Potsdam Institute for Climate Impact Research

# Long-term strategies to ensure a robust performance of the European electricity system

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Leibniz Gemeinschaft

# MOTIVATION

# Motivation

The European electricity system is…

…characterized by high capital intensity and long-living assets.

*Long-term planning is indispensable for investors, regulators, etc.*

Several investment models exist:

*ReEDS* *US-REGEN*
*SWITCH* *PRIMES* *PowerACE*
*URBS-EU* *TIMES* *MESSAGE* *ReMIND*
*EMMA*
*REMix* ***LIMES-EU*** *DIMENSION*
*ELMOD*
*LIBEMOD*
*PERSEUS*

# LIMES-EU *Long-term investment model of the electricity sector*

## Objective

- minimizing cumulated costs for electricity provision
- optimal investment and dispatch decisions for generation, storage and transmission capacities

## Linear optimization model

- GAMS / CPLEX Solver

## Technologies

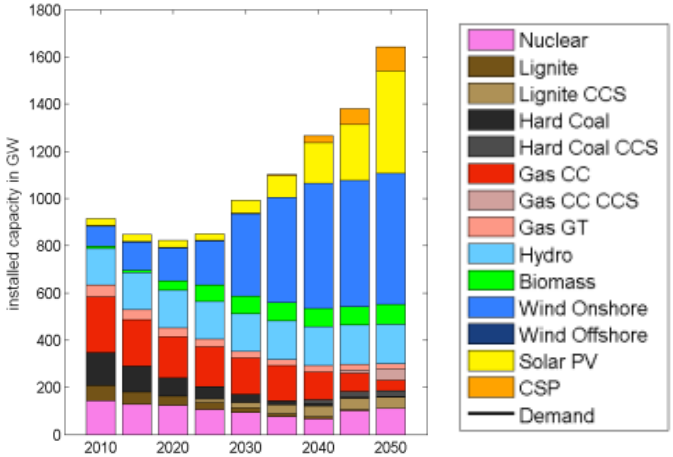
- generation *[nuclear, hard coal (+ccs), lignite (+ccs), natural gas cc/gt, hydro, wind on-/offshore, solar pv/csp, biomass]*
- storage *[diurnal, seasonal]*
- transmission *[net transfer capacities between regions]*

## Geographical scope & resolution

- EU28 countries w/o Malta & Cyprus
- plus Norway & Switzerland & Balkan

## Temporal scope & resolution

- 5 year steps 2010 – 2050
- representative days per year
- perfect foresight




Installed generation capacities 2010-2050

## Policy equations

- $CO_2$ targets / RES targets
- EU or Member State level

## Exogenous parameters

- electricity demand per region
- nuclear / ccs policies
- investment costs
- fuel costs
- …

Nahmmacher et al. (2014)

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*Long-term planning is indispensable for investors, regulators, etc.*

2. constantly exposed to political, techno-economic and natural risks.

*It is crucial to design the system in a way that it ensures*
*security of supply and minimum costs*
*for a variety of future scenarios and shocks.*

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*It is crucial to design the system in a way that it ensures*
*security of supply and minimum costs*
*for a variety of future scenarios and shocks.*

***What are the characteristics of a cost-efficient and robust European electricity system***
considering a large variety of possible future shocks
***and***
given the assumption that the liberalized market does not provide for these shocks
***what are (political) strategies needed to achieve such a system?***

# Scenarios – Strategies – Shocks

***Scenarios***

A scenario is a possible future development of external parameters. Scenarios can be expected but their probability is unknown. Investment decisions are taken based on scenarios.

***Strategies***

A strategy is an additional constraint that has to be satisfied when planning the electricity system.

***Shocks***

A shock is an unexpected sudden change of external parameters, such that assets of the electricity system cannot be changed accordingly. Shocks may result in a different dispatch, a shortage of electricity supply, and/or a failure to meet the emission target.

# MODELLING FRAMEWORK

# Absence of certainty

Three levels of incertitude (the absence of certainty)

| Risk | Uncertainty | Ignorance |
|---|---|---|
| *Possibility is known*<br>*Probability is known* | *Possibility is known* | *Nothing is known* |
| *Stochastic approaches* | *Scenario analysis* | *Diversity* |

Stirling (1994)

# Scenarios

Optimisation for each scenario separately

- most studies usually cover less than five possible future scenarios
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# Stochastic approaches

Multiple possible future states are considered within one optimization run

- only limited number of future states computationally possible
- need to assign probabilities

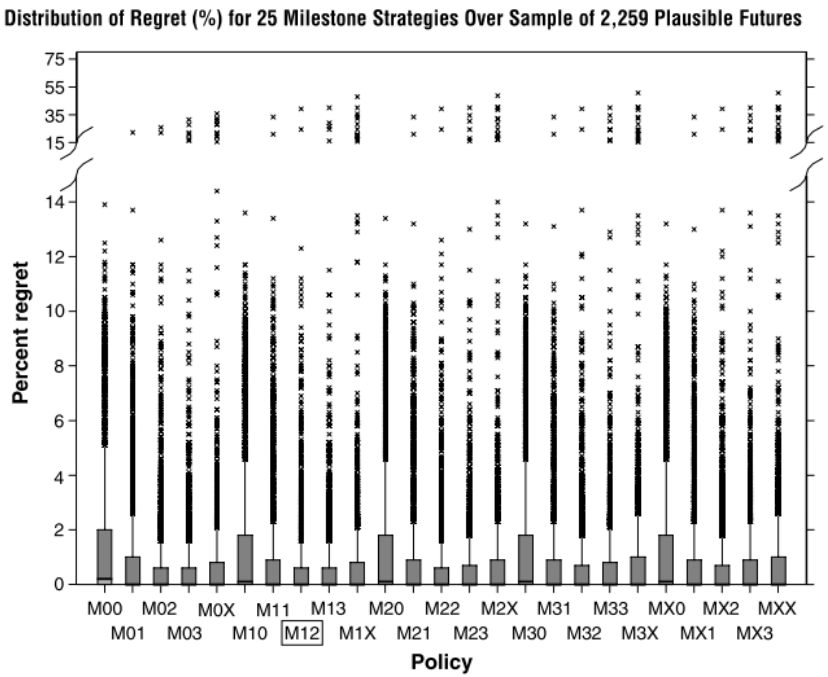
*Both scenario analysis and stochastic analysis*
*find the optimal solution for a specific set of assumptions*
*and usually focus on a very limited number of futures*

