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The Impact of Distribution Grid Injection Limits on the Investment Strategy of Prosumers

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Prosumers

- *Energy customers who actively manage both their production and consumption of energy. [1]*
- They are on the rise!
  - Advances in PV and storage technologies
  - Cost decline
  - Planned roll our of smart metering
  - Favorable regulation
- Grid connected decentralized PV installations
  - 2011 = 44.5 GW
  - 2017 = 169 GW [2]
- Important value creators → additional services: demand response, ancillary services, storage capacity…
- Centralized to decentralized generation → large, variable injection quantities (energy & power) straining electricity grid infrastructure.

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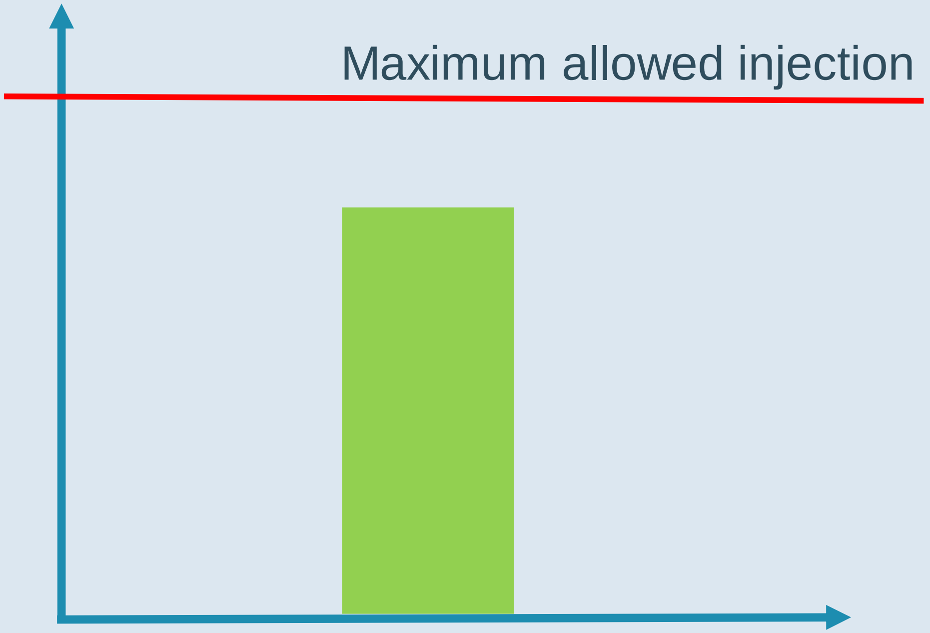

Distribution Grid Injection Limits

- *Grid-feed in limit, a physical cap on how much power prosumers can inject into the distribution grid. [3]*
- Coupling distributed PV systems + storage with grid injection limits → common solution found in literature. [4], [5]
- Impose a certain characteristic on the system, for example:
  - Large amounts of PV with little storage
  - Charging/discharging schemes for batteries
  - Favor self-consumption
- Added value of my research
  - Prosumers decide for themselves based on market forces
  - Observe system level changes

