Uncertainties in the Power System: What methods for which challenges?

Prof. Christoph Weber
Trans-Atlantic Infaday

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Energy has been a risky business…
Oil price forecast from 2009 onwards

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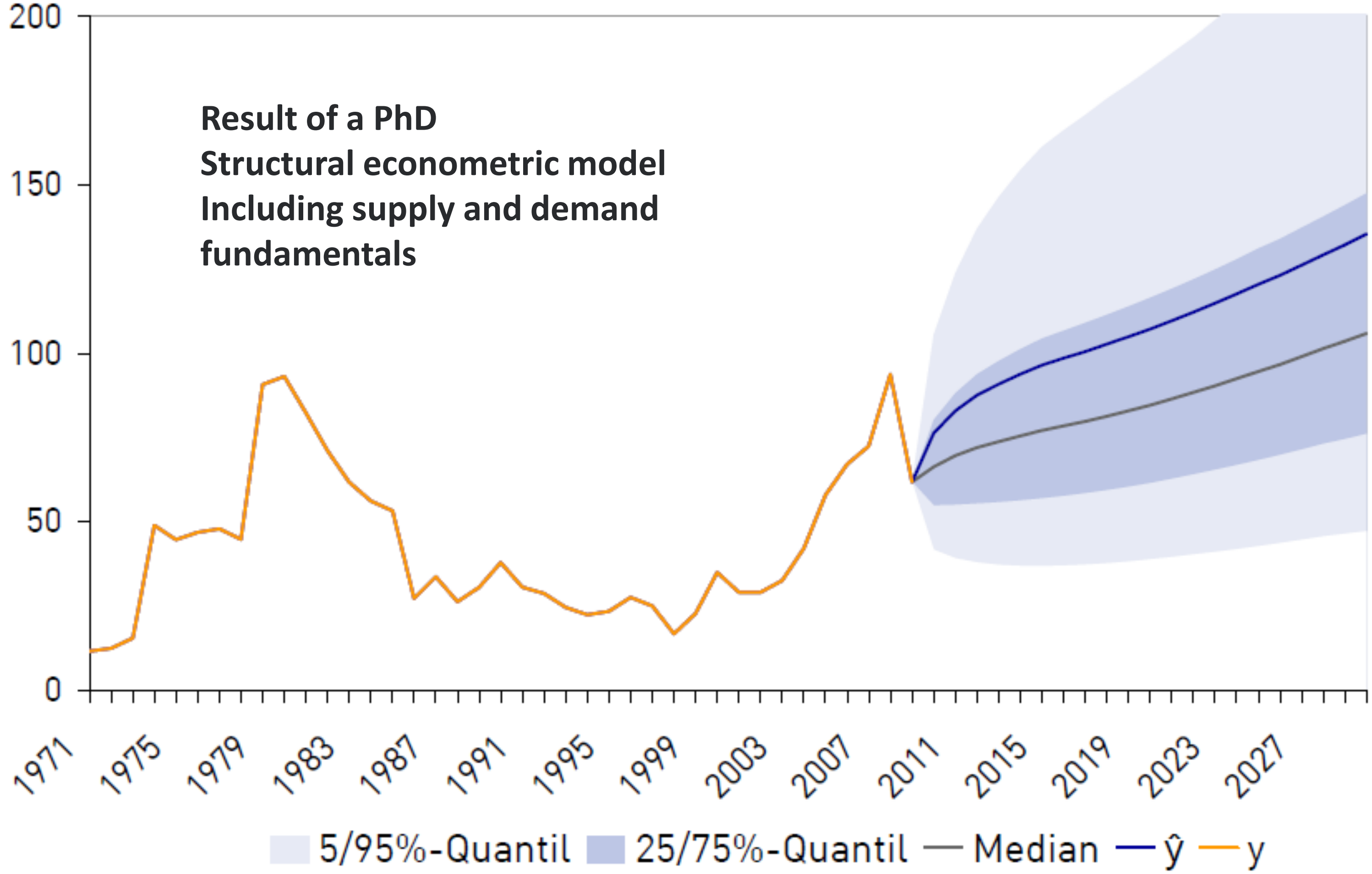
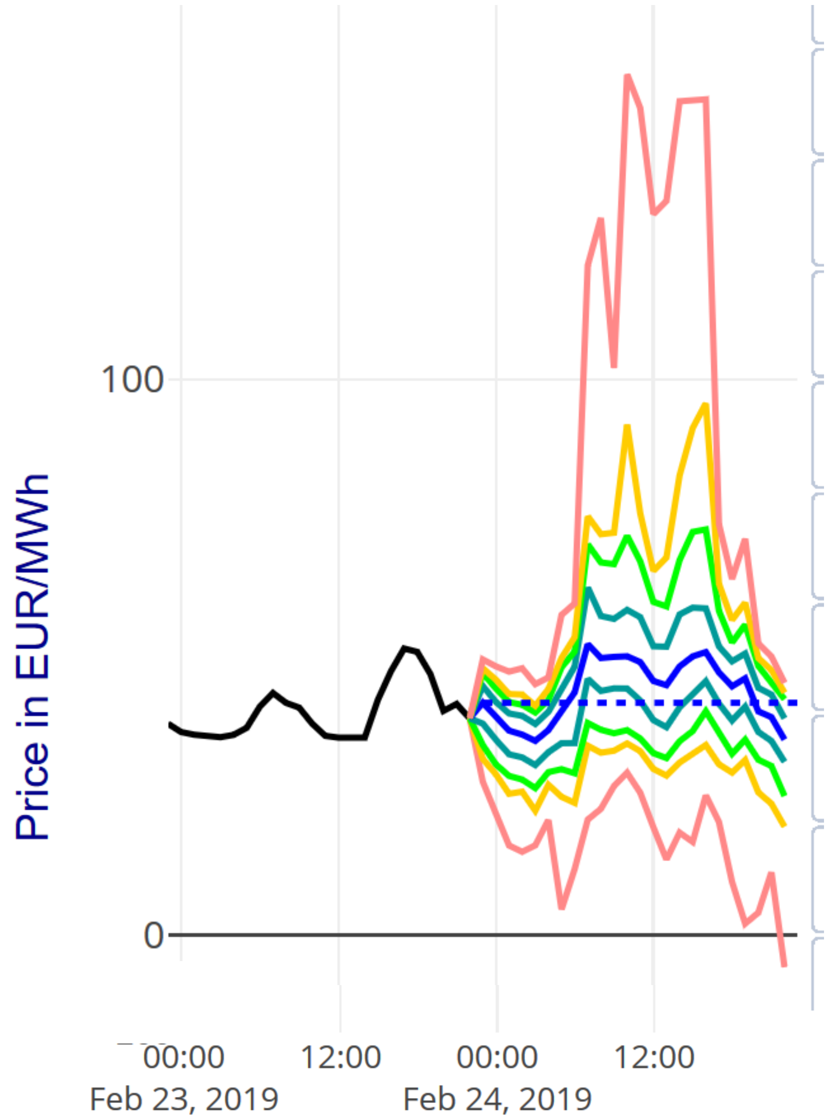