# Robust Decision Making

*Lempert et al. (2006):*

*A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios*

- "Robustness is an important criterion for good decisions under uncertainty" (Robustness vs. Optimality)
- "A robust strategy performs relatively well – compared to alternatives – across a wide range of plausible futures"
- Performance of a strategy for a specific scenario is measured by its regret (i. e. additional cost) compared to the best-performing strategy

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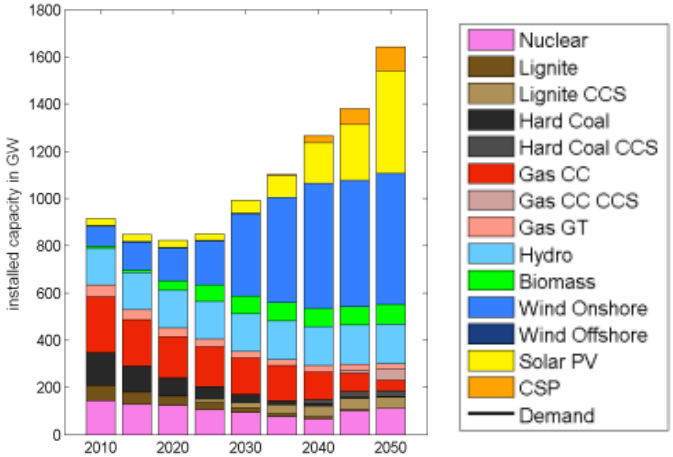


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# Scenarios – Strategies – Shocks

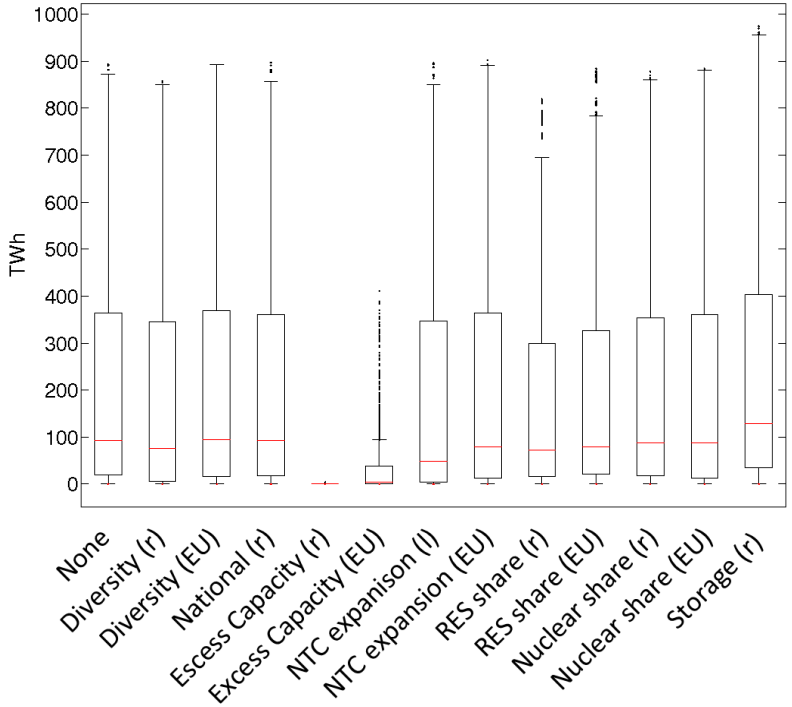
| Scenarios | Strategies | Shocks |
|---|---|---|
| nuclear cost<br>- default / high<br>ccs cost<br>- default / high<br>wind FLH<br>- default / low<br>solar investment cost<br>- default / low<br>biomass price<br>- default / high<br>gas price<br>- default / high | none<br>- default<br>diversity in fuels<br>- upper bound on share of single fuel<br>import of electricity<br>- upper bound on share of imported electricity<br>redundant (reserve) capacities<br>- target on excess capacity<br>transmission expansion<br>- lower bound on transmission expansion<br>RES-share<br>- lower bound on RES-share<br>nuclear power<br>- lower bound on nuclear capacity<br>storage<br>- lower bound on storage capacity | low wind / solar<br>- long periods of low wind and solar<br>heat wave<br>- availability of thermal and hydro power plants is decreased<br>transmission system<br>- limited availability of selected interconnectors<br>gas supply<br>- availability of natural gas is reduced<br>gas price<br>- deviation from expected gas price |

