

Agentenbasierte Modellierung und Simulation zur Analyse sozio-technischer und energieökonomischer Effekte bei der Strommarktintegration und Refinanzierung erneuerbarer Energien

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Vortrag am Lehrstuhl für Energiewirtschaft, Prof. Müsgens
im Energiewirtschaftliches Forschungsseminar
BTU Cottbus-Senftenberg

Knowledge for Tomorrow



Agenda

Part I): Sustainable Development seen from a Socio-Technical System Perspective

- General Understanding of Socio-Technical Systems and Sustainable Development

Part II): Agent-based Modelling for Socio-Technical Transition Research

- Challenges for Modelling Policies in complex adaptive systems – The ABM approach

Part III) Agent-based Modelling of Market Integration of RES-E

- Impacts of market and policy design on Market Values, Support Costs and Refinancing Conditions



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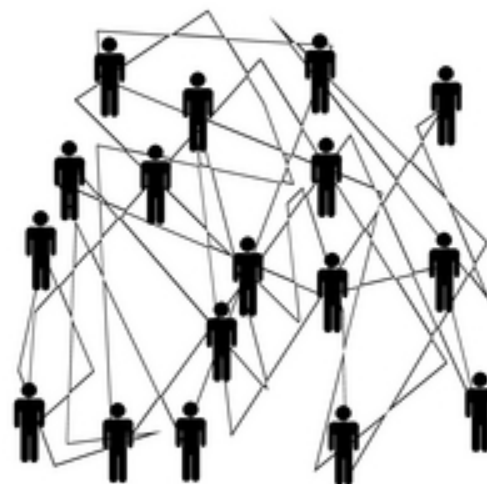
What is a socio-technical system (STS)

- One understanding comes from organizational development:
 - Here a STS is an approach that recognizes the interaction between people and technology in workplaces.
- Another understanding comes from complexity science:
 - Here STS refers to the interaction between society's complex infrastructures and human behavior.
- In this sense, society itself, and most of its substructures, are complex socio-technical systems.
- The energy system is often conceptualized as such a socio-technical system
 - This is the understanding of the term STS used in this seminar



Analyzing Transitions of Socio-Technical Systems (STS)

- Systems and their borders are constructs that are built for a certain purpose.
- Systems consist out of elements and relations between these elements. They have borders and they divide the world in things or elements which are *in the system* and in those that are *outside the border*.
- For analyzing STS the interplay and the interfaces between societal demand patterns and technological development is crucial.
- These terms exemplify that a transition of the energy system is more than the substitution of old technologies by new ones.



Source: Gerd Altmann/pixelio.de

→ However, often it is far from being clear what exactly a socio-technical system is and what should be transformed in this system.



Knowledge for Sustainable Development

- The Brundtland definition of sustainable development (SD):

*“Sustainable development is development that meets the needs of the present **without compromising the ability of future generations to meet their own needs.**”*

Origins of uncertainty¹⁾:

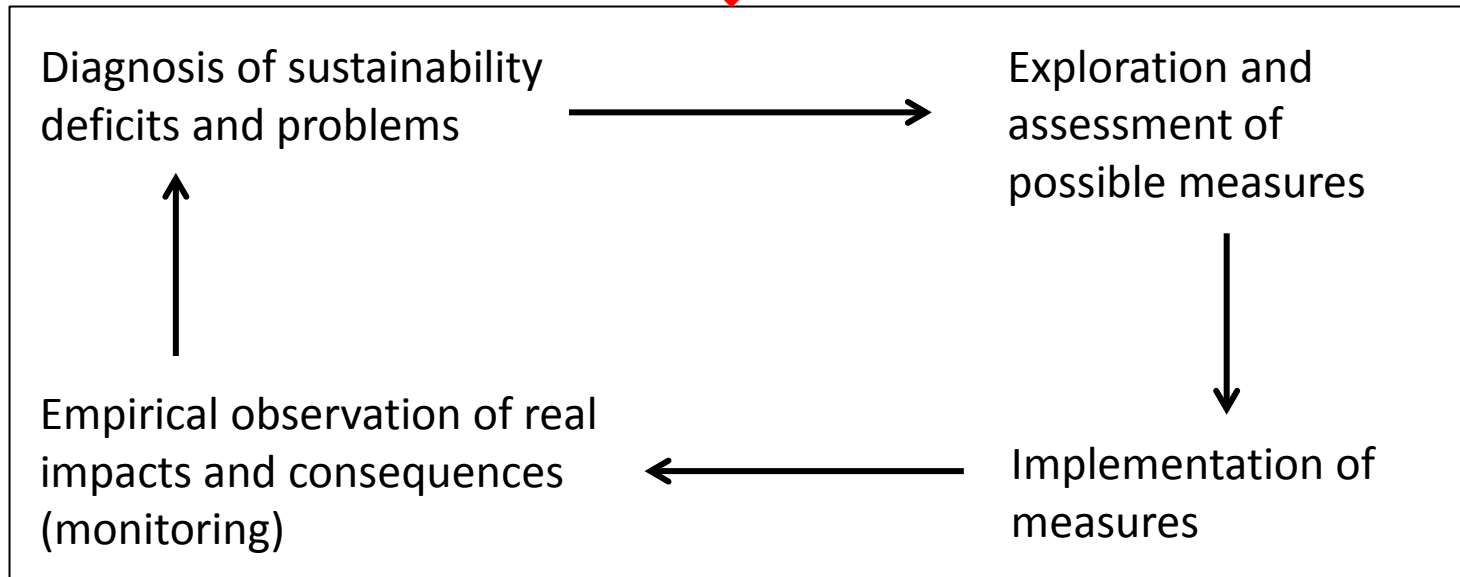
- *inseparability* issue: co-evolution of many developments (e.g. technology and society);
 - inadequacy of closed models increased
 - complexity and systemic feedback loops
- *incompleteness* issue: unlimited manifold of sustainability aspects
 - decisions on relevance and priorities required showing own risks
- *incommensurability* issue: no common scale available for measuring sustainability effects
 - limited use of quantitative approaches, uncertainties of integrated knowledge
- *prediction* issue: future developments are depending on present and future decisions and cultural evolution
 - uncertainties due to the prospective nature of SD assessments



Normative foundation of Sustainable Development¹⁾

- Development towards more sustainability as a feedback loop involving normativity, measures, empirical measurement and reflection

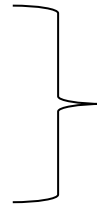
Normative foundation of sustainable development



SD requires strategic knowledge of different kinds¹⁾

1) System Knowledge:

- systemic interrelations,
- causal links,
- functionalities



classical task of positive or descriptive science

2) Orientating Knowledge:

- Goals of Transformation,
- Assessment Criteria,
- Picture of the Future, Scenarios



Classical task of normative science (Ethics) and future studies (Prospection)

3) Knowledge for Action:

- Measures
- Consequences
- Incentives
- Not-intended side-effects



Classical task of decision and behavioral science, psychology, sociology, economics

→ Strategic Knowledge for Sustainability combines all three kinds of knowledge



Organization of Socio-Technical change (I)¹⁾

1) Problem structuring and goal envisioning:

“Multi-Stakeholder transition arenas, usually facilitated by a government department, develop a shared vision for attaining **sustainability goals** (van der Brugge and Van Raak 2007). Scenario-building techniques turn sustainability goals into practical **visions for future sustainable socio-technical systems** (Sondeijker et al. 2006). Visions provide a promising orientation for subsequent governance activities.”

2) Transition pathways and experiments:

“Participants identify pathways toward transition visions using **back-casting methods** (Quist 2007). Pathways provide a framework for the subsequent development of **niche experiments**. A portfolio of niches is created. Successful niche pre-development is followed by a period of take-off and acceleration, before culminating in stabilization within **a more sustainable regime** (Rotmans et al. 2001).”



Organizing socio-technical change (II)

3) Learning and adaptation:

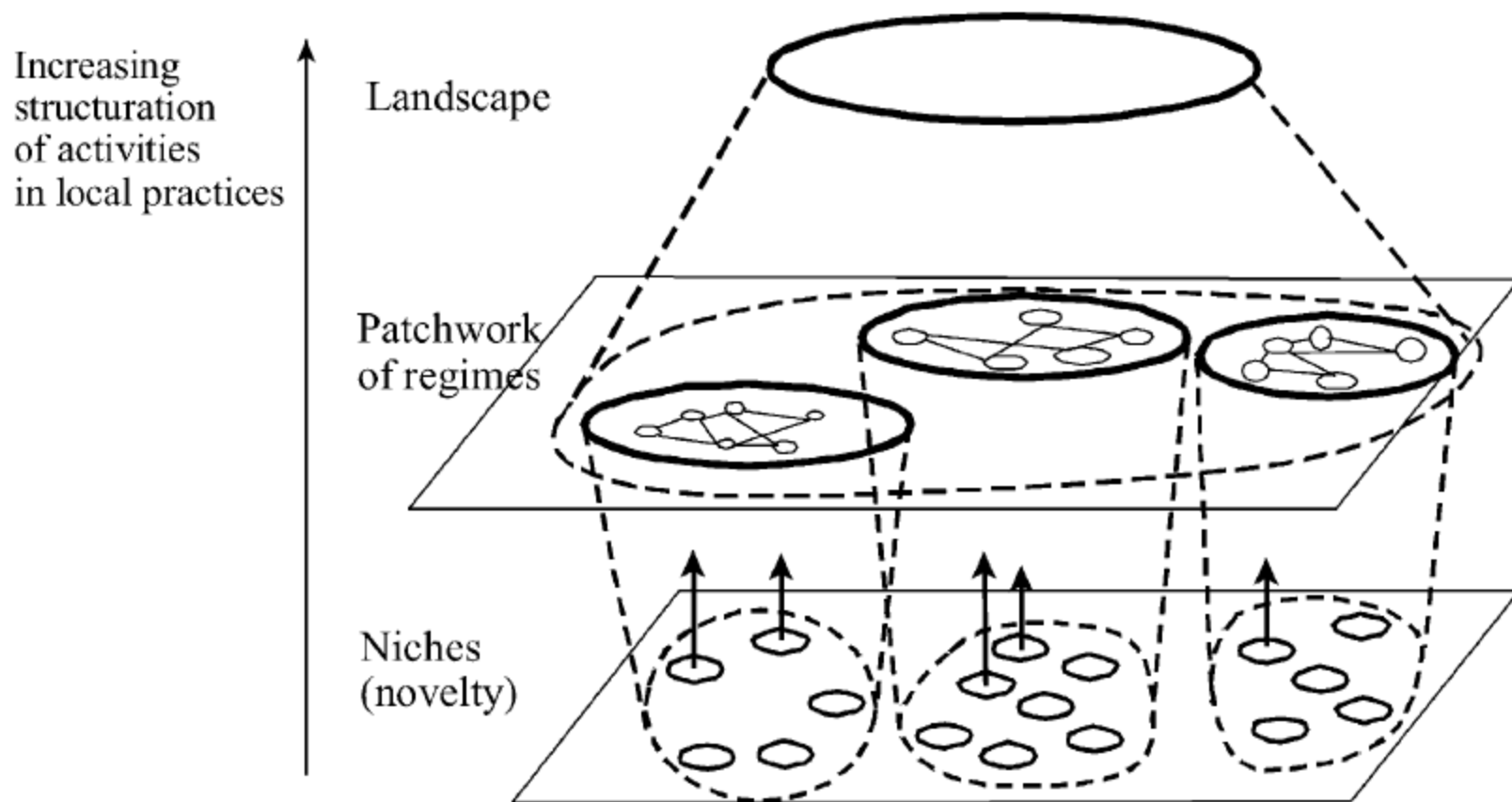
“Learning and adaptation provide the essential links among long-term goals, socio-technical pathways, and short-term actions in niche experiments. **Lessons are drawn** not just for instrumental improvement of the niche, but **also institutional reforms**. A **better understanding of the institutional constraints** and opportunities for the sustainable practices is at the heart of niche experiments (Hoogma et al. 2002).”


4) Institutionalization:

“Acknowledged to be the most important element, institutionalization is considered least in the transition management literature (Smith and Kern 2009). This is the point at which **serious commitments** are needed, to such an extent that the incumbent regime suffers and is undermined if they are not made (Smith et al. 2005, Shove and Walker 2007). Politically and economically, institutionalization is very difficult. It involves **mobilizing serious selection pressures against the incumbent regime** and redirecting vast institutional, economic, and political commitments into promising niches along desired pathways.”



