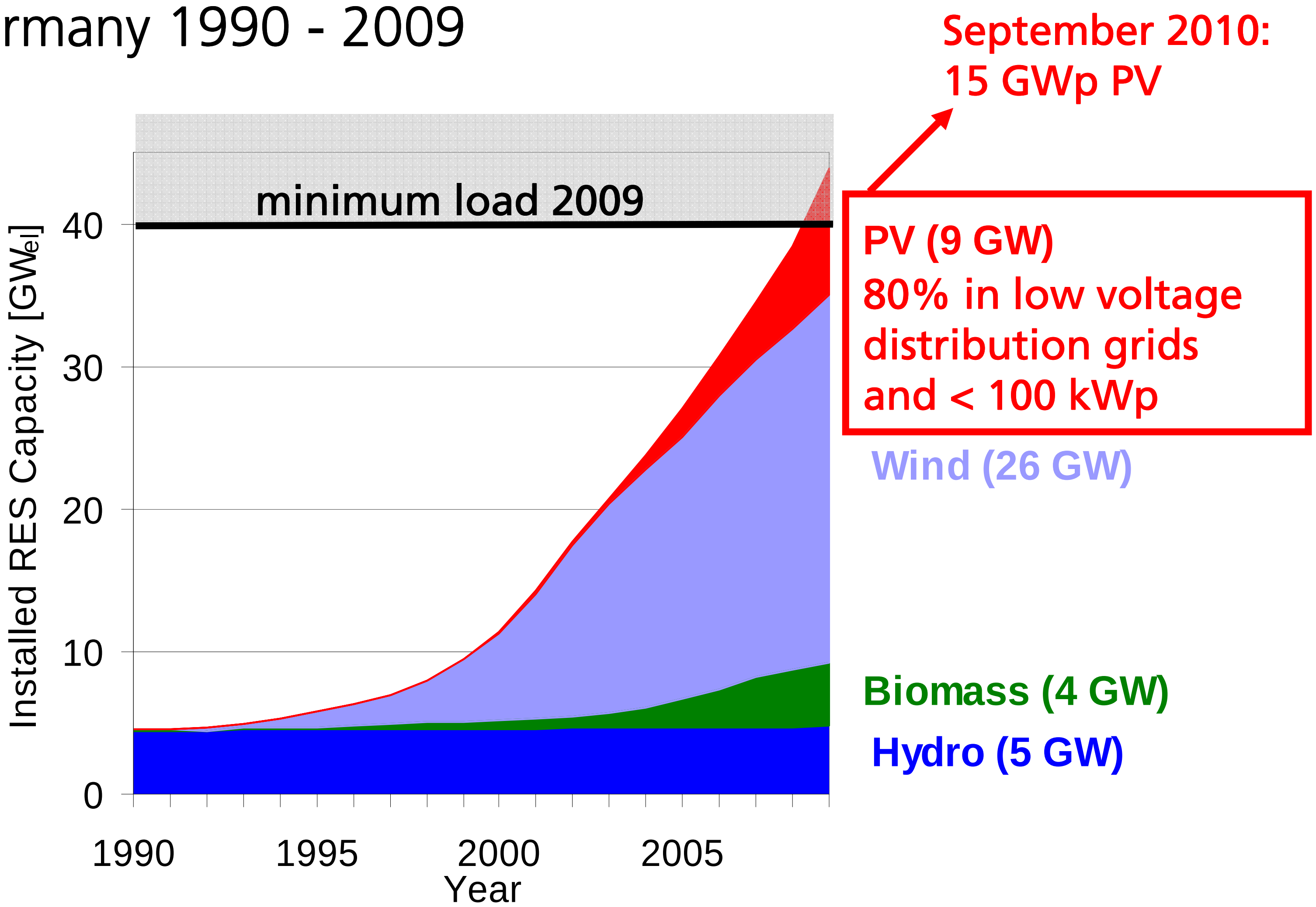
Grid-Friendly
Local Consumption of PV Energy

Prof. Dr.-Ing. Martin Braun
Kathrin Büdenbender, Heike Barth

5th International Renewable Energy Storage Conference
Berlin, 24 November 2010

Increase of Renewable Energy Sources in Germany 1990 - 2009

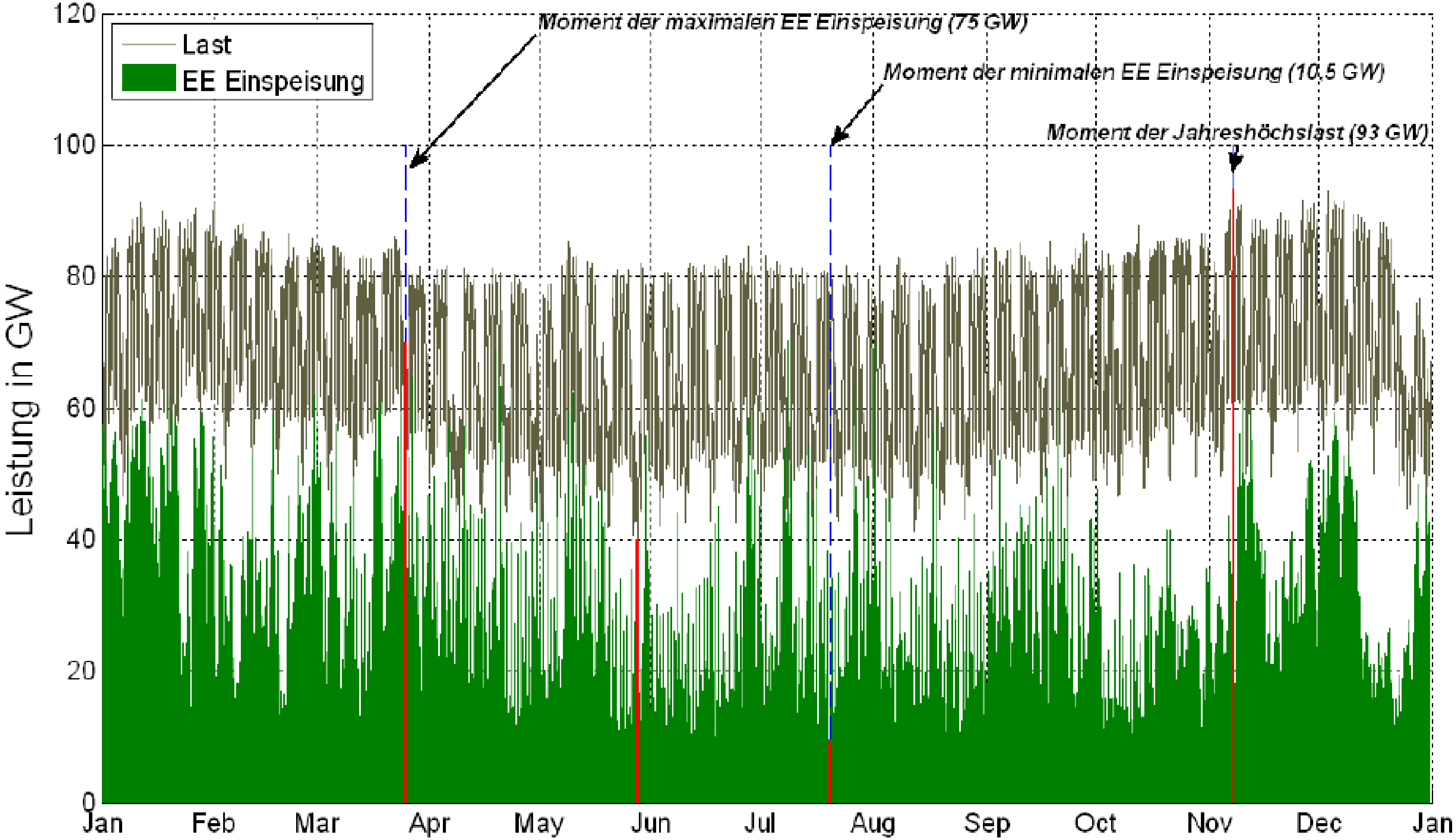


Data Source: BMU, March 2010

Photovoltaic Power Generation > 10 GW at certain times

Source: SMA.de

47% RES Scenario (2020) incl. 39.5 GWp Photovoltaic



Source: Y.-M. Saint-Drenan et al 2009 (IWES)