# (PRELIMINARY) RESULTS

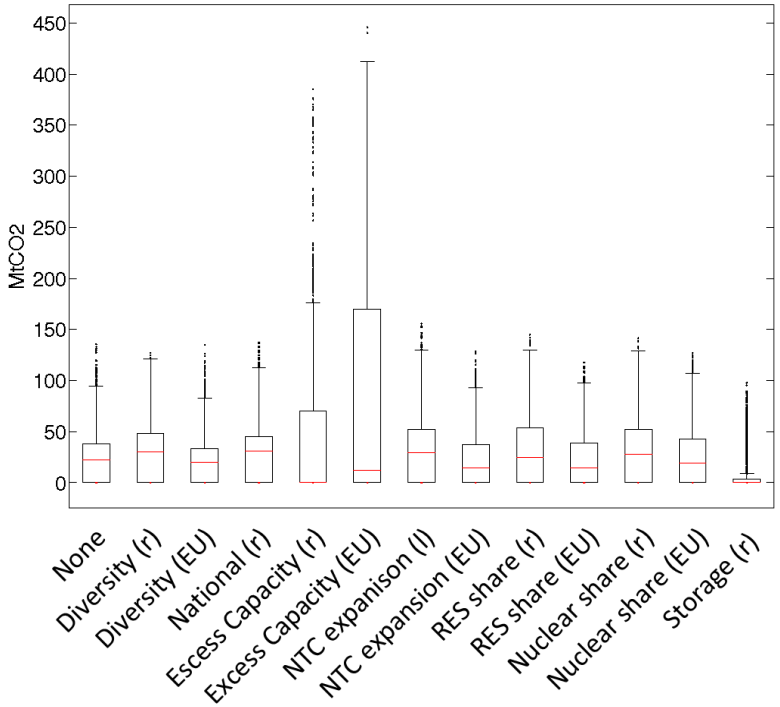
# vRES shock

- Excess capacities avoid shortage of supply but add emissions

shortage of supply



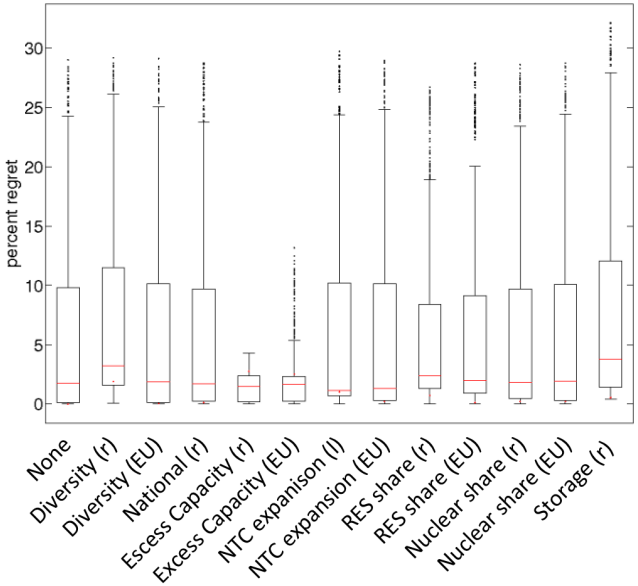

excess $CO_2$ emissions



# vRES shock

- Installation of excess capacities most viable option

Overall costs
(VOLL = 500 €/MWh)

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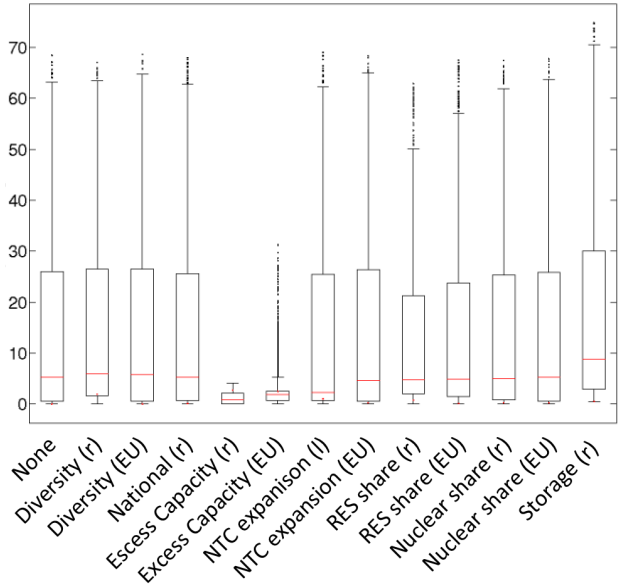


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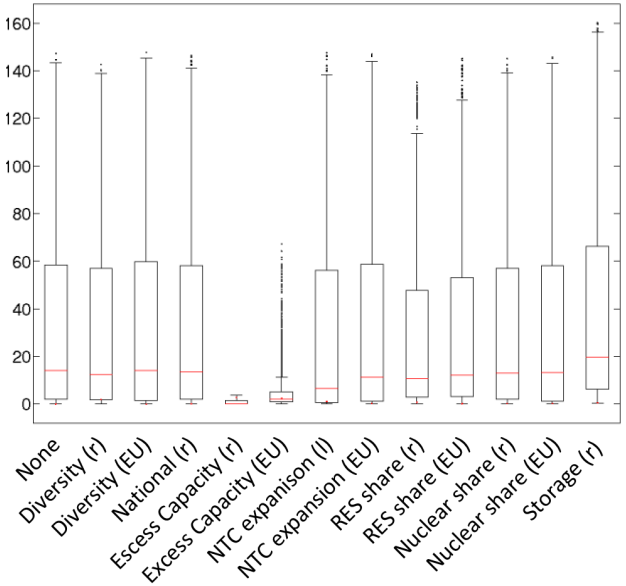
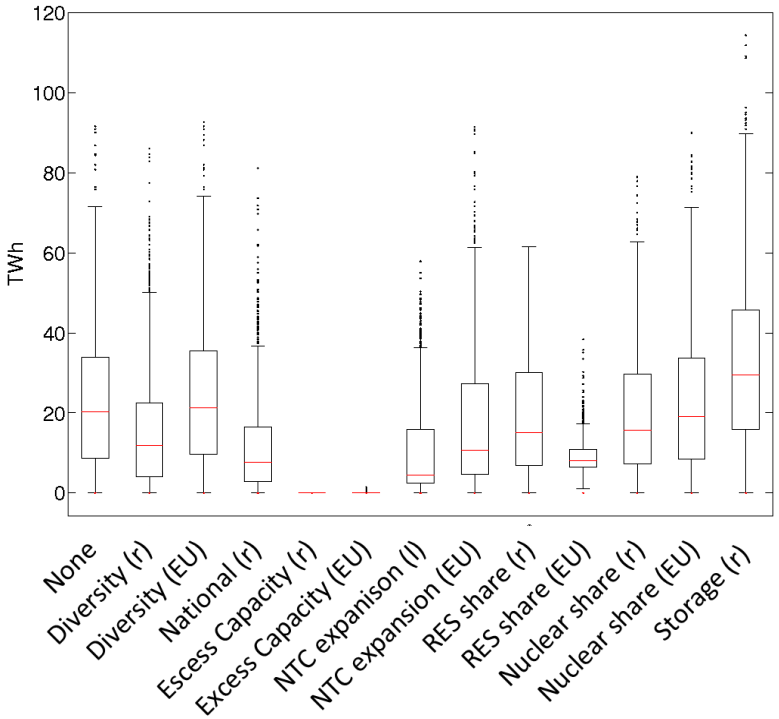