Source: March, C. (2012)

… and will remain so: Electricity price forecasts from Friday 23 onwards



Probabilistic forecasts available online on

https://www.uee.wiwi.uni-due.de/forschung/prognose-von-strompreisen/

- Short-term forecasts
- Huge uncertainties
  - Red: 1%/99% quantiles
  - Green: 25%/75% quantiles

Source: Florian Ziel (2019)

Dimensions of decisions under uncertainty

- What type of uncertainties is present?
  - Cf. next slide
- Who decides?
  - Individual vs. group
  - Policy makers vs. companies vs. households/citizens
- What is decided?
  - Operation
  - Investment
  - Regulation

Typology of energy decisions (covers "Who decides?" and "What is decided?")

- What interdependencies with other decisions are relevant?

Normative Decision Theory: Decision settings

- Decisions under certainty

- Decisions under risk

  Objective probabilities for events available

  ➢ Optimal decision rule: Bernoulli Principle, Maximization of expected utility

- Decisions under incertitude

  in the Anglo-Saxon literature frequently: "Knightian uncertainty"

  No objective probabilities

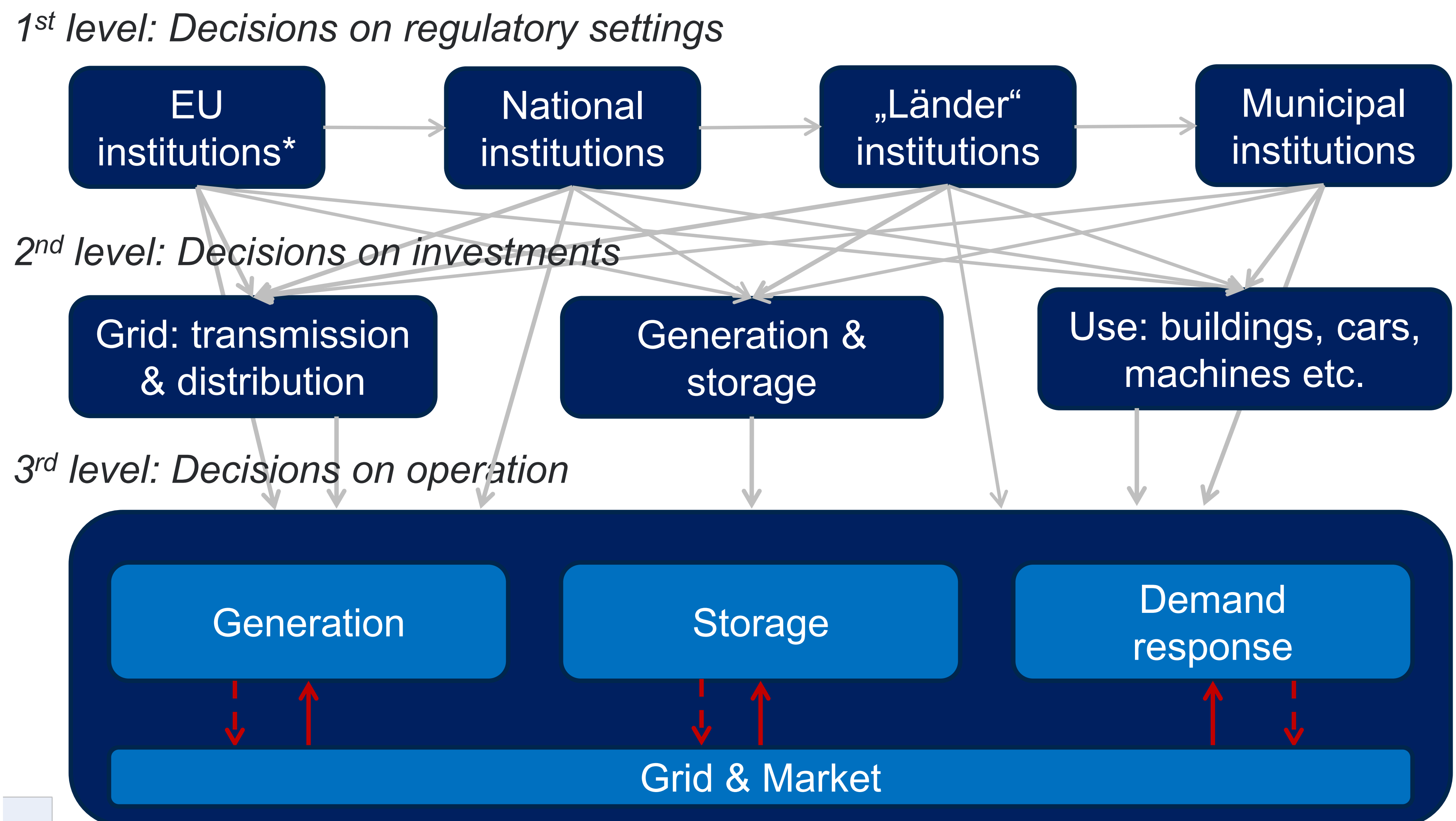
  ➢ Typical case for political uncertainty