Impact Levels of PV Self-Consumption

1. National:
   political objectives of 20% → 30% → 50% → 80% renewable energies
   → Wind & PV power generation variable
   → **energy management** required: controllable generation limited
   → load has to follow demand & storage has to balance
   → **variable prices** to improve market integration

2. Regional:
   a) **Physically correct** energy balance (no energy distribution of locally produced and consumed energy to other consumers reasonable)
   b) High penetration of PV requires **grid reinforcements**
      → reduction of PV peak power generation
      → ancillary services (reactive power, congestion management)

?

3. Local:
   Prepare Grid-Parity Situation (energy generation costs < purchase costs)
   → incentive for locally produced power
   → **behavioural changes & automation**
   → **technology development** for decentralized energy management

Categories of Energy Management Measures (in order of increasing costs)

1. Change of Consumer Behaviour by Price Information
   e.g. „Washing with the Sun“
2. In-House-Automation → controllable electrical appliances
   e.g. **heat pump**, air conditioning, washing machine, refrigerator etc.
   → process flexibility and use of thermal storage
3. Use of **Electrical Storage**
   e.g. Sol-ion

Structure

1. Impact of PV with Self-Consumption on Electrical Low Voltage Grids
2. New Designs of Incentive Systems

Structure

1. Impact of PV with Self-Consumption on Electrical Low Voltage Grids

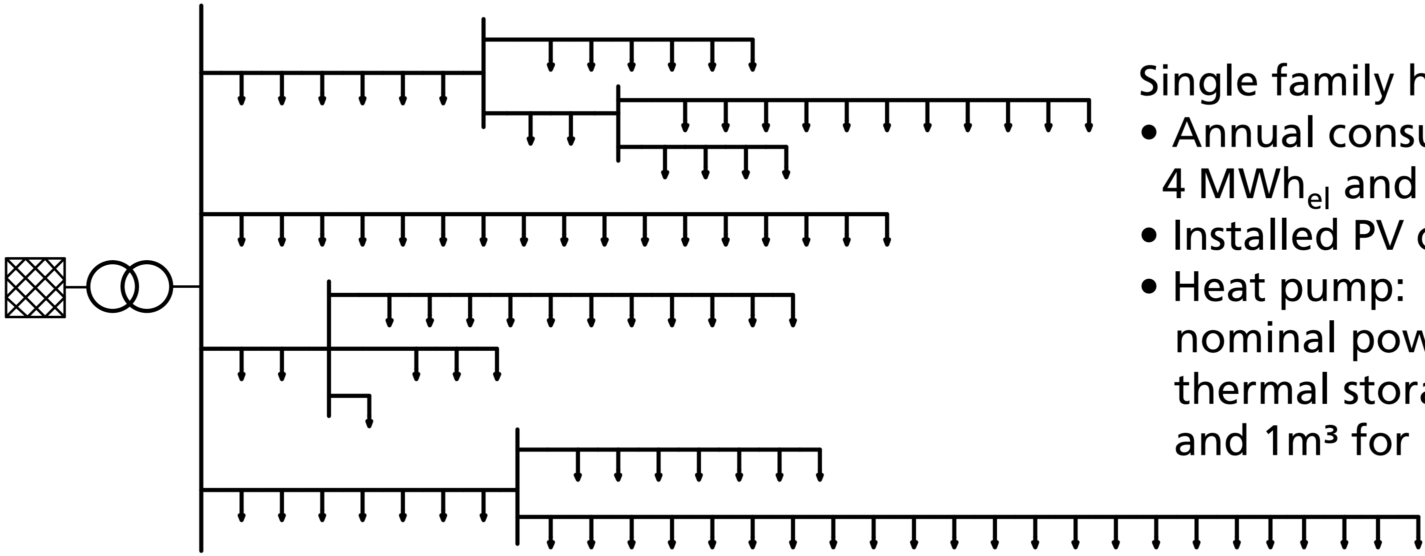
2. New Designs of Incentive Systems

Impact of PV on Electrical Grids (compared to Wind)

	Wind	Photovoltaic
Voltage Level	Medium Voltage (42% of inst. power 2009) High Voltage (48% of inst. power 2009)	Low Voltage (80% of installed power 2009) Medium Voltage (20% of installed power 2009)
Geographical dominance	North → coast with more wind & offshore	South → more sun
Seasonal generation dominance	Autumn → Winter → Spring	Spring → Summer → Autumn
Daily generation dominance	24 hours	only at daylight
Grid connection point	Separate at medium and high voltage	hundred of thousands at Point of Common Coupling of households
Congestions	Transmission System: component overloading often long grid extension process	Distribution System: voltage limits often fast grid extension process

Generic Low Voltage Test Grid

→ 1 year grid simulation in 15 min resolution with individual load profiles derived from VDEW Standard Load Profile H0 and VDI 4655