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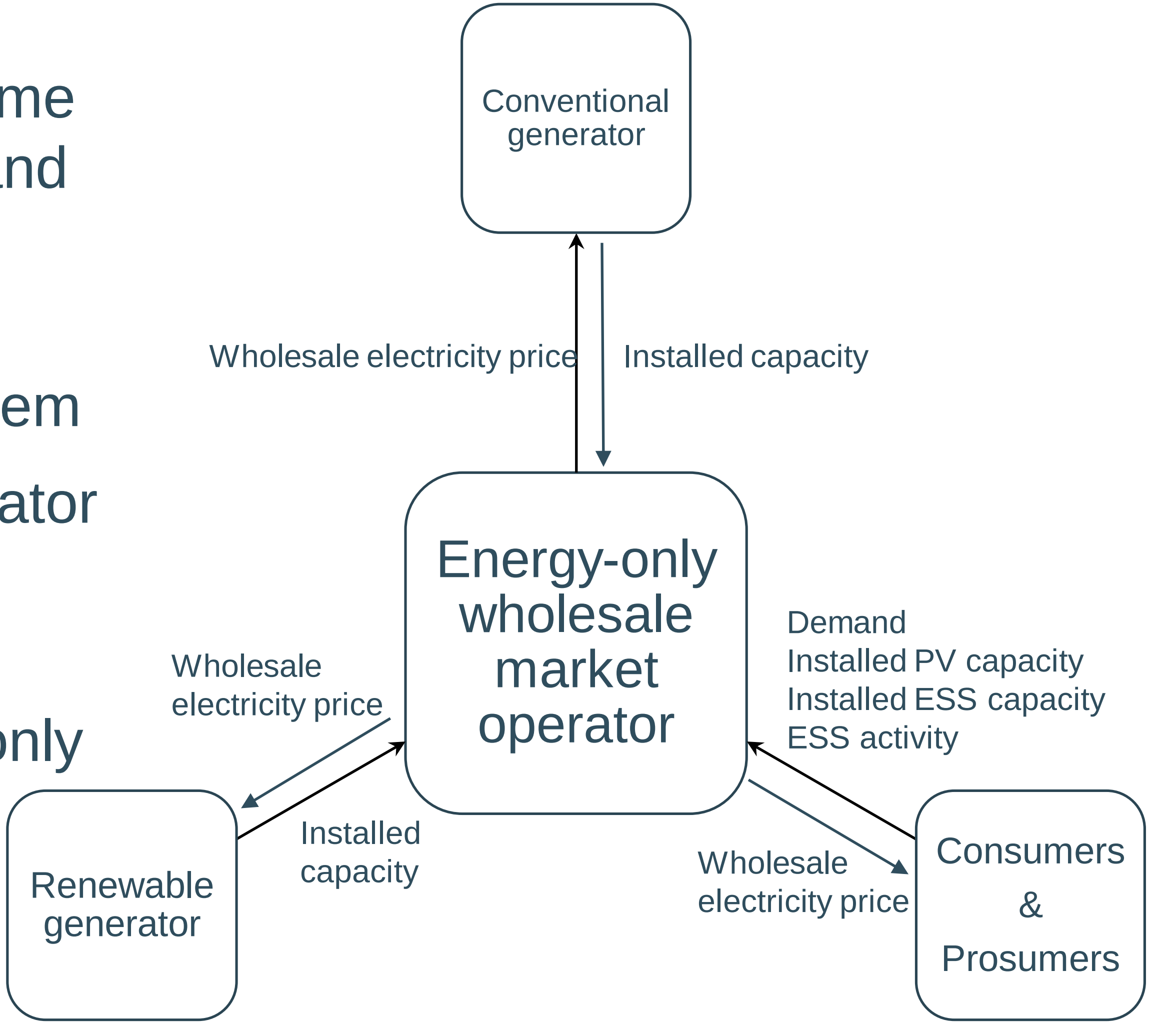
Methodology

- Non-cooperative game between suppliers and consumers on a wholesale market
- An equilibrium problem
- Energy market operator linking all gents and clearing the market
- Assume that PV is only residential roof-top



