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Strommarkttreffen

# Reserve provision by electric vehicles in Germany: model-based analyses for 2035

This work was carried out within the project
"ImpRES – Impact of Renewable Energy Sources in Germany",
supported by the Federal Ministry for Economic Affairs and Energy BMWi

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Berlin, September 2, 2016

## Energy system development – not only in Germany

- Expansion of fluctuating renewables
- Introduction of electric vehicles (EVs)

## Questions of interactions between these trends arise

- Particular focus here:
  provision of reserves by EVs and role of vehicle-to-grid (V2G)
- Under different assumptions on charging strategy
- In the context of other flexibility options

## Scenario-based analyses for Germany 2035 with DIETER
## (Dispatch and Investment Evaluation Tool with Endogenous Renewables)

## We use the open-source model DIETER

- Power sector model for medium-/long-term analyses
- Fully open source including input data
- www.diw.de/dieter

## Minimization of overall system costs

- Subject to a range of constraints
- Energy balance for wholesale and reserve markets

## Detailed representation of flexibility options

- Power storage, DSM, flexible biomass & conventionals
- Hourly resolution, solved for whole year

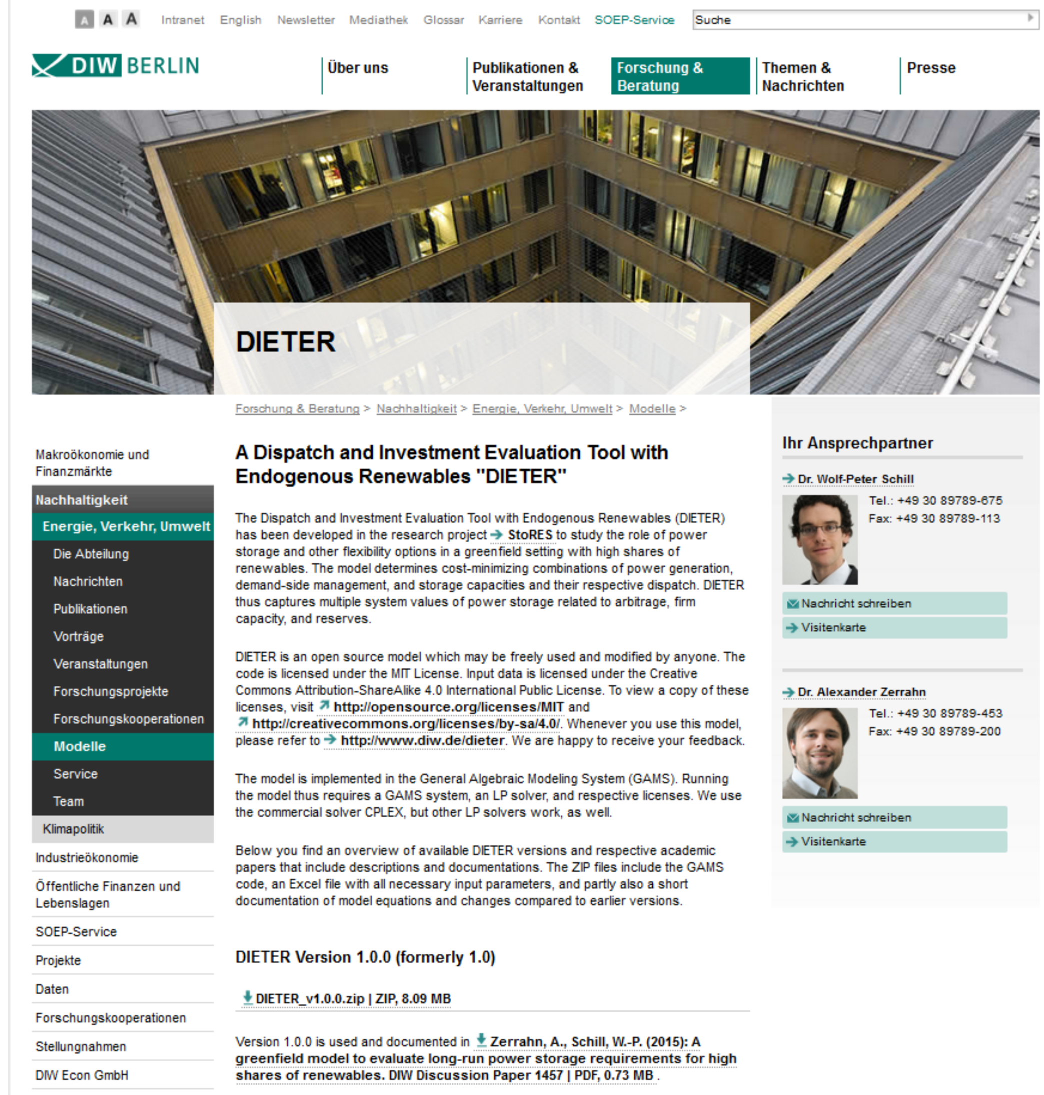
# DIETER is open-source

## DIETER‘s website

- www.diw.de/dieter

## DIETER grows and improves

- Electric vehicles
- District heating
- Bottom-up wheather data
- Multiple countries
- Dynamic investment framework
- Stoachsticity
- …



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**A Dispatch and Investment Evaluation Tool with Endogenous Renewables "DIETER"**

The Dispatch and Investment Evaluation Tool with Endogenous Renewables (DIETER) has been developed in the research project → StoRES to study the role of power storage and other flexibility options in a greenfield setting with high shares of renewables. The model determines cost-minimizing combinations of power generation, demand-side management, and storage capacities and their respective dispatch. DIETER thus captures multiple system values of power storage related to arbitrage, firm capacity, and reserves.

DIETER is an open source model which may be freely used and modified by anyone. The code is licensed under the MIT License. Input data is licensed under the Creative Commons Attribution-ShareAlike 4.0 International Public License. To view a copy of these licenses, visit ↗ http://opensource.org/licenses/MIT and ↗ http://creativecommons.org/licenses/by-sa/4.0/. Whenever you use this model, please refer to → http://www.diw.de/dieter. We are happy to receive your feedback.