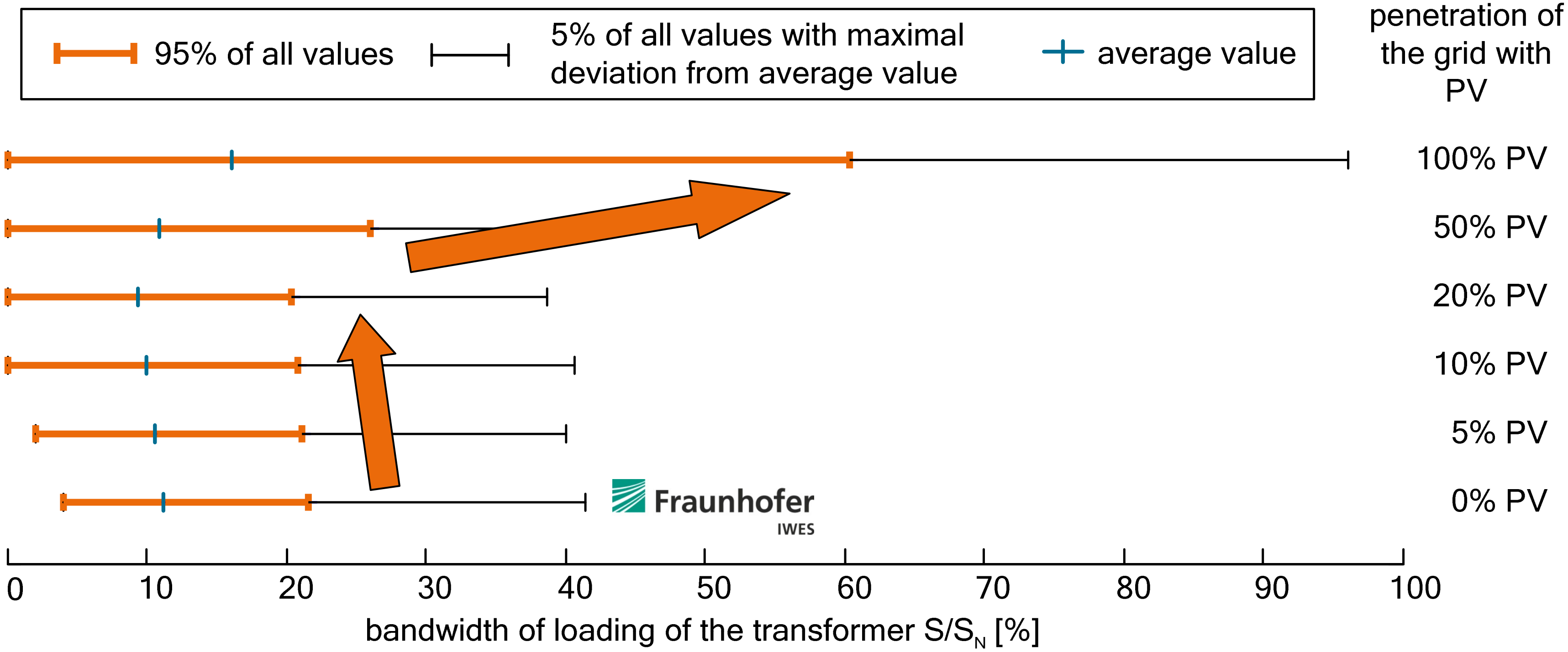


Single family households:

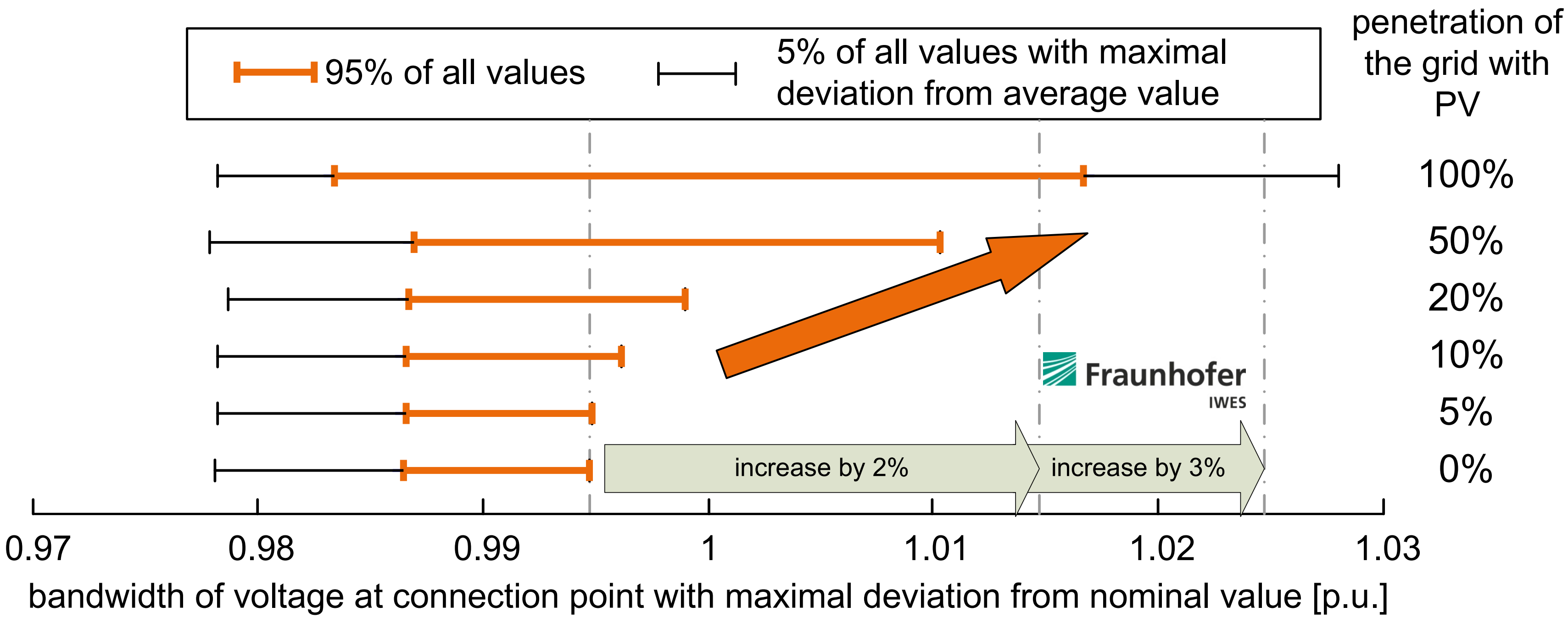
- Annual consumption:
  4 MWh_{el} and 18.2 MWh_{th}
- Installed PV capacity: 5 kWp
- Heat pump:
  nominal power: 10 kW_{th}
  thermal storage: 0.5m³ hot water and 1m³ for heating

Number of connection points	100
Type of loads	Single family households
Size of transformer	400 kVA
Length of feeders	350 – 720 m
Average distance between two houses	22 m

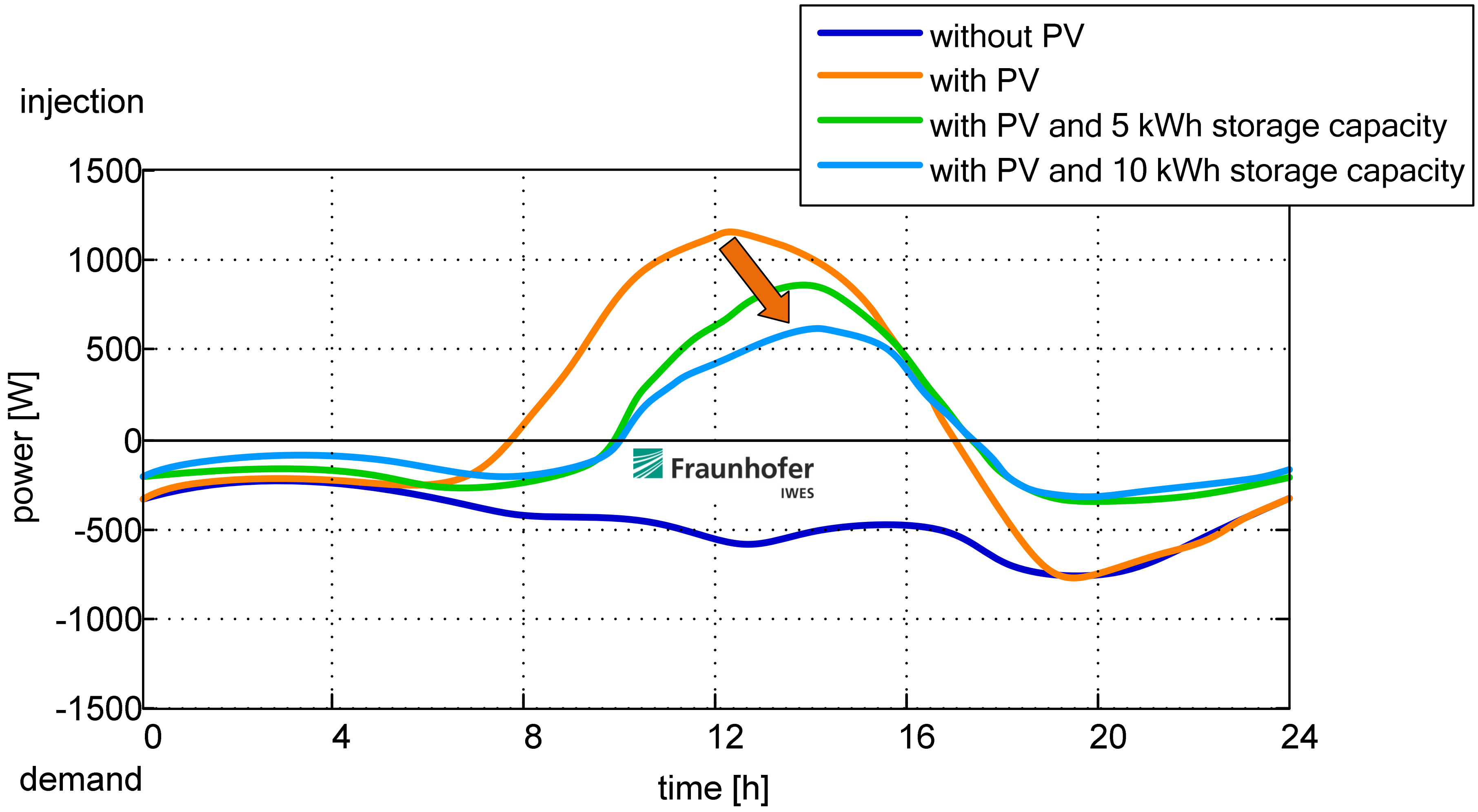
Low Voltage Test Grid: Impact of PV on Transformer Loading



