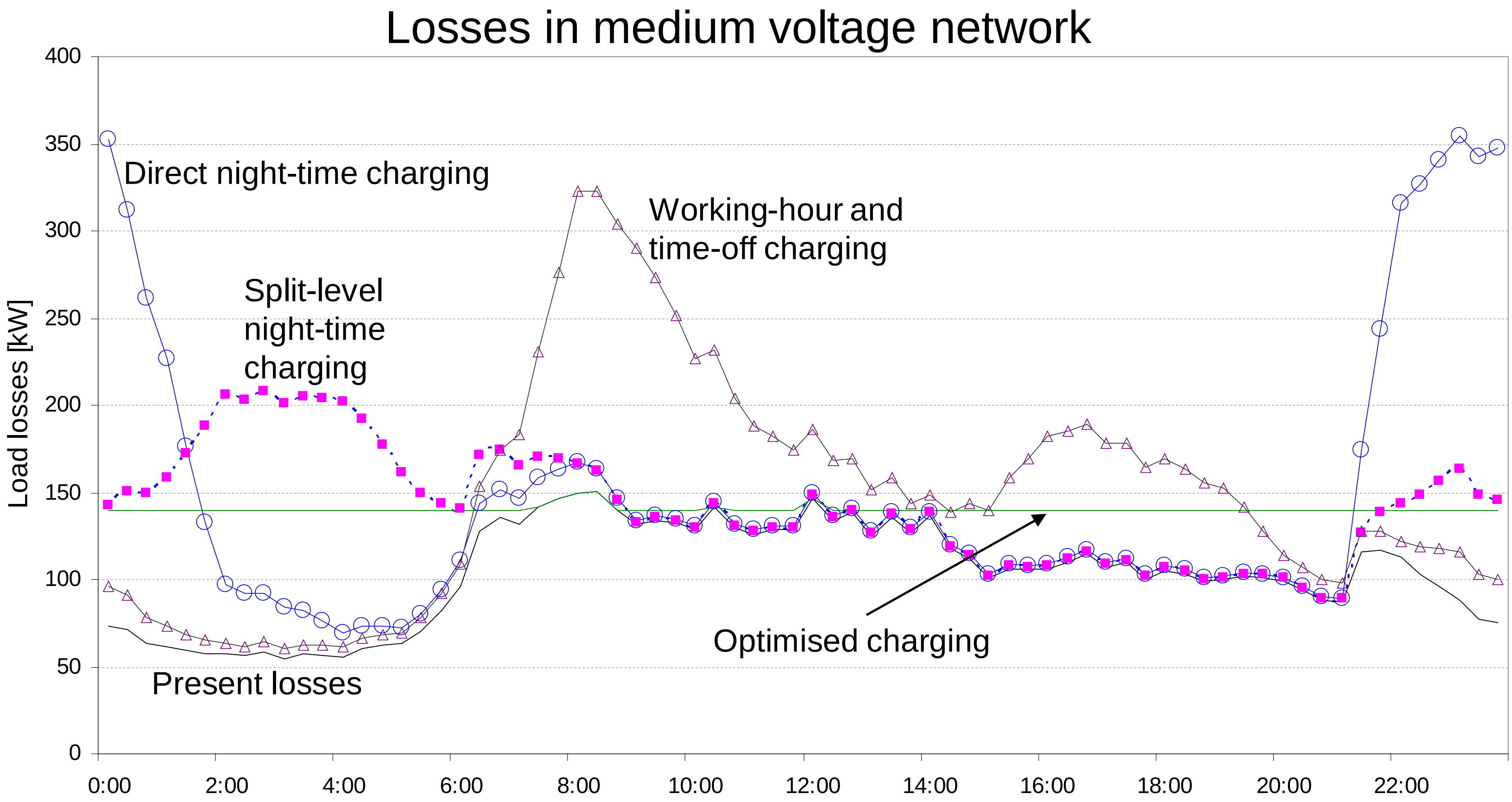
300 €/kW x 3000 kW = 900 000 €

Network value compared with the peak load in

- low-voltage networks	320 €/kW
- medium-voltage network	300 €/kW
- primary substation level (110/20 kV)	100 €/kW