Conventional generator

Wholesale electricity price

Installed capacity

Energy-only wholesale market operator

Wholesale electricity price

Installed capacity

Renewable generator

Demand
Installed PV capacity
Installed ESS capacity
ESS activity

Wholesale electricity price

Consumers & Prosumers

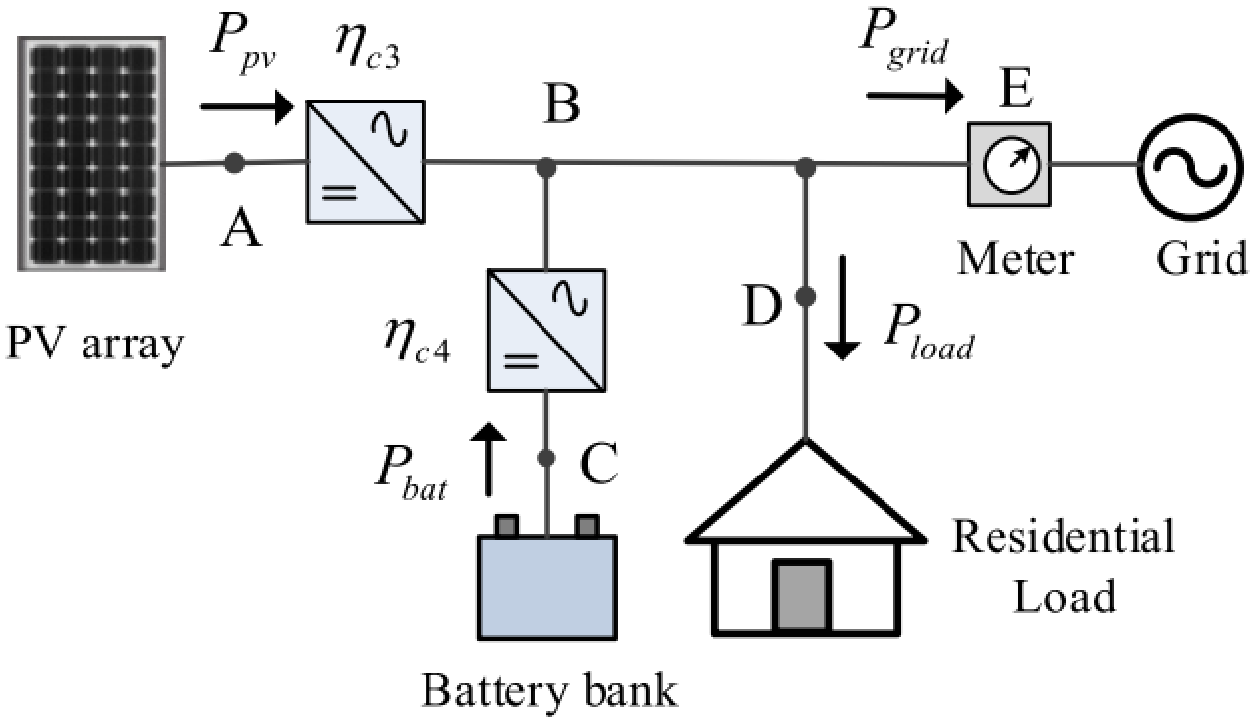
Mathematical formulation

$$\text{Minimize} \sum_{k\in K}\left(IC_k^{conv}\times cap_k^{conv}+\sum_{t\in\tau} VC_k\times g_{d,t,k}^{conv}\times weights_d\right)+IC^W\times cap^W$$
$$+\sum_{j\in J}\left(IC^{store}\times cap_j^{store}+IC^{PV}\times cap_j^{PV}+IC^{inv|PV}\times cap_j^{inv|PV}+IC^{inv|s}\times cap_j^{inv|s}\right)$$

- Equivalent optimization problem
  - Consider constraints of all agents
  - Minimize sum of all costs – overall minimizing system costs

Decision Variables	
Prosumer	- Charge/discharge of battery - PV generation (based on load factor) - Net injection $\max_{withdraw} \geq w \geq -\max_{inject}$ - Battery, PV module, inverter capacities
Conventional and Wind Generators	- Capacity - Generation

AC Coupled Topology



Picture from: Ranaweera, I. & Midtgård, O. M. Optimization of operational cost for a grid-supporting PV system with battery storage. *Renew. Energy* **88**, 262–272 (2016).