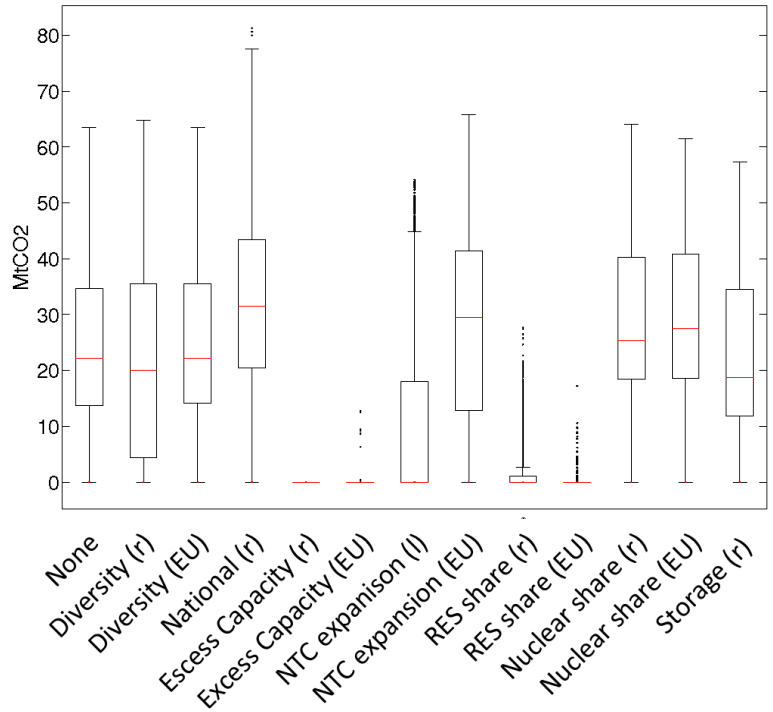
# Heat wave

- Excess capacities are the best way to mitigate the impacts of a heat wave.
- European-wide RES-target also helpful.

shortage of supply




excess $CO_2$ emissions



# Heat wave

- Excess capacities are only viable, when high VOLL.
- European wide RES-target viable.

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Overall costs
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Overall costs
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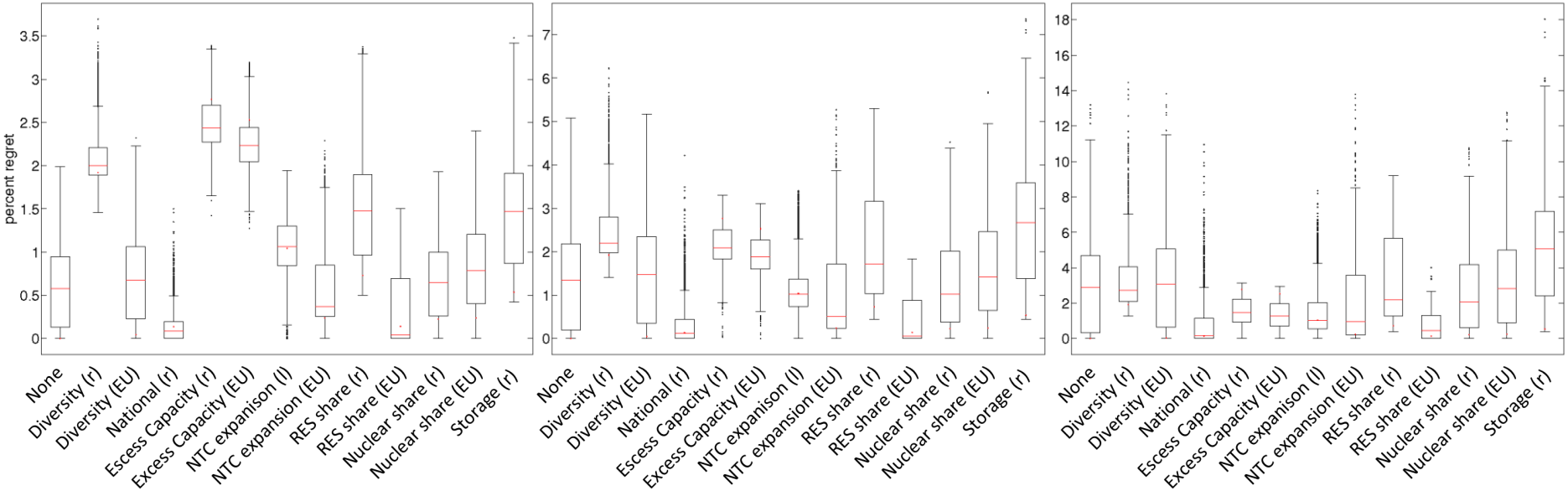
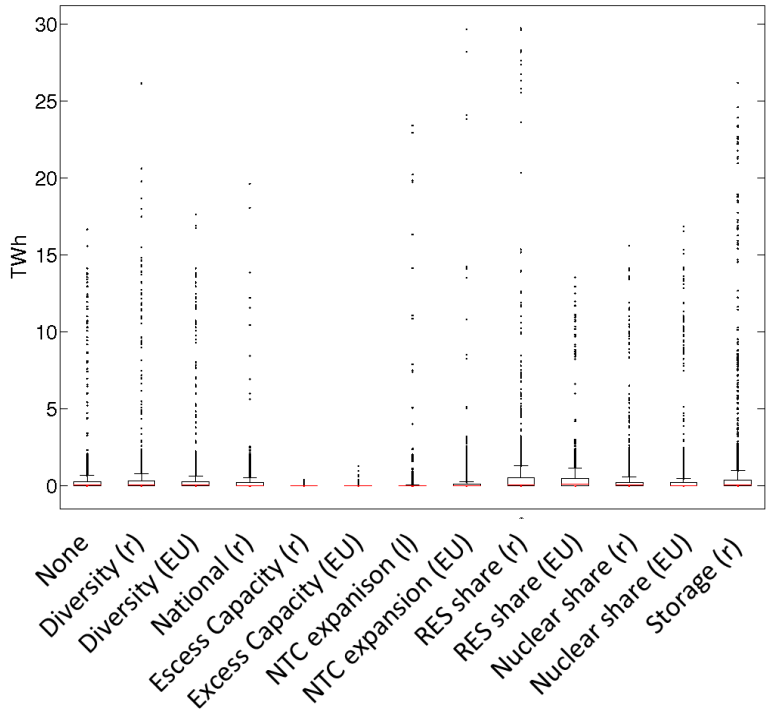