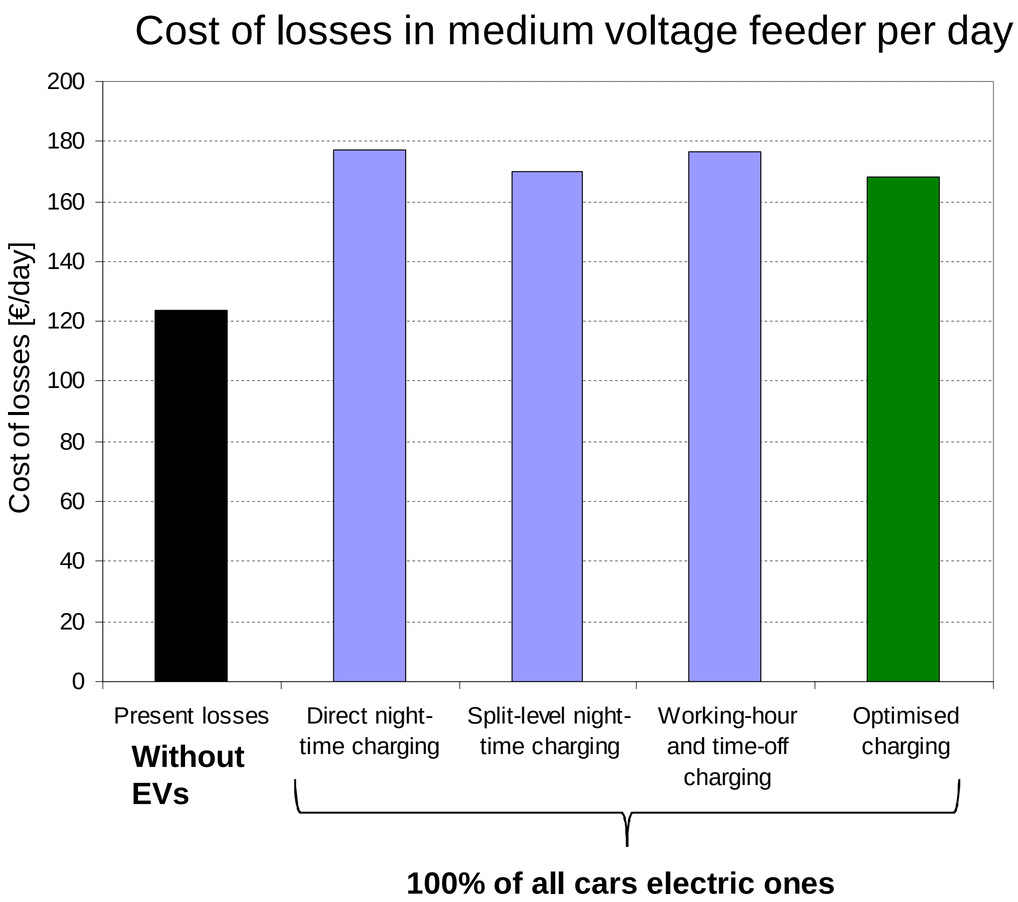
→ Using intelligent charging system (Optimised charging) charging can be adjusted fully into low-load moments

Case Network
Losses



Case Network

Losses vs. network capacity costs



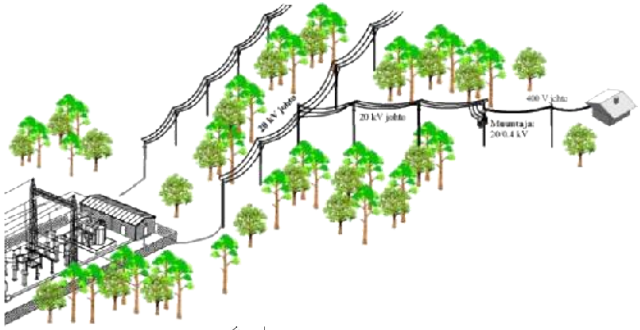
The difference in **losses** about 10 €/d and **1300 €/a** (the price of losses 5 cents/kWh).

The difference in the **required network reinforcement** investments in the optimized and non-optimized charging is 900 000 € (equivalent to **52 500 €/a** when *t* is 40 a and *p* is 5%).

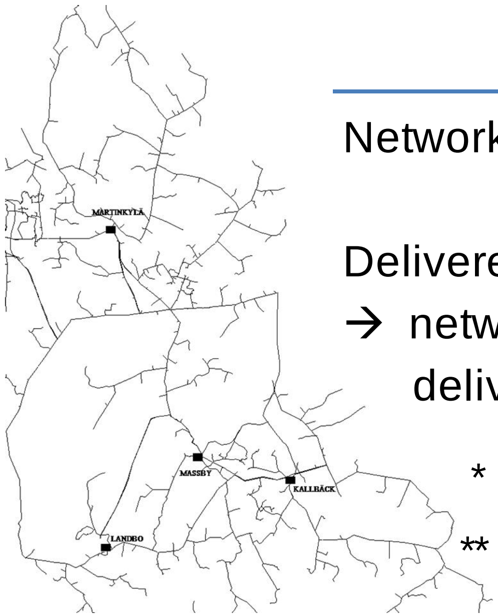
$$\text{Reincorcement} = \text{Average marginal cost} \cdot \Delta P$$
$$= 300\,€/\text{kW} \cdot 3000\,\text{kW} = 900\,000\,€$$

→ Loss costs **do not** play a significant role compared with the price of transmission capacity when considering the charging method.