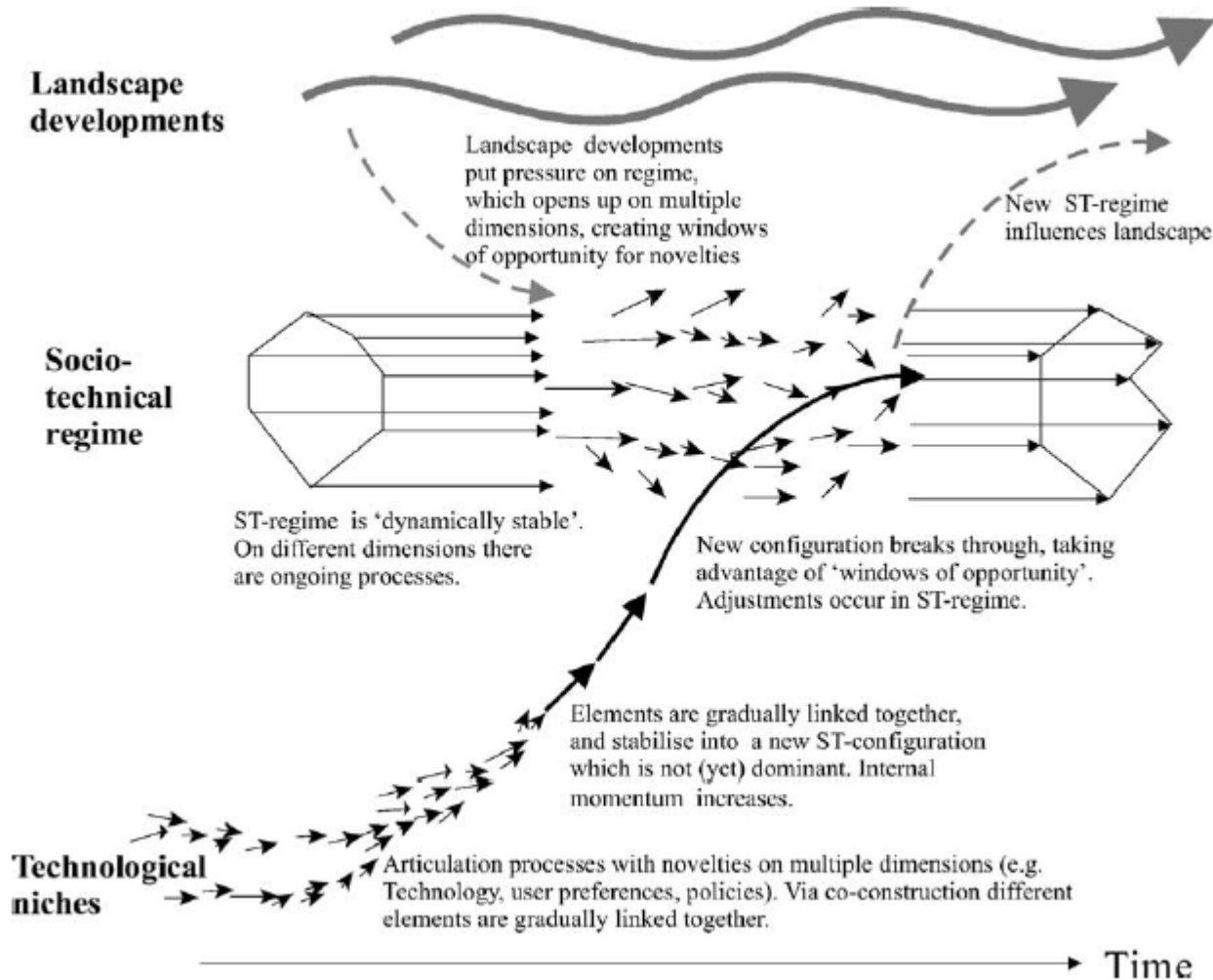
The Multi-Level Perspective of Technological Change¹⁾



 ¹⁾ Adopted from Geels (2002)



A dynamic multi-level perspective on system innovations¹⁾



¹⁾ Adopted from Geels (2004)



The “Energiewende” in Germany: Starting Point for the Research Work

	Climate Change	Renewables		Efficiency				
	GHG (vs. 1990)	Power	Primary energy balance	Primary energy	Power	Energy productivity	Transport	Upgrading of buildings
2020	-40%	35%	18%	-20%	-10%	+2.1%/a	-10%	Upgrading the energy performance 1% -> 2%
2030	-55%	50%	30%				By 2020 reduction of heat requirement by 20%	
2040	-70%	65%	45%					
2050	-80% to -95%	80%	60%	-50%	-25%		-40%	By 2050 reduction of primary energy demand by 80%



Structuring the Objectives

Designing **interventions** for the transformation

Providing **orientation** for the transformation

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2040	-70%	65%	45%					
2050	-80% to -95%	80%	60%	-50%	-25%			-40%

Understanding the system transformation



Challenges Associated with the Transformation

- RES Volatility → grid stability and supply security has to be ensured in a system with a highly variable feed-in (Wind and PV)
- Innovation strategies (social + technological) including adequate framework conditions and incentive systems are needed
- New value-added chains and business models are required
- Strong increase in the number of actors involved (e.g., prosumers). New forms of innovation and risk governance needed
- Traditional user and consumer behavior will be challenged (e.g., demand side management, e-mobility)
- Complex systemic interrelations between technical developments, diffusion, economic performance, social acceptance, and legal & ethical acceptability
- Major problems of acceptance and conflicts related to new infrastructures slow down the transformation process

→ Interdisciplinary perspectives, interdisciplinary culture, transdisciplinary projects



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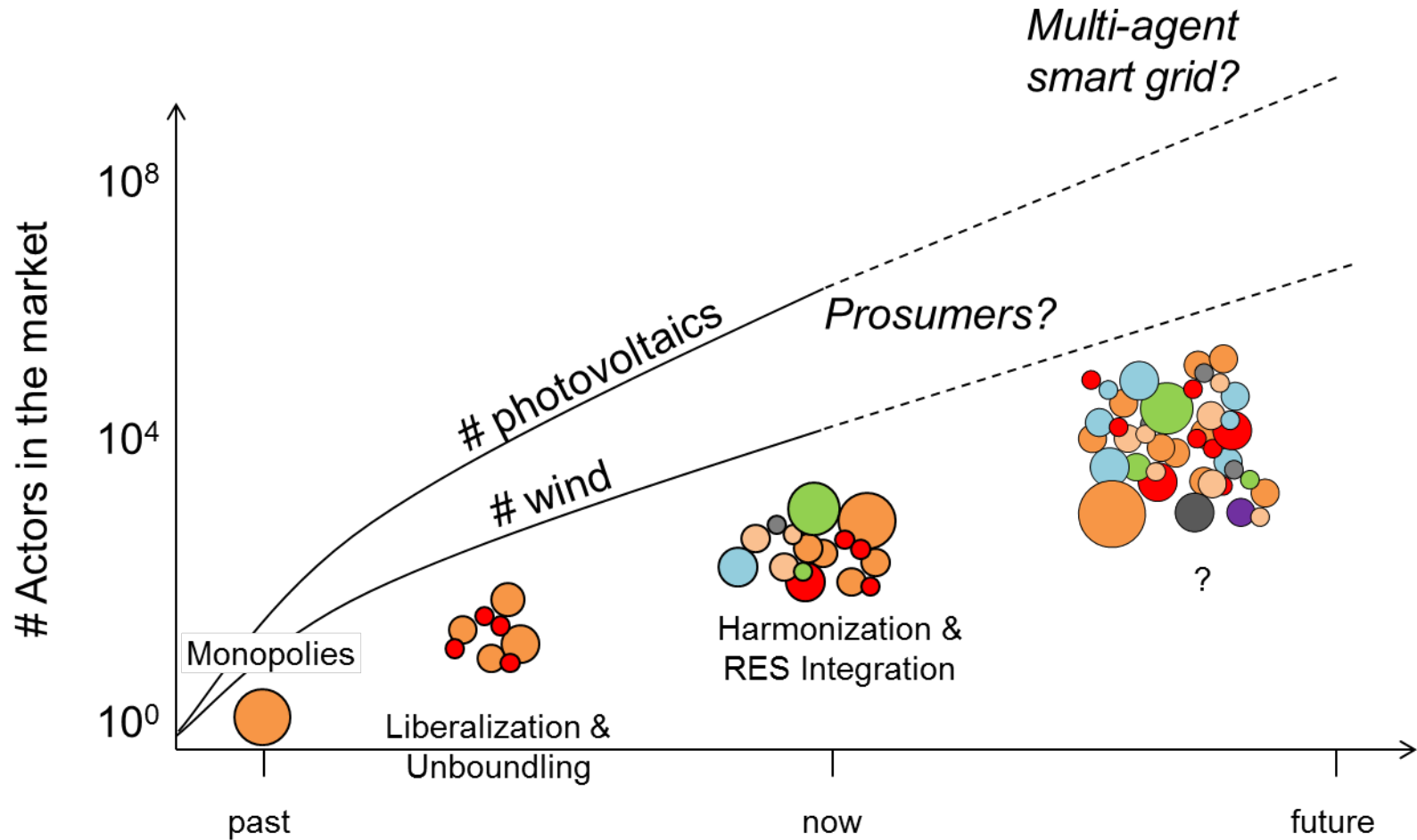
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Challenge I): Heterogeneity of market participants

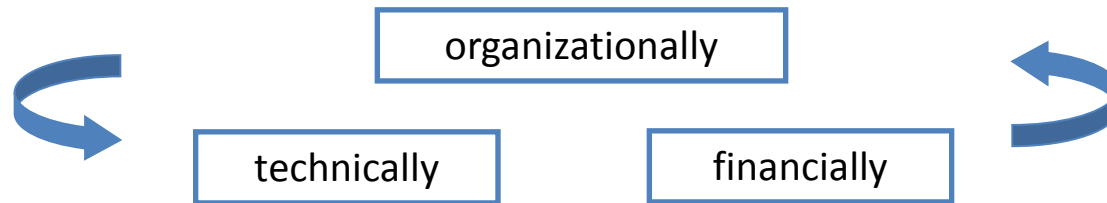


→ We have to deal with much more, highly differentiated actors that differ partially strongly in goals and expectations



Challenge II): Complex Interactions of system entities

- RES-E Power Production has reached a energy economic relevant magnitude on total power production
- Reorganization of different aspects is needed in order to reach political targets

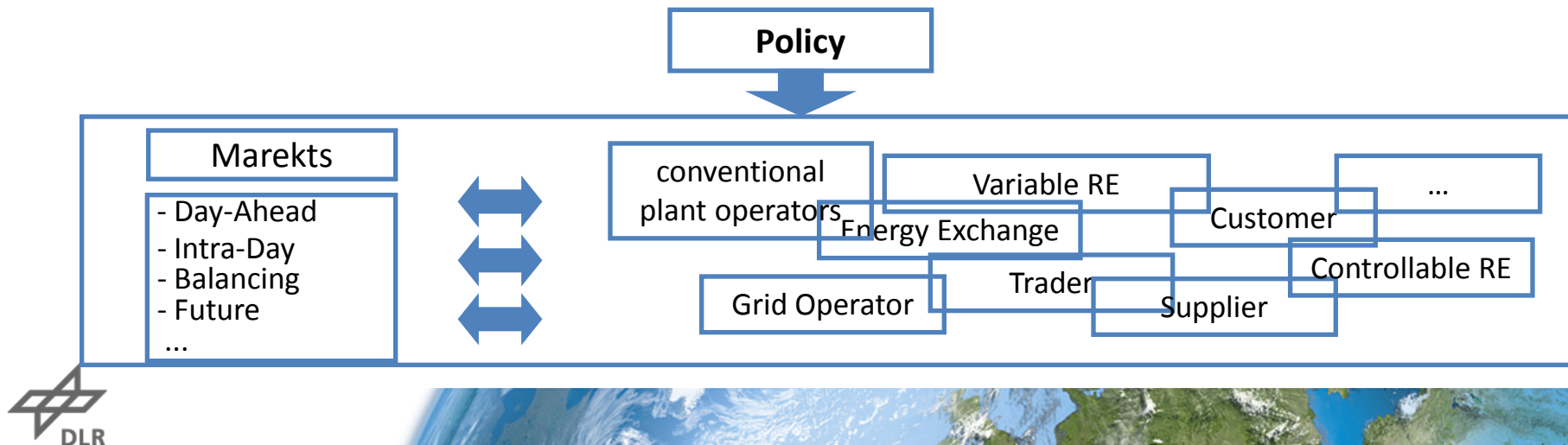


→ In this process

...a **huge variety of actors** is involved, who

...connected via **complex interdependences** and

...who can **react very differently** to changes on incentives or framework conditions



Static Equilibrium Economics

- Economic actors continually adjust their market moves (investments, prices, forecasts etc.)

⇒ **Individual behaviour collectively creates an aggregated outcome.**

- **General equilibrium** theory asks: “What prices and quantities of goods produced and consumed are consistent with the overall pattern of prices and quantities in the economy’s markets?” ¹⁾
- **Game theory** asks: “What strategies, moves or allocations would be the best course of action for an agent given the strategies, moves, allocations his rivals might choose?” ¹⁾
- **Rational expectations** theory asks: “What expectations are consistent with the outcomes these forecasts and expectations together create?” ¹⁾

⇒ Approaches follow the concept of **rational expectations/behaviour** under the paradigm of **perfect information**.