  ➢ Savage (1954) and others use subjective (Bayesian) probabilities

  ➢ But also other, heuristic decision rules available: Maximin, minimum regret …

Decisions under uncertainty (comprises decisions under risk and decisions under incertitude)

Decisions and decision makers in a national energy system perspective



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Characteristics of operational decisions

- Repeated decision making
- Varying circumstances, e.g.
  - Renewable infeed
  - Demand
  - Power plant & line availabilities
  - Fuel & CO_2 prices
- Considerable short-term uncertainty
  - Especially on first three factors
- Numerous situations rather standard
- But sometimes exceptional and critical situations occur

Examples of operational day-to-day decisions – European context

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- **Grid / System operators**
  - D-2: parameters for flow-based market coupling
  - **D-1: procurement** of secondary and tertiary reserve
  - D-1 & D: redispatch
  - **D: operation** of phase shifters and topology changes
  - D: activation of reserves
- **Power plant operators & portfolio marketers**
  - D-1: submission of bids to secondary and tertiary reserve markets
  - **D-1: submission of bids to day-ahead** trading (before DA auction)
  - D-1: day-ahead planning of power plant, storage and DSM operation (after DA auction)
  - D: submission of bids to intraday trading
  - **D: intraday planning** of power plant, storage and DSM operation

Methods for dealing with uncertainties

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- **Linear and Mixed Integer Optimization using the deterministic equivalent**
- Sensitivity calculations
- **Stochastic optimization**
- Chance-constrained optimization
- **(Stochastic) (Dual) Dynamic Programming**
- **Robust optimization**
- Distributionally robust optimization
- Heuristic approaches
- …

Example Unit Commitment and Dispatch: Approaches for dealing with uncertainties

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- **Linear and Mixed Integer Optimization using the deterministic equivalent**

  e.g. Sheble & Fahd (1994), Baldick (1995), Tovar-Ramirez (2016)
- **Two-stage stochastic optimization**

  e.g. Caroe et al. (1997), Dentcheva et al. (2000)
- **Multi-stage stochastic optimization**

  e.g. Carpentier et al. (1996), Takriti et al. (2000), Meibom et al. (2011)
- **Stochastic Dynamic Programming**