Case Network
Reinforcement costs



Power flow



	Without EVs	With EVs
Network value:	50 M€	50–70 M€
	= 2.9 M€ per year*	= 2.9–4.0 M€ per year*
Delivered energy:	200 GWh per year	246 GWh per year**
→ network cost per delivered energy:	1.46 cent/kWh	1.18–1.66 cent/kWh

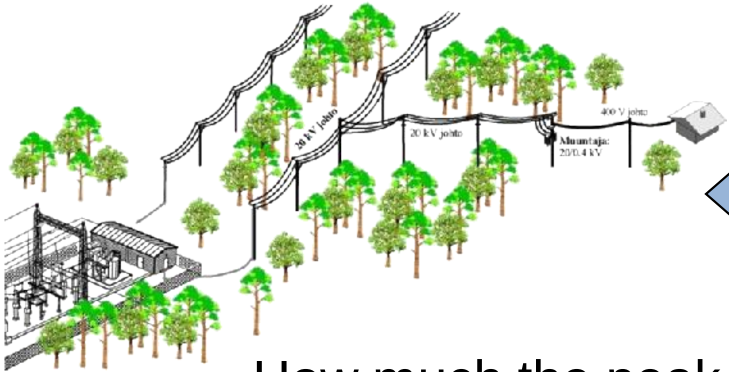
* *annual cost calculated by interest rate p = 5 % and life-time t = 40 years*

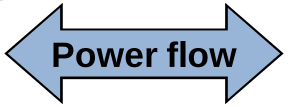
** *charging energy 46 GWh comes from 11 000 cars, 20 900 km/car per year and 0.2 kWh/km per car*

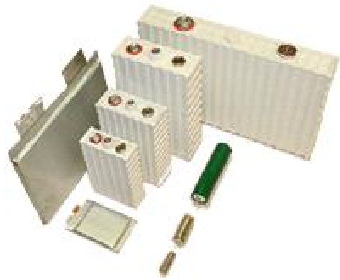
NOW: Network value per delivered energy 1.46 cent/kWh