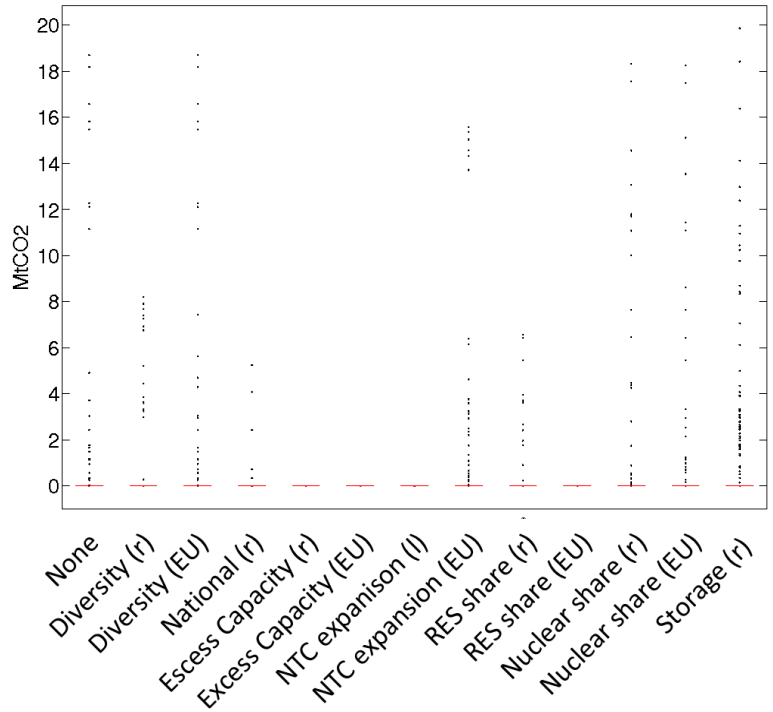
# Transmission shock

- Overall, transmission shock no serious threat for security of supply
- Excess capacities increase security of supply

shortage of supply



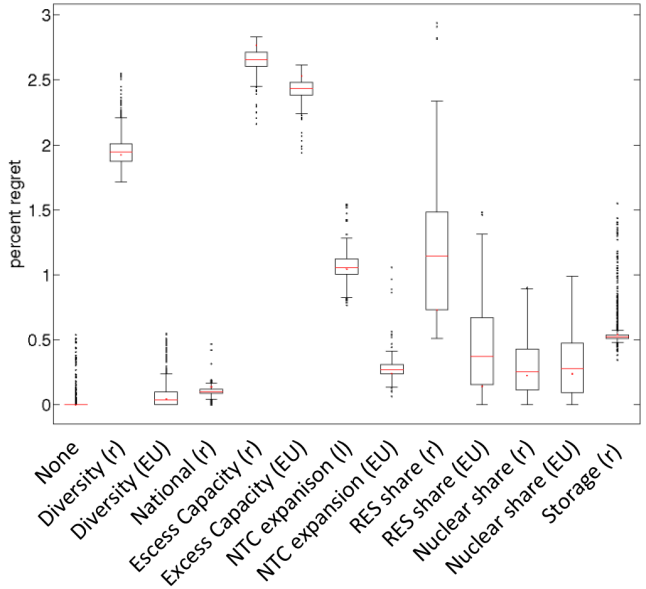

excess $CO_2$ emissions



# Transmission shock

- Excess capacities too expensive
- „No strategy“ is best

Overall costs
(VOLL = 500 €/MWh)

