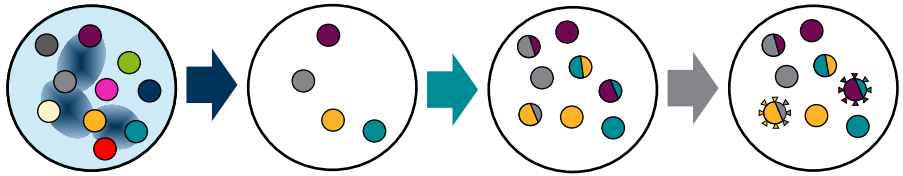

Potential Grid-Oriented and Market-Oriented Optimisation of a Local Charging Infrastructure Through a Genetic Algorithm

18. Symposium Energieinnovation

David Cano-Tirado | david.cano@uni-wuppertal.de
Wuppertal, 16.02.2024

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Agenda

- Motivation & Goals
- Methodology
  - EV Charging process model
  - Standing times forecast for electric vehicles
  - Charging processes' optimisation through genetic algorithms
- Results & Analysis
- Conclusions

Agenda

- **Motivation & Goals**
- Methodology
  - EV Charging process model
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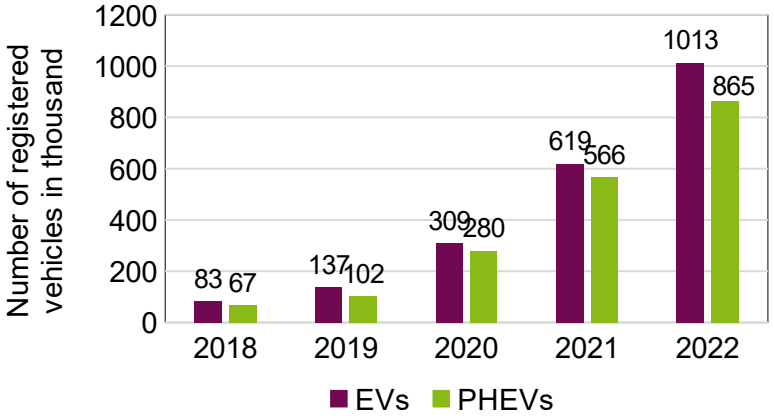
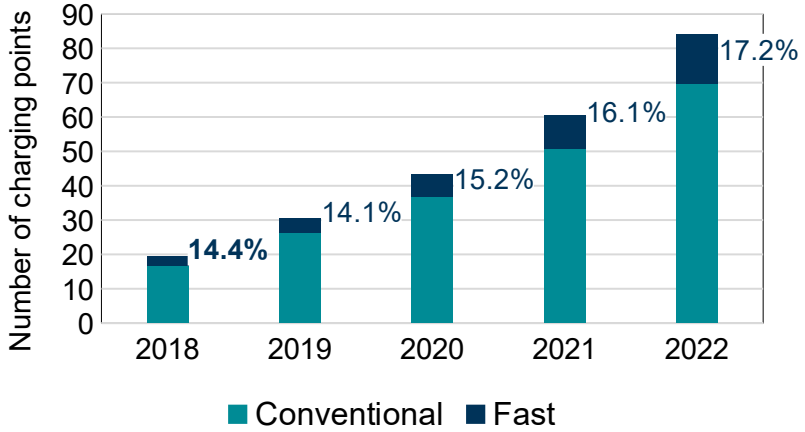
- Results & Analysis
- Conclusions

Motivation & Goals

Motivation: Electromobility growth and charging points' development





"Potential simultaneous charging power demand of 2.8 GW" - Bundesnetzagentur, *Elektromobilität: Öffentliche Ladeinfrastruktur.*

- Critical operational conditions in the power grid
  - ► **Voltage limit violations & overloads**

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EV: Electric vehicle | PHEV: Plug-in hybrid electric vehicles

Motivation & Goals

Goals: Optimisation of EVs' charging processes

Potential optimisation of charging processes for EVs

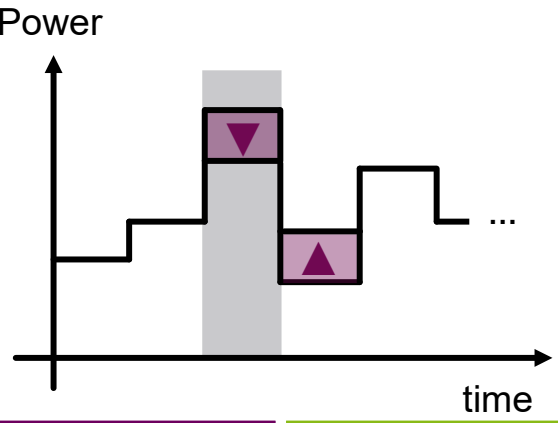
- Grid-oriented optimisation

  Power grid's bottlenecks mitigation in the context of Smart Grids

- Market-oriented optimisation

  Energy trading in the Day-Ahead market to reduce operating costs

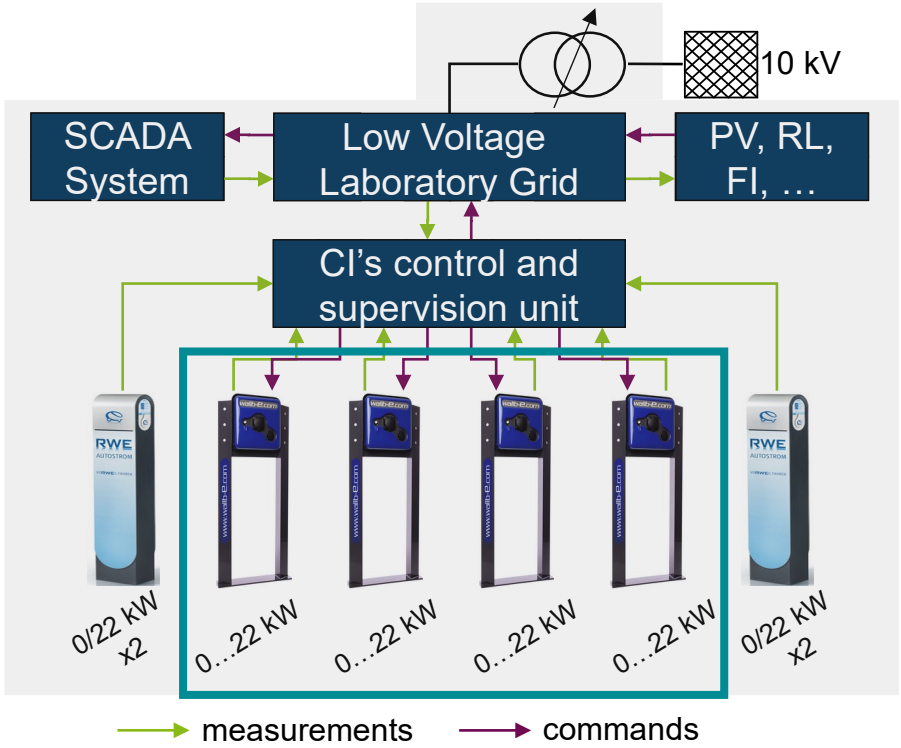
► Charging processes' optimal scheduling through load shifting