WITH EVs: New distribution fee: 1.18 – 1.66 cent/kWh

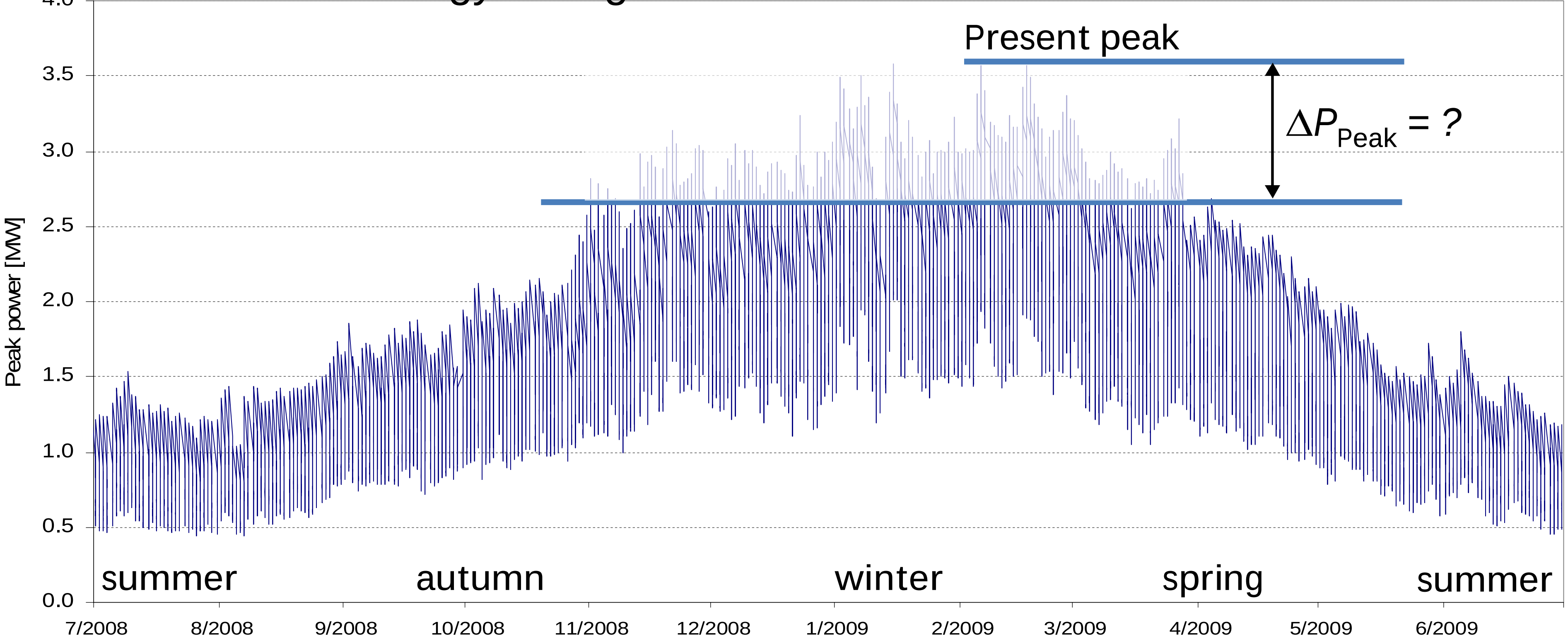
Network effects
EVs as energy storages



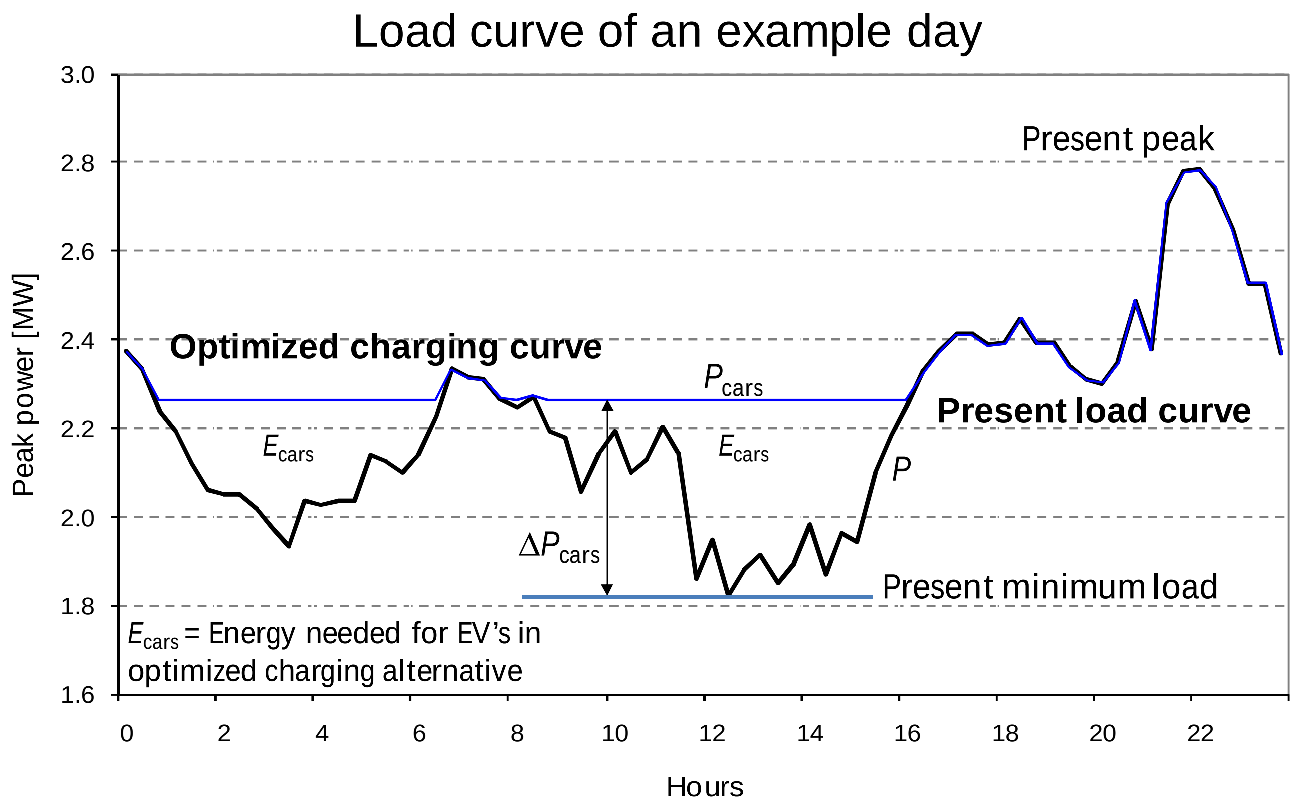




How much the peak power could be decreased by utilizing electric vehicles as energy storages on the network ?



Network effects
EVs as energy storages



An optimized charging curve for all electric cars on an example day. The daily need for energy (E_{cars}) for driving is 2.9 MWh/day (250 x 11.5 kWh/car,day).