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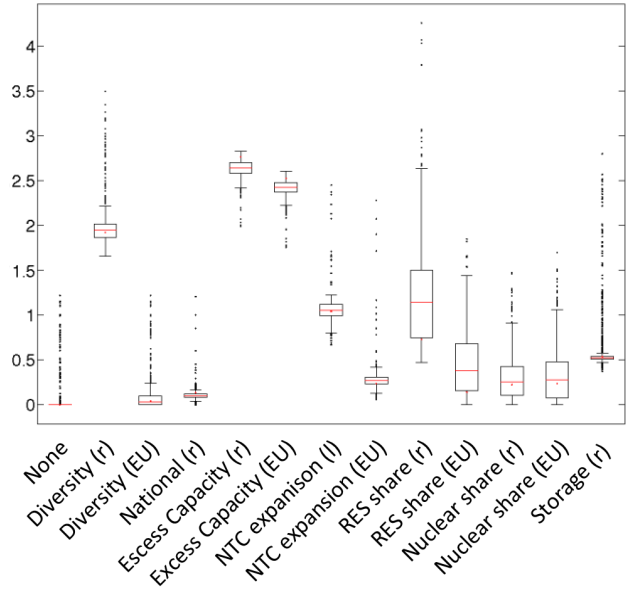


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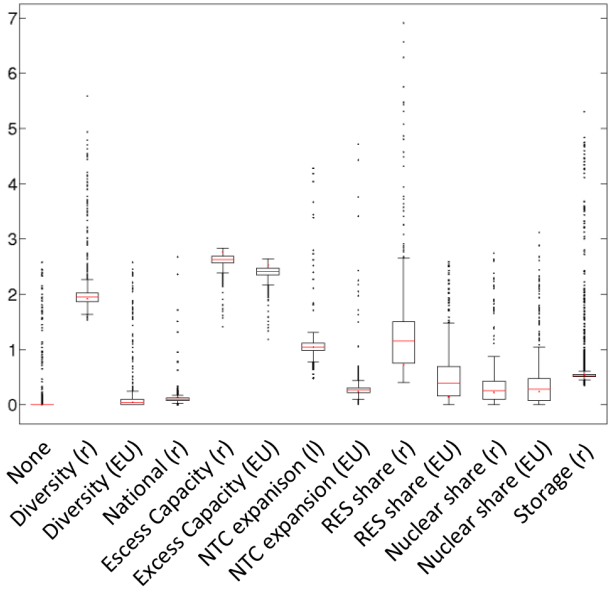
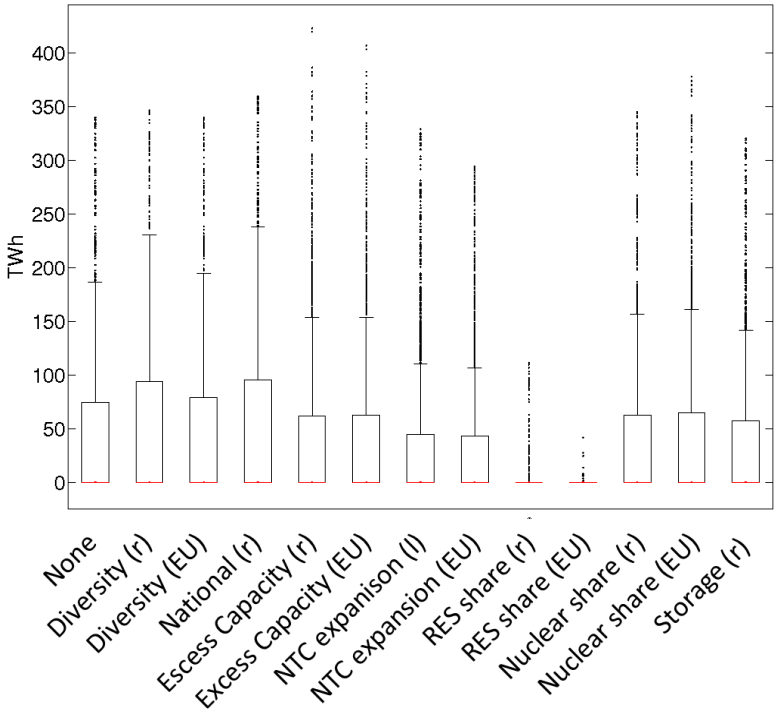


# Gas supply (quantity) shock

- A RES-target mitigates the negative impact of a shortage in gas supply.
- NTC expansion also helpful.

shortage of supply

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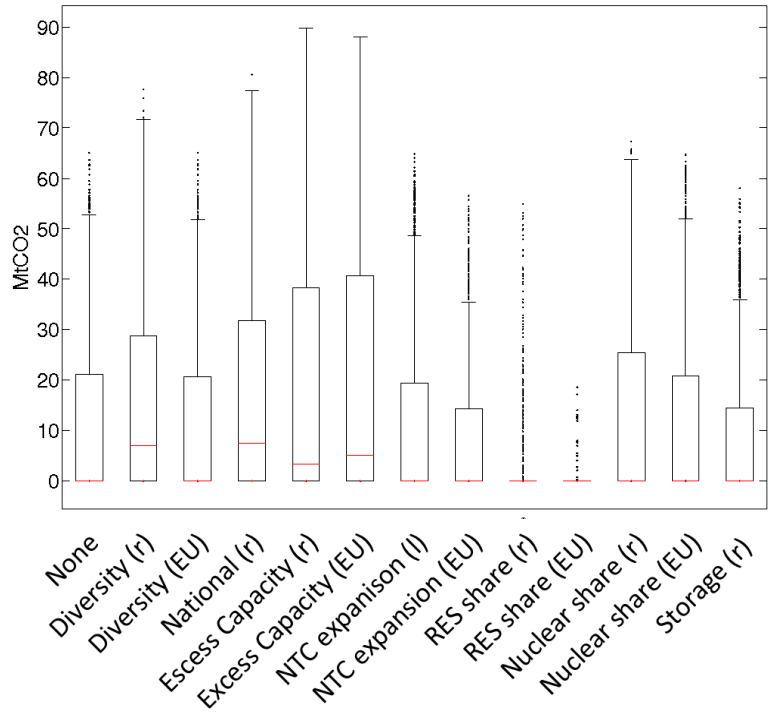