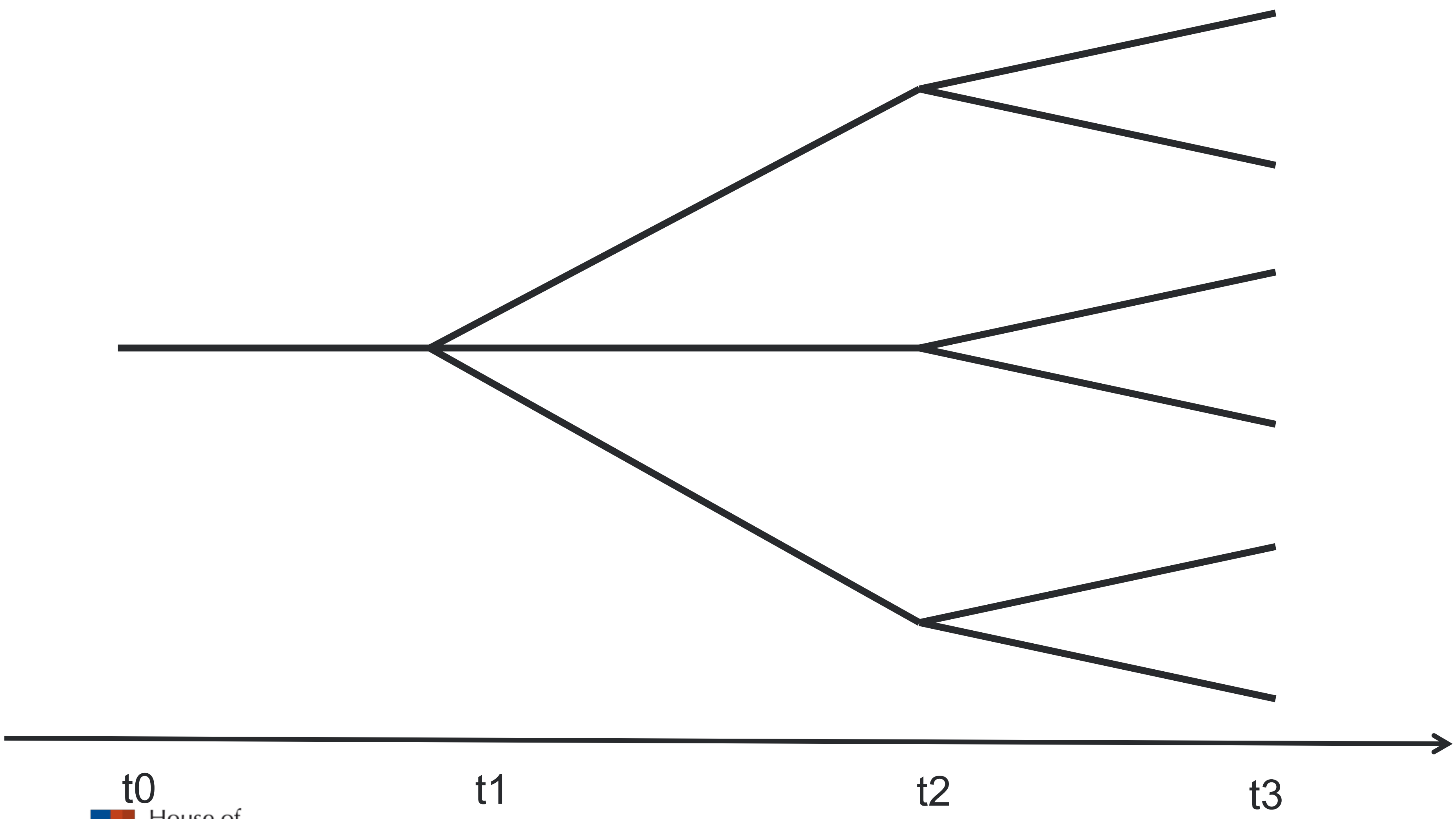
  e.g. Wolfgang et al. (2009), Felix, Weber (2012),
- **Stochastic Dual Dynamic Programming**

  e.g. Pereira and Pinto (1991), Guiges and Römisch (2012)
- **Robust optimization**

  e.g. Jiang et al. (2012), Bertsimas et al. (2013), Zhao et al. (2013)

cf. also reviews by Zheng et al. (2015), van Ackooij et al. (2018)

Tree as a representation of stochastic states



Stochastic Optimization: Stoch. Programming vs. Stoch. Dynamic Programming

- Numerical Stochastic Optimization solves a deterministic equivalent of the original stochastic problem
- I.e. the branches and leafs of the tree are taken as given

Strategy 1:

Solve the entire problem at once → **Stochastic Programming**

→ Only feasible for a limited number of branches and leaves

Strategy 2:

Decompose the problem using the Bellman Principle*

→ **Stochastic Dynamic Programming**

→ Only feasible if the number of decision states is limited

e.g. option exercised yes/no, plant on/off

*loosely: each part of an optimal trajectory must be itself optimal

Challenges of stochastic programming
1) Multidimensional trees are really hard

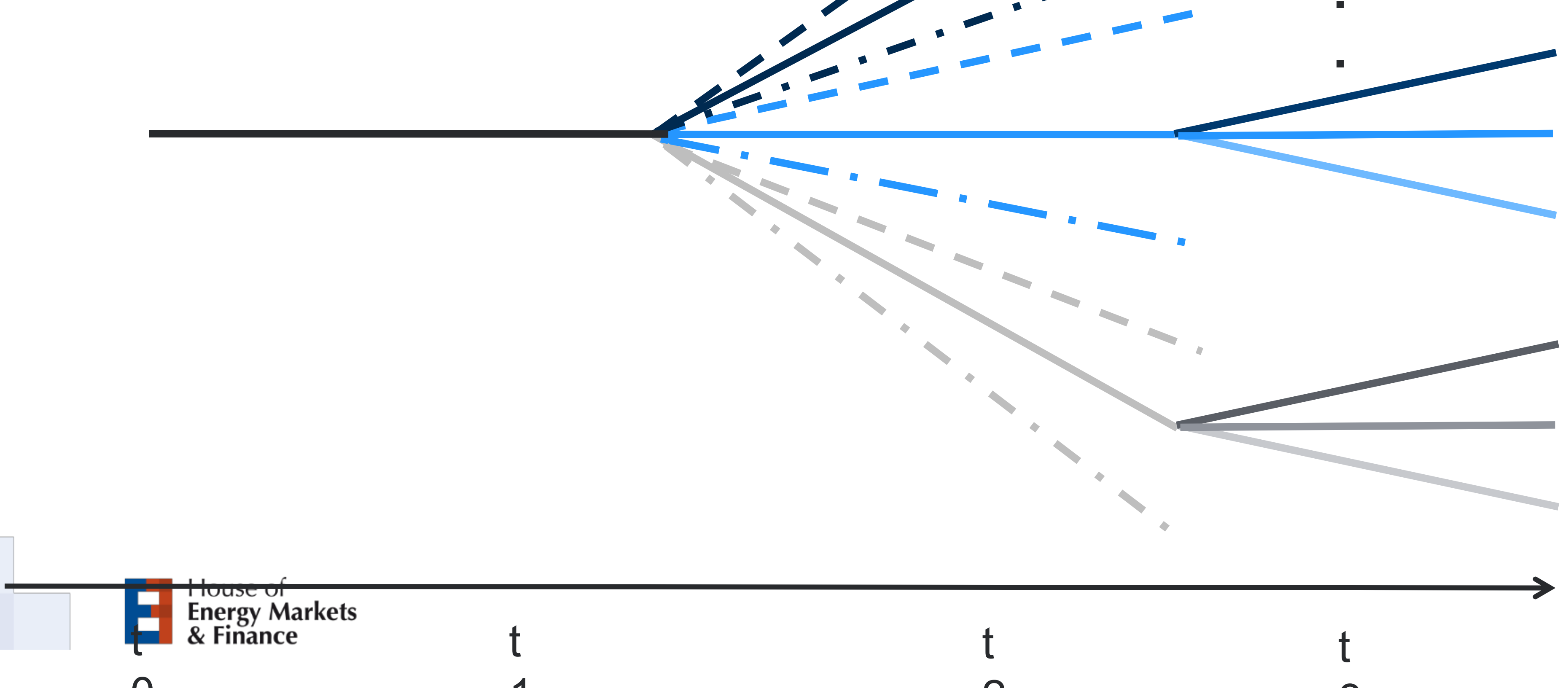
Example:

1 stochastic factor, 2 stochastic stages, trinomial tree:

9 leafs

2 stochastic factor, 2 stochastic stages, trinomial tree:

81 leafs



Challenges of stochastic programming
2) Adequate determination of scenarios

- Scenario reduction techniques have been repeatedly developed

  e.g. Dupacova, Römisch (2003), Hoyland, Wallace (2001), Rubasheuski et al. (2014)

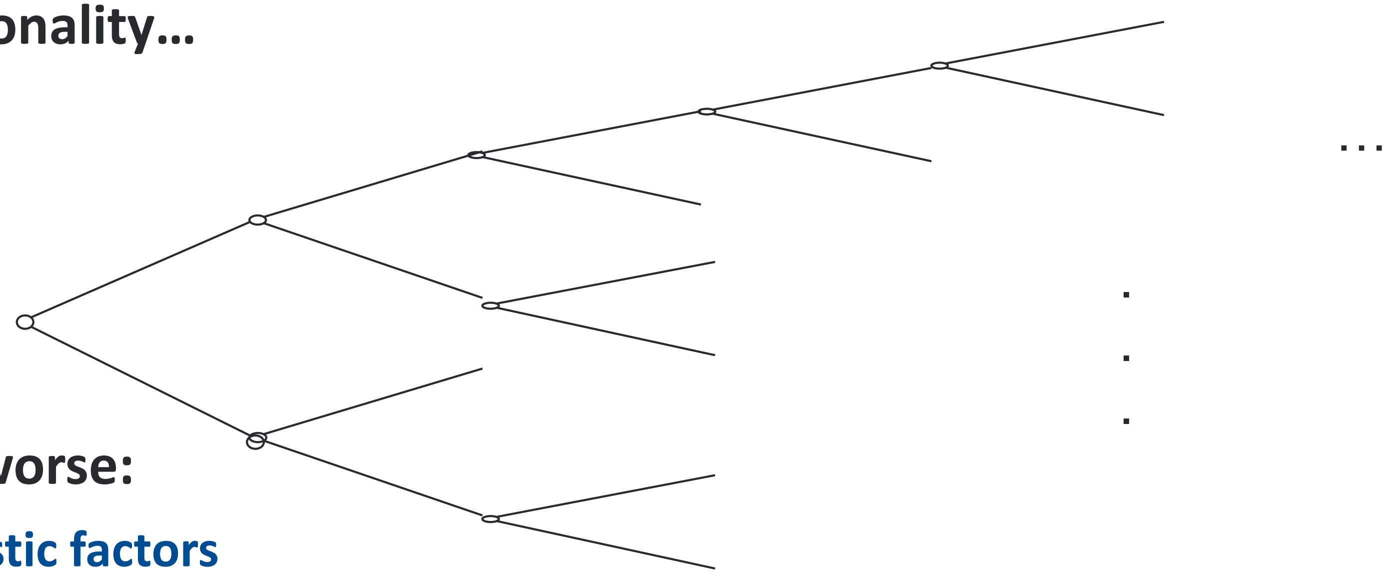
- Yet the metrics used to determine the scenarios are generally not reflecting the cost differences

➢ Importance (in terms of cost impact) based sampling of scenarios is preferable

  Cf. Pöstges & Weber (2018) for time aggregation

Why not just doing it stochastically?