Network effects
EVs as energy storages

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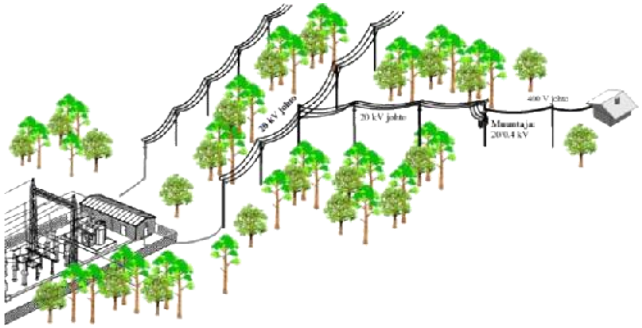
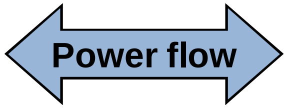
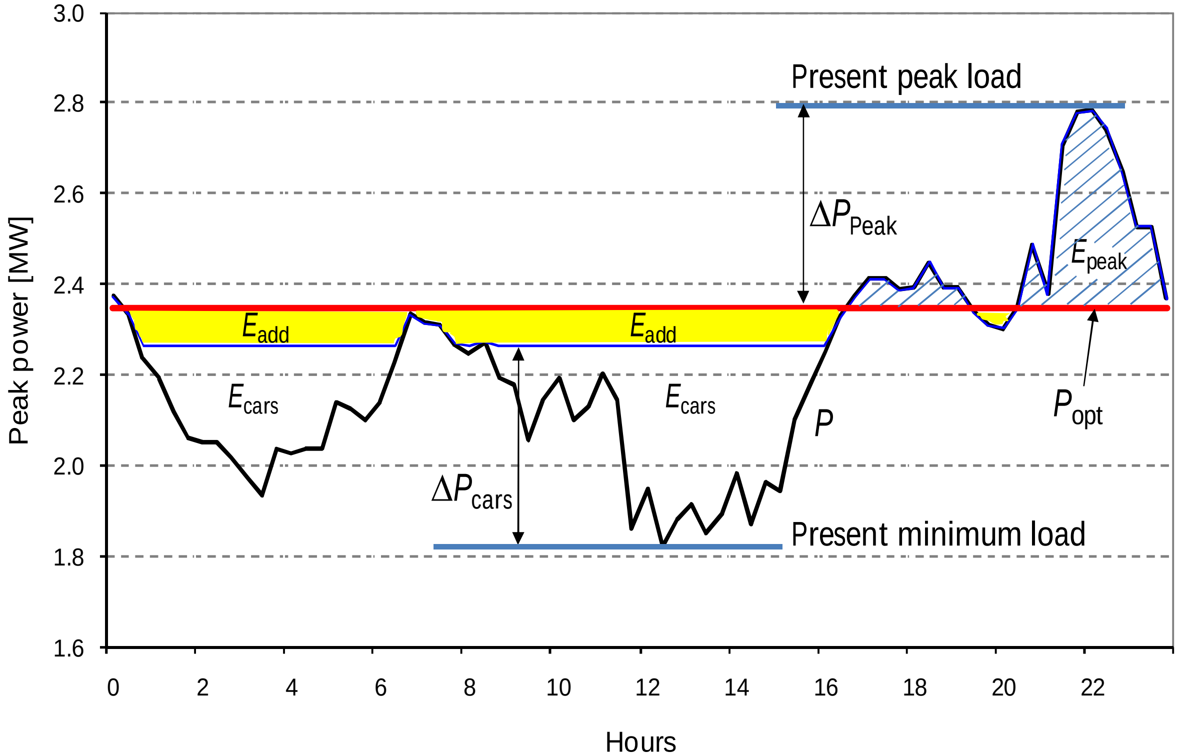