Motivation & Goals

Goals: Optimisation of EVs' charging processes

- Charging infrastructure for EVs at Campus Freudenberg, University of Wuppertal



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EV: Electric vehicle | PV: Photovoltaic system | RL: Resistive loads | CI: Charging Infrastructure

Agenda

- Motivation & Goals
- **Methodology**
  - EV Charging process model
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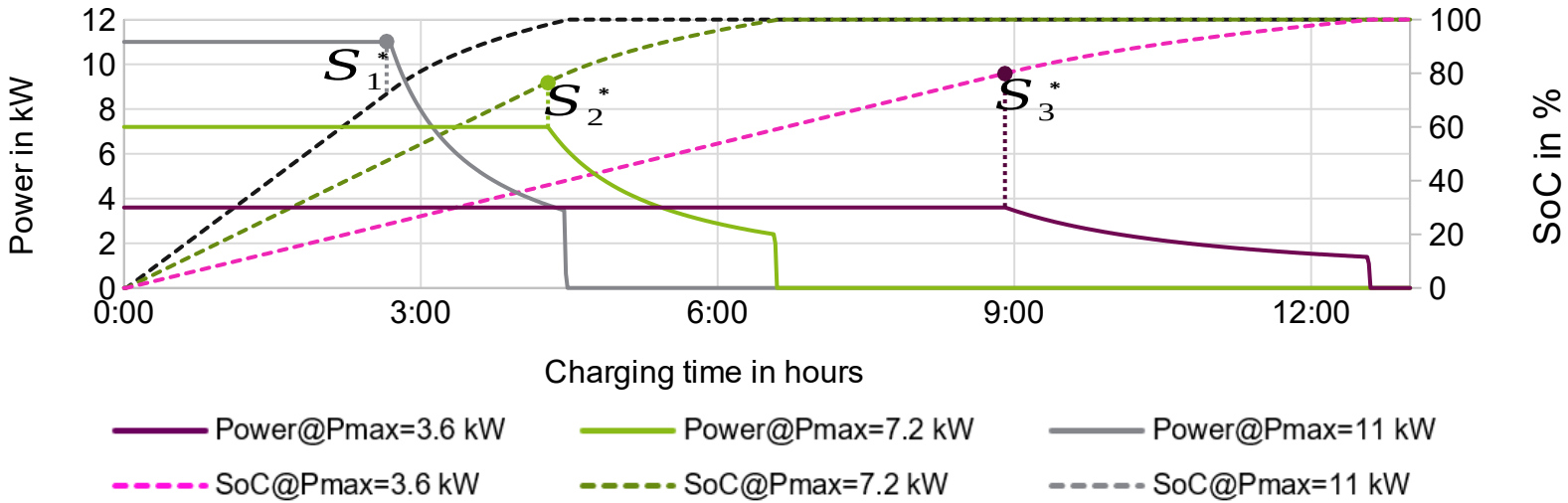
Methodology

EV charging process model

- The state of charge (SoC) of the battery is influenced by the value of the maximum charging power
- Mathematical model based on Fasthuber's research (2020)

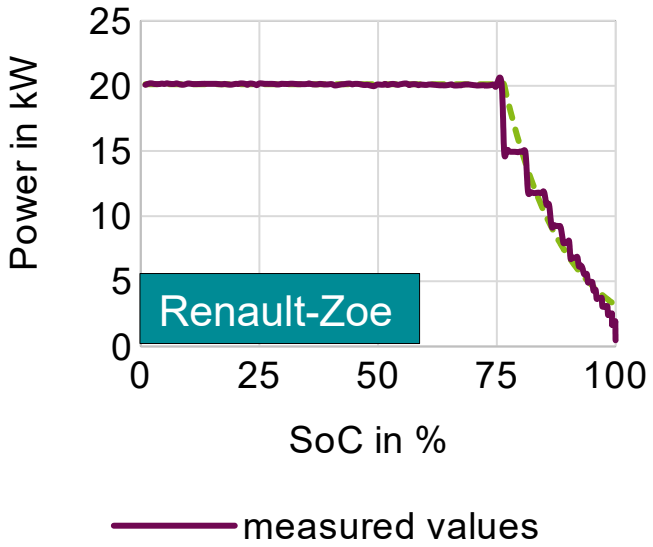


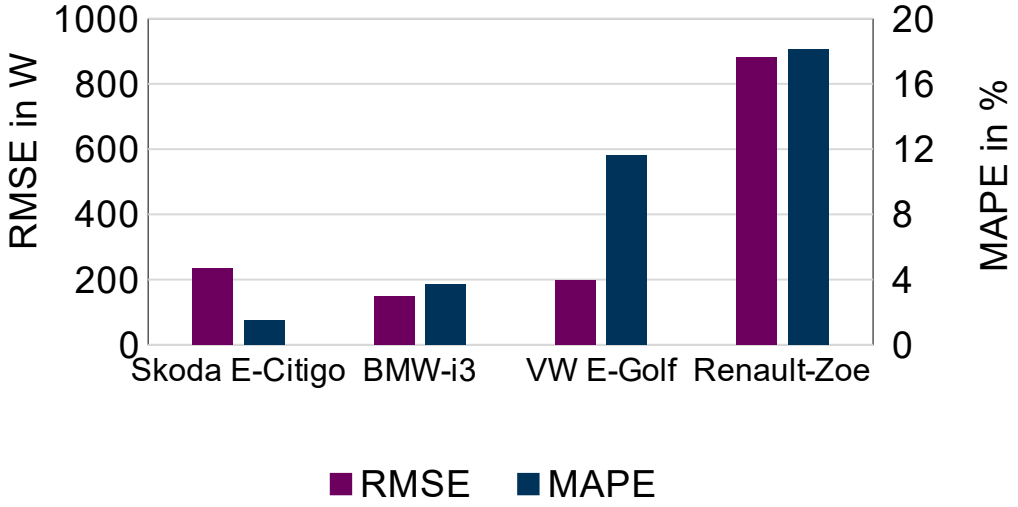
EV: Electric vehicle | D. Fasthuber, "Integration der Ladeinfrastruktur in das elektrische Energiesystem," Elektrotechnik & Infor-mationstechnik, vol. 137, 2020.