Low Voltage Test Grid: Impact of PV on Voltage Profile



Self-Consumption with Electrical Storages
Annual Average Daily Profile

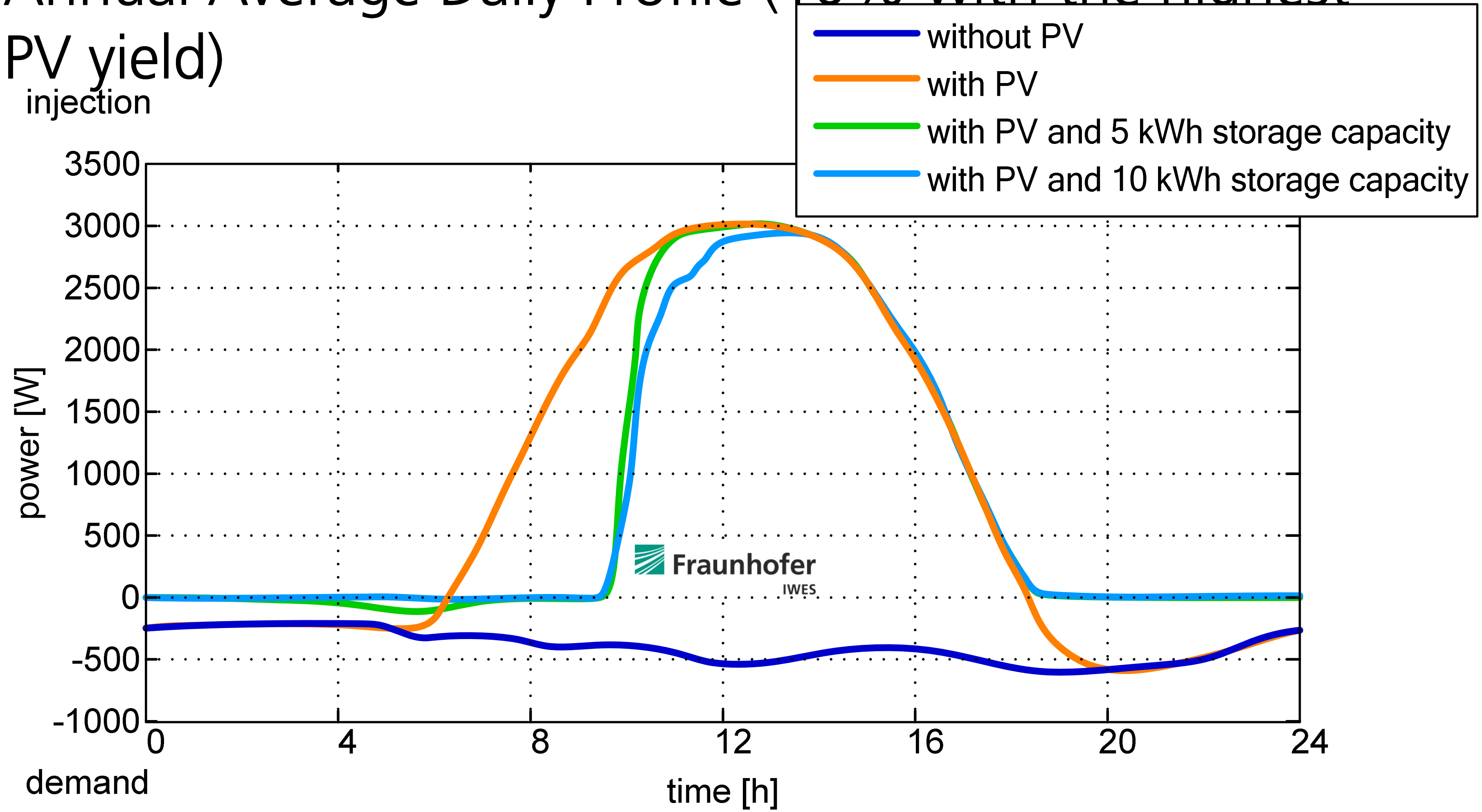


Universität Stuttgart

IEH

Fraunhofer IWES

Self-Consumption with Electrical Storages
Annual Average Daily Profile (10% with the highest PV yield)



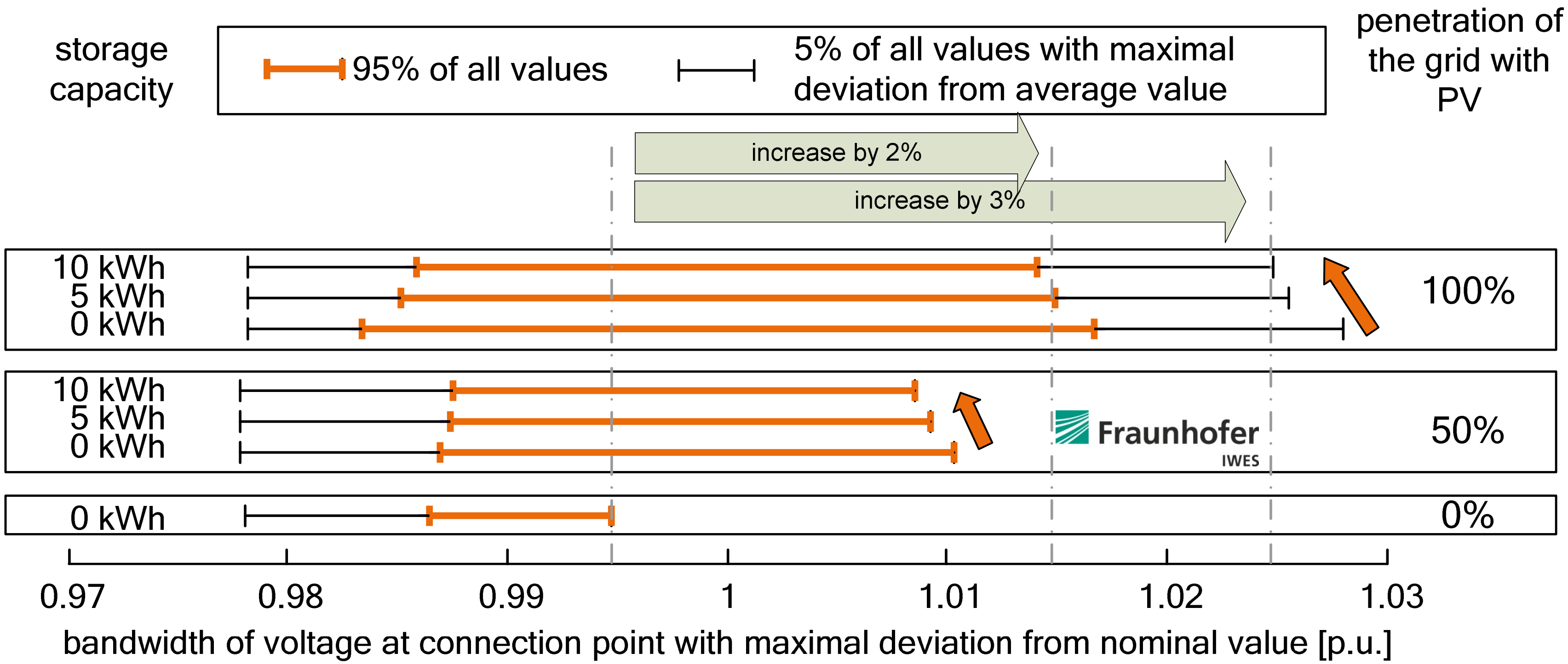
Prof. Dr.-Ing. Martin Braun
„GRID-FRIENDLY LOCAL CONSUMPTION OF PV ENERGY"
5th International Renewable Energy Storage Conference
Berlin, 24 November 2010