¹⁾ Arthur (2005) p. 1554



Out of Equilibrium Economics as Generative Approach

Characteristics of complex systems like energy markets:

- Often not at equilibrium but under on-going change
- States are results of a multitude of small events and are not determinate up front (“Feedback-Loops”)
- Economic actions depend on expectations and actions of others
- Strategic behaviour of market participants

↪ Agent-based Modelling (ABM) or Agent-based Computational Economics (ACE) tries to analyse **the dynamics between** the equilibriums (“generative or adaptive approach”)^{1),2)}

- Includes inductive behaviour
- No a-priori “solution” → learning by doing

↪ The generative approach might converge to the rational expectations norm **but does not have to!**

1) Holland et al. (1986)

2) Sargent (1994)



Basic Principles of Agent-Based Modelling (ABM)

- **Bottom-up Approach** from the field of Artificial Intelligence (AI).
- **Autonomous Agents** acting in a changing environment.
- **Event based** simulation

Typical characteristics of Agents^{1),2)}:

- „World view“ as internal representation of outside world
- Autonomous behaviour with own goals
- Development and adjustment of strategies through learning processes
- Communication and cooperation

↳ **Turning away from the general principle of the „homo oeconomicus“:**

- limited information, uncertainty and bounded rationality
- Heterogeneity of actors
- Taking into account of social processes (e.g. cooperation, innovation)

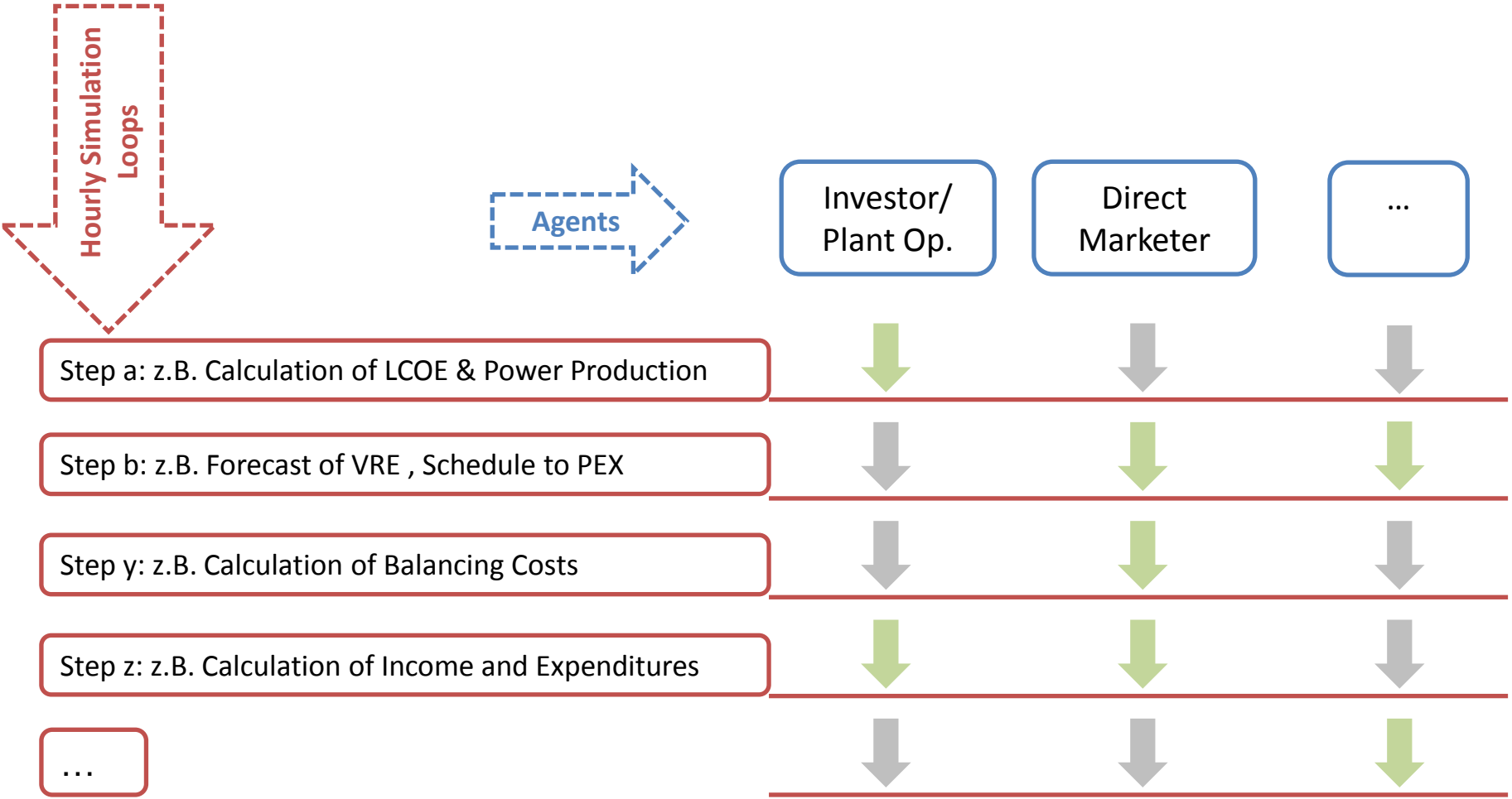
↳ **Analysis of complex („emergent or adaptive“) systems.**

1) Wooldridge (2002)

2) Schmidt (2000)

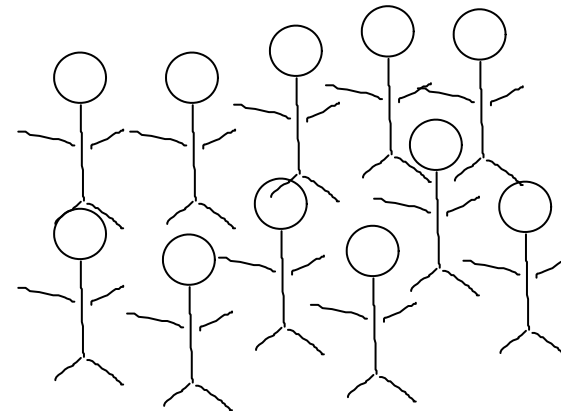


Simulationsablaufscheema



Comparison of optimization and agent-based models

Optimization model	Agent based model
Get a system with different technologies that ensures security of supply and is cost optimized	Economic success/failure of actors in a system with different technologies, markets and policy measures
<i>What high are system costs?</i>	<i>How to make money?</i>



Objectives of policy design modelling

Open Questions

- What policy instruments support new technologies?
- Which markets are necessary for (new) actors?
- Market or regulation – What's the effect on actors?
- How to prevent unintended side-effect?

Solution Approach

- Analyze actors and their inter-dependencies and interactions
- Study impact of changes in policy & market design on actors
- Evaluate impact on overall system

Methodology

- Document research, interviews and expert workshops
- Review and study of markets and policy instruments
- Agent-based Modelling (ABM)



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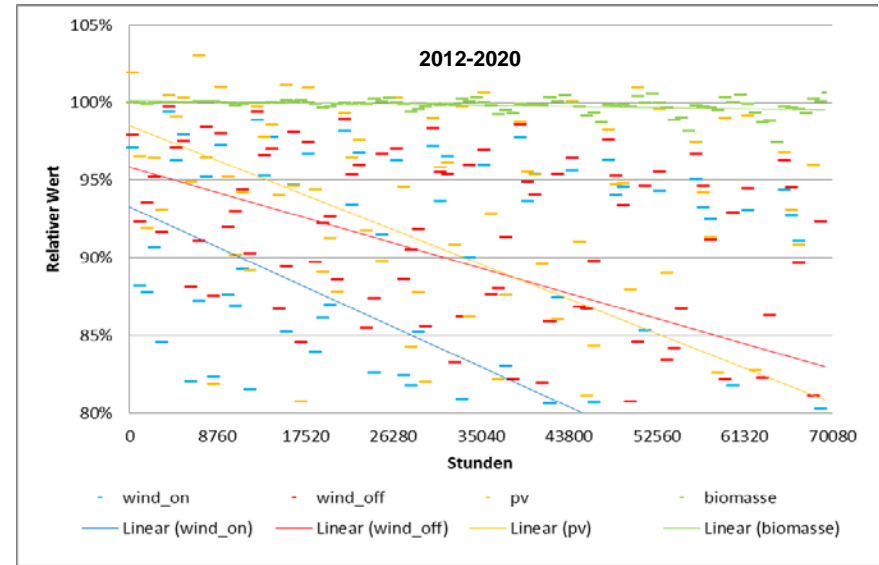
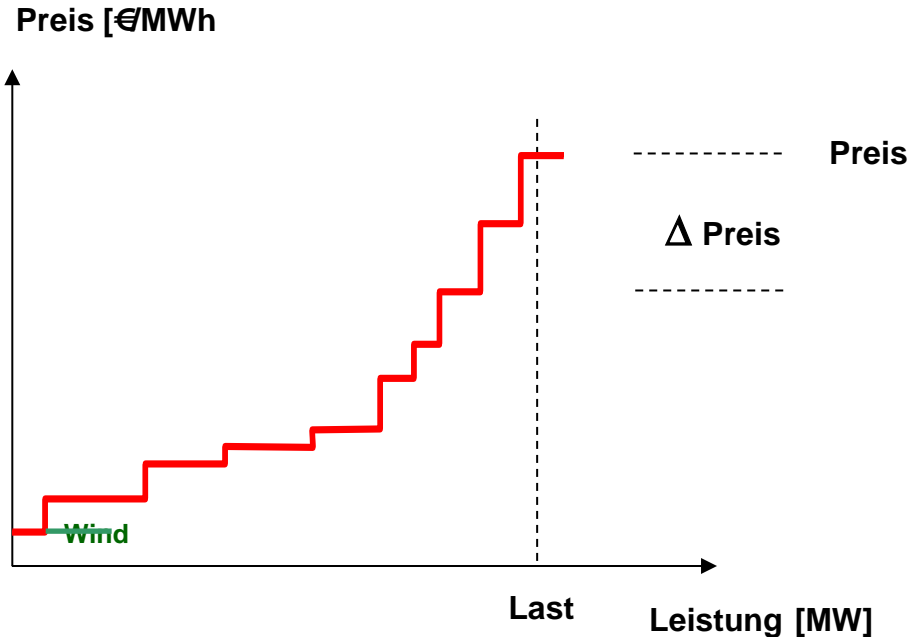
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I) Herausforderung bei der EE-Strommarktintegration: Merit-Order Effekt und Marktwertverlust der FEE

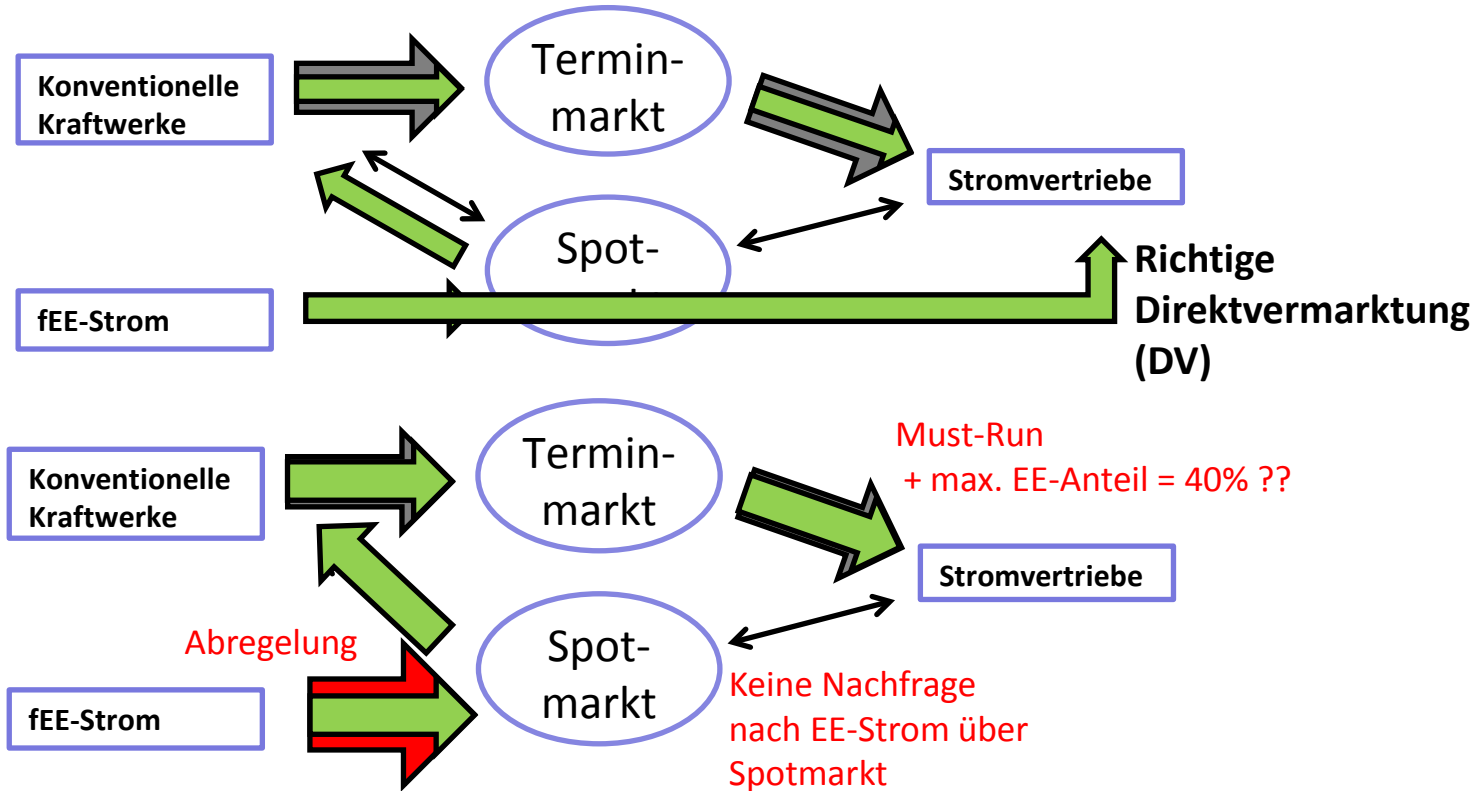


→ Antworten auf das Investitionsparadoxon in Bezug auf EE muss gefunden werden

→ Modellierung muss aus Akteursperspektive erfolgen, um dezidierte Aussagen über Erlössituation der Anlagenbetreiber treffen zu können