Methodology

EV charging process model

- Mathematical model's validation through real measurements

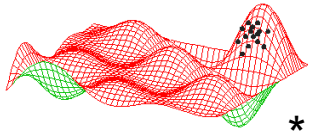




RMSE: Root Mean Squared Error | MAPE: Mean Absolute Percentage Error

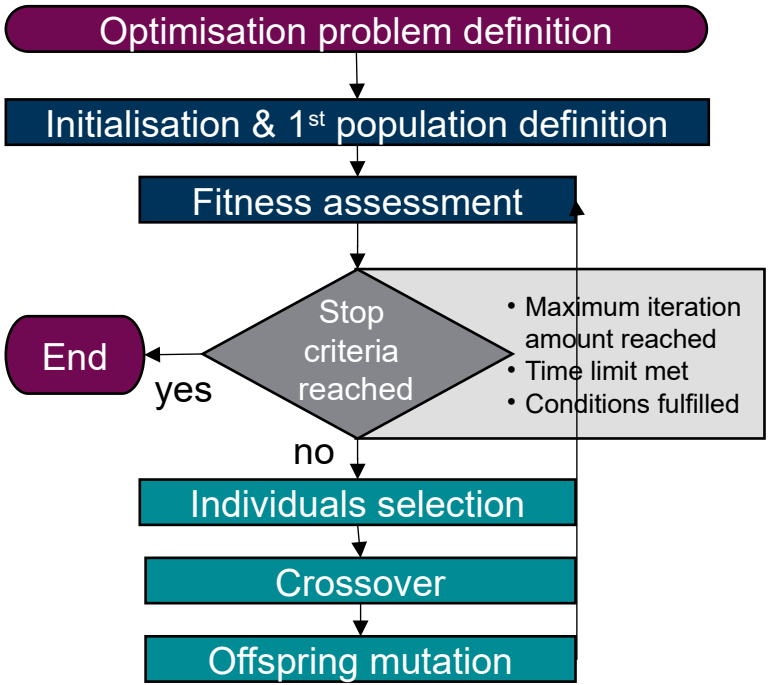
Methodology

Charging processes' optimisation through genetic algorithms



*

- Biological evolution in numerical form
- The population evolves through **genetic operators**
- Optimisation results:
  - Gradient-based optimization method
    ► Results and convergence strongly depend on the starting point
  - Genetic algorithms (metaheuristic method)
    ► Continuous population improvement
- Suitable for problems where nonlinearities exist
- **An individual contains the set points throughout the day**



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* Institut für Informatik Albert-Ludwigs-Universität Freiburg

Methodology

Charging processes' optimisation through genetic algorithms

Optimisation problem definition

- Market-oriented operation
  - Determination of the set points for each charging point **for each** time block ("long"-term schedule)
  - ► Operating cost reduction by participating in the Day-Ahead market

- Grid-oriented operation
  - Determination of the set points for charging point **for specific** time block ("short"-term schedule)
  - Major variations with respect to the schedule in operation must be avoided
  - ► Grid service

- User comfort variables must be considered!

Agenda

- Motivation & Goals
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- **Results & Analysis**
- Conclusion

Market-oriented optimisation

Results & Analysis

Market-oriented optimisation

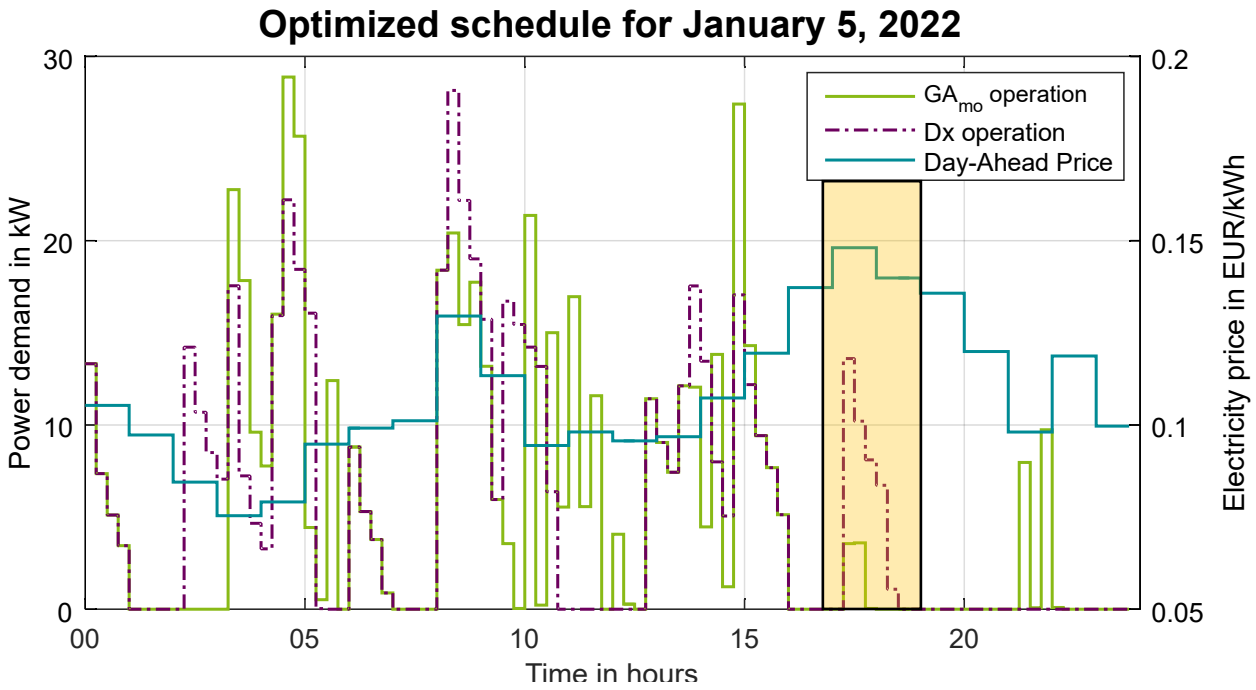
- Energy fees, Grid charges, taxes and other levies are not included
- Administrative and management costs by aggregation not included

- Fx:
  Operation with fixed energy prices

  Average value for…
  - the 1st half of 2022: 0.27 €/kWh
  - the 2nd half of 2022: 0.51 €/kWh

- Dx:
  Operation with dynamic energy prices (without optimisation)

- GA:
  Operation with dynamic energy prices (with optimisation)



mo: market oriented

Results & Analysis

Market-oriented optimisation

- Energy fees, Grid charges, taxes and other levies are not included
- Administrative and management costs by aggregation not included