Universität Stuttgart

IEH

Fraunhofer IWES

Self-Consumption with Electrical Storages
Low Voltage Test Grid: Impact of PV on Voltage Profile



Universität Stuttgart

Structure

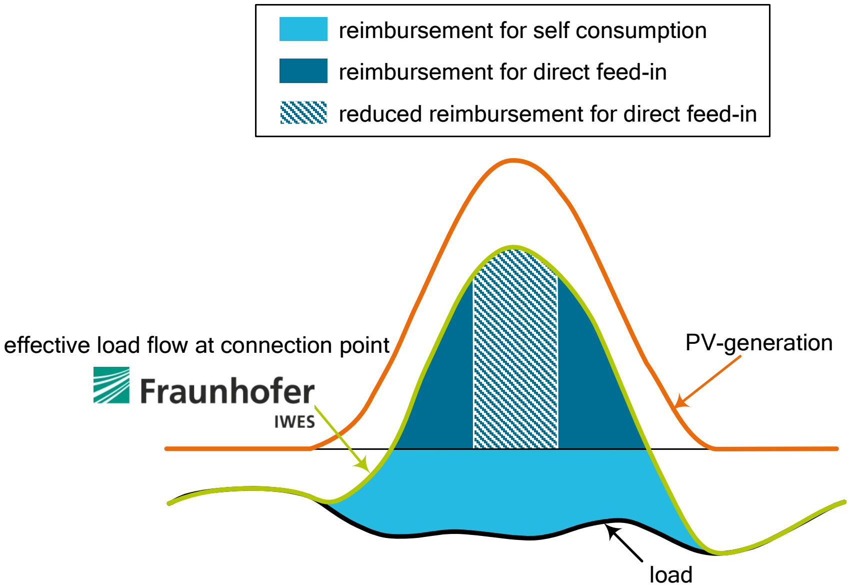
1. Impact of PV with Self-Consumption on Electrical Low Voltage Grids

2. New Designs of Incentive Systems

Universität Stuttgart
IEH
Fraunhofer
IWES

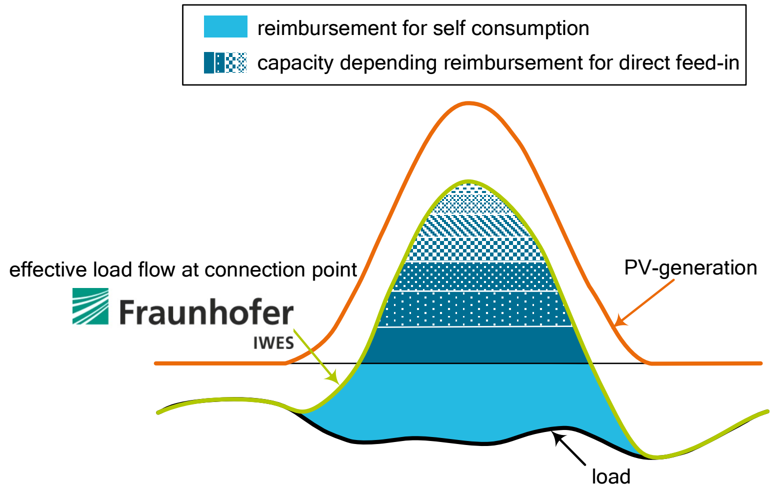
New Design of Incentive System to Reduce PV Impact on Grid

time depending reimbursements



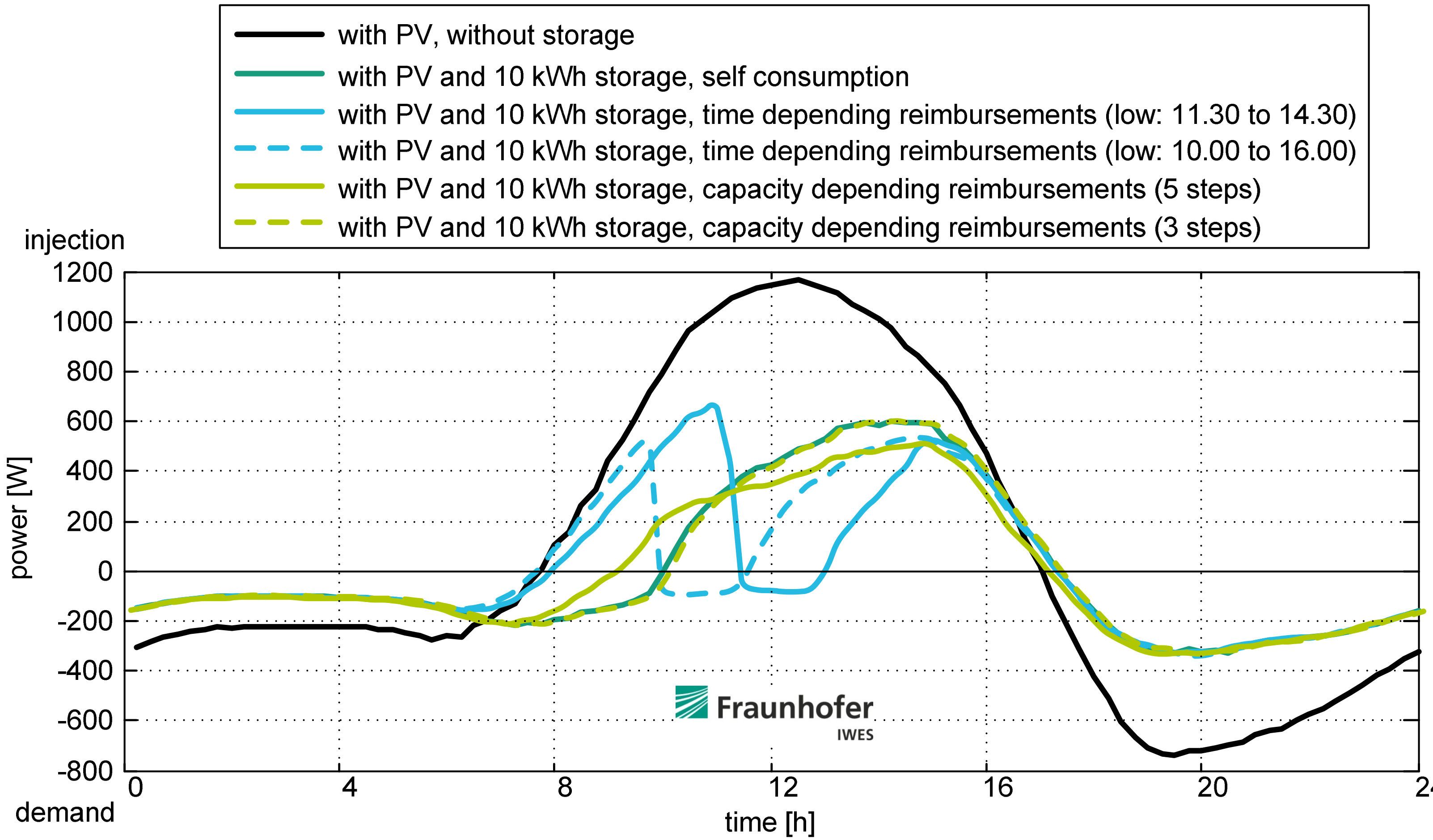
- one reimbursement for self consumed energy
- two different reimbursements for injected energy (similar to time variable prices for energy consumption)
  - lower tariff during peak injection time
  - higher tariff in remaining time