II) Herausforderung bei der EE-Strommarktintegration: Friktionen bei der Vermarktung von Strom:



- Liberalisierte Märkte sind auf konv. Kraftwerke ausgelegt
- Die Vermarktungslogik der ÜNB und der bisherigen DV ist nahezu die gleiche.
- Abregelung bei extrem niedrigen oder negativen Börsenpreisen, d.h. neue Mengenrisiken sind Markt- und Förderdesign bedingt!



AMIRIS - Our Agent-Based Modelling Approach at DLR-STB

1

We use advantages of ABM to model agents with:

- Autonomous behavior
- Own goals
- Adaptation of strategies
- Cooperation
- Imperfect knowledge
- Heterogeneity
- Prototyped market orientated behavior

2

We conduct sound actor analysis based on theoretical assumptions derived from sociological neo-institutionalism with:¹⁾

- Document analysis
- Semi-structured interviews
- Expert workshops

3

We build an agent-based Model as policy analysis and design tool to:

- Analyse impact on agents as result of changes in policy design (micro-economic effects)
- Analyse interdependencies and interactions of agents
- Analyse impacts on overall system (macro-economic effects)



→ So far focus on market integration of RES electricity

1) This is primarily done by our colleagues from the ZIRIUS at University of Stuttgart



Fragestellung und Zielsetzung

1. Kann sich ein rein auf den heutigen liberalisierten Marktmechanismen basierendes erneuerbares Stromsystem refinanzieren?
2. Oder braucht ein Stromsystem, das langfristig auf hohen Anteilen erneuerbarer Energien (fEE) mit fluktuierenden Energieträgern wie Wind und Sonne basieren soll, neue und andere Preisfindungsmechanismen, Anreizsysteme und neue (oder auch alte Instrumente) wie beispielweise (Ausschreibungen) für langfristige Lieferverträge für Strom und/oder gesicherter Leistung?

→ Simulationsgestützte Analysen zur Marktintegration und Refinanzierung der fEE mit AMIRIS

→ Es werden folgende Fördermechanismen zur Integration der fEE (Wind und PV) untersucht, die sich auf der Vermarktung über Spotmärkte konzentrieren:

- **Ex-post Marktprämie (var MP in €/MWh)**
- **Ex-ante Marktprämie (fixe MP €/MWh)**
- **Ex-post Kapazitätsprämie (var CP €/MW)**
- **Ex-ante Kapazitätsprämie (fixe CP €/MW)**

→ Refinanzierungsbedingungen bewerten: werden Stromgestehungskosten – LCOE gedeckt?

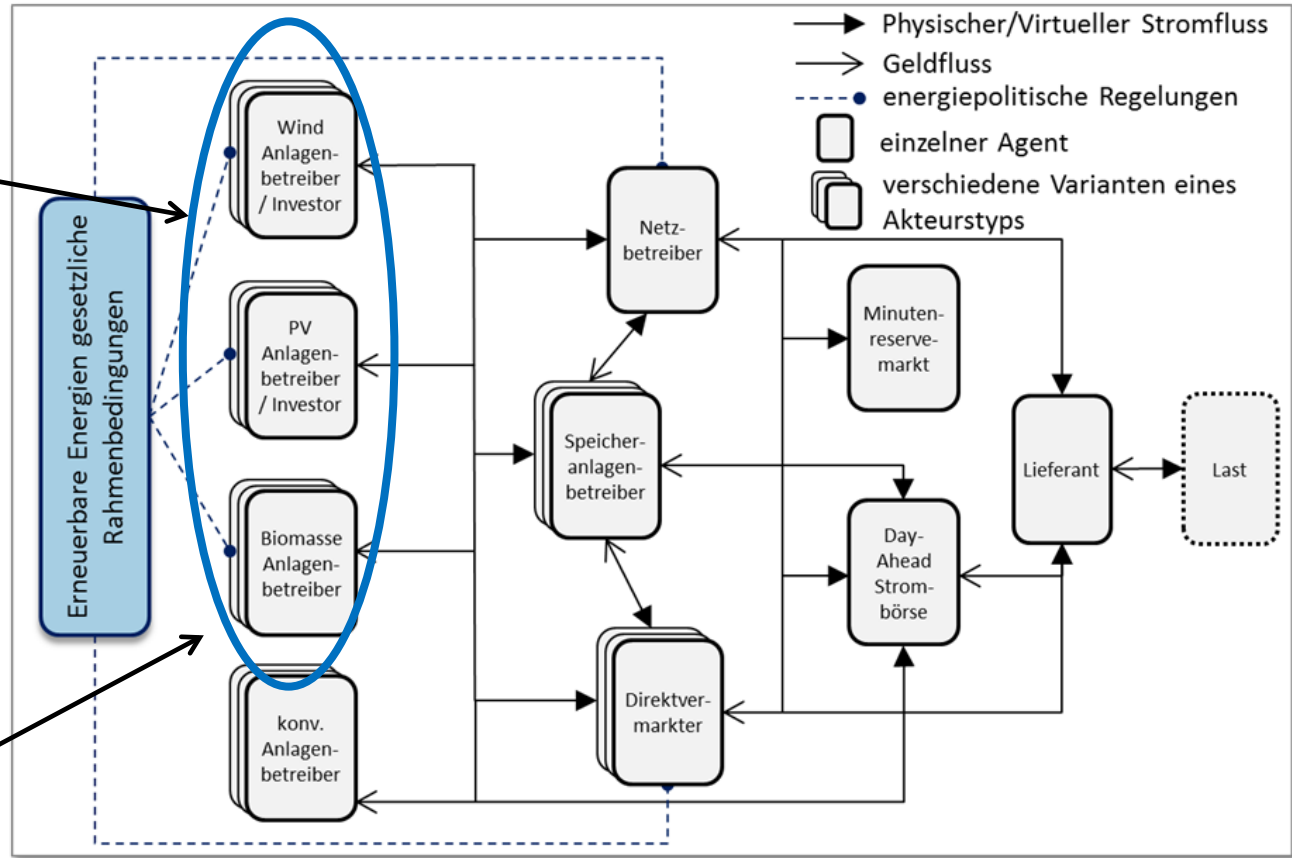
→ Auswirkung auf Förderkosten für fEE-Anlagen bei vollständiger Integration in den Strommarkt beurteilen



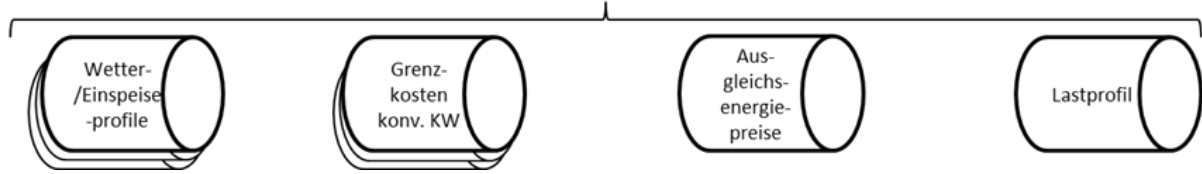
Modellstruktur AMIRIS

Parameter für Refinanzierungskosten mittels Experteninterviews erhoben: EK-Renditeerwartung
Risikoaufschläge bei Förderinstrumenten
Risikoperzeption hinsichtlich neuen Markt- und Politikrisiken

Kosten für Investition in fEE werden abgebildet: spez. Investitions- und Betriebskosten
Standortqualität (Volllaststunden - FHL)



- Physischer/Virtueller Stromfluss
- - - Geldfluss
- - - energiepolitische Regelungen
- ☐ einzelner Agent
- ☐☐☐ verschiedene Varianten eines Akteurstyps



Typen and Charakteristika der identifizierten Investoren und Anlagenbetreiber (I)

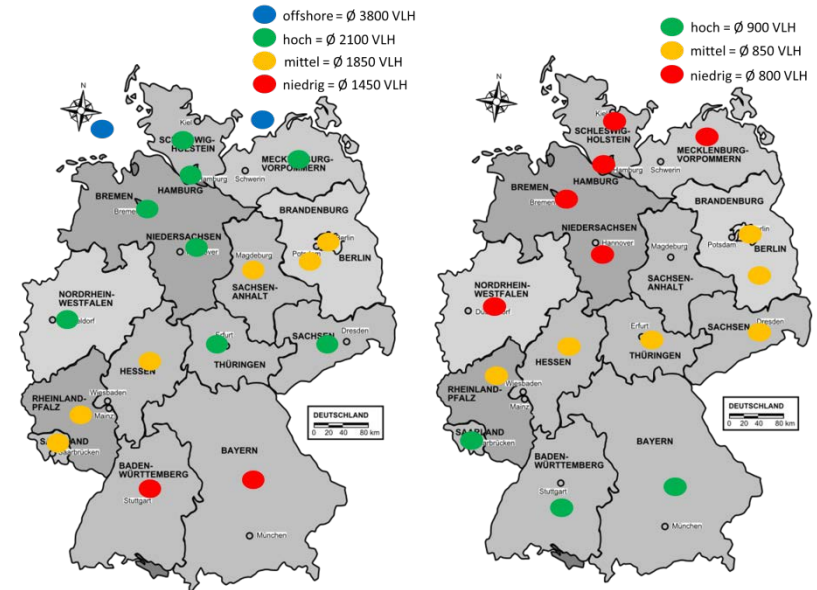
1) Differenziert nach Eigentümer

- Private Personen
- Landwirte
- Banks und Fonds
- Projekt Entwickler
- Stadtwerke
- Große EVU
- Industrie/Gewerbe

2) Differenzierte Kostenstruktur:

- ➔ Akteurspezifisch:
 - Erwartete Eigenkapitalrendite (RoE)
 - Risikoneigung (niedrig, mittel, hoch)
- Anlagen- bzw. standortspezifisch:
 - Investitions- & O&M Kosten (low/mid./high)
 - Ressourcen Potential (plant site)

LCOE	Klasse 1	Klasse 2	...	Offshore
2015	61,90	86,15	...	173,9
...
2030	59,31	84,21	...	150,3



➔ Es können bis zu 252 vers. „Typen“ von Wind- und 756 PV-Anlagenbetreiber initialisiert werden