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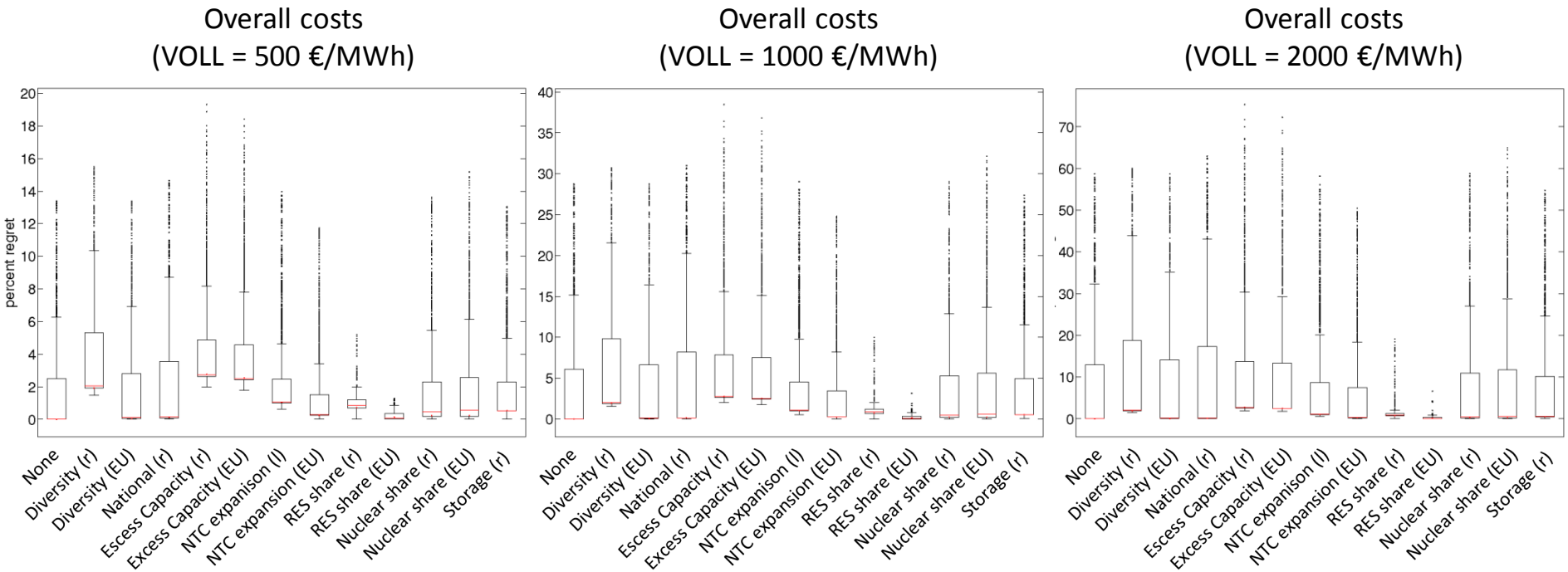
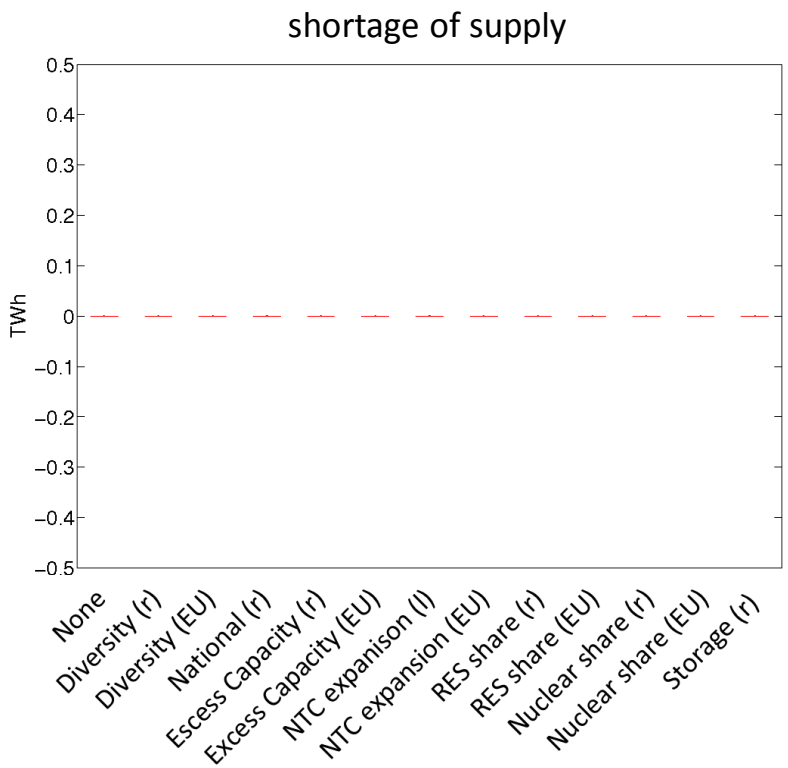
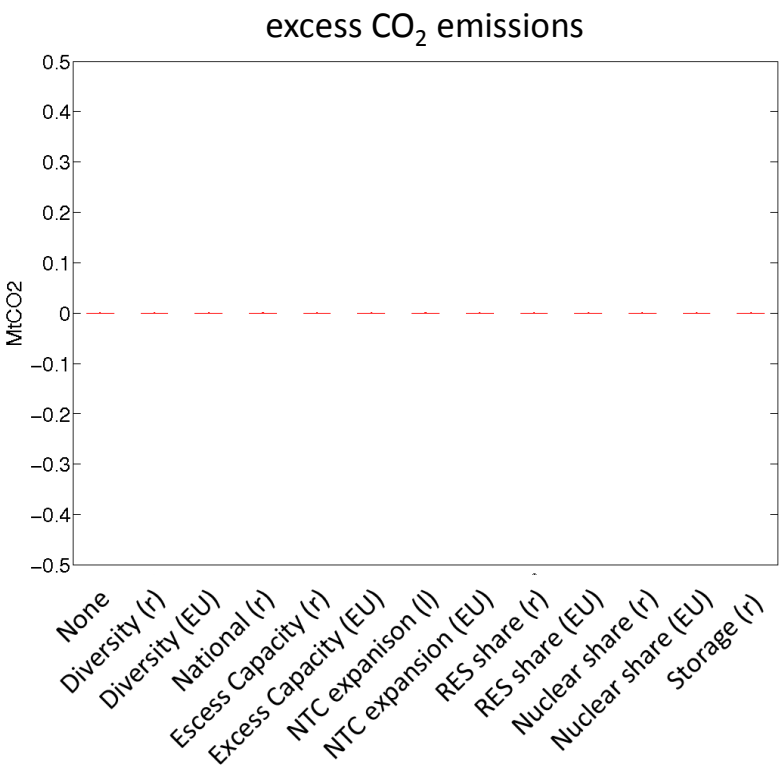