Country Level System

- Considering 300 different prosumer and consumer types
  - ➢ Each scaled to represent 8,000 households
  - ➢ Total = 4.8 million residential consumers
  - ➢ Non-residential
- Maximum connection capacity of 10 kW = no injection limit.
  - ➢ Observe what happens as this imposed limit decreases.
- Time-frame: one year
- Repeat for 5 ‘States of the World’ (SOW)
  - ➢ Different plausible price structures

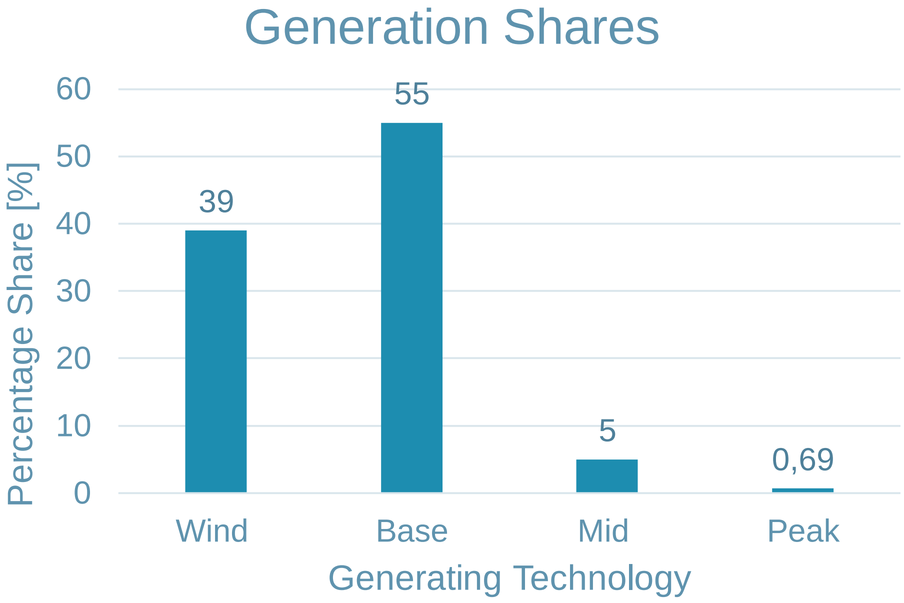
States of the World (SOW)

	PV Module [€$_{2019}$/kW]	Solar Inv [€$_{2019}$/kW$_{AC}$]	Battery [€$_{2019}$/kWh]	Battery Inv [€$_{2019}$/kW$_{AC}$]
1: Today's Prices	**710**	**255**	**690**	**355**
2: 2030 IRENA Prediction Expensive	**450**	**200**	**550**	**300**
3: 2030 IRENA Prediction Average	**370**	**155**	**310**	**215**
4: 2030 IRENA Prediction Cheap	**270**	**115**	**75**	**140**
5: Cheaper Inverters	**270**	**40**	**75**	**55**

SOW 1 & SOW 2

- No investments made by prosumers regardless of injection limits → all households remain as consumers
- Two states yield equivalent outcomes