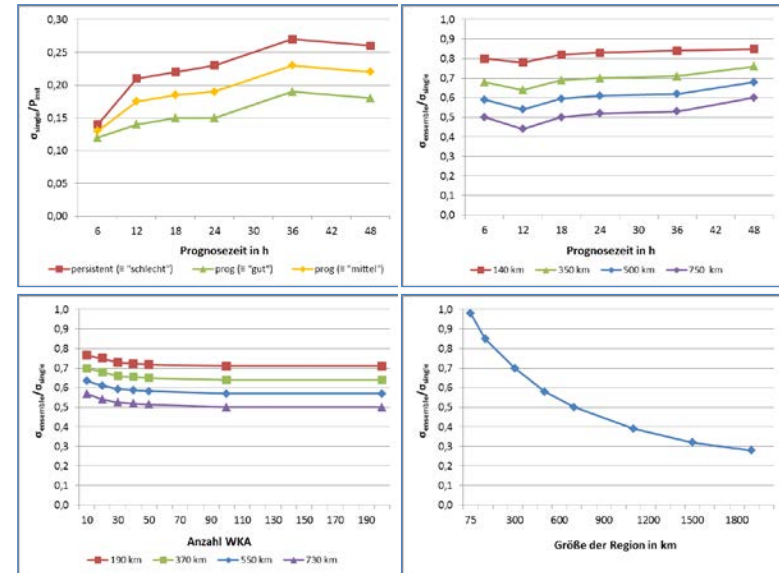
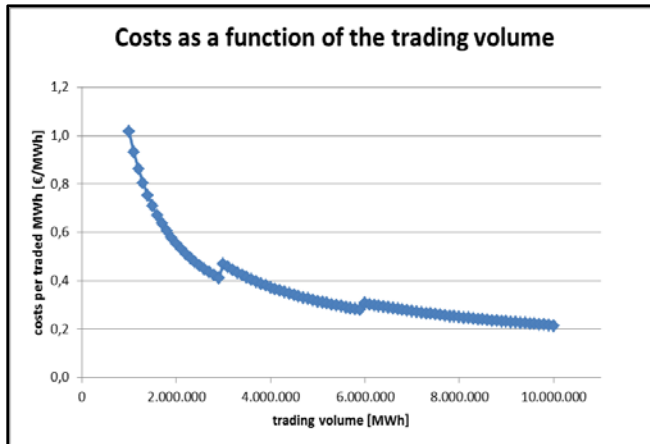


Typen and Charakteristika Direktvermarkter

- | | |
|--------------------|-------------------------------|
| große EVU | (1) ‚großen 4‘ |
| Internationale EVU | (2) Internationale EVU |
| Stadtwerke | (3) Große Stadtwerke |
| | (4) First Mover |
| | (5) kleine Stadtwerke |
| Grünstromversorger | (6) Für HH-Kunden |
| | (7) Für Gewerbe-Kunden |
| | (8) Für lokale DV |
| Händler | (9) Neugründung mit Erfahrung |
| | (10) Ohne Erfahrung |

Charakterisiert nach:

- Affinität und Legitimität
- Qualität der Leistungsprognose¹⁾
- Qualität der Preisprognose
- Suchkosten für neue Vertragspartner



1) Focken et al. (2002)



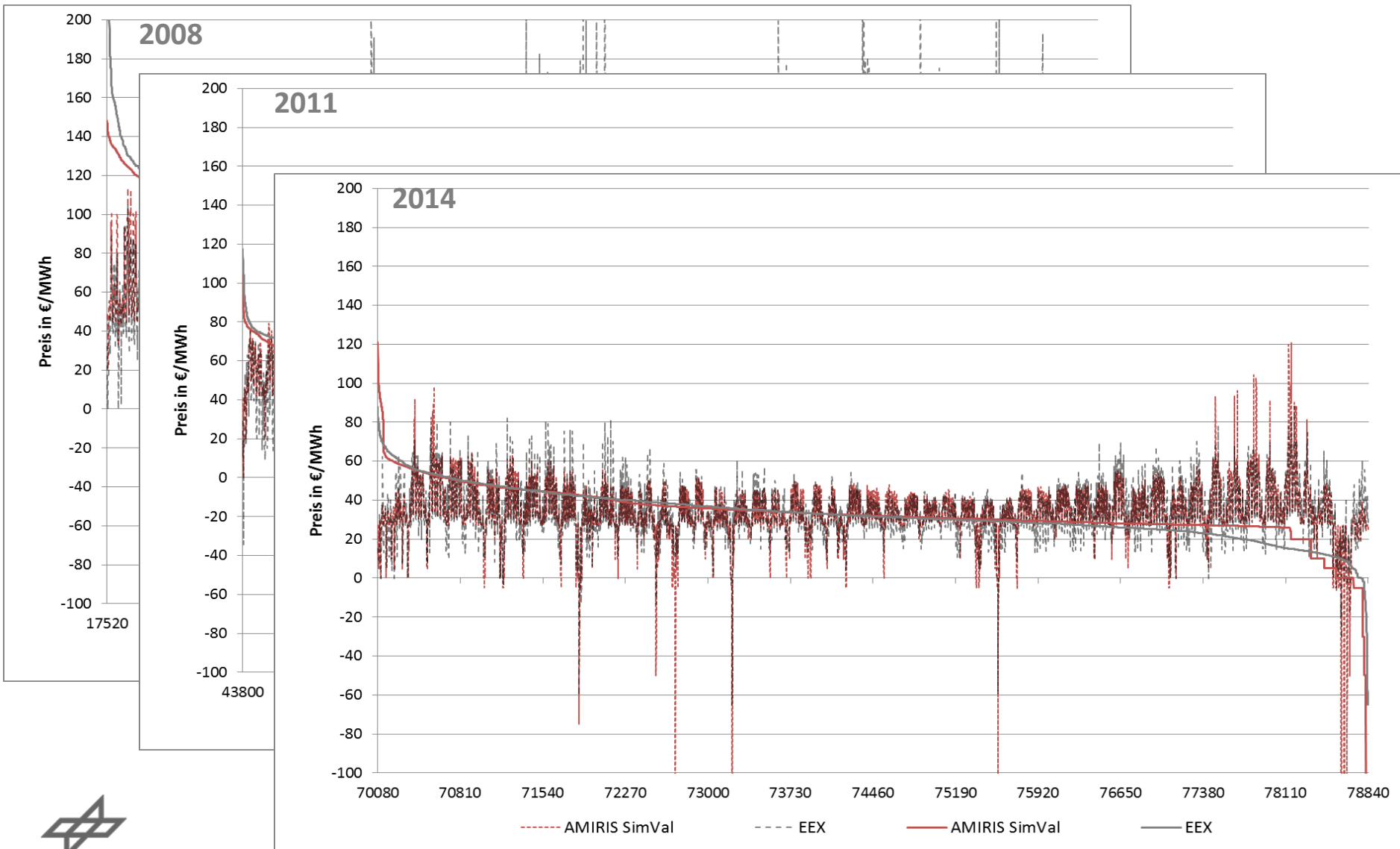
Validierung des Day-Ahead-Spot Modell (I)

	EEX/EPEX 2008	AMIRIS Simulation	EEX/EPEX 2011	AMIRIS Simulation	EEX/EPEX 2014	AMIRIS Simulation
Minimalwert	-101.52	-5.00	-36.82	-5.00	-65.03	-150.00
Maximalwert	494.26	148.33	117.49	103.66	87.97	120.93
Mittelwert	65.84	67.52	51.12	49.68	32.76	33.16
Standardabweichung (SD)	28.69	26.00	13.59	11.59	12.77	15.46
Varianz	822.91	676.17	184.81	134.42	163.18	239.12
Co-Varianz		567.56		129.84		160.97
Multipler Korrelationskoeffizient	-	0.7534	-	0.8238	-	0.8149
Bestimmtheitsmaß	-	0.5676	-	0.6786	-	0.6641
Multipler Rangkorrelationskoeffizient	-	0.7534	-	0.8238	-	0.8149

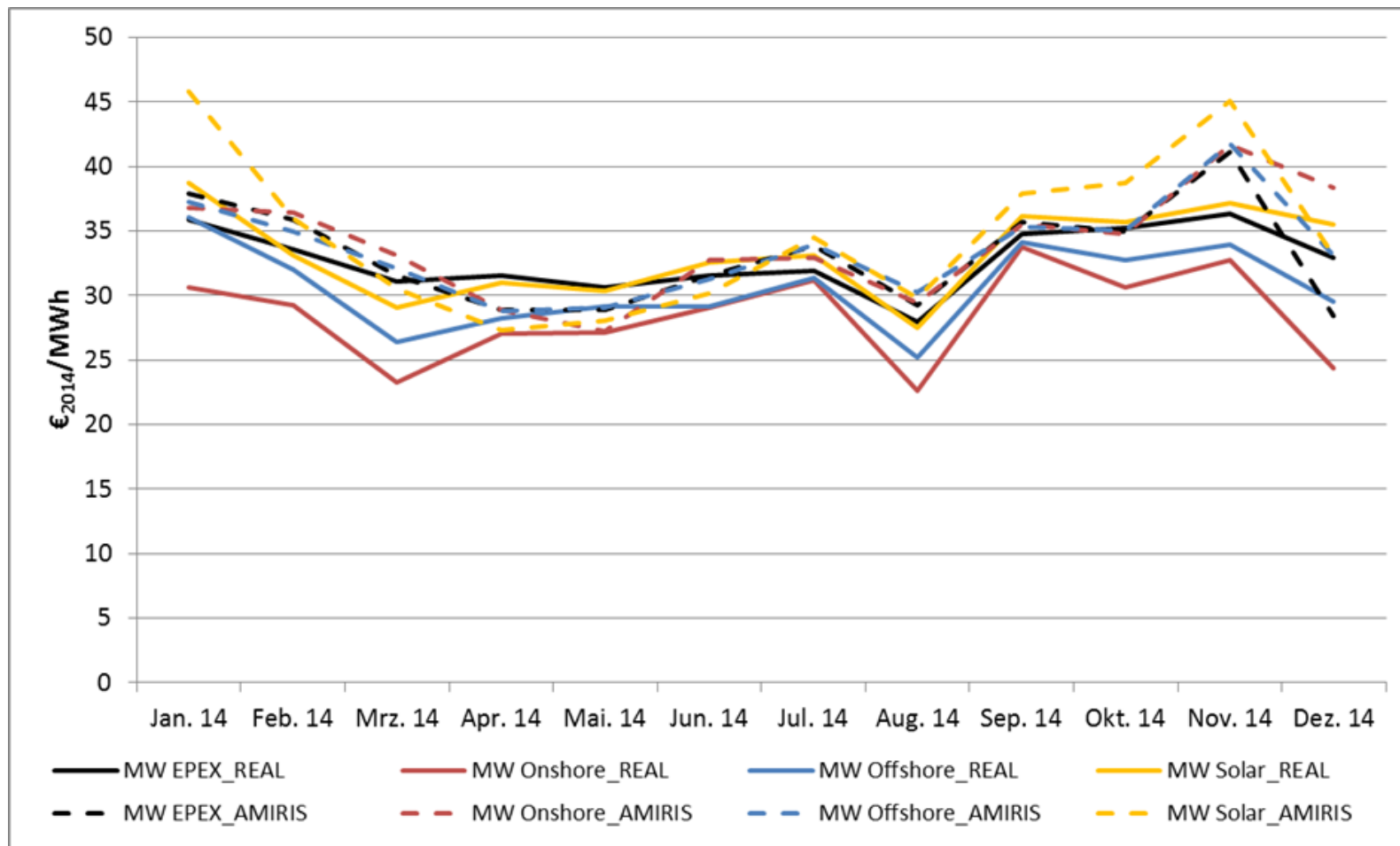
→ Stochastische Simulation der Brennstoffpreise (Monte-Carlo) führt zu deutlich besserer Abbildung der Varianz der Preise.