The model is implemented in the General Algebraic Modeling System (GAMS). Running the model thus requires a GAMS system, an LP solver, and respective licenses. We use the commercial solver CPLEX, but other LP solvers work, as well.

Below you find an overview of available DIETER versions and respective academic papers that include descriptions and documentations. The ZIP files include the GAMS code, an Excel file with all necessary input parameters, and partly also a short documentation of model equations and changes compared to earlier versions.

**DIETER Version 1.0.0 (formerly 1.0)**

DIETER_v1.0.0.zip | ZIP, 8.09 MB

Version 1.0.0 is used and documented in **Zerrahn, A., Schill, W.-P. (2015): A greenfield model to evaluate long-run power storage requirements for high shares of renewables. DIW Discussion Paper 1457 | PDF, 0.73 MB**.

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## DIETER Version 1.1.0 includes electric vehicles

- Building on European research project DEFINE (Schill and Gerbaulet, *Applied Energy* 2015)

## Grid-to-vehicle (G2V) and vehicle-to-grid (V2G)

- For both wholesale and reserve markets

## EVs may provide reserves in different ways

- Positive reserves
  - Additionally feed back electricity to the grid (V2G)
  - Do not charge in wholesale market (G2V)
- Negative reserves
  - Additional charging (G2V)
  - Do not feed back electricity to the grid in wholesale market (V2G)

## Model setup allows representing different system values of EVs

- Arbitrage in wholesale market
- Reserve provision
- Capacity value (substitution of other flexibility options)

## Scope

- 2035, Germany only

## Calibrated to grid development (NEP) scenario framework 2035

- Installed capacities, fuel prices
- Gross RES share of ~60%

## Historic hourly profiles

- Load, RES availability, reserve activation, EVs

## EVs

- Hourly patterns of grid availability and power consumption
- 28 different vehicle profiles: 16 BEV, 12 PHEV
- 4.4 million: 25% BEV, 75% PHEV
- V2G incurs additional depreciation costs: 41 €/MWh

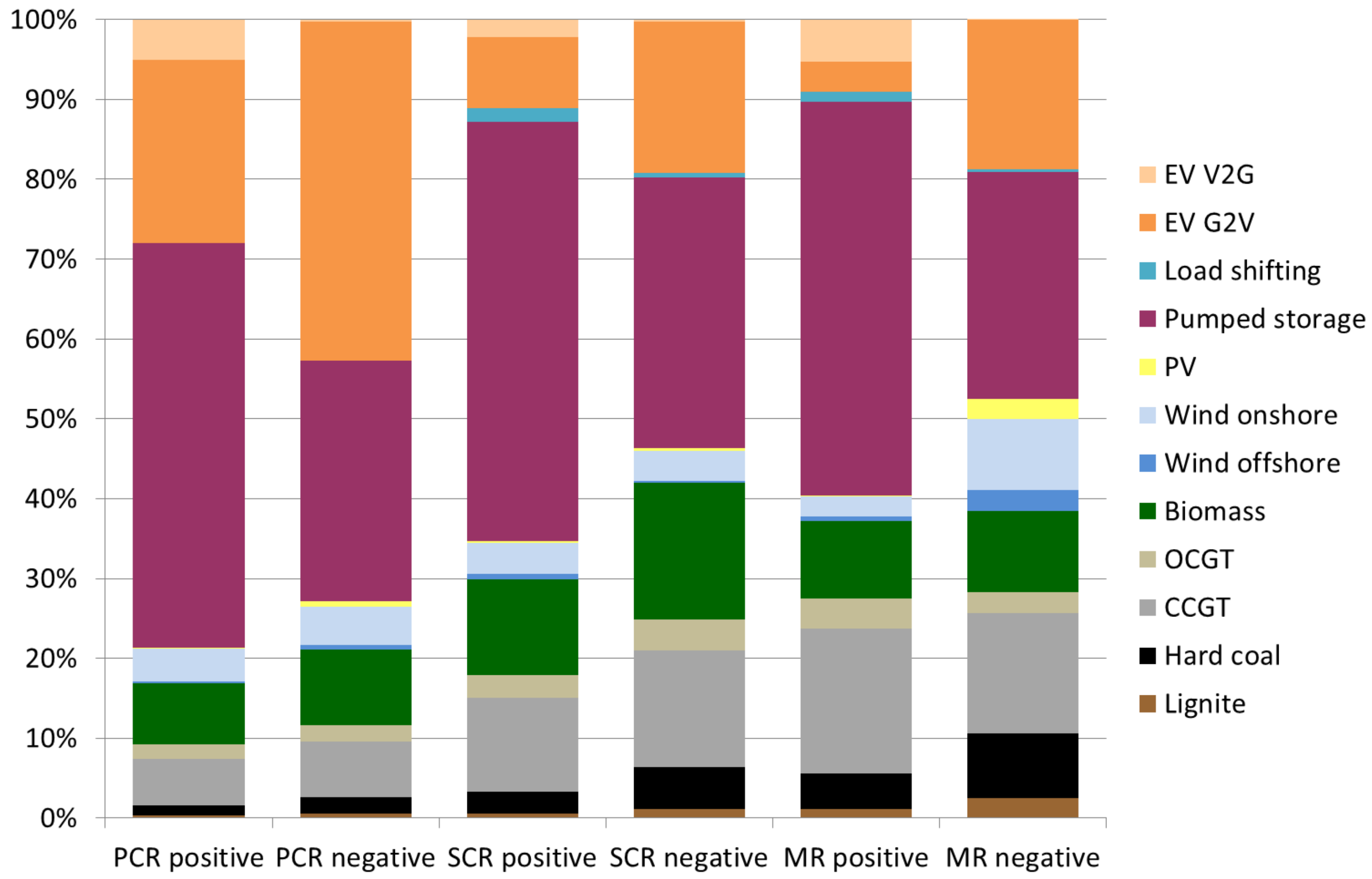
## Scenarios

- Baseline: all capacities like NEP
- Adjusted portfolio: CCGT, OCGT, PHS, DSM partly endogenous
- Each for different charging strategies
- Sensitivity analysis: zero V2G costs