capacity depending reimbursements



- one reimbursement for self consumed energy
- multiple (number depending on number of steps) different reimbursements for injected energy (approach similar to power prices for industry)
  → maximum injection power per day determines the reimbursement for the injected energy during this day), the higher the power, the lower the reimbursement tariff

New Incentive Design
Self-Consumption with Electrical Storages
Annual Average Daily Profile

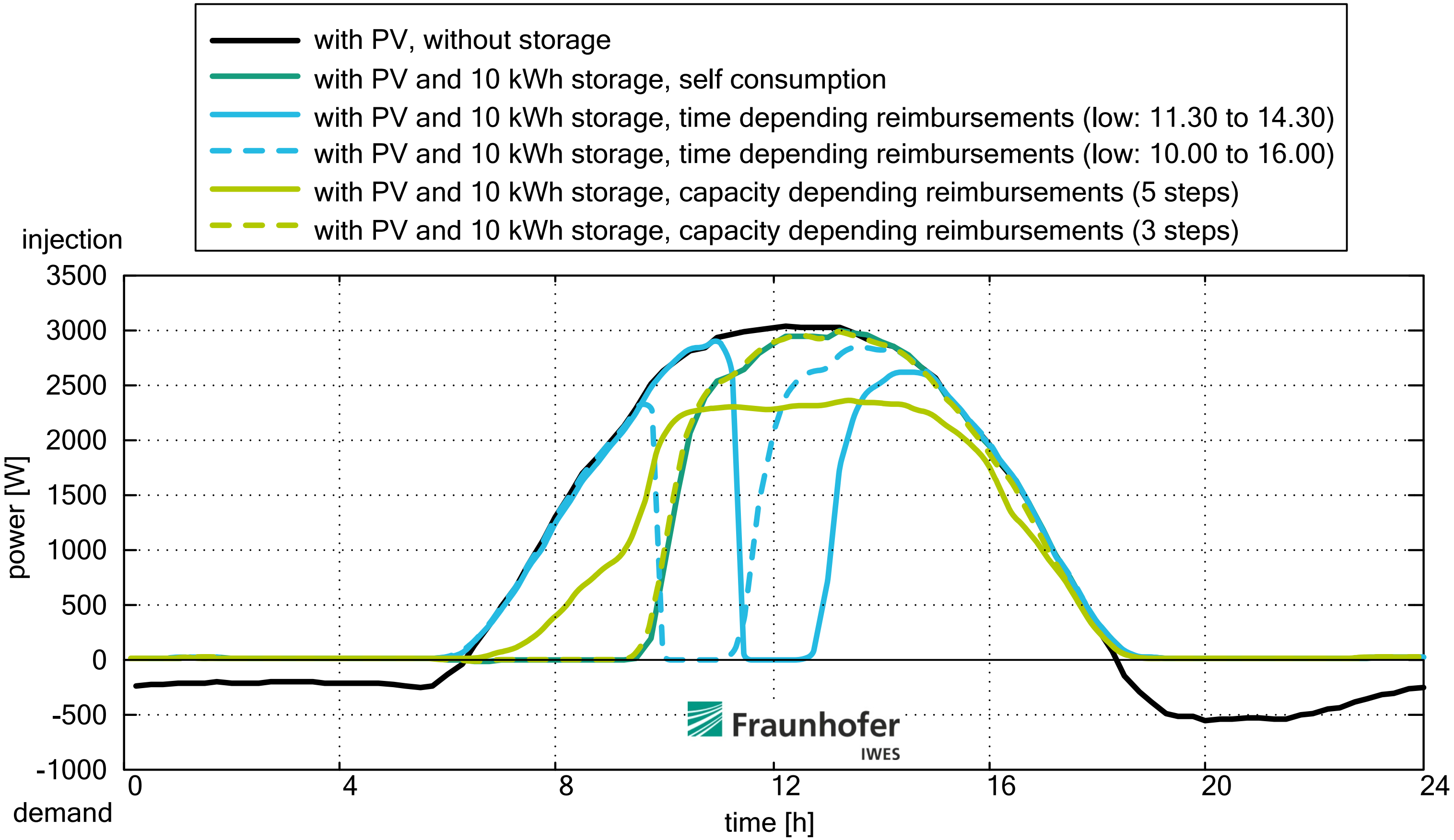


Universität Stuttgart