Validierung des Merit-Order-Models (II)



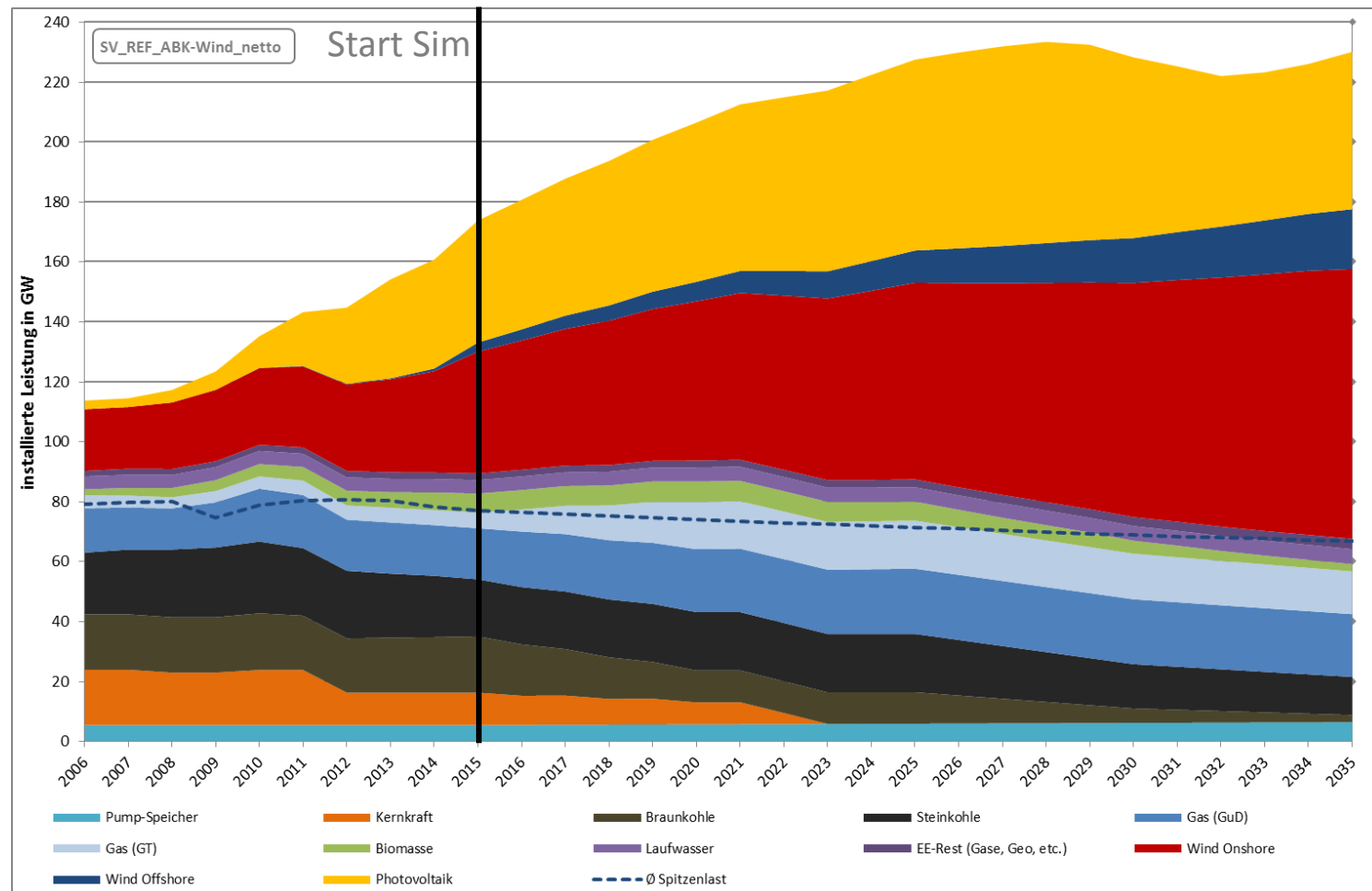
Validierung des Merit-Order-Modells – FEE Marktwerte



→ Simulierte Marktwerte (MV) werden im Modell sogar noch leicht „überschätzt“



Annahme zur Kraftwerksparkentwicklung (SV-REF)



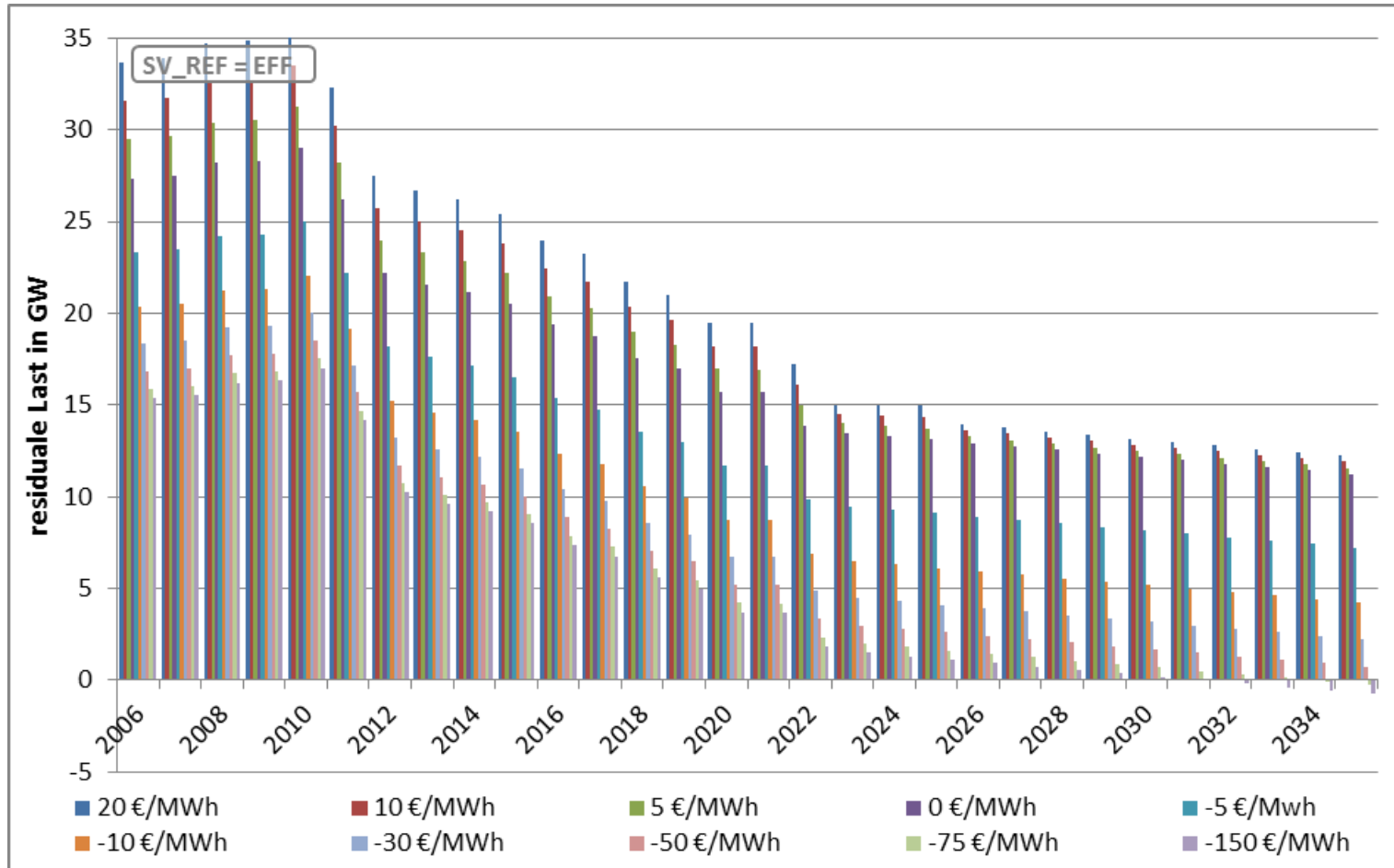
→ EE: Ausbaukorridore nach EEG 2014 (Wind netto , PV und BM brutto)

→ Konv KW: nach Leitstudie (2012)¹⁾ und Lastausgleich (2014)²⁾



Entwicklung von Flex-Optionen

(SV-REF = EFF, d.h. Effizienz-Szenario, sehr restriktiv, d.h. keine neuen Verbraucher!)

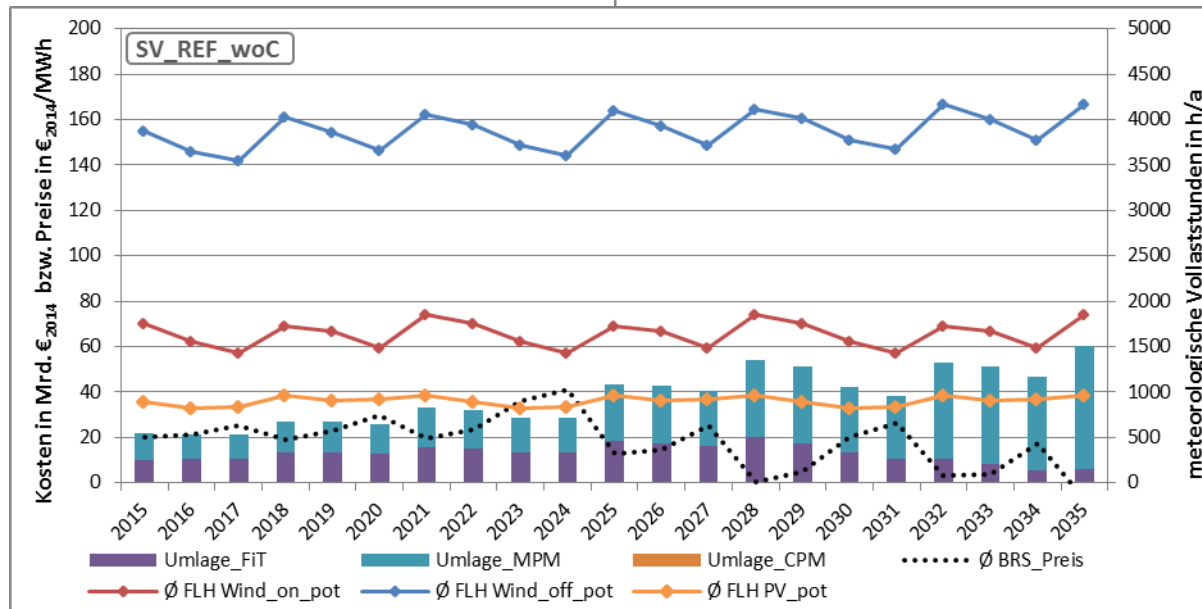
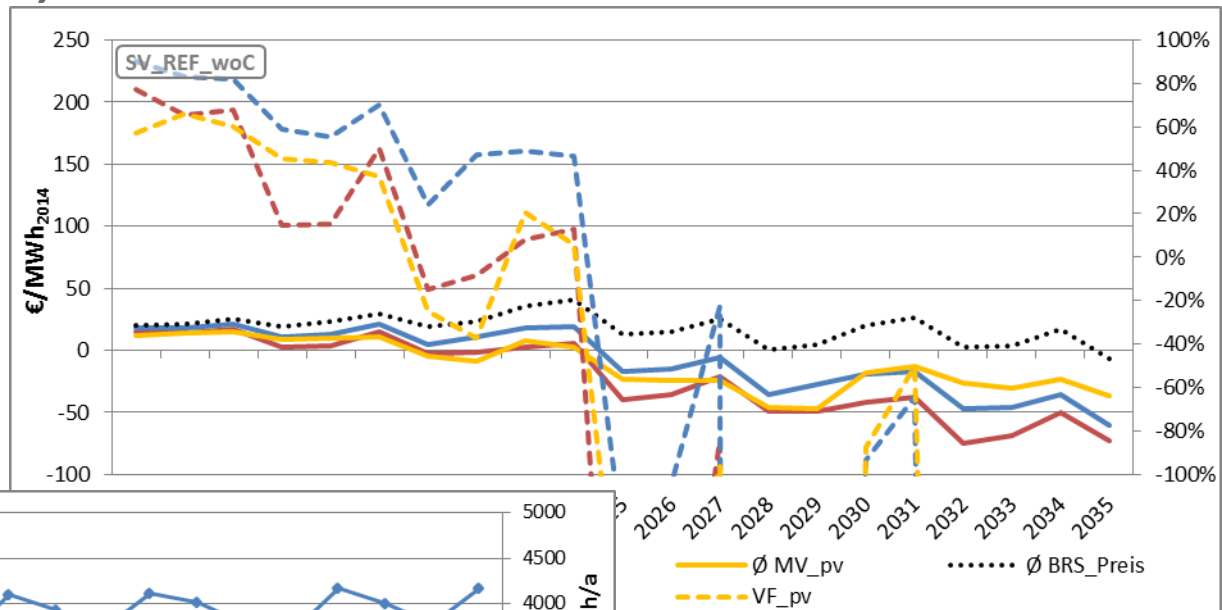


→ Die Residuallastintervalle bestimmen im Merit-Order-Modell, ab wann extrem niedrige bzw. negative Preise auftreten



Ergebnisse Marktwerte und Förderkosten des REF-Szenarios (Status Quo Anfang 2015)