# Scenarios and input data: Different charging strategies

| | Charging (G2V) | | Discharging (V2G) | | Description |
|---|---|---|---|---|---|
| | Wholesale | Reserves | Wholesale | Reserves | |
| a) Charging only | ✓ | - | - | - | Only cost-minimal charging (for mobility purposes) |
| b) Reserves only by G2V | ✓ | ✓ | - | - | Reserves by adjusted charging |
| c) Reserves by G2V and V2G | ✓ | ✓ | - | ✓ | Reserves by adjusted charging and discharging |
| d) Only arbitrage | ✓ | - | ✓ | - | Wholesale arbitrage by V2G, but no reserves |
| e) Full flexibility | ✓ | ✓ | ✓ | ✓ | Reserves by adjusted charging and discharging and wholesale arbitrage |

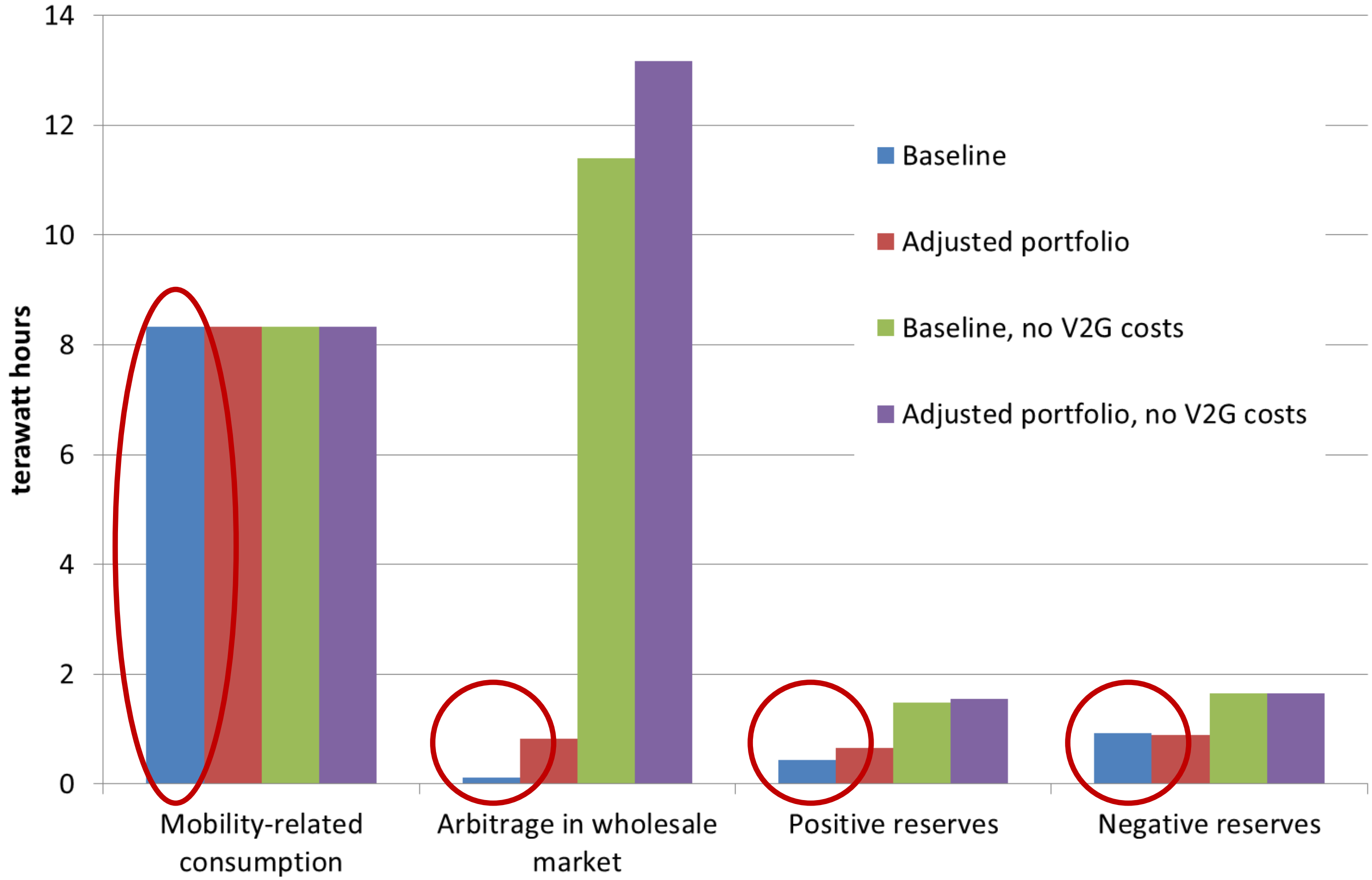
# Results:
# Reserve provision shares (Baseline, Full Flexibility)