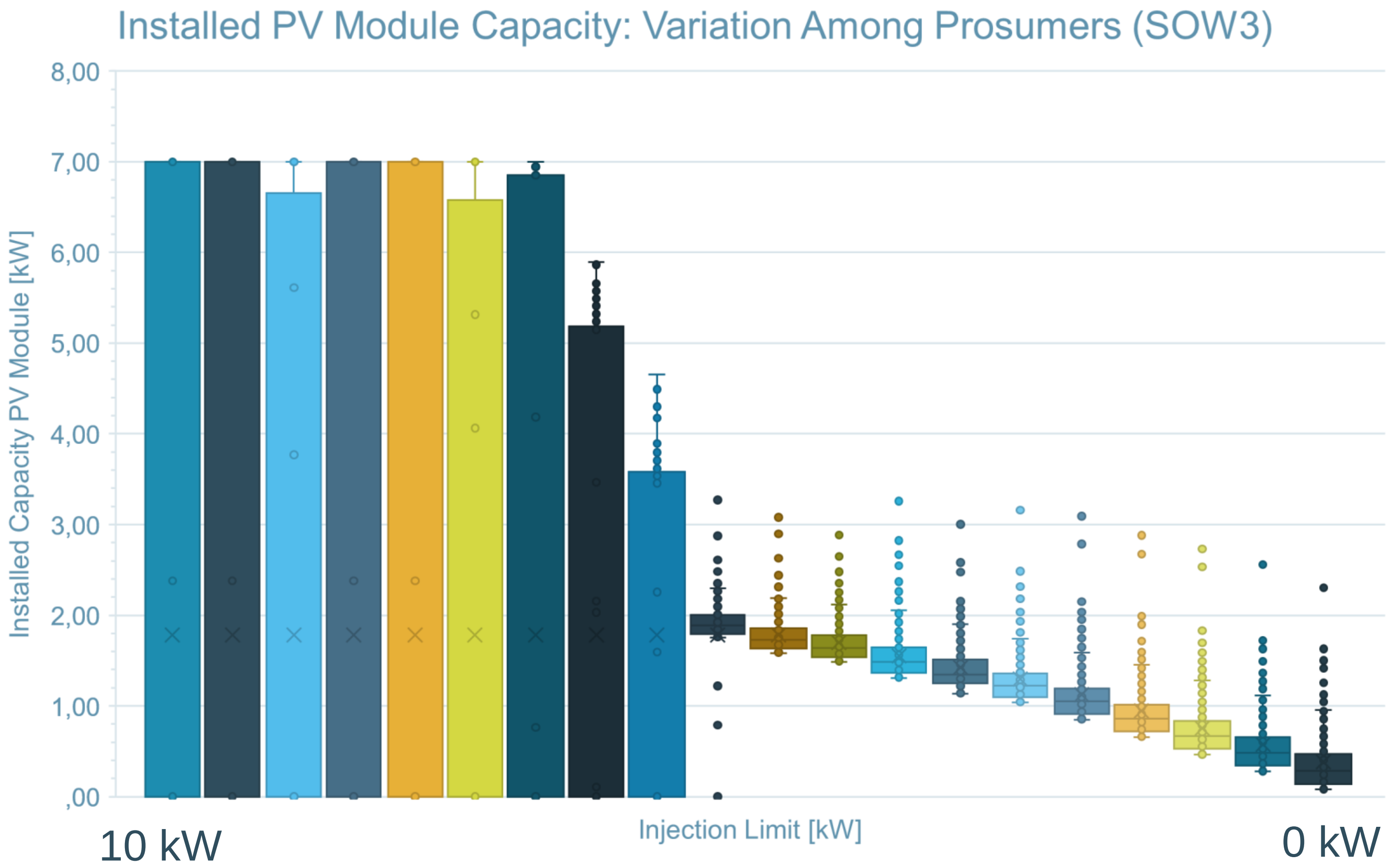
Total system cost = €4.48 billion



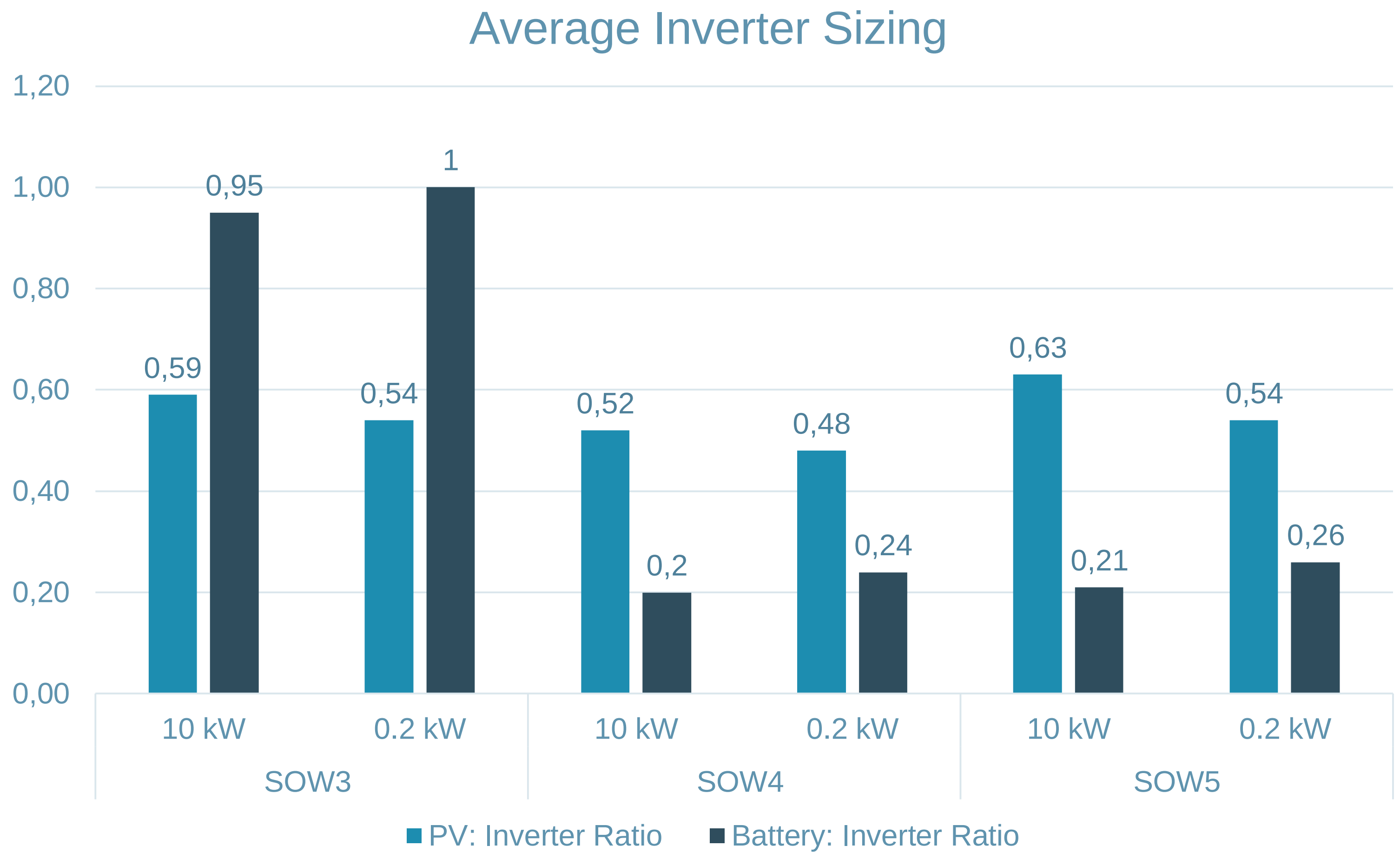
		At 10 kW Limit	At 0.2 kW Limit	Percentage change
Total PV capacity [MW]	SOW 3	4275	1817	-57.5
	SOW 4	16010	3821	-76.1
	SOW 5	16800	4626	-72.5
Total battery capacity [MWh]	SOW 3	25	18	-38.9
	SOW 4	5845	3190	-45.4
	SOW 5	7166	5197	-27.5
Total system cost [bil €]	SOW 3	4.46	4.47	+0.2
	SOW 4	4.34	4.42	+1.8
	SOW 5	4.26	4.39	+3.0

1. Cheaper states of the world → more PV, more battery, lower system cost
2. More stringent limits → less PV, less battery, higher system cost
    - Counterintuitive – why not install as much PV/battery as in no limit case?
    - Not cost optimal to invest if they cannot inject
    - More stringent limit = lose out on injection benefit (higher opportunity cost)