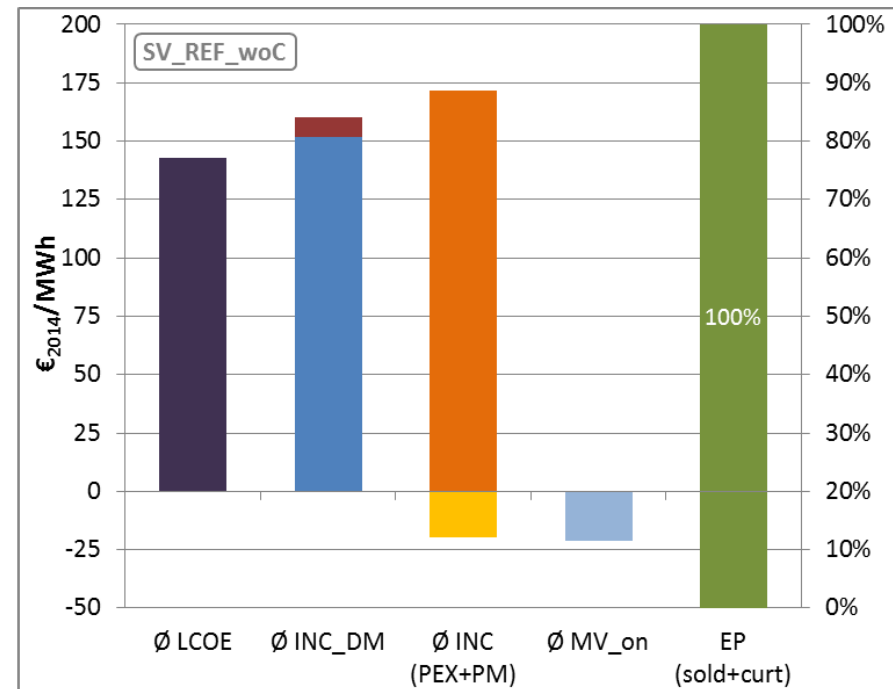
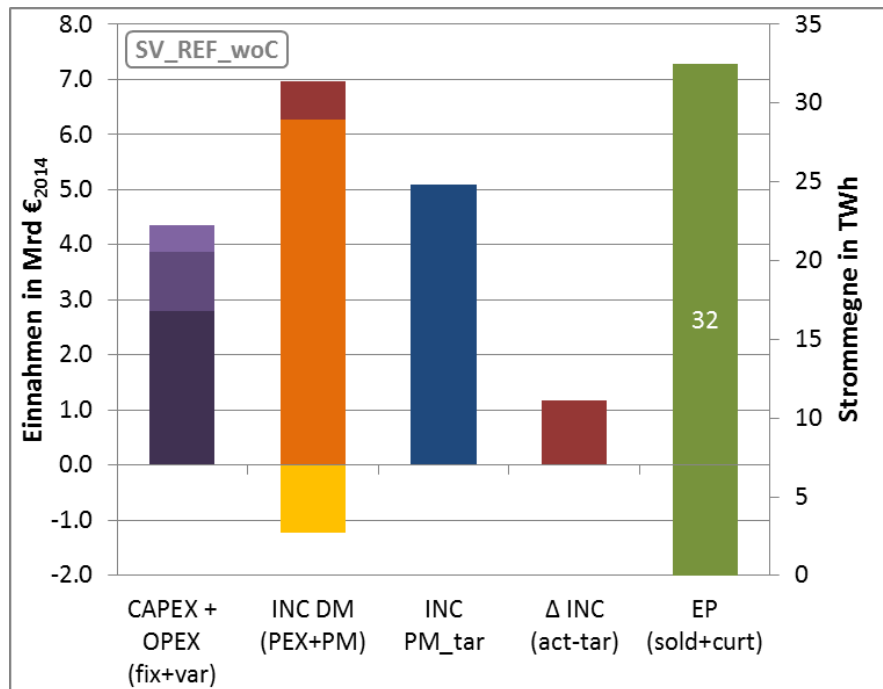
- Alte Bestandanlagen teilweise noch mit FiT
- Vor allem bei Wind schon ca. 85 % in DV über MPM / PV ca. 15 % / Biomasse ca. 25 %
- Lineare Zunahme der Anteile über Simulationszeitraum
- **ABER:** hier keine marktgetriebene Abregelung!



Ergebnisse für Windanlagenbetreiber des REF-Szenarios (SV_REF: Status-Quo 2015)

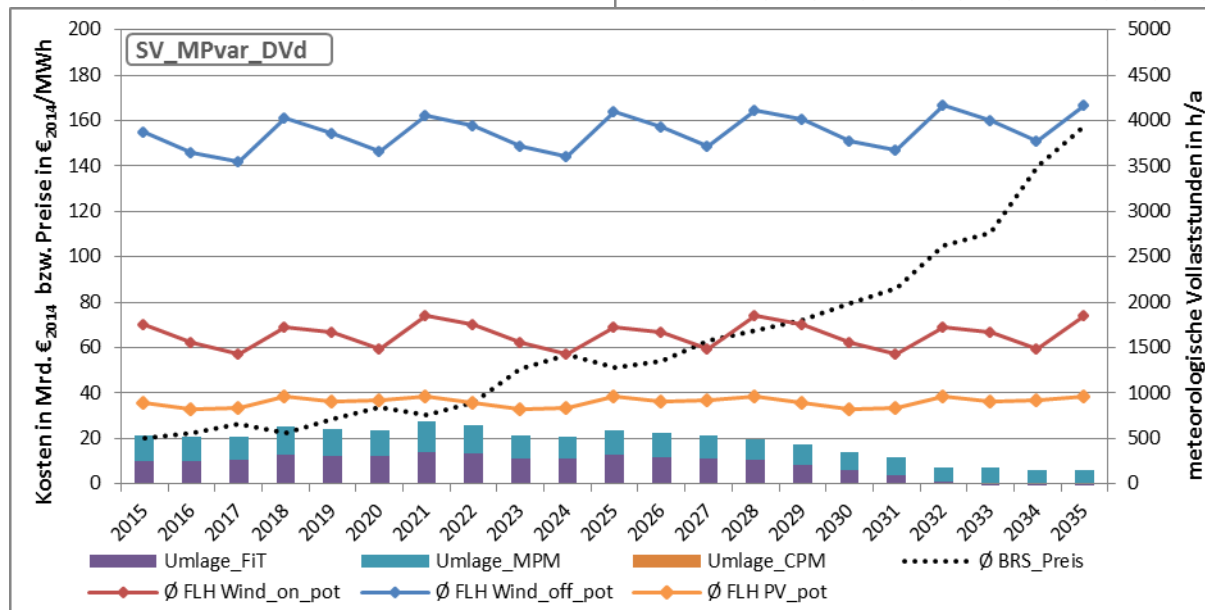
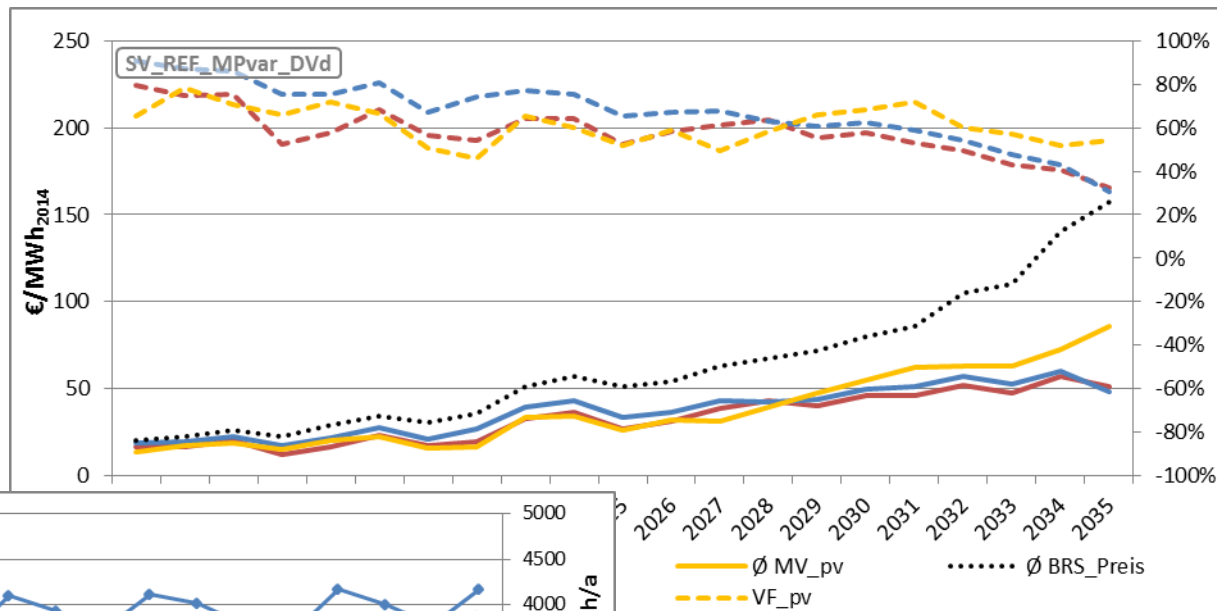
Beispiel Windanlagenbetreiber (WAB11):
Investor: Privatperson (55% von P_inst in dieser Klasse)
Standortgüte: schlecht (Süddeutschland)

INC – Income
PEX – Power Exchange
PM – Premium Model
EP – Electric Power
MV – Market Value
act - actual
tar - target



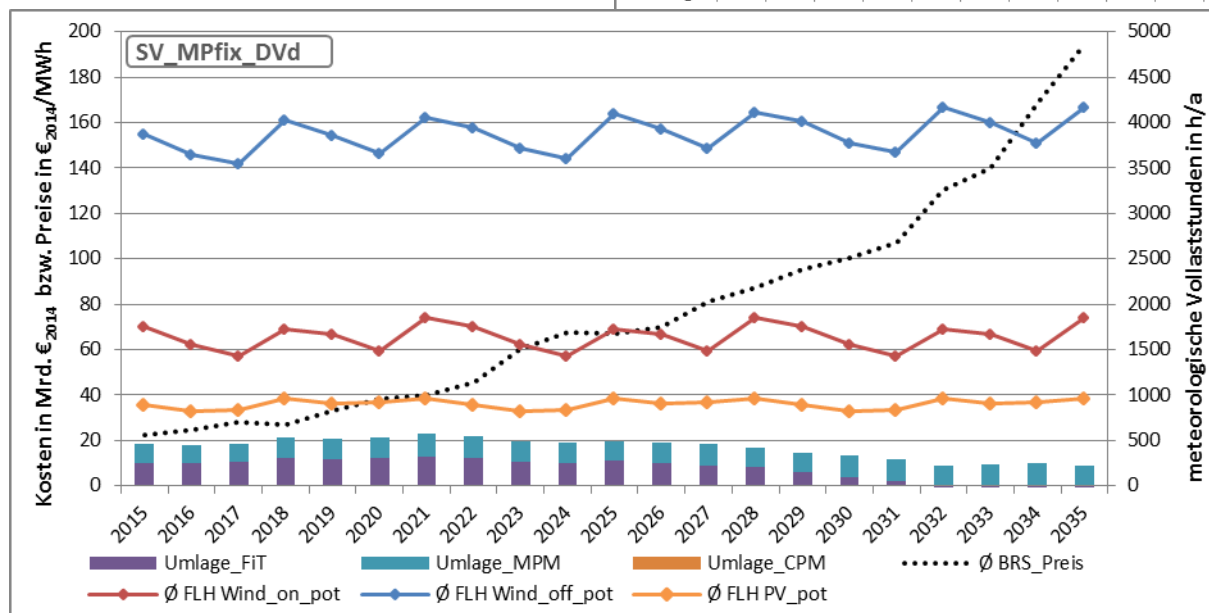
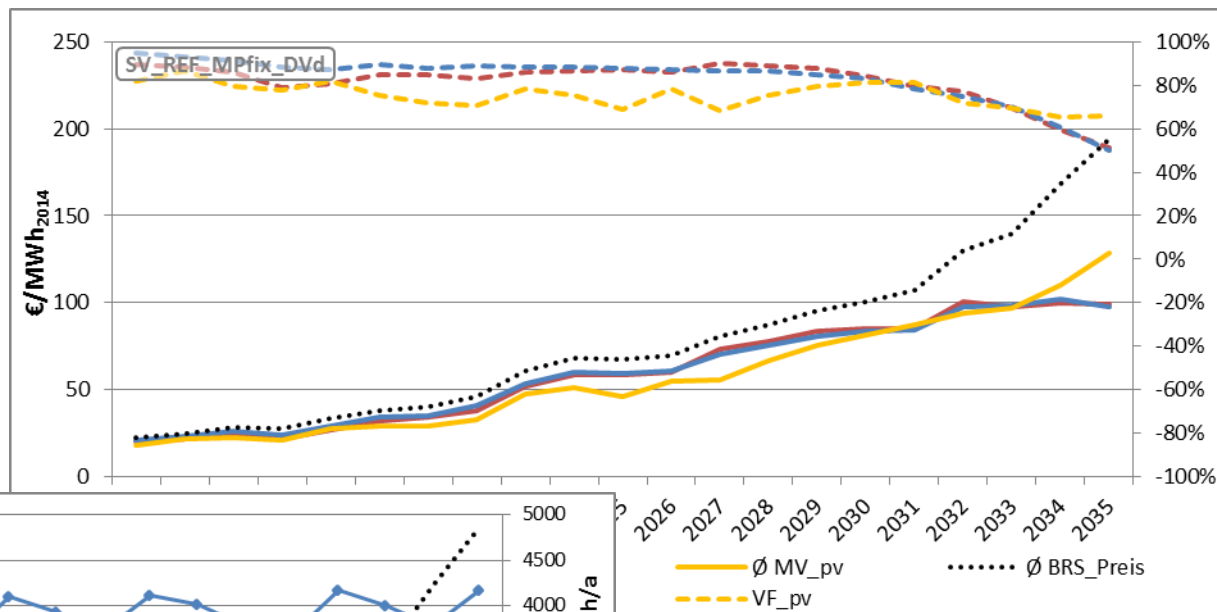
Ergebnisse Marktwerte und Förderkosten des Lauf MP_var (mit Abregelung)

- Anlange in der DV werden abgeregelt, sobald der Betrag des neg. Börsenpreises die antizipierte Prämienhöhe übersteigt