**→ EVs substantially contribute to reserve provision**

**→ Even in case of a pure G2V operation mode**

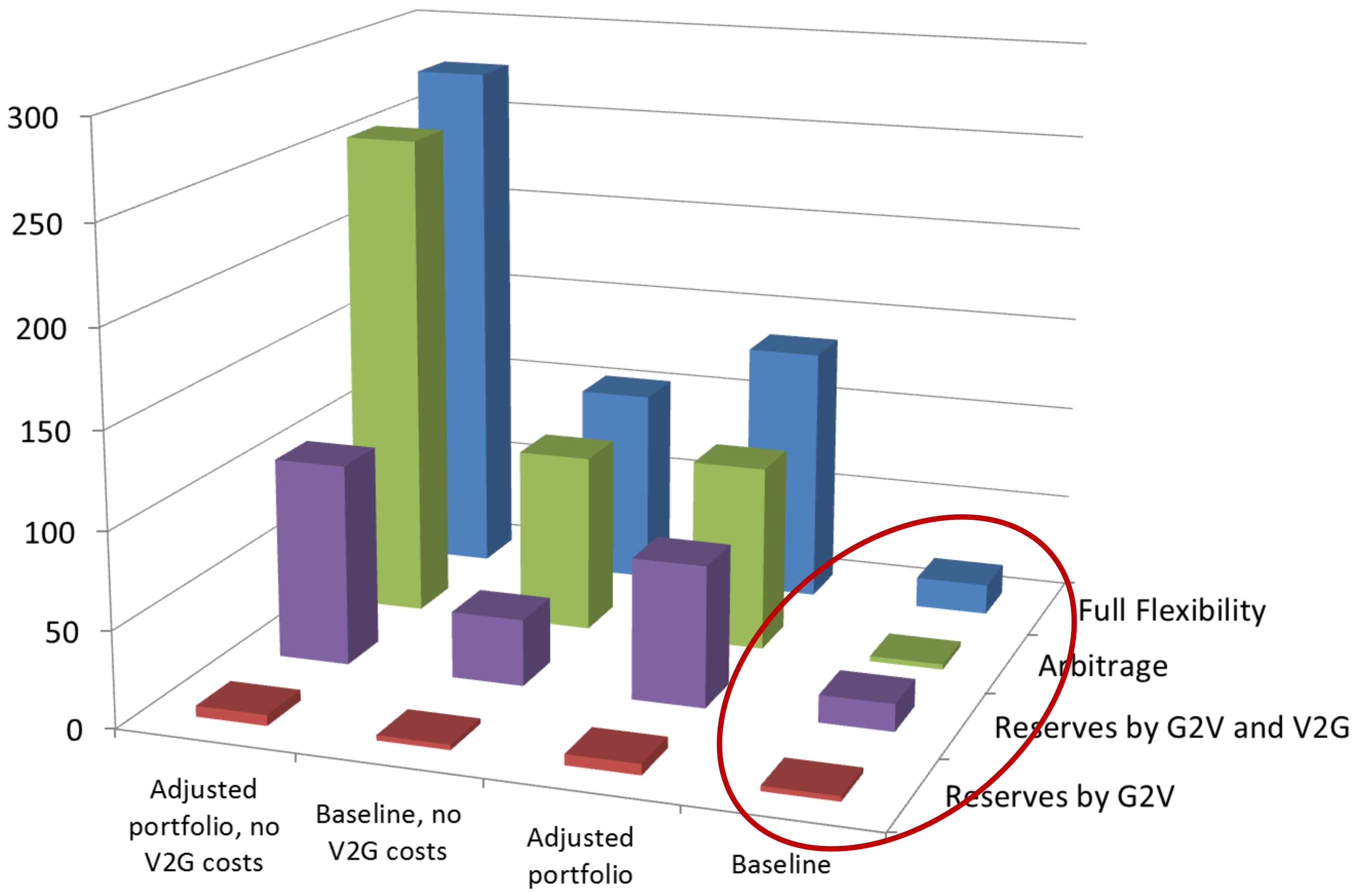
# Results: Yearly energy provided by EVs in different markets (Full Flexibility)




→ **Baseline: reserve activation small cp. to mobility-related consumption**

→ **Arbitrage negligible**

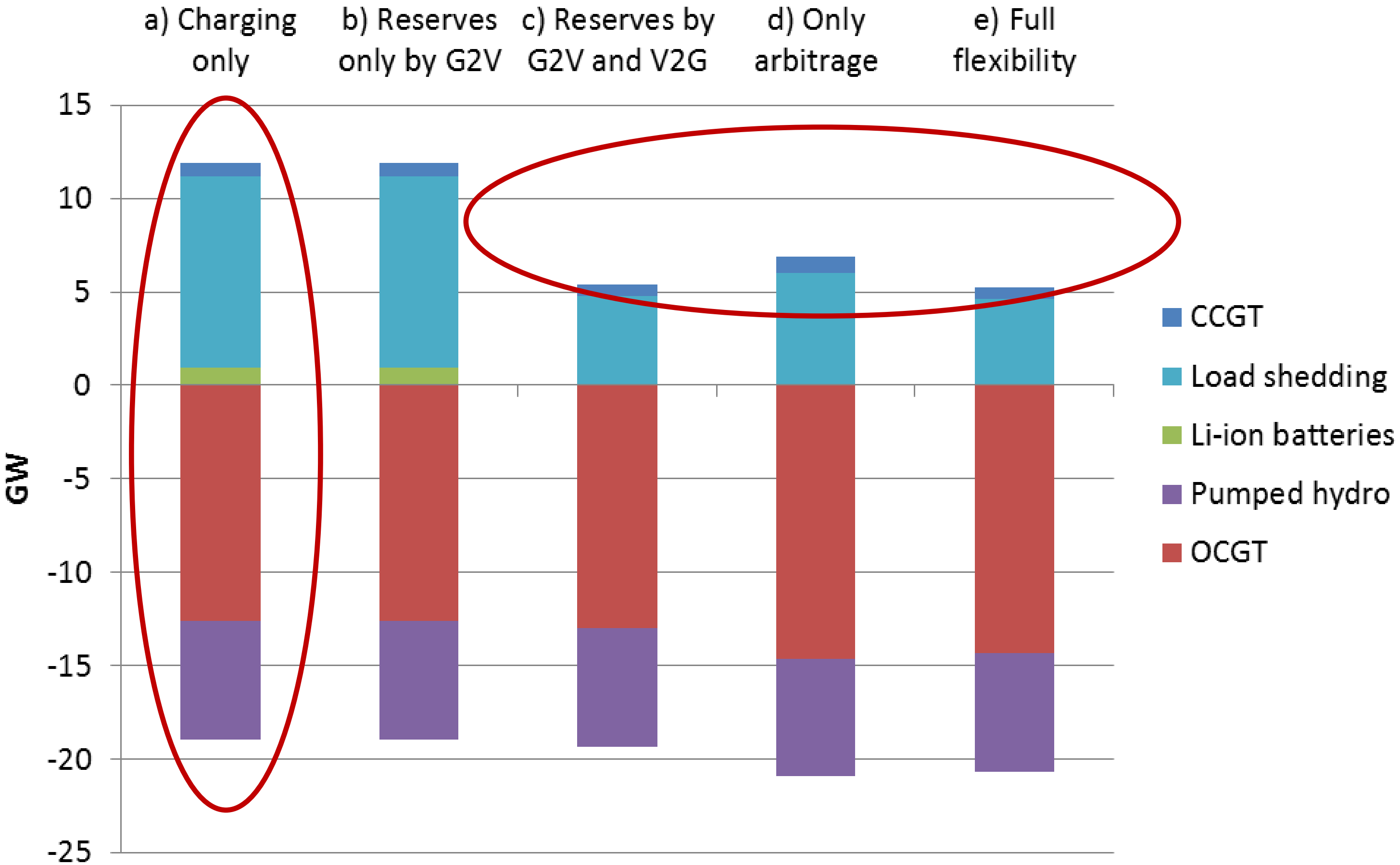
# Results:
# System cost differences to reference scenario