IEH

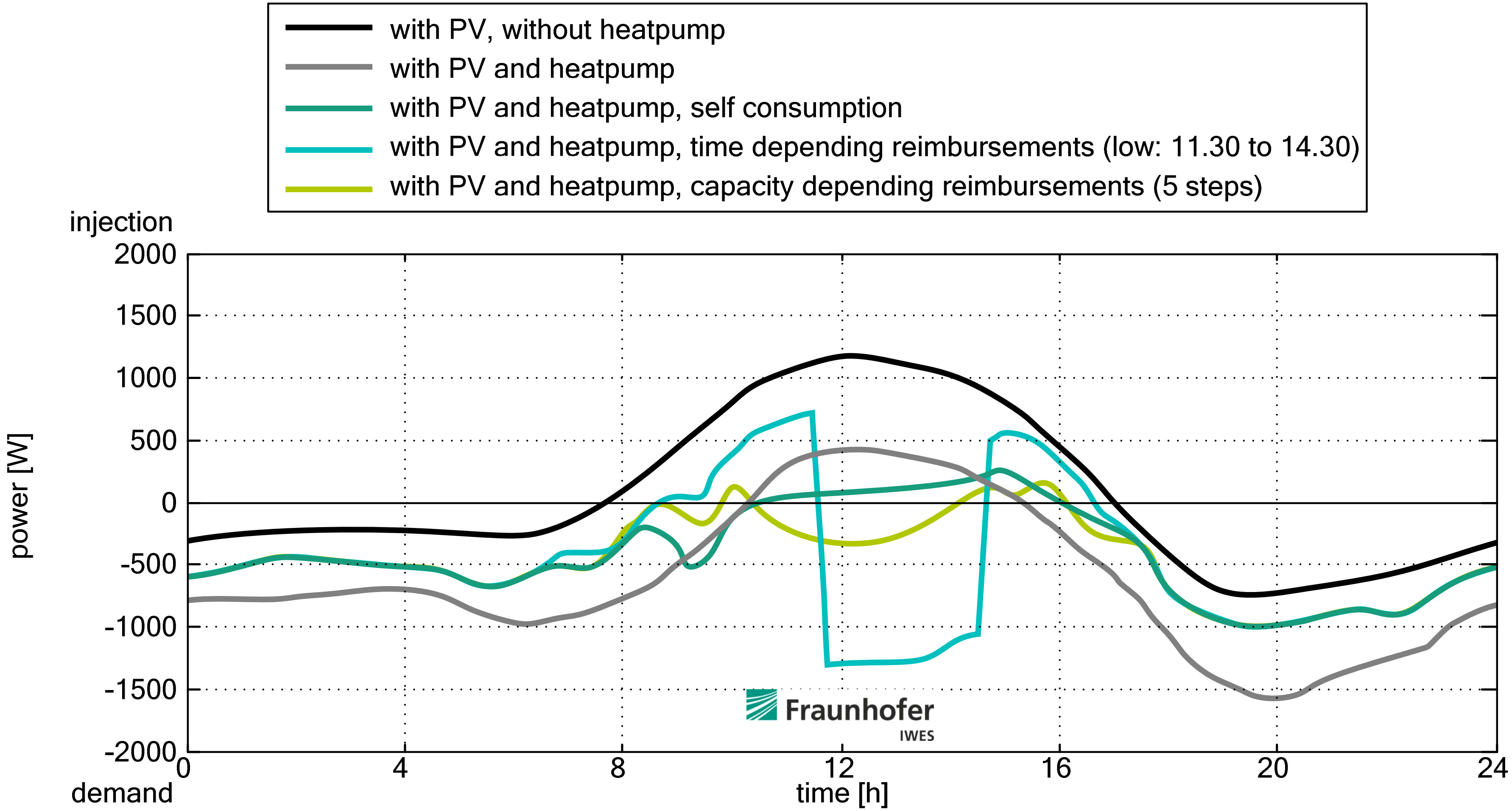
Fraunhofer IWES

New Incentive Design
Self-Consumption with Electrical Storages
Annual Average Daily Profile (10% with the highest PV yield)



Universität Stuttgart

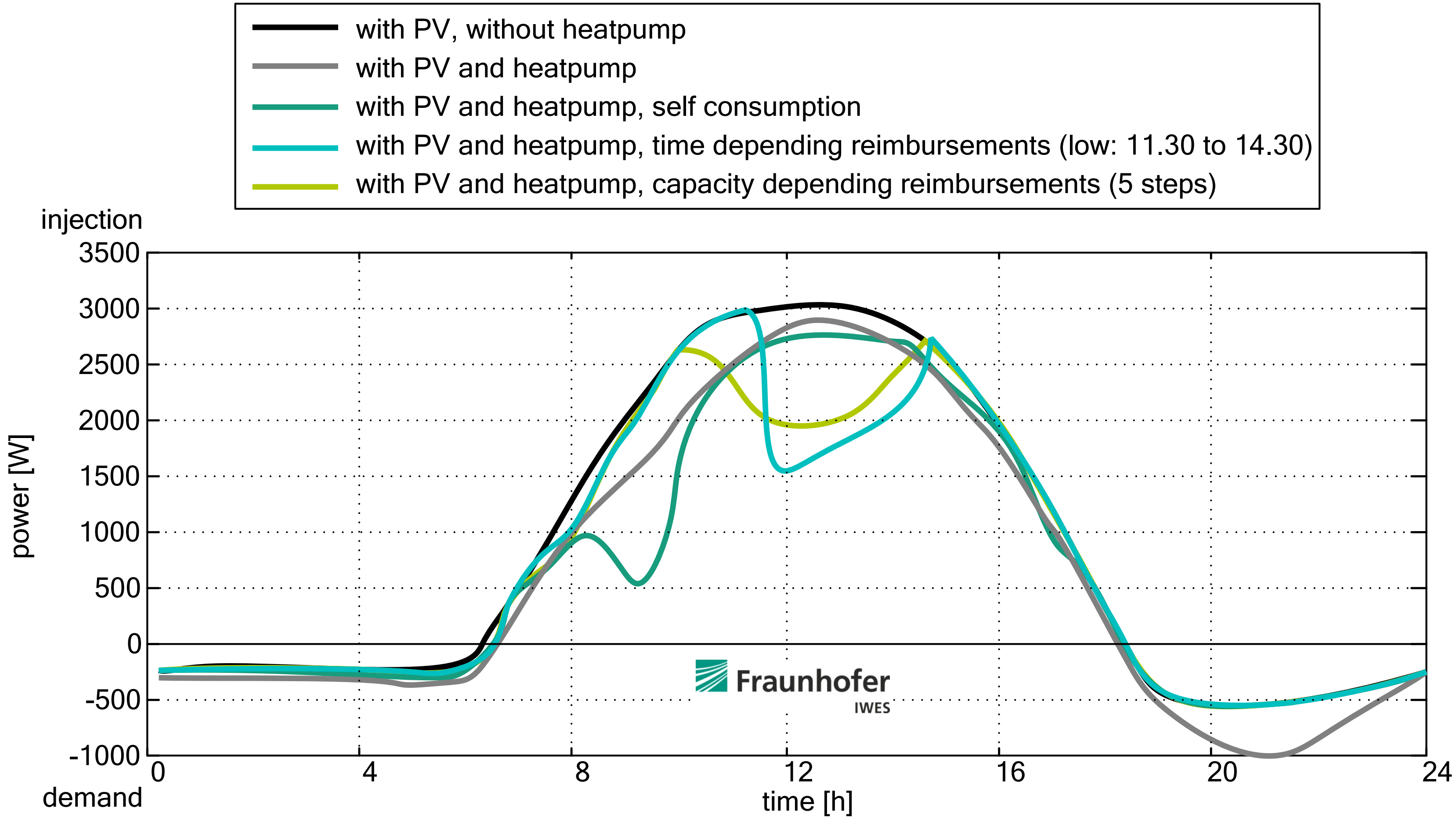
New Incentive Design
Self-Consumption with Thermal Storages (Heat Pump)
Annual Average Daily Profile



Universität Stuttgart

Fraunhofer IWES

New Incentive Design
Self-Consumption with Thermal Storages (Heat Pump)
Annual Average Daily Profile (10% with the highest PV yield)