# Gas price shock

- A gas price shock does not pose a threat to the security of supply



# Gas price shock

- The additional costs for implementing the considered strategies are higher than their benefits in case of a gas price shock.

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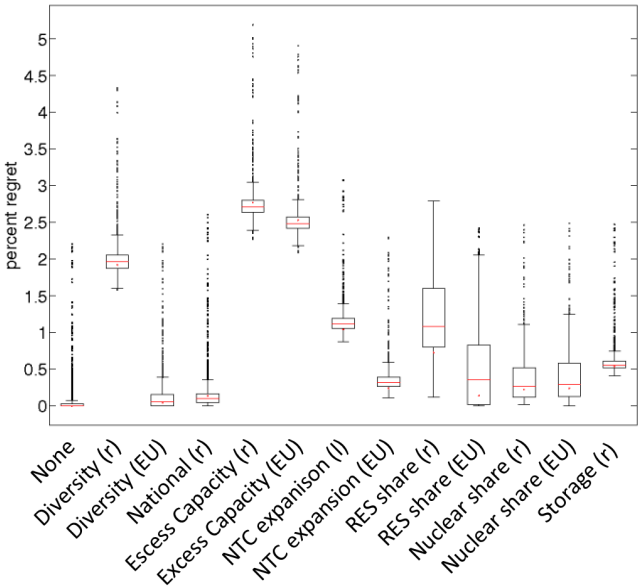


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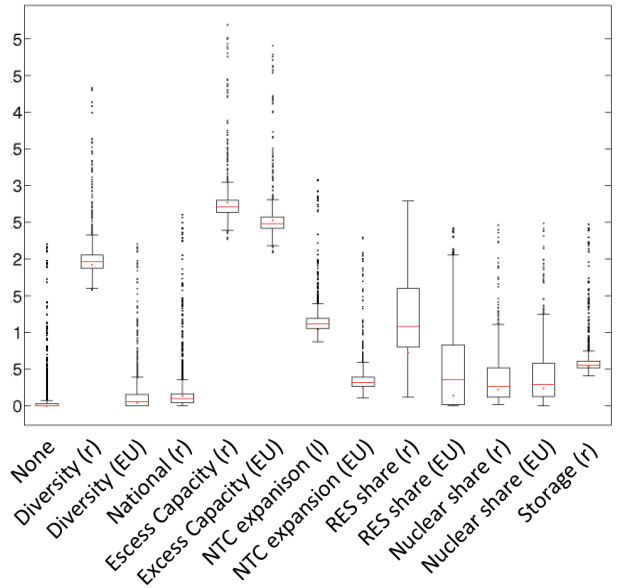


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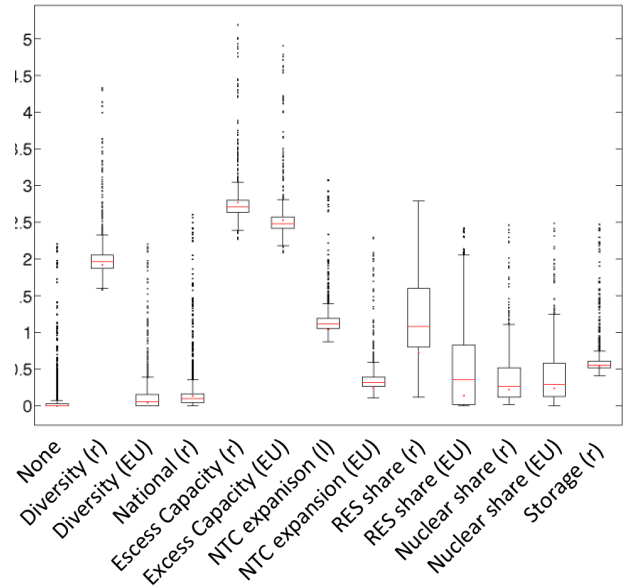

# CONCLUSION

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- Analysis of strategies for a large variety of possible shocks to the electricity sector
- Combination of optimization model with robustness analysis
- Useful in case that stochastic analysis fails to provide meaningful results
  - when probabilities of the shocks are unknown
  - when there are more than only a few possible futures.

- Viable strategies against considered shocks:
  - highly depending on VOLL
  - installation of excess capacities / RES expansion

- Work in progress: Suggestions for additional scenarios, strategies and shocks are welcome!

**Thank you!**

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