Load curve and peak reduction



Additional energy (E_{add}) needed to decrease the peak load

$$E = \int P(t)dt$$

$$E_{cars} = \int \Delta P_{cars}\, dt$$

$$E_{peak} = \int \Delta P_{Peak}\, dt$$

$$E_{add} = E_{peak}$$

$$E_{cap} = \sum (E_{battery})$$

$$\mathrm{Max}(\Delta P_{Peak}) = \text{Number of EVs} \cdot P_{supply}$$

$$\mathrm{Max}(E_{add}) = E_{cap} - E_{cars}$$

Network effects
EVs as energy storages

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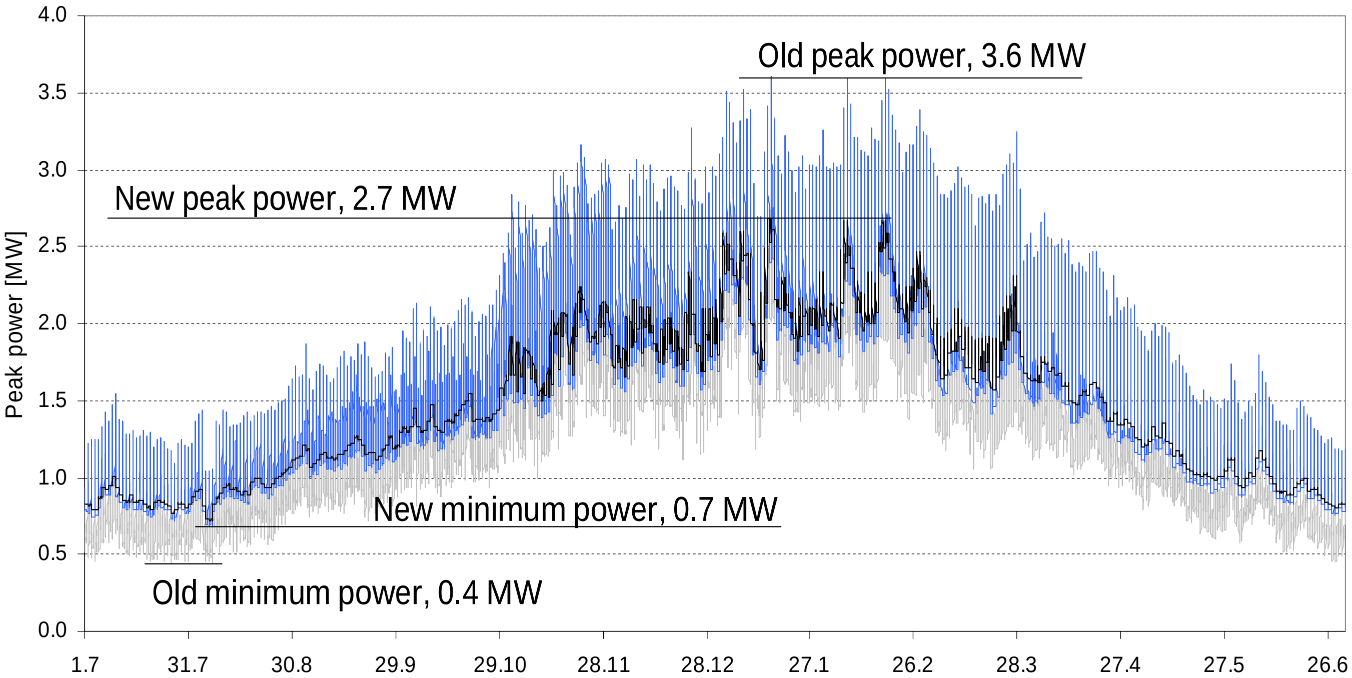
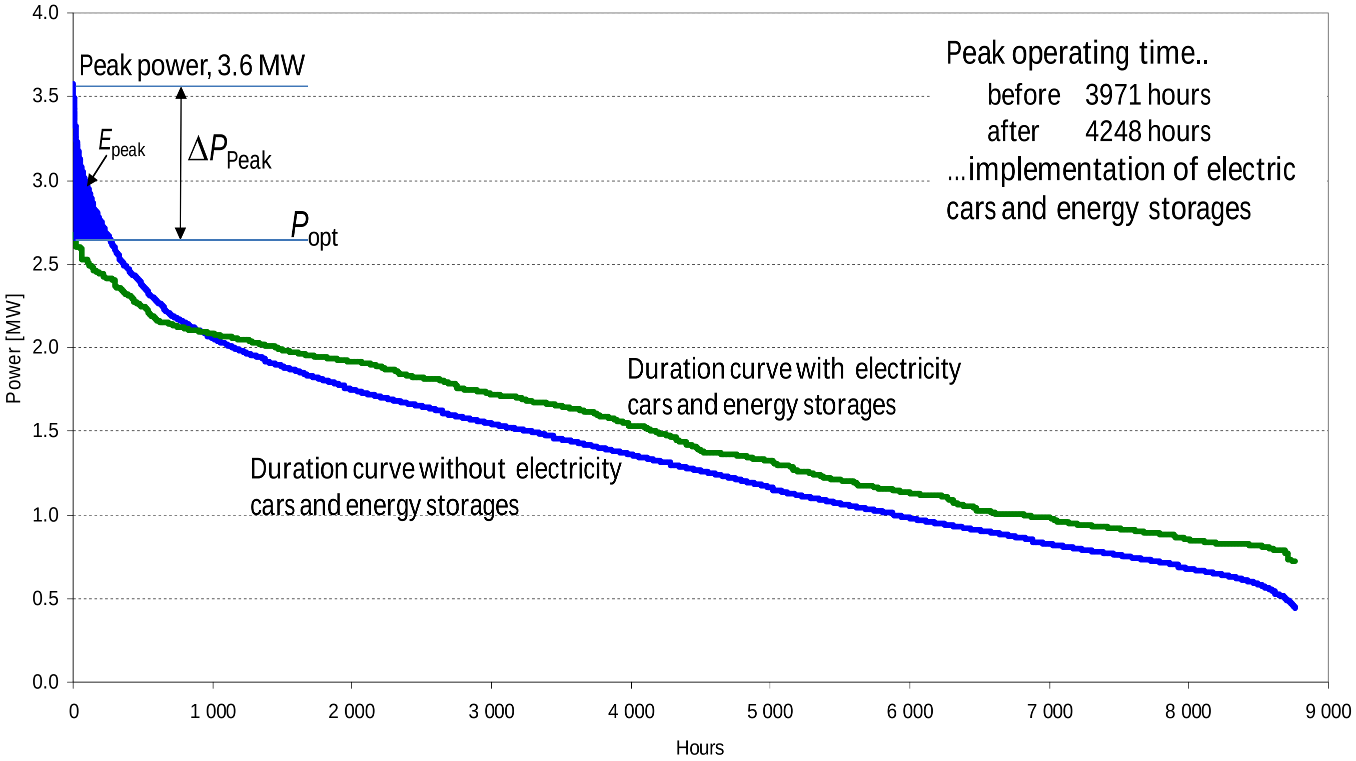
One-year load curve with and without energy storages