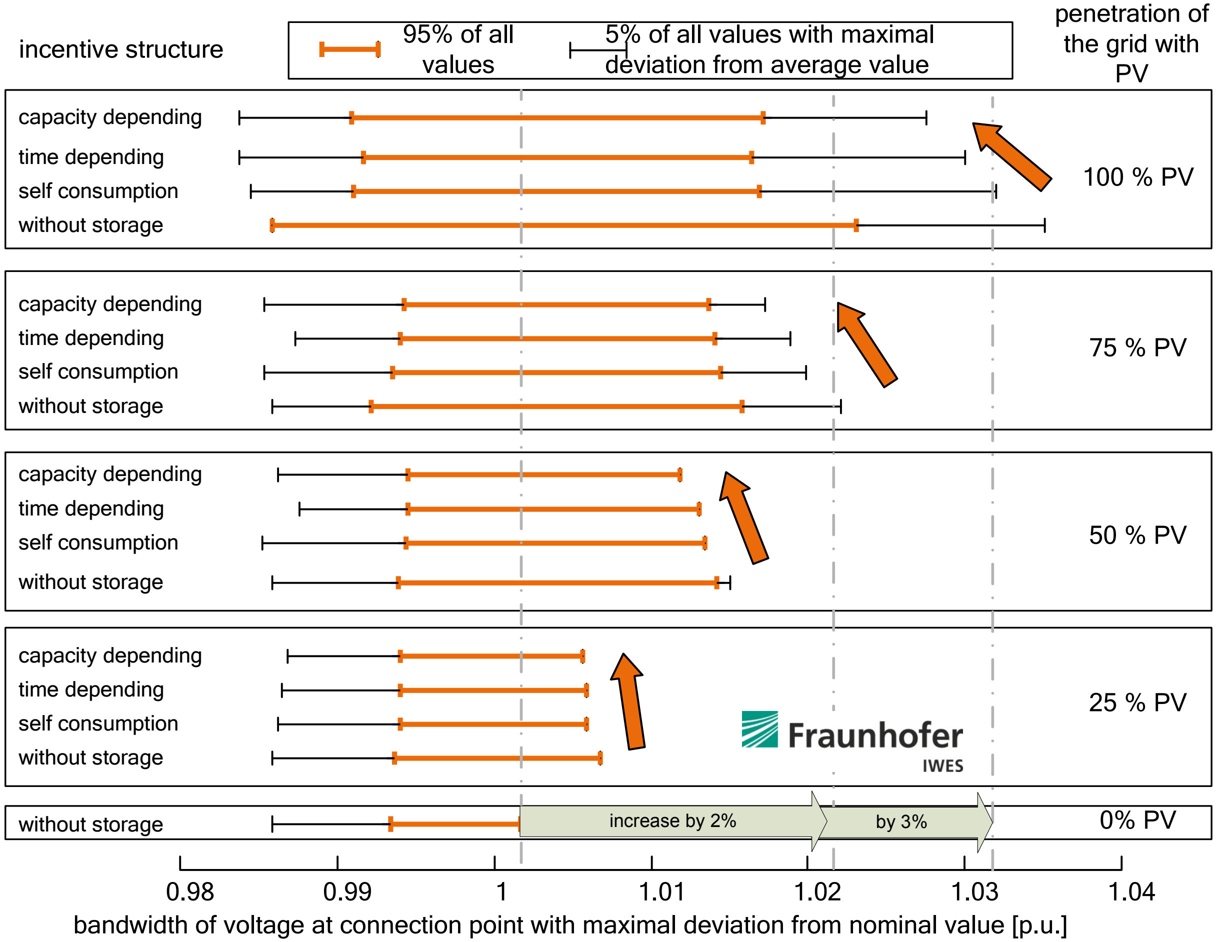


Universität Stuttgart

IEH

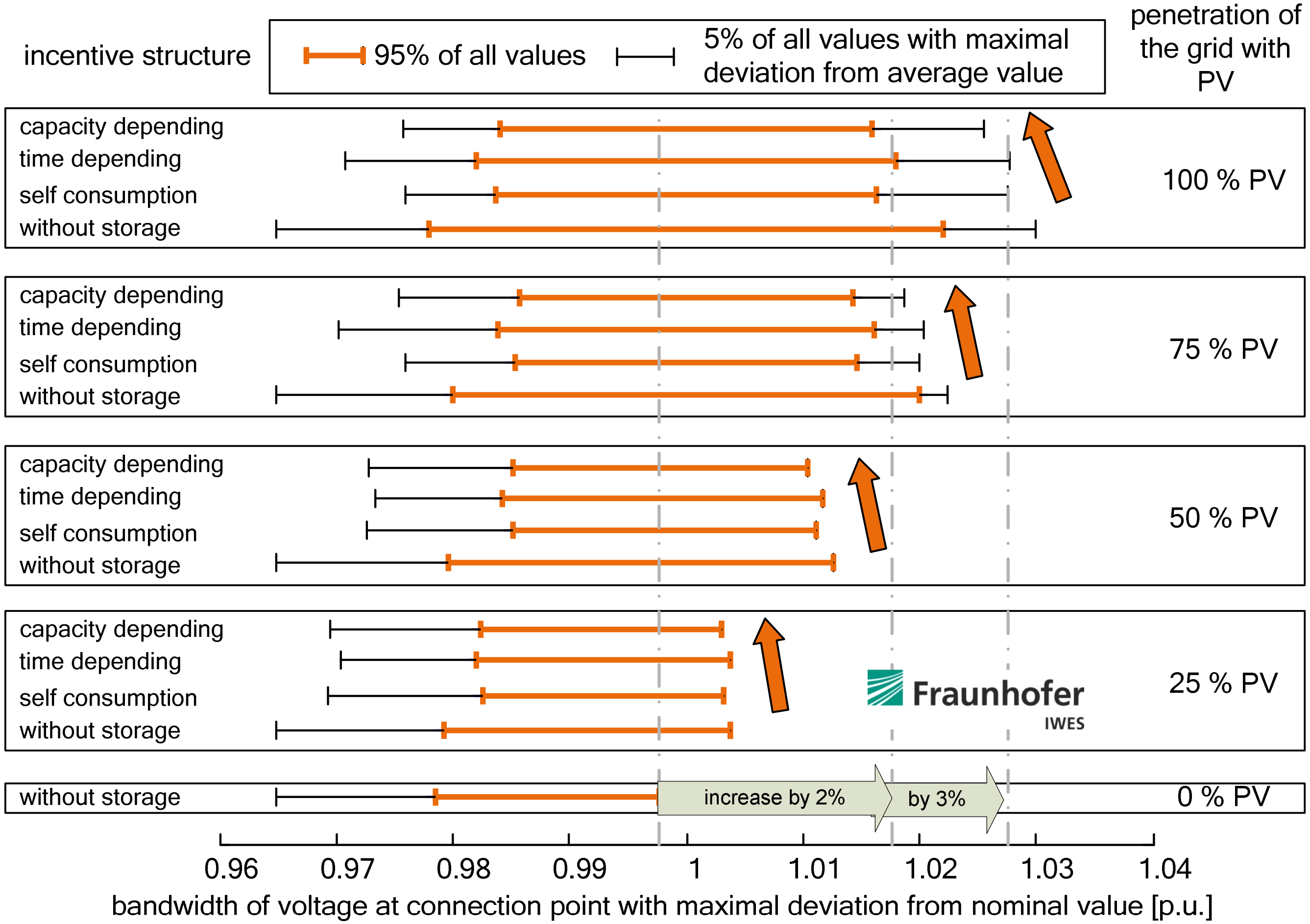
Fraunhofer IWES

New Incentive Design
Self-Consumption with Electrical Storages
Low Voltage Test Grid: Impact of PV on Voltage Profile



Universität Stuttgart

New Incentive Design
Self-Consumption with Thermal Storages (Heat Pump)
Low Voltage Test Grid: Impact of PV on Voltage Profile



Universität Stuttgart

Summary (Self-Consumption Incentive System Designs)

1. High Penetration of PV
   → Peak Power Flows → Voltage above Limits → Grid Reinforcement
2. Present Incentive Design for Self-Consumption
   → Energy Management e.g. with Batteries and Heat Pumps
   → Reduces Peak Power Flows → Grid Reinforcements Marginally
3. New Designs of Incentive Systems
   - time-dependent design (easier to implement but lower impact)
   - capacity-dependent design
   → Reduce Peak Power Flows → Grid Reinforcements more
   Difficult to Design for Maximum Grid Benefit (→ we are working on it!)
4. Benefits of Self-Consumption Incentive System
   → Physically correct
   → Step towards Energy Management (required in future RES Scenarios)
   → Prepares for Grid-Parity Situation
   → Incentivizes Technology Development: e.g. Variable Prices, SmartMeters, Gateways, Energy Management Systems, Controllable Appliances, Inhouse Automation, Behaviour Changes etc.

Universität Stuttgart

IEH

Fraunhofer IWES