→ **System cost savings very low in baseline: no scarcity of flexibility!**

→ **Up to €16 mio, € 4 per vehicle and year**

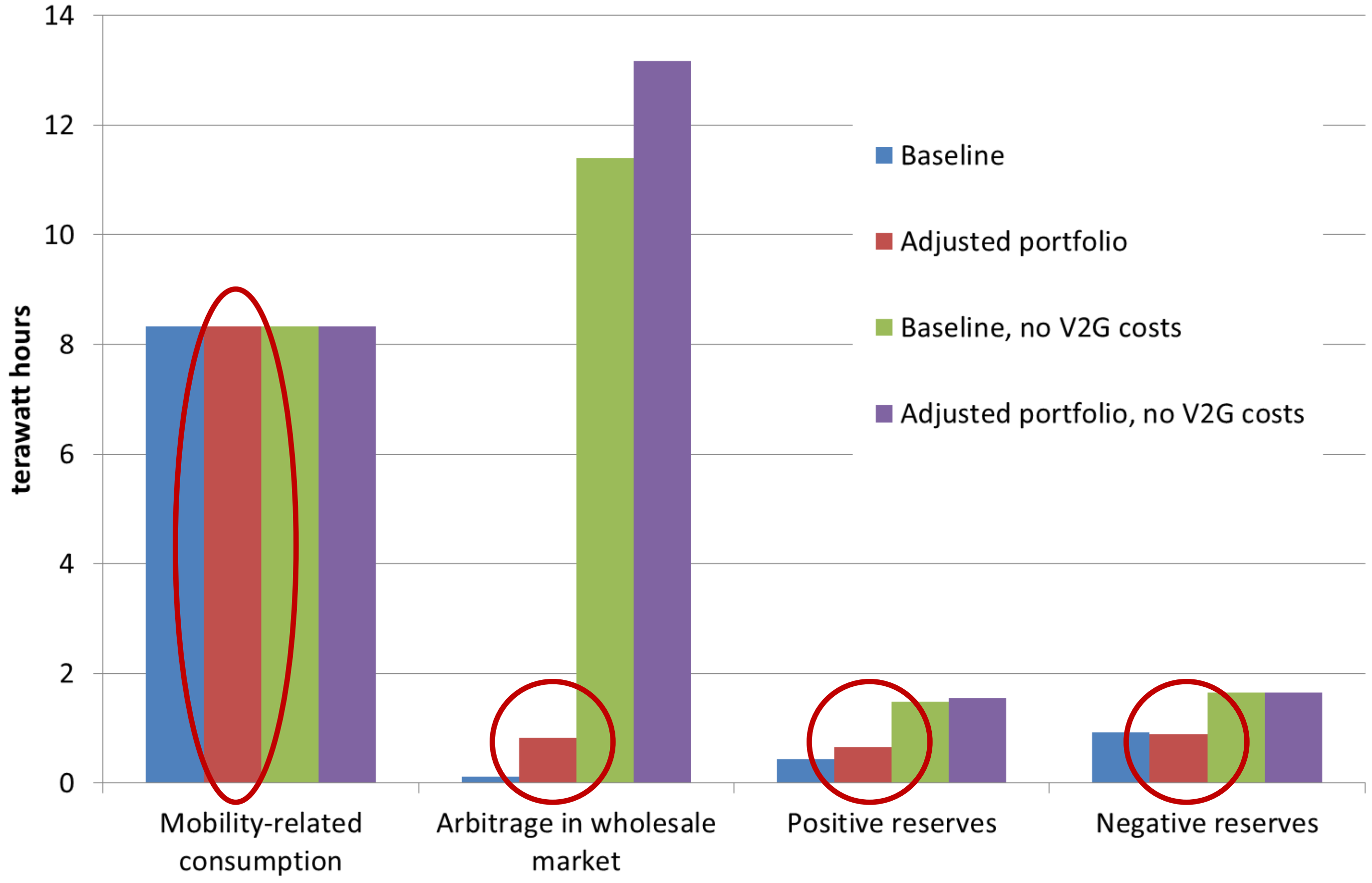
# Results for „Adjusted portfolio“: Installed capacity (differences to baseline)