One-year load curve with electric cars but without energy storages (the topmost curve) and in the situation where electric cars and energy storages are included (in the middle). The bottom curve illustrates the minimum powers without cars and storages.

Network effects
EVs as energy storages

One-year duration curves



$$Savings = costs\ of\ use\ of\ storages$$

$$\Delta P_{Peak} \cdot C_{inv} = C_{e\text{-}storage} \cdot \Delta P_{Peak} \cdot t_{peak}$$

$$\rightarrow t_{peak} = \frac{C_{inv}}{C_{e\text{-}storage}}$$

$$E_{peak,limit} = \frac{21700€}{0.2\,€/\text{kWh}} = 109\text{MWh}$$

$$t_{peak} = \frac{24.1\,€/\text{kW,a}}{0.2\,€/\text{kWh}} = 120\ \text{h/a}$$

One-year duration curves of the medium voltage feeder based on load curves

Network effects
EVs as energy storages

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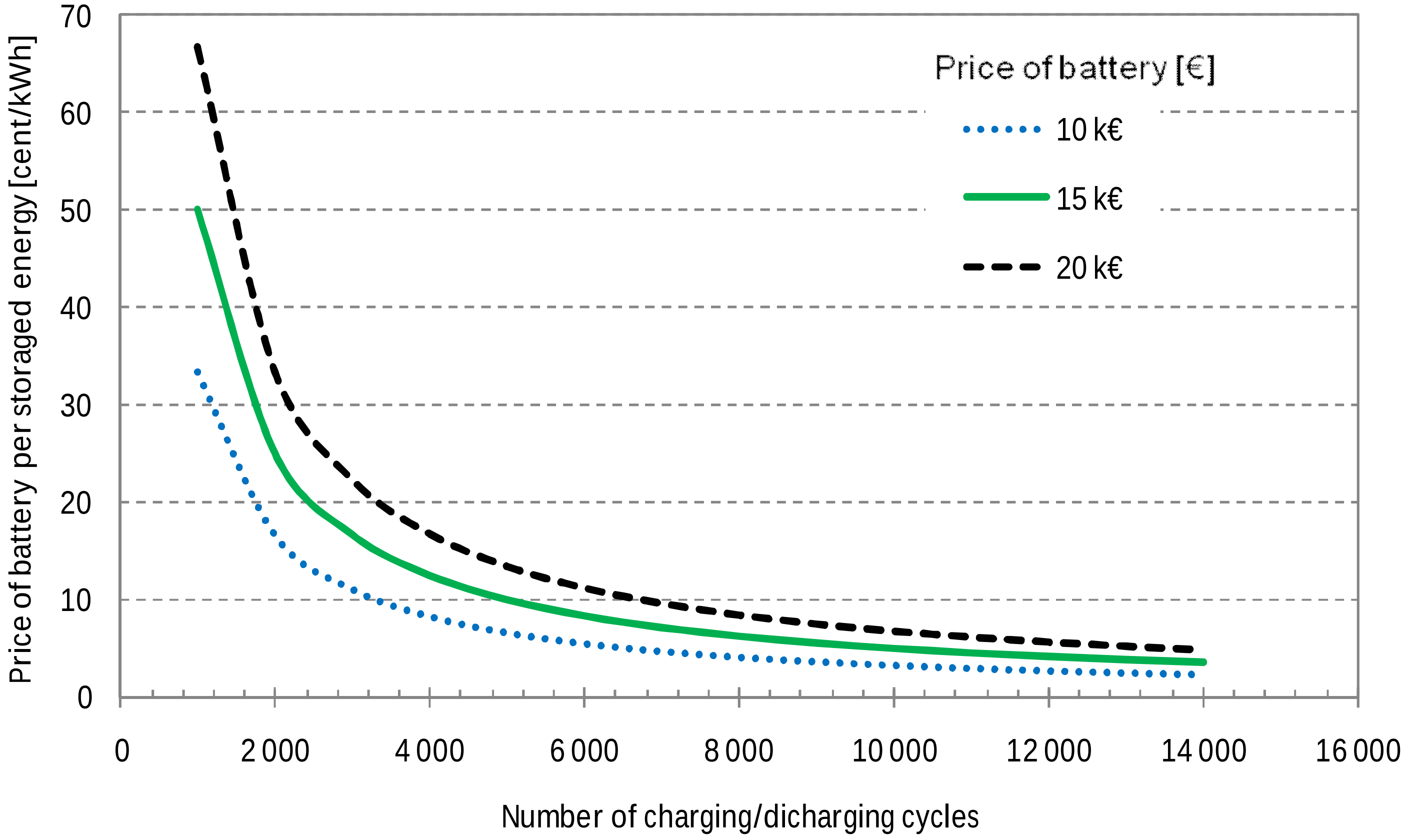
Price of batteries (30 kWh) used as an energy storage