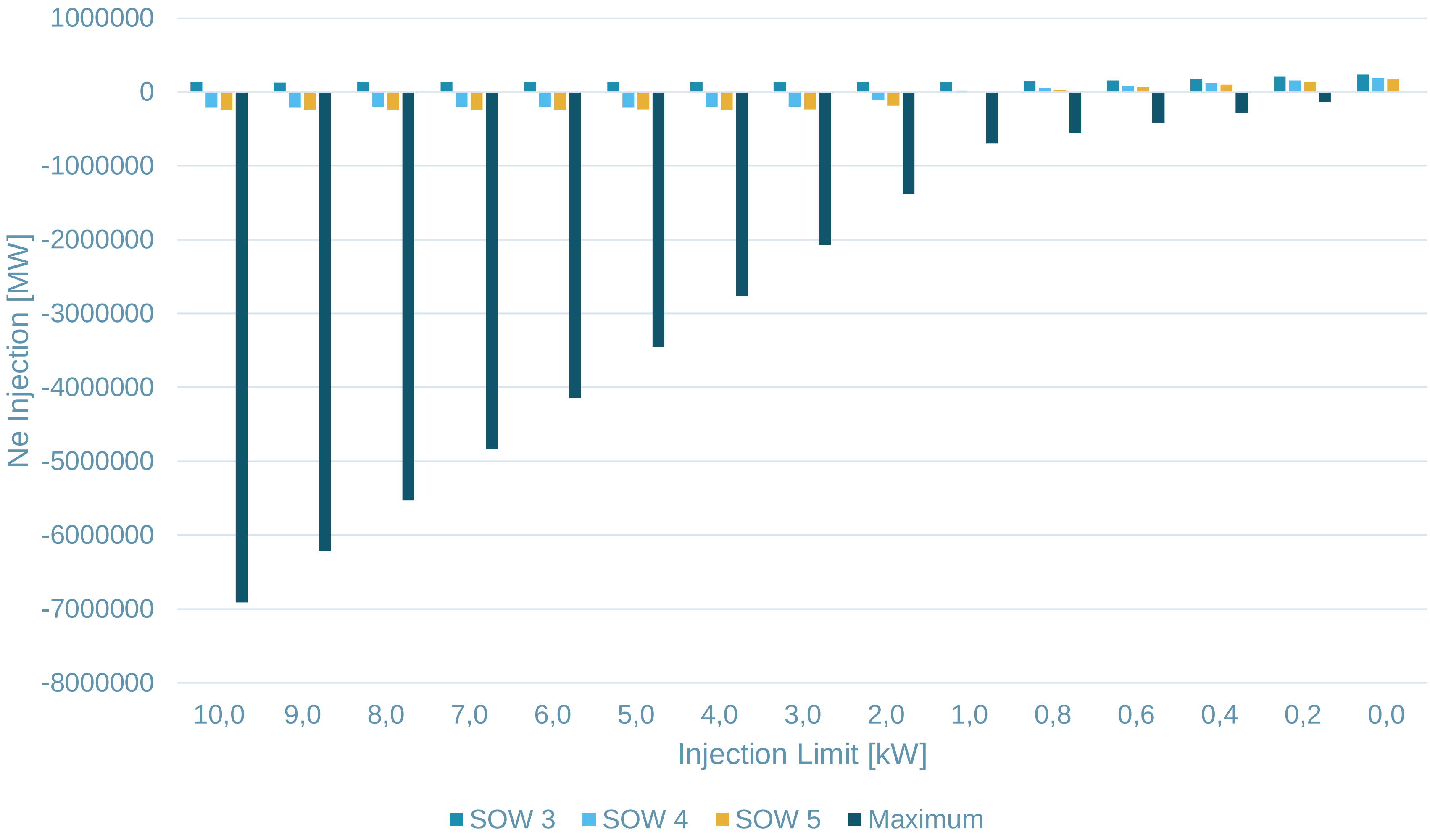
PV Capacity at Prosumer Level



Sizing of Inverters



Total Injection at System Level for Decreasing Injection Limits



Conclusions

As grid feed-in limits become more stringent:

1. Total installed PV and battery capacity decreases.
2. A greater number of prosumers installs PV modules and batteries and there is less variation regarding installation capacity.
3. Solar inverters are increasingly undersized, while the opposite holds for battery inverters.
4. Total injection is always well away from the maximum limit.

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