→ **a) Less OCGT and PHS, more load shedding**

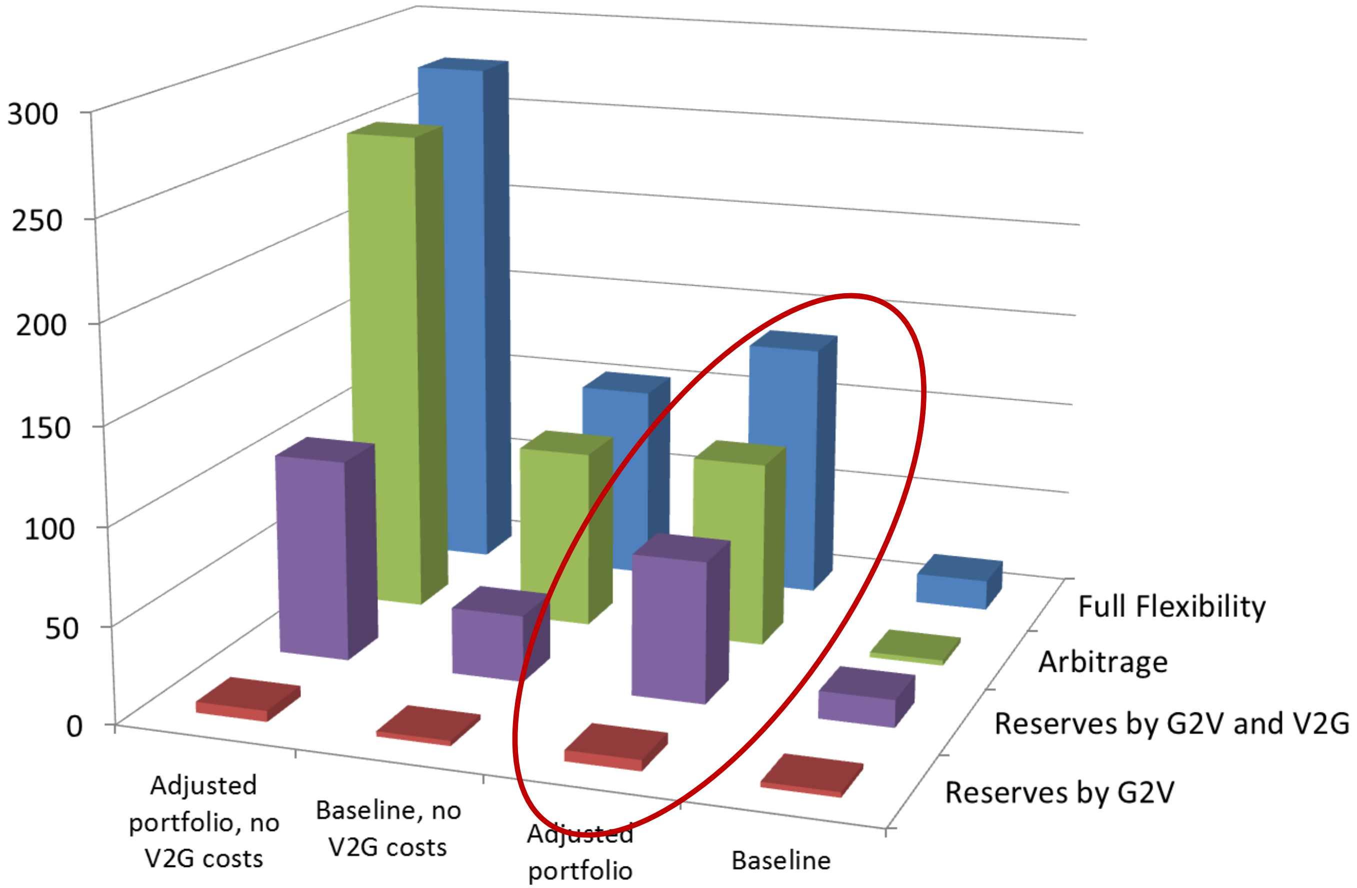
→ **c), d), e) additional vehicle flexibility substitutes capacity**

# Results:
# Yearly energy provided by EVs in different markets (Full Flexibility)




**→ Because of lower "flexibility reserves" in adjusted generation portfolio**

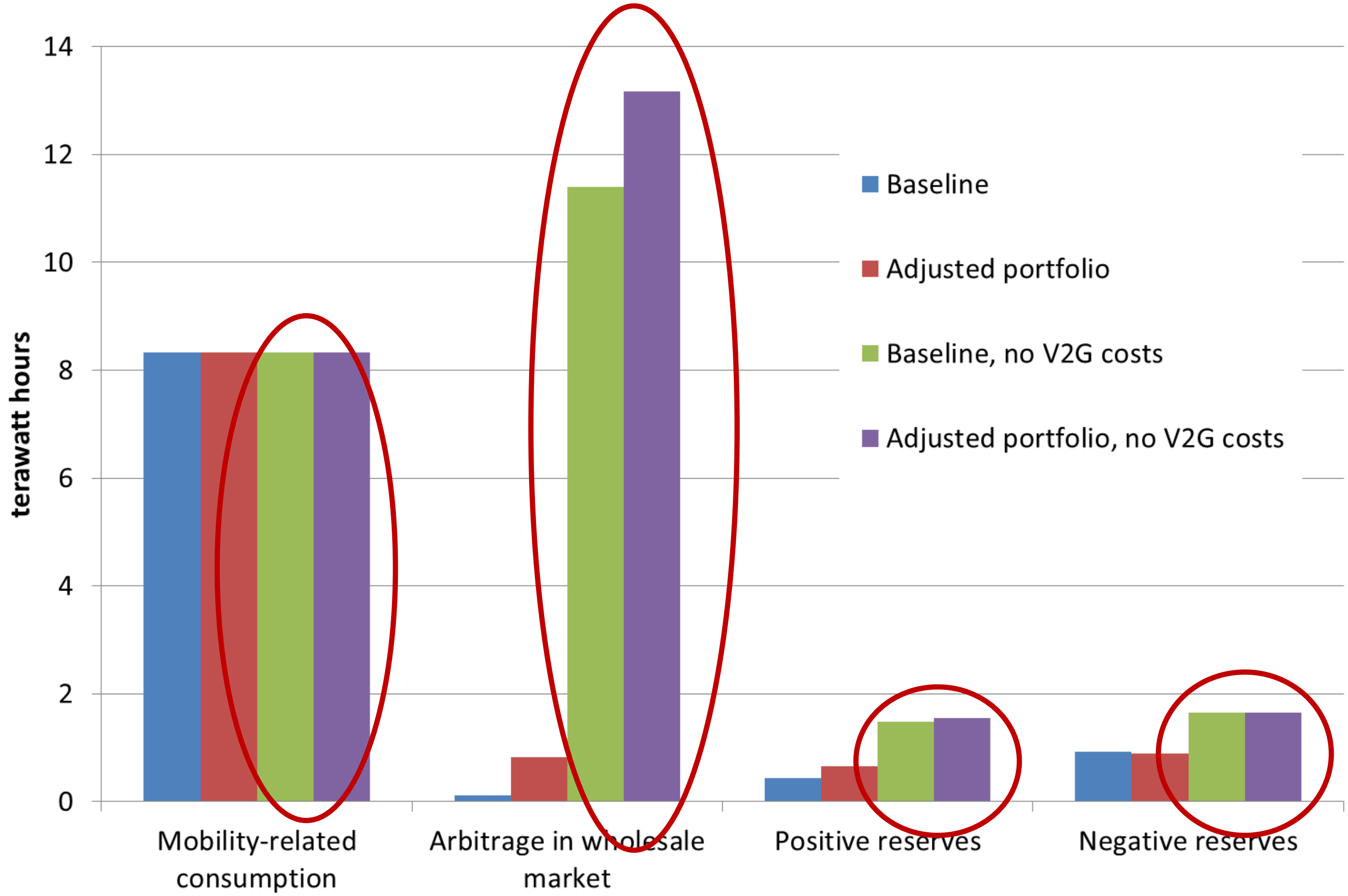
# 4 Results: System cost differences to reference scenario