If the price of a car battery is 10 000–20 000 € and the lifetime is 2000–4000 cycles, the investment price per discharged energy is 8–33 cent/kWh

Network effects
EVs and network planning

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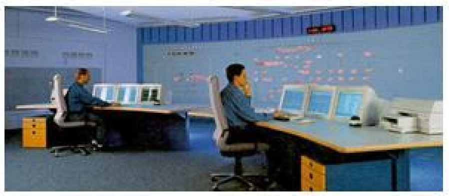
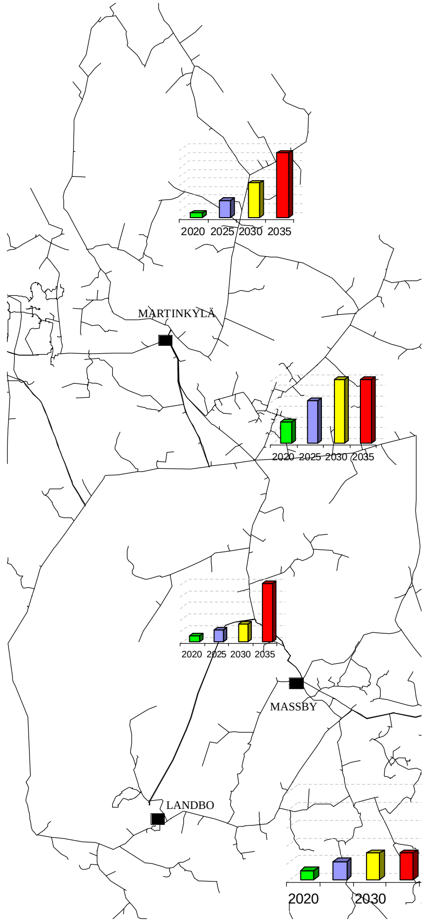
- Medium-voltage feeder and distribution network –specific load growth estimations and reasonable overdimensioning of new and renovation targets
- Dimensioning of customer points; Additional intelligence in measurements and demand respeoce (controllable alternation; electric heating, sauna, charging of EVs, etc.)
- Data transfer between distribution transformers and network operator to ensure optimized fast charging (3-phase) in low-voltage networks (NIS, DMS, CIS, SCADA…)

Electric Vehicles and Networks, conclusions

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- Charging mode has a significant impact on the peak load level
- It is possible to cut the distribution fees charged to electricity end-users
- Load variations of medium-voltage feeders have to be taken into account
- No remarkable reinforcement network investments needed in 2010-2020, (local investments; parking halls, substations for fast recharging?)

- Charging of cars will be mostly slow type charging (1 x 16 A) at home, work places and holiday homes
  - In the most cases, households are equipped with car pre-heating poles ← Upgrading requirements, Smartgrids?
  - Investments and renovation are needed in work place, apartment house and public parking areas; typically charging power restricted to ~500 W, 2-hour limited use etc.
- Fast charging option to ”gasoline” stations
  - Fast charging (~80 kW) in low-voltage network is too much
  - Super fast charging (~ 250 kW) will be located in primary subtations (for instance 20 cars → several MW)

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