- **Curse of dimensionality…**



- **… and it is even worse:**
  - **Multiple stochastic factors**

    Power prices, fuel prices, inflows, temperatures…
  - **Multi-factor models for stochastic models**

    e.g. seasonal factor, long-term factor…
  - **Multiple decision states**

    several power plants with up/down times, large storages…
  - **…**

→ **Making good stochastic models remains a challenge**

Robust optimization

- **Stochastic Optimization**:
  - Minimization of Expected Cost or
  - Minimization of a Risk functional of Cost (Mean-Risk optimization), e.g. CVaR
  - ➢ Risk neutral or (mildly) risk averse approach
- **Robust Optimization**:
  - Minimization of the worst outcome
  - Minimax-strategy
  - ➢ Rather pessimistic approach
    - ➢ Not easily aligned with concepts of maximization of expected utility/welfare as favoured by mainstream economics
  - Security constrained optimal power flow may be considered as an example of a robust optimization (N-1 criterion satisfied)
  - ➢ Robustness always measured again a set of possible events (contingencies)
  - ➢ “Milder” forms of robustness: local robustness, distributional robustness

What is different with investments?

- Discrete decisions
- Long-lasting impacts
- Heavy financial impact

- Empirical foundations for stochastic (or robust) optimization weaker
  - Less independent observations
  - Likelihood of structural breaks higher
  - Extrapolation of probabilities from the past to the future more dangerous

- More recourse actions
  - Modelling has to anticipate the multitude of operating decisions during lifetime

Coping with uncertainties in investment decisions (I)

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Strategy 1:

Use of **high discount rates** (or low payback times)
& **deterministic equivalent**

- Implicit assumption: linear addition of uncertainty over time
- According to CAPM: uncertainty related to (market) systematic risk

Strategy 2:

Use of **scenarios**

e.g. Shell or IEA scenarios

- Reduction of multiple uncertainties to a limited number of scenarios (3 – 5)
- Focus on coherent and complementary world-views ("scenario family")
- In general no probabilities associated with scenarios

Coping with uncertainties in investment decisions (II)

Strategy 3:

Use of **stochastic optimization with subjective probabilities**

- Or if probabilities based on statistical model: unknown model risk
- Agreement on subjective probabilities difficult to reach in multi-person decision-making context

Strategy 4:

Focus on **mean scenario + risk assessment**

- Standard approach in corporate reporting
- Risks are frequently not quantified

A few remarks on scenarios (I)

- Or rather a key question:

Why are we developing and using scenarios?

- Simple answer:

To inform decision makers and to enlighten decisions

- But…

Answer - Version 1: an idealistic concept of enlightenment

Analysis

- Scenarios enable good decision making under uncertainty
- They structure the multiple uncertainties that decision makers are facing
- Underlying decision model: (as taught in 1st year business administration course)

Uncertainties ➢ **Scenarios** / ➢ **Decision alternatives**	s_1	s_2	. . .	s_n
a_1	$r_{11.}$	$r_{12.}$	. . .	$r_{1n.}$
a_2	$r_{21.}$	$r_{22.}$	. . .	$r_{2n.}$
	⋮	Decision consequences (cost, emissions, …)		
	$r_{m1.}$	$r_{m2.}$	. . .	$r_{mn.}$