- **Fx:**
  Operation with fixed energy prices

  Average value for…
  - the 1st half of 2022: 0.27 €/kWh
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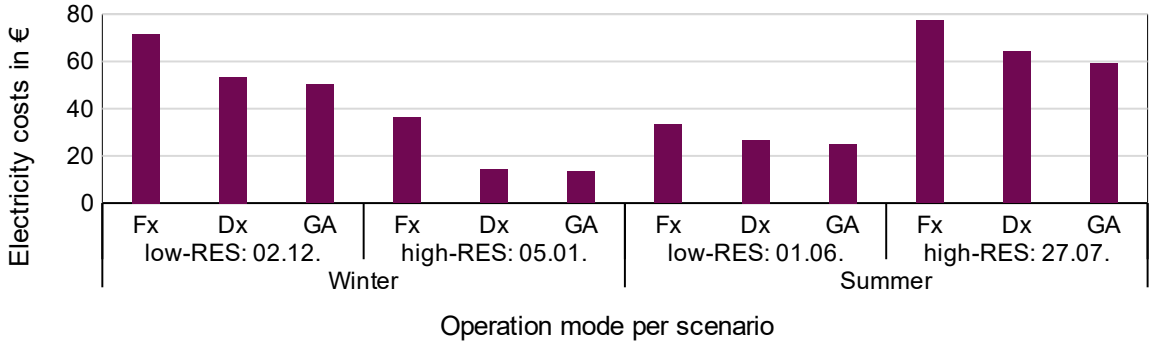
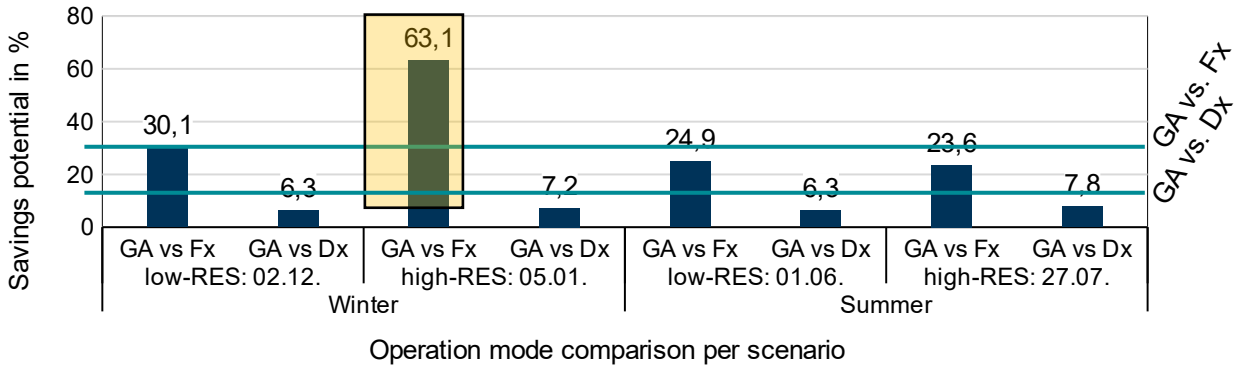




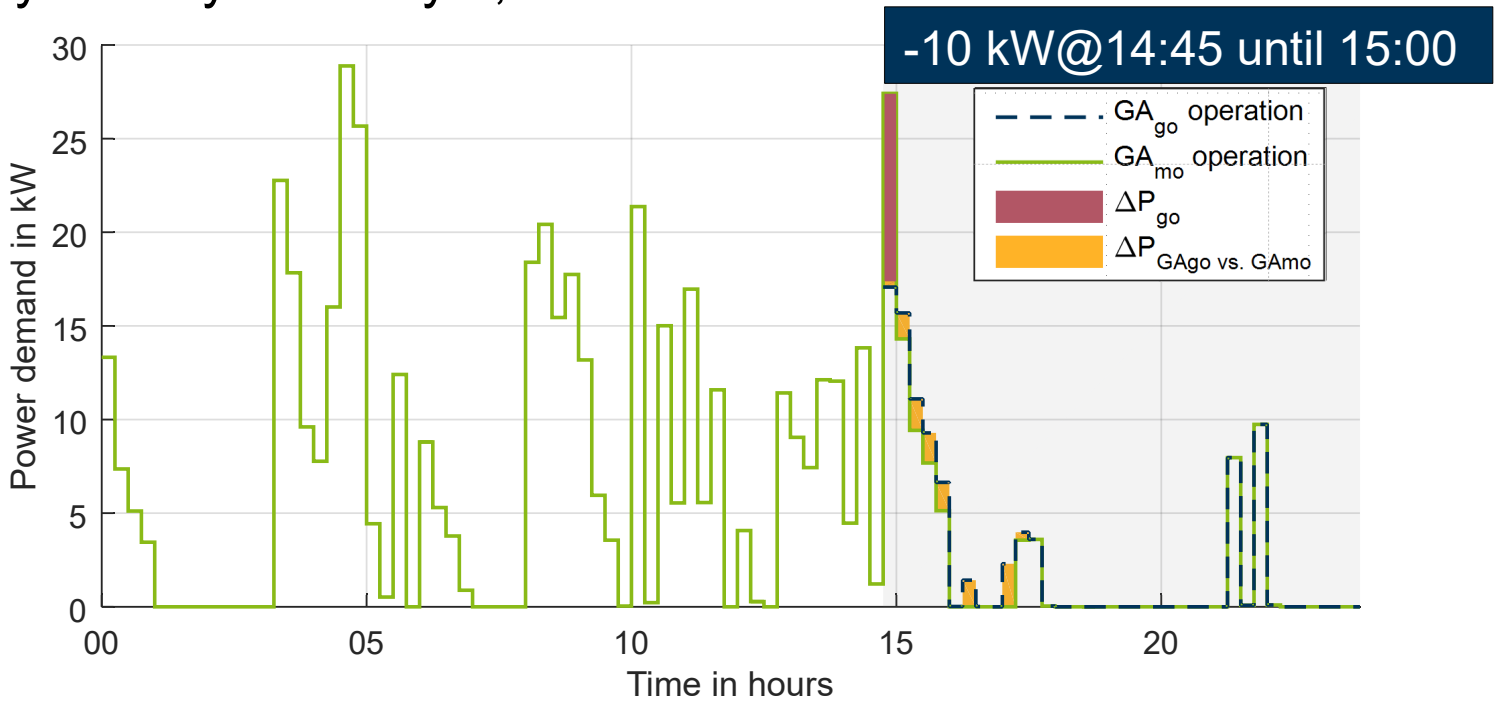
low/high RES: Representative days of low or high contribution of renewable energies in the power generation matrix in Germany