Ergebnisse Marktwerte und Förderkosten des Lauf MP_fix (mit Abregelung)

- Anlange in der DV werden abgeregelt, sobald der Betrag des neg. Börsenpreises die ex ante definierte Prämienhöhe übersteigt

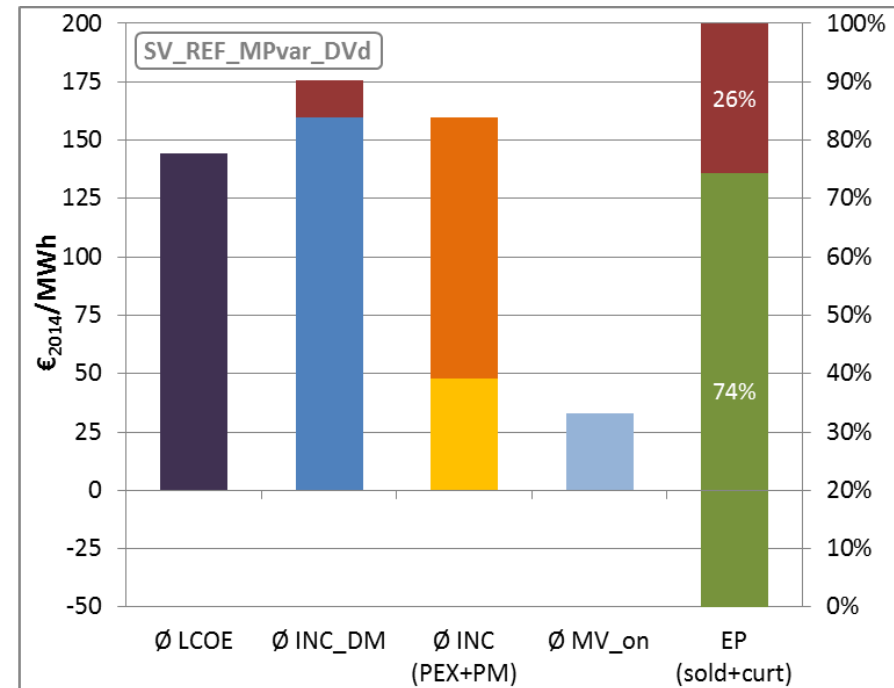
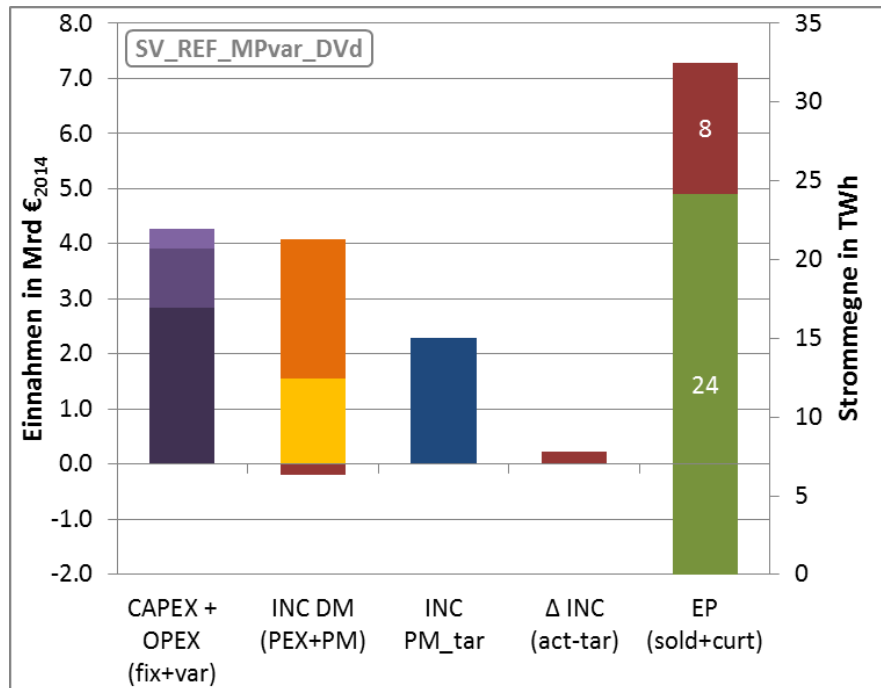


Ergebnisse für Windanlagenbetreiber des Lauf MP_var (mit Abregelung)

Beispiel Windanlagenbetreiber (WAB11):

Investor: Privatperson

Standortgüte: schlecht (Süddeutschland)

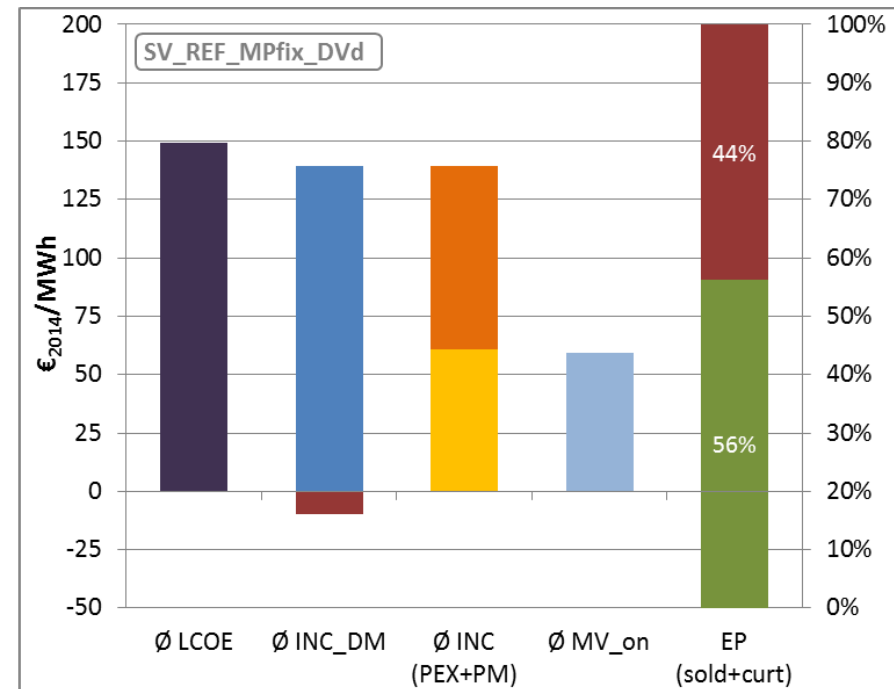
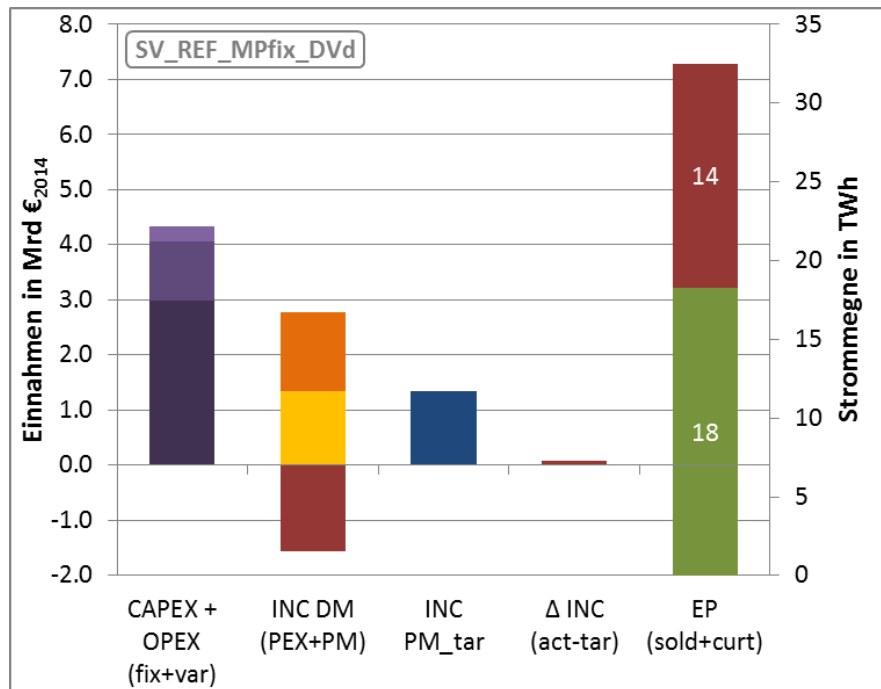


Ergebnisse für Windanlagenbetreiber des Lauf MP_fix (mit Abregelung)

Beispiel Windanlagenbetreiber:

Investor: Privatperson

Standortgüte: schlecht (Süddeutschland)



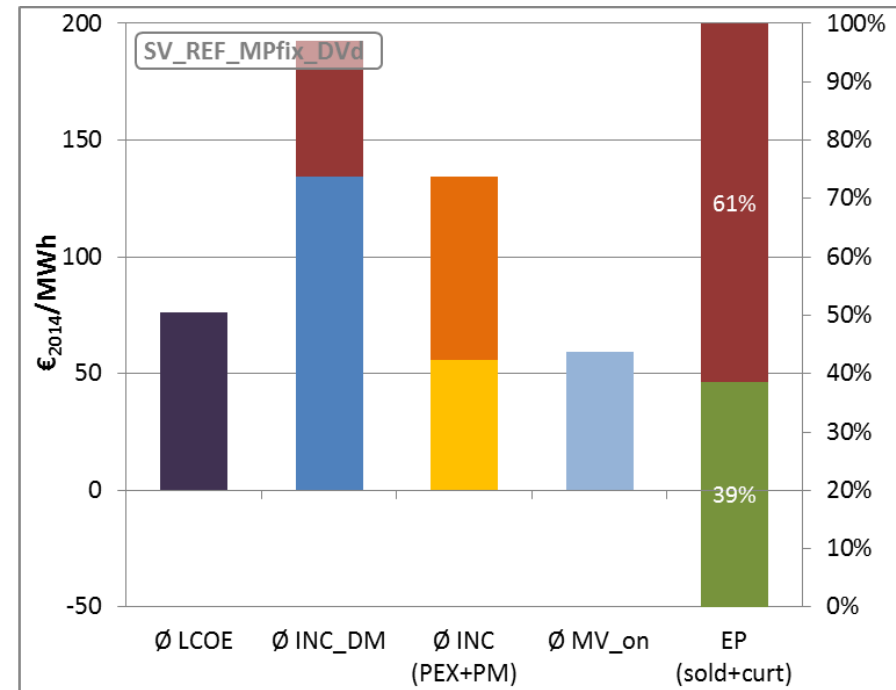
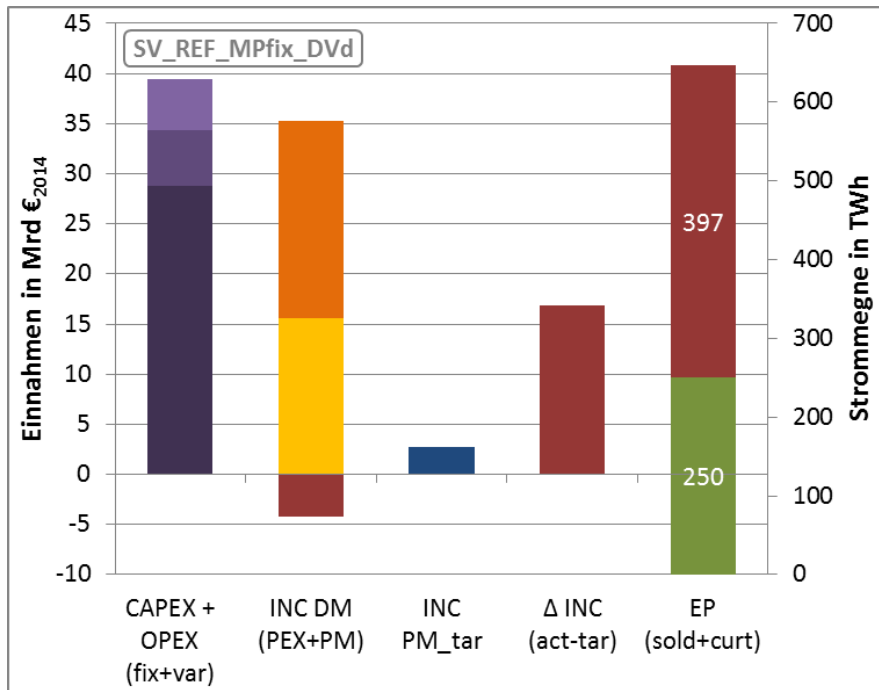
Ergebnisse für Windanlagenbetreiber des Lauf MP_fix (mit Abregelung)

Beispiel Windanlagenbetreiber (WAB31): erhält gleiche MP_fix wie WAB11!

Investor: Privatperson

Standortgüte: gut (Norddeutschland)

ACHTUNG:
andere Skala