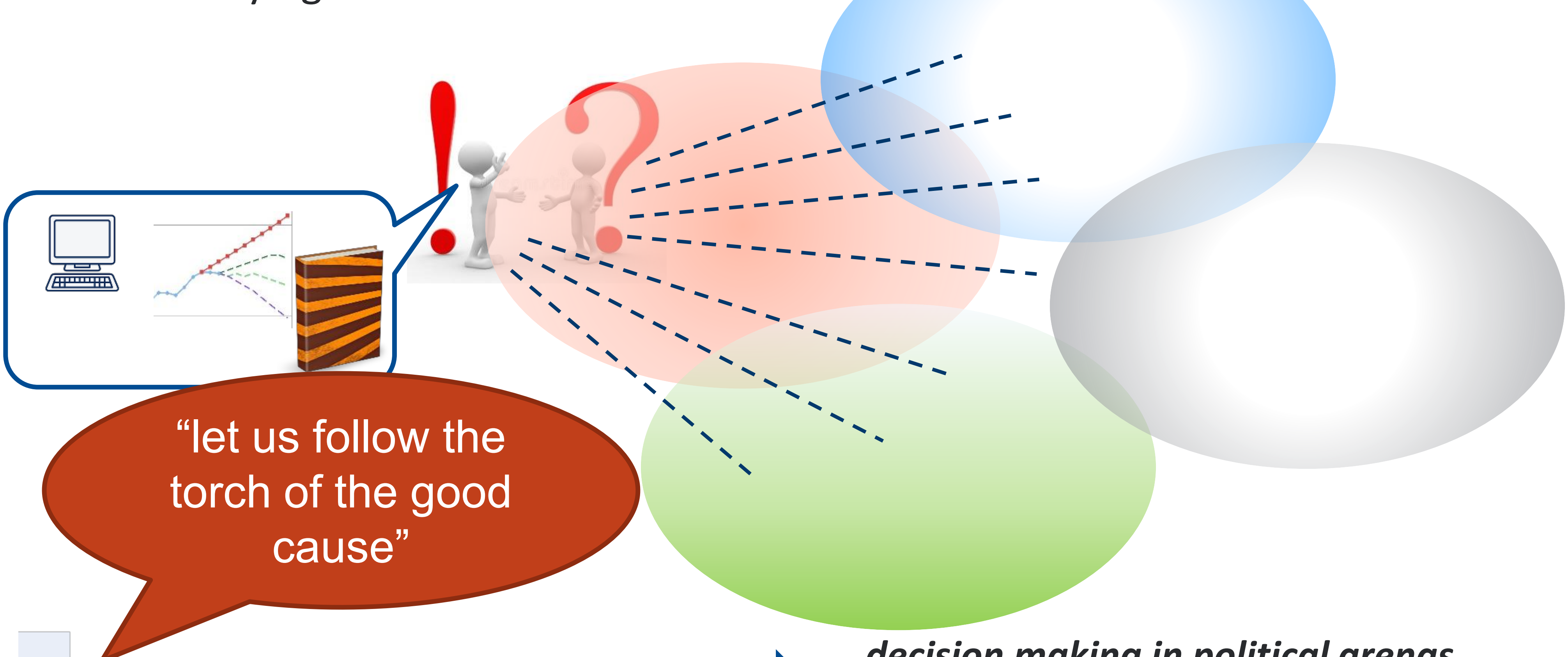
"let us contribute to the rising of the sun of knowledge"

Rule-based, rational decision making

Answer – Version 2:
a partisan concept of enlightenment

Analysis

- Scenarios help to make the right decisions
- Scenarios show pathways to achieve objectives
- Underlying decision model:



→ ***decision making in political arenas***
multi-level stakeholder interactions

A few further remarks on scenarios

If scenarios are focusing on **depiction of uncertainties**:

- They should capture **key uncertainties exogenous** to the **decision maker**

  E.g.

  – World market **prices for fossil fuels** and **renewable technologies**

  – **Global & European Climate Policy objectives** and **instruments** – if the decision maker is a company or a national government

- The **same decisions** should be evaluated against different scenarios

  Key questions:

  – Which decision yields the **best outcome "on average"**?

  – Is there a **scenario** where a decision leads to **extremely negative consequences**?

  ➢ A not (fully) formal way of implementing a **mean-risk perspective** on decisions

➢ The **process of scenario construction and parameter selection** is as important as the scenarios itself

  – Avoidance of "group think" key for appropriate dealing with risk

What is different in political decision making?

- **Multiple objectives**
- **Multiple stakeholders**
- ➢ Advocating the own cause important
- ➢ Evoking the uncertainties may frequently be perceived as "not helpful" for the own cause
  - Scenarios rather used as arguments to convince than as tools to inform (cf. above "partisan concept of enlightment")
- **Cause-effect relationships** for many **policy instruments uncertain**
  - Not (as much) true for command & control type policies, e. g. schedule for coal phase out
  - But certainly true for price-based instruments and support mechanisms, e.g.
    CO_2 tax
    subsidies for electric vehicles or renewables
- **Multi-level decision hierarchy**