→ **System cost savings increase substantially in less flexible system**

→ **Up to €135 mio, € 31 per vehicle and year**

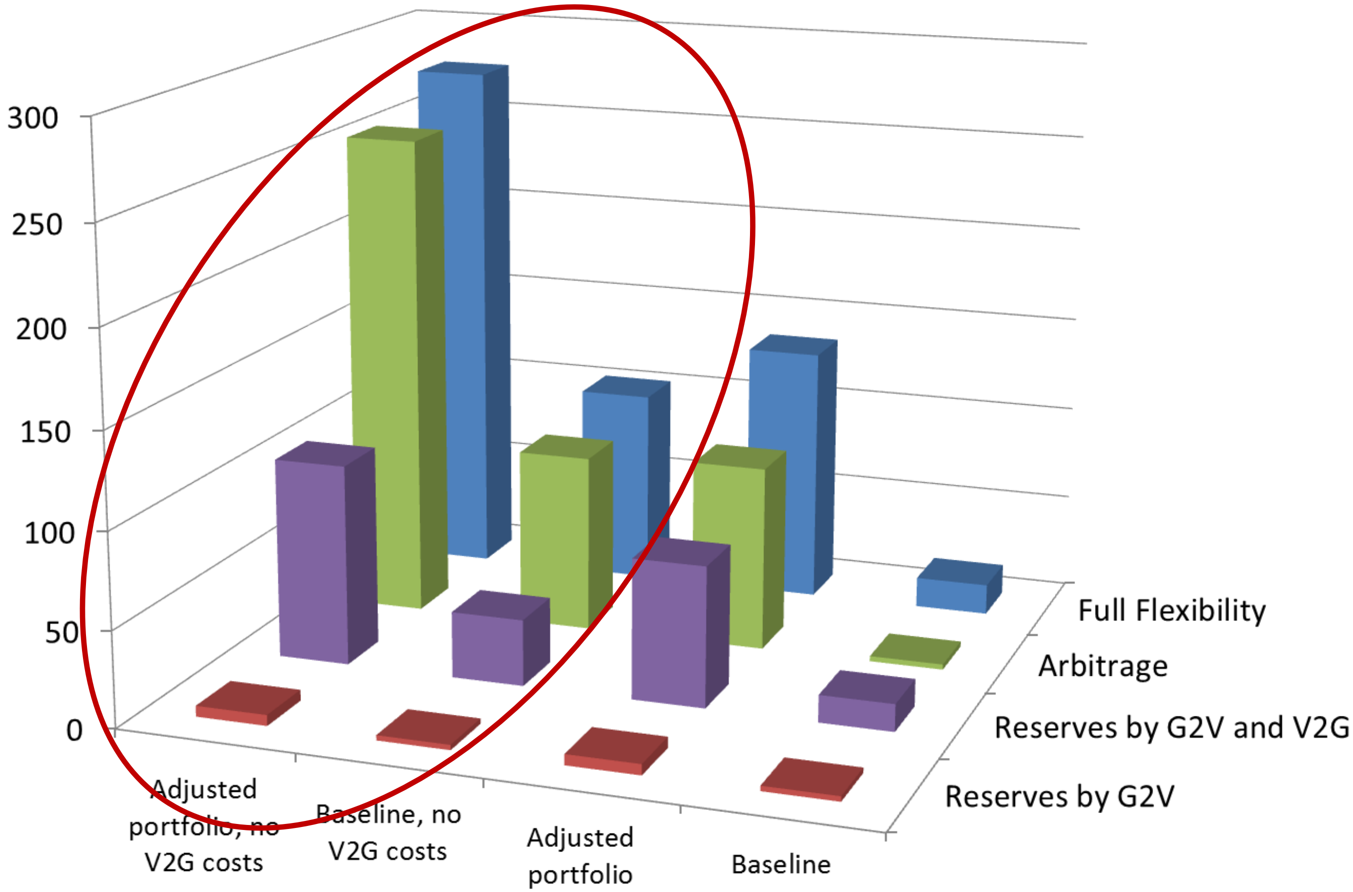
# Results:
# Yearly energy provided by EVs in different markets (Full Flexibility)




→ **No V2G costs: EVs provide even more reserves**

→ **EVs heavily used for arbitrage**

# Results:
# System cost differences to reference scenario




→ **No V2G costs: much higher system cost savings**

→ **Up to €276 mio, € 63 per vehicle and year**

## EVs can contribute substantially to reserve provision

- Even without vehicle-to-grid

## Yet the system value is low under baseline assumptions

- Plenty of other (short-term) flexibility options in the future
- Challenge to find viable business cases
- But only little additional costs cp. to optimal charging?

## The value of EV flexibility grows if…

- … the power plant portfolio considers EVs
- … V2G does not incur additional battery depreciation costs

## EVs become a relevant bulk storage option only under optimistic V2G cost assumptions

# German version appeared in *Zeitschrift für Energiewirtschaft* 40(2), 73-87 DOI 10.1007/s12398-016-0174-7

Z Energiewirtsch
DOI 10.1007/s12398-016-0174-7

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## Bereitstellung von Regelleistung durch Elektrofahrzeuge: Modellrechnungen für Deutschland im Jahr 2035

Wolf-Peter Schill[1] · Moritz Niemeyer[1] · Alexander Zerrahn[1] · Jochen Diekmann[1]



**Zusammenfassung** Sowohl beim Ausbau erneuerbarer Energien als auch im Bereich der Elektromobilität hat sich die Bundesregierung ambitionierte Ziele gesetzt. Im Kontext der Energiewende soll der Anteil fluktuierender erneuerbarer Energien an der Stromerzeugung weiter deutlich steigen. Dies erfordert tendenziell eine erhöhte Vorhaltung von Regelleistung. Gleichzeitig sinkt die Stromerzeugung aus thermischen Kraftwerken, die bisher einen großen Teil der Regelleistung vorgehalten haben. Vor diesem Hintergrund wird untersucht, welche Rolle eine angenommene Flotte von 4,4 Millionen Elektrofahrzeugen im Jahr 2035 bei der Bereitstellung von Regelleistung in Deutschland spielen könnte. Dabei werden zwei verschiedene Szenarien des Kraftwerksparks sowie unterschiedliche Möglichkeiten der Bereitstellung von Regelleistung mit und ohne Rückspeisung elektrischer Energie von den Fahrzeugbatterien in das Stromnetz untersucht. Berechnungen mit einem hierfür weiterentwickelten, quellenoffenen Simulationsmodell zeigen, dass die Elektrofahrzeugflotte einen nennenswerten Beitrag zu einer kostengünstigen Regelleistungsvorhaltung leisten kann. Dies gilt auch dann, wenn keine Rückspeisung von den Fahrzeugbatterien in das Stromnetz möglich kann es dagegen zu nennenswerten Arbitrageaktivitäten am Großhandelsmarkt, zu einer noch höheren Regelleistungsbereitstellung und zu wesentlich größeren Systemkosteneinsparungen kommen.

**JEL-Classification** Q40 · Q42

### Reserve provision by electric vehicles: model-based analyses for Germany in 2035

**Abstract** The German government has set ambitious goals for both the expansion of renewable energy supply and electromobility. According to its *Energiewende* policy, electricity supply from fluctuating renewables is supposed to further increase considerably. This will tend to require a greater provision of balancing reserves. At the same time, supply from conventional dispatchable plants, which used to provide the bulk of reserves, will decrease. Against this background, this article analyzes the scope for an assumed fleet of 4.4 million electric vehicles to supply balancing reserves in 2035. Examining two different future power

German version appeared in *Zeitschrift für Energiewirtschaft* 40(2), 73-87
DOI 10.1007/s12398-016-0174-7

Vielen Dank für Ihre Aufmerksamkeit.

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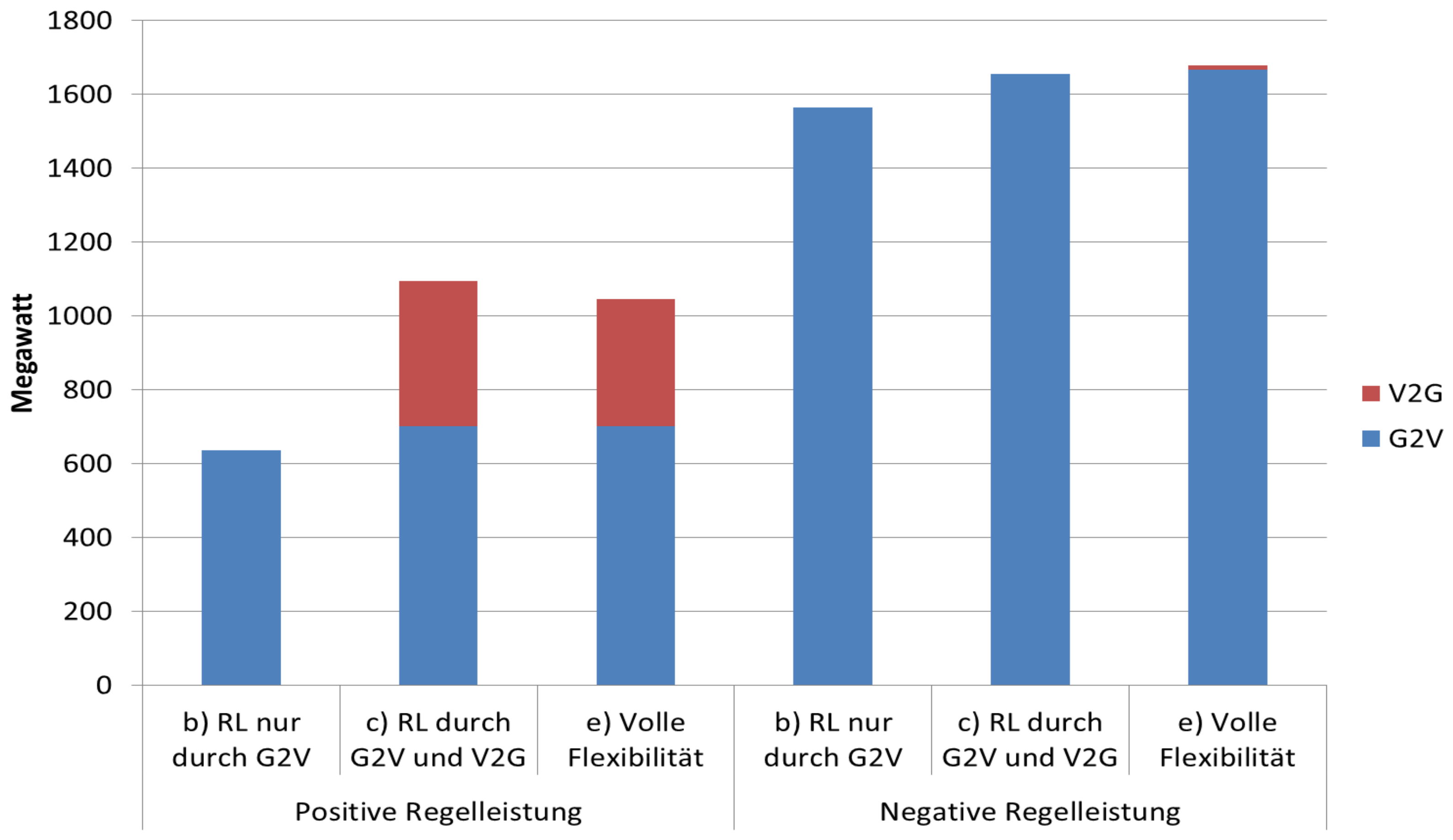
# Results
## Reserve provision for different charging strategies (Baseline)



# Results
## Energy provided in wholesale market by DSM, PHS and EV