Grid-oriented optimisation

Results & Analysis

Grid-oriented optimisation

- Analysed day: January 5, 2022



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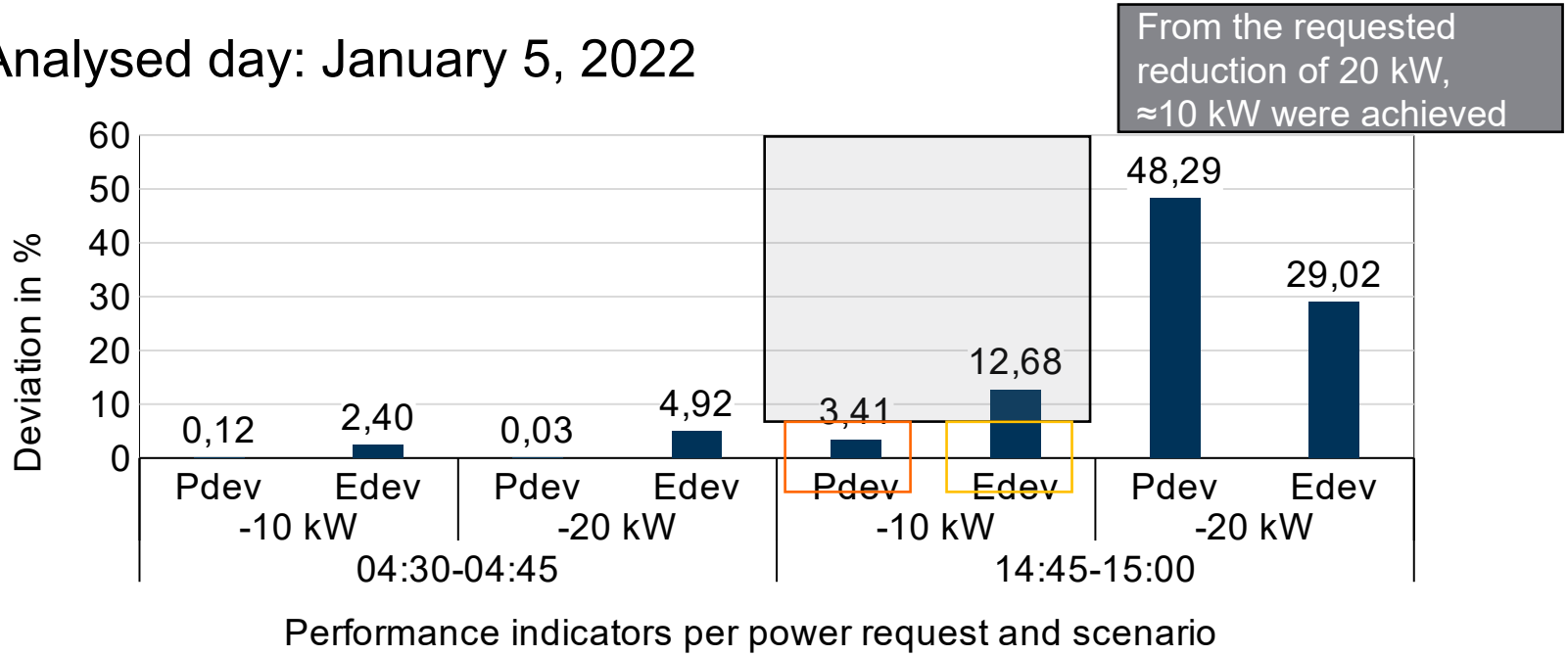
mo: market-oriented | go: grid-oriented | GA: Genetic Algorithm

Results & Analysis

Grid-oriented optimisation

- Analysed day: January 5, 2022



The support hours were selected based on peak power demand

Dev: Deviation

Agenda

- Motivation & Goals
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- **Conclusions**

Conclusions

- Potential operational cost reduction by considering an Genetic-Algorithm-based optimisation and participating in the Day-Ahead market
  - Between 20 % and 30 % cost effective compared to an operation with the fixed energy price
  - Between 6 % and 8 % cost effective compared to an operation with a dynamic energy price (but without an optimisation)

- In three of the four presented scenarios:
  - Smart Grid system's requirements were met by more than 96 %
  - User comfort could limit the support capabilities of the charging infrastructure

Thank you for your attention

Do you have any questions?

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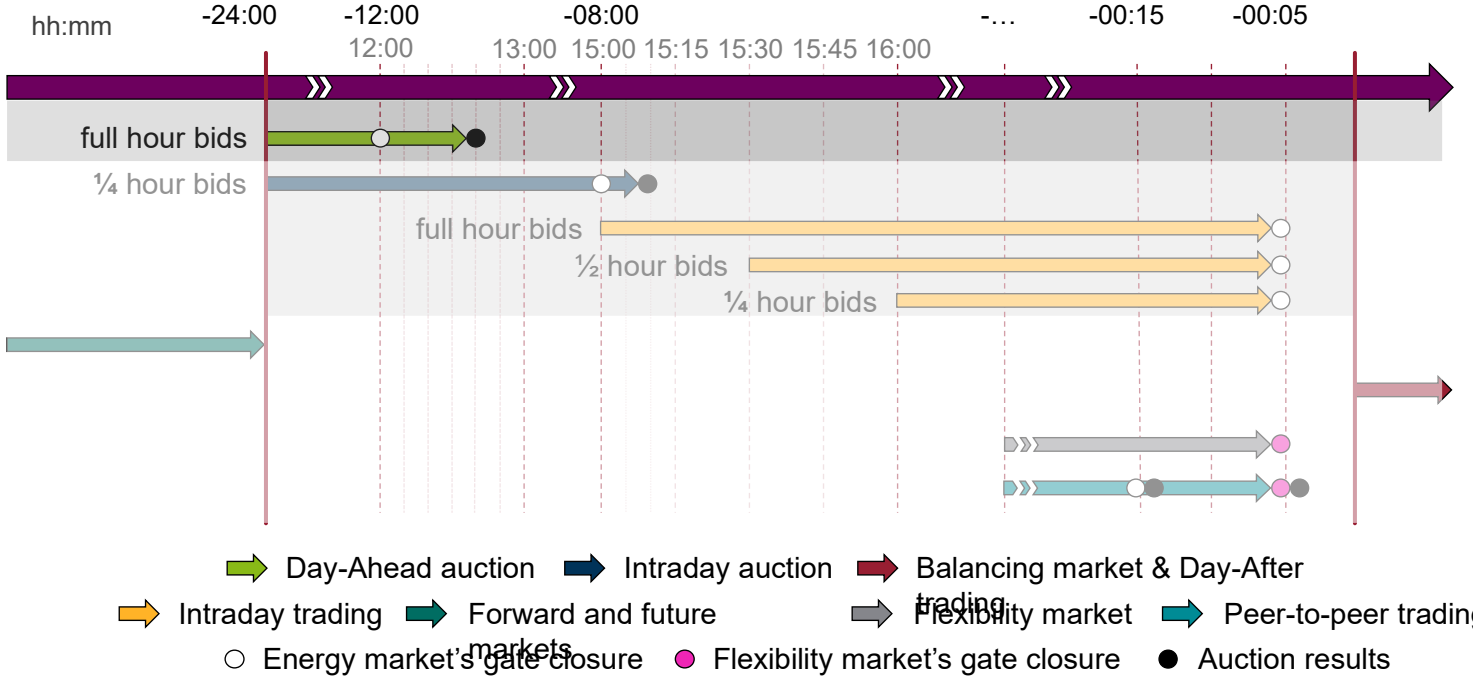
Backup

Methodology

Suitable energy markets for charging stations

Backup

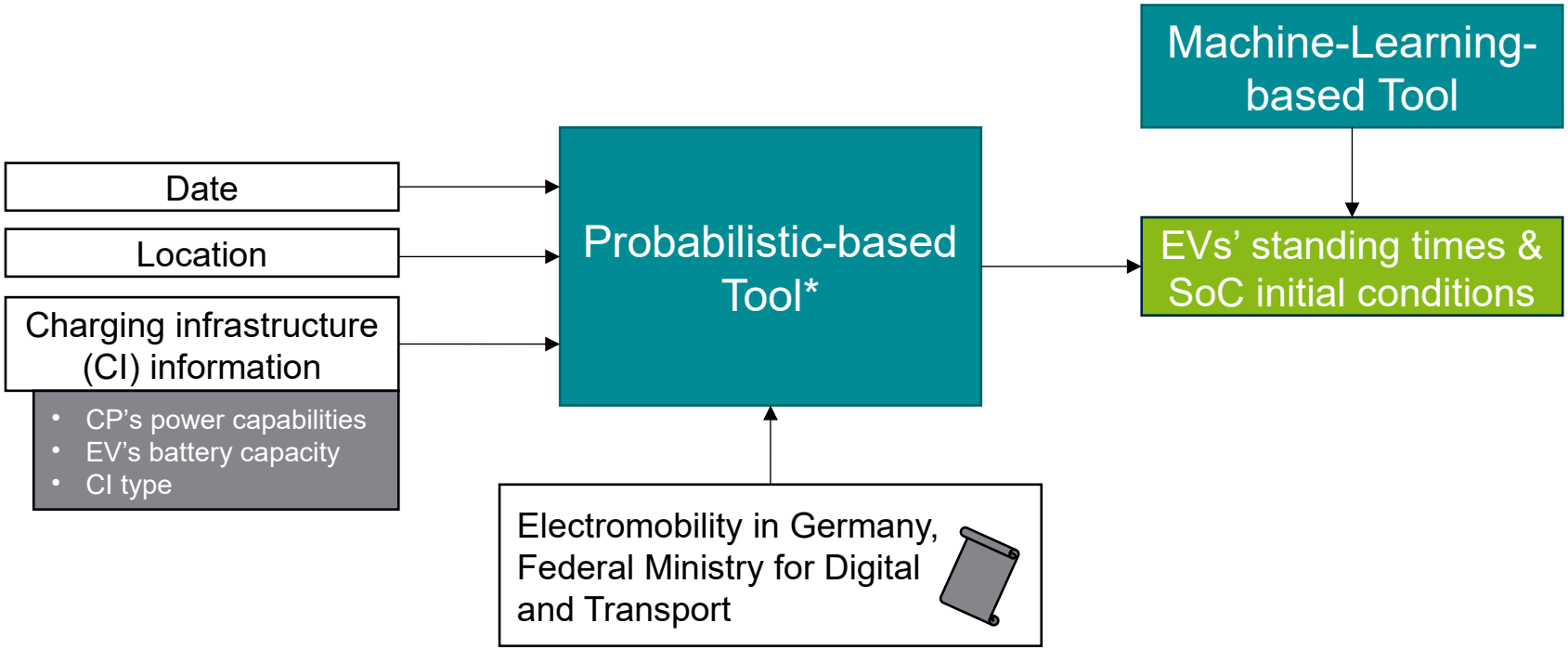
- Day-Ahead market as a trading option



Methodology

Standing times forecast for electric vehicles

Backup

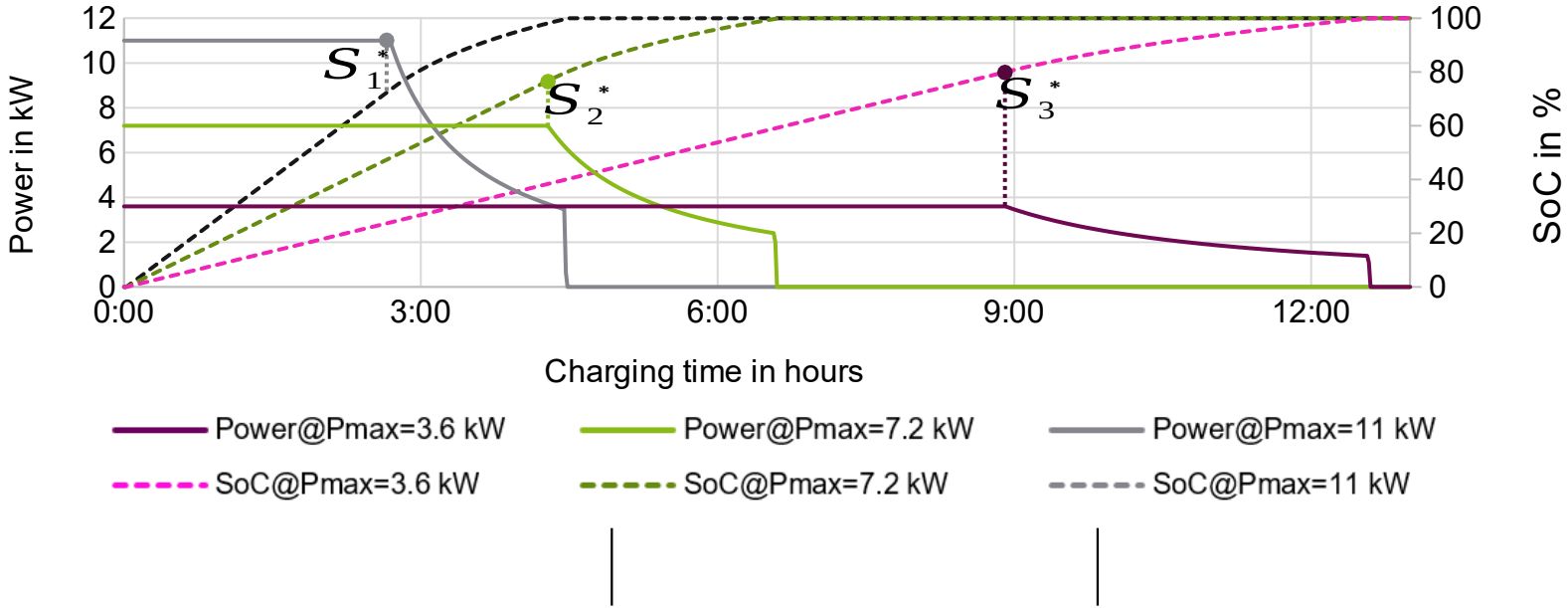


CP: Charging point | *R. Uhlig, M. Stötzel, M. Zdrallek, and N. Neusel-Lange, "Dynamic grid support with EV charging management considering user requirements," CIRED Workshop, 2016

Methodology

EV charging process model

Backup



: Maximum charging power | Maximum battery's usable capacity | : Cell battery's nominal voltage

: cell battery's maximum final charging voltage | : Final charging current

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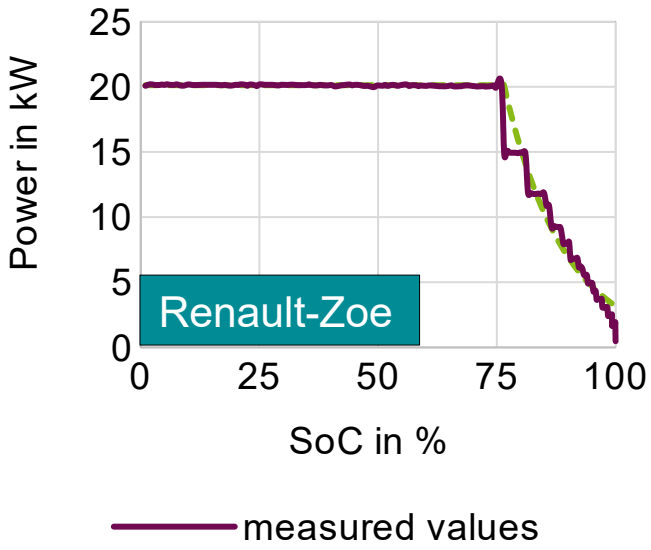
EV: Electric vehicle | D. Fasthuber, "Integration der Ladeinfrastruktur in das elektrische Energiesystem," Elektrotechnik & Infor-mationstechnik, vol. 137, 2020.

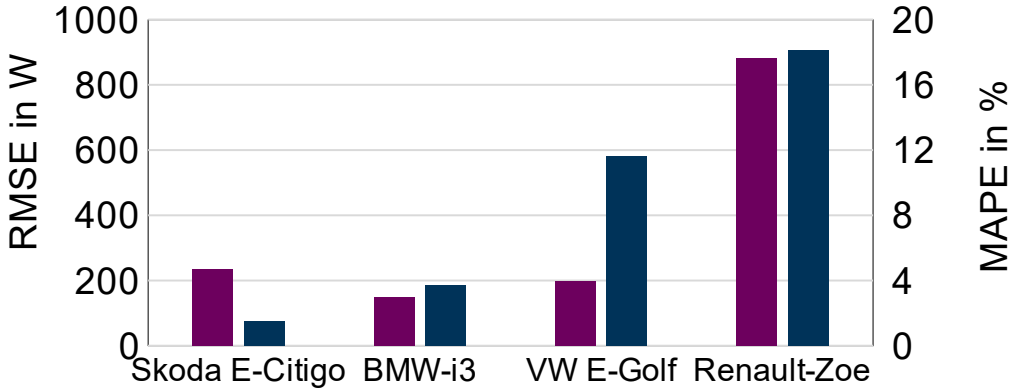
Methodology

EV charging process model

Backup

- Mathematical model's validation through real measurements





$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{x_i - \hat{x}_i}{x_i}\right|$$

measurements values | : simulation values

RMSE: Root Mean Squared Error | MAPE: Mean Absolute Percentage Error

Methodology

Charging processes' optimisation through genetic algorithms

Backup

Optimisation problem definition

- Market-oriented operation
  - Determination of the set points for each charging point **for each** time block ("long"-term schedule)
  - ▶ Operating cost reduction

$$GA_{mo} = min \sum_{i=1}^{N} \sum_{j=1}^{ccp} \left\{ P_j^{mo}(i) \cdot \Delta n \cdot k(i) \right\}$$

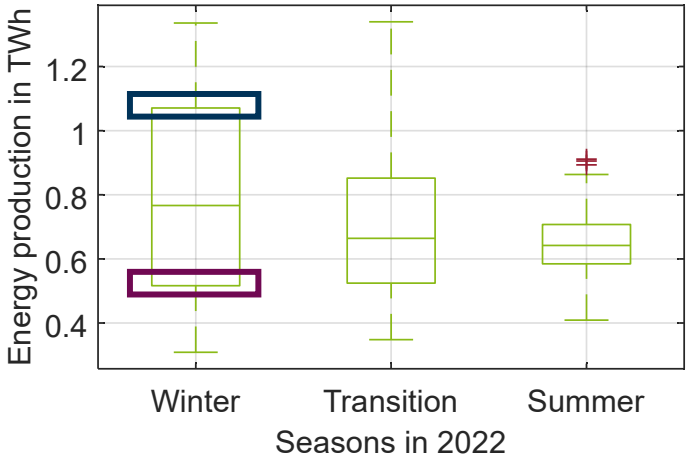
- Grid-oriented operation
  - Determination of the set points for charging point **for specific** time block ("short-term schedule)
  - Major variations with respect to the schedule in operation must be avoided
  - ▶ Grid service

$$GA_{go} = min \sum_{i=i_{go}}^{N} \left| \left\{ \sum_{j=1}^{CP} \left[P_j^{mo}(i) + \Delta P_{go}(i=i_{go}) \right] \cdot \Delta n \right\} - P_j^{go}(i) \cdot \right.$$

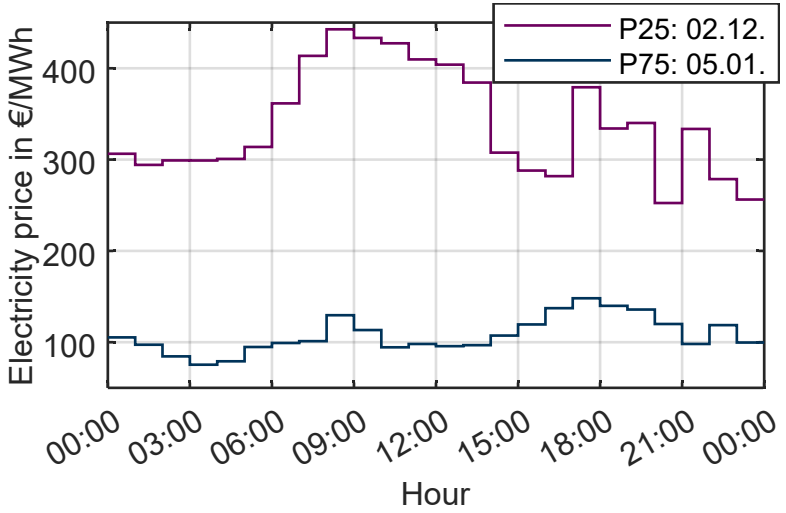
Methodology

Scenario background

Backup



Daily energy production in Germany from renewable energies by season

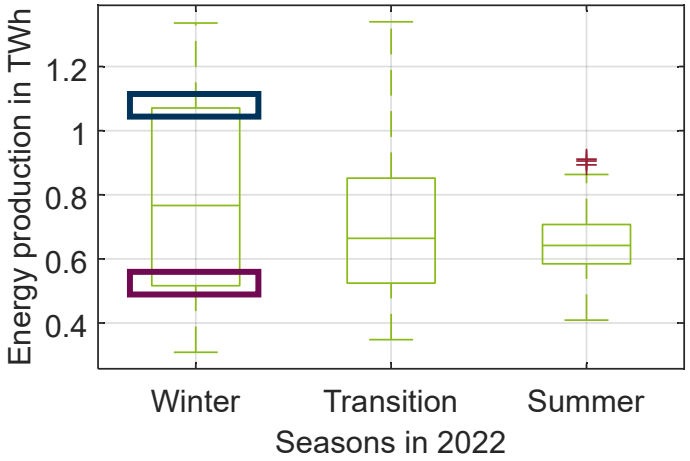


Prices for the Day-Ahead market for the winter season 2022 considering determined percentile distributions

Methodology

Scenario background

Backup



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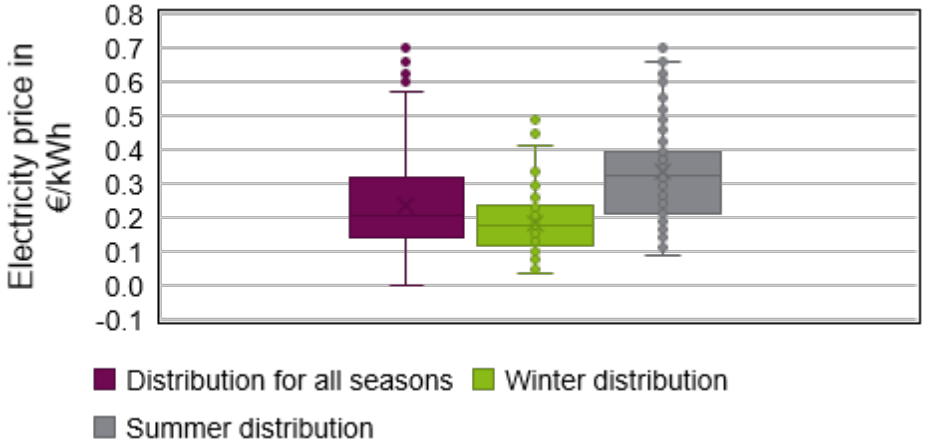
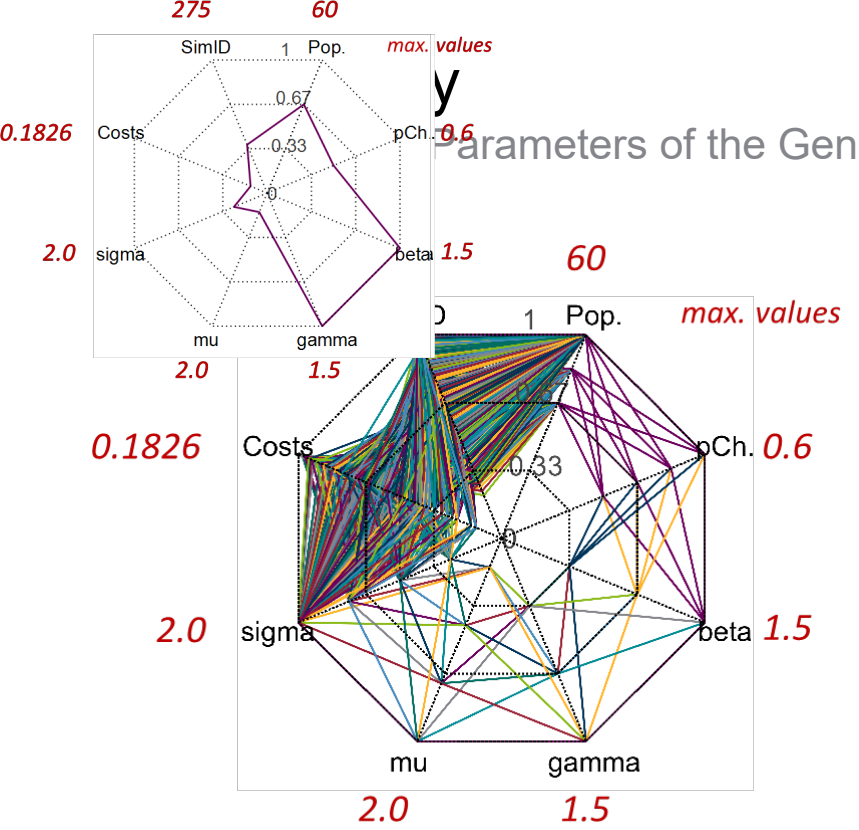


Daily average electricity price on the Day-Ahead market in 2022

Backup

Parameters of the Genetic Algorithm



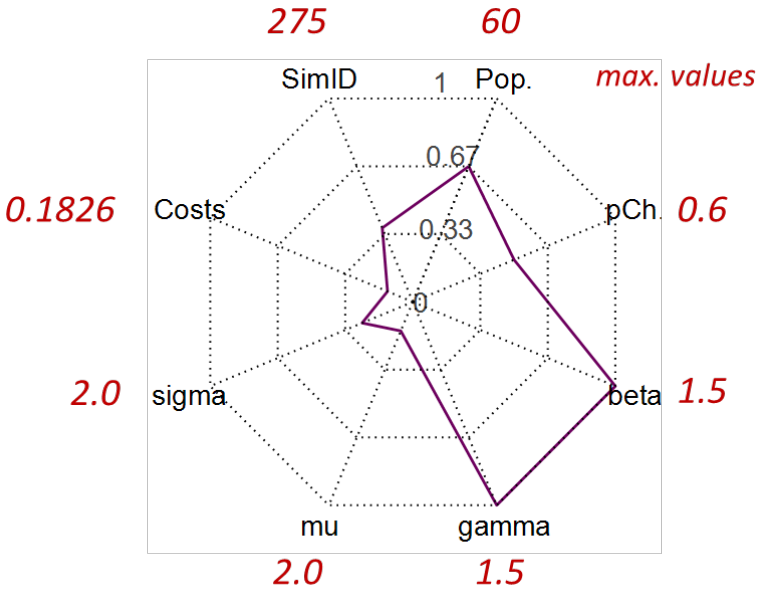
Normalised GA -parameter optimisation chart

- *nIt*: Maximum number of iterations (generations)
- *Pop*: Size of the population of candidate solutions of each generation
- *pCh*: Offspring rate as a proportion of population size
- *ParSel*: Parent selection criteria
- *beta*: Pressure factor for the selection of suitable individuals
- *CrossMod*: Crossover mode
- *gamma*: Crossover's exploration factor for new potential solutions
- *mu*: Mutation factor
- *sigma*: Mutation step size
- *zeta*: Damping factor of the mutation factor after each generation

Methodology

Calibration of the Parameters of the Genetic Algorithm

Backup



Optimised GA-parameter values

- *nIt*: Maximum number of iterations (generations)
- *Pop*: Size of the population of candidate solutions of each generation
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- *zeta*: Damping factor of the mutation factor after each generation

Conclusions

Outlook

- Machine-learning-based as a tool to forecast EVs' standing time and the initial SoC conditions instead of the considered probabilistic-based model

- Scheme to determine the price of electrical energy that can be sold in short-term markets due to variations caused by the grid-oriented operation mode