Decisions and decision makers in a national energy system perspective

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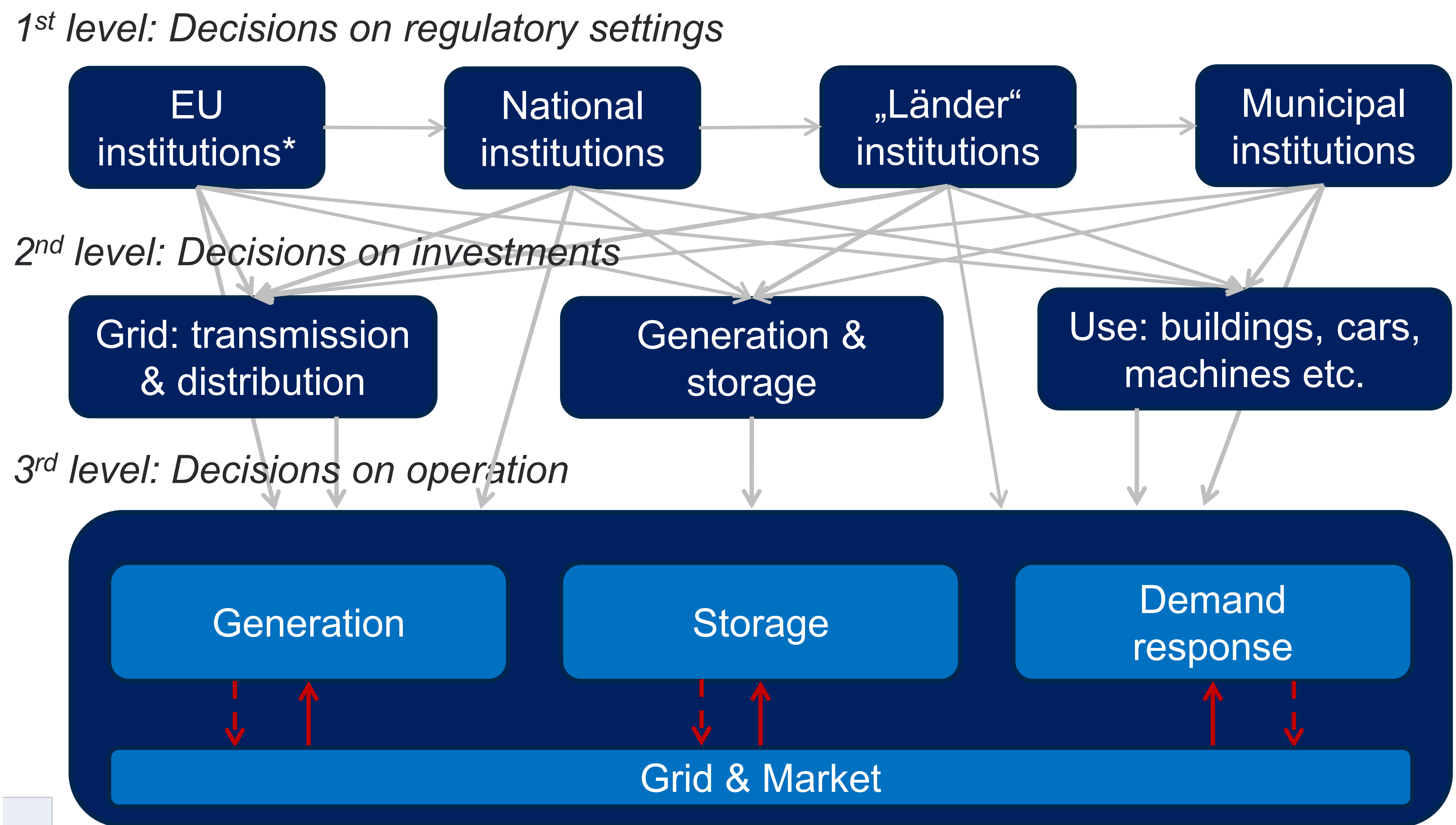

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Dealing with uncertainties in political decision support (I)

- **Use scenarios**
  - Reflecting also truthfully exogenous uncertainties, e.g. technology cost
- **Make sensitivity analyses**
  - Notably on uncertain **behavioural assumptions**
    e.g. on uptake of flexibility provision through V2G for electric vehicles,
    on restrictions on land use for renewables due to limited acceptance
  - But also on **technological assumptions**
    e.g. cost of PV vs. wind

➢ Scenarios: many parameters are varied simultaneously
  ➢ Enable an assessment of choices against contrasting world views

➢ Sensitivities: one parameter is varied at a time
  ➢ Enable a transparent assessment of the impact of single parameter choices on results

Dealing with uncertainties in political decision support (II)

- Take into account **behavioural heterogeneity** among stakeholders:
  - Energy users, investors, governments

  - Take existing **empirical evidence** serious
  - Model behavioural uncertainty through parameter variations
  - Conduct **further empirical studies** on key behaviours of stakeholders (investors and users)
    - E.g. choice of (electric) car
    - Investment in heat-pumps

Dealing with uncertainties in political decision support (III)

- **Do not rely excessively on results from linear programs**

  Explicit assumptions:

  – one overarching, **unique objective function**

  – **homogenous technology classes** with known parameters

  ➢ False certainty

  ➢ Penny-switching

  ➢ Control illusion

  … or at least do sensitivity analyses

- **Investigate operational risks induced by policy instruments** in detail

  – Security of supply key challenge for energy transition

  – Modelling of operational uncertainties can build on established stochastic methods

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Conclusion

- There is **no silver bullet** to cope with uncertainties
  - But to make the world a better place we have to take them seriously

- A major step is already taken when **uncertainties/risks are thoroughly identified**

- When you use an **optimization** model, **adjust your shot well** to hit your target:

  i.e. reflect carefully your choice of method and your representation of uncertainties (distribution)

➢ All models are false… but only the fool will not acknowledge

Future Directions for Research

There are many…

But if the focus is on contributing to sustainable energy transitions around the globe:

- Particular attention has to be paid to longer-term decisions regarding investments and political/regulatory frameworks.
- The preceeding reflections lead me to suggest the following routes to explore:
  - **Empirical research** on how people **adjust their purchases** of long-living consumer goods (cars, heating systems) in response to policies – and its embedding in long-term optimization / equilibrium models by including **heterogenous agents**
  - Development of **advanced but communicable methods for mean-risk analyses** when probabilities are at best guess-estimates
  - Investigations on **improved interaction processes between modellers and decision makers** to support rational choices in **multi-stakeholder environments**

Thank you for listening.

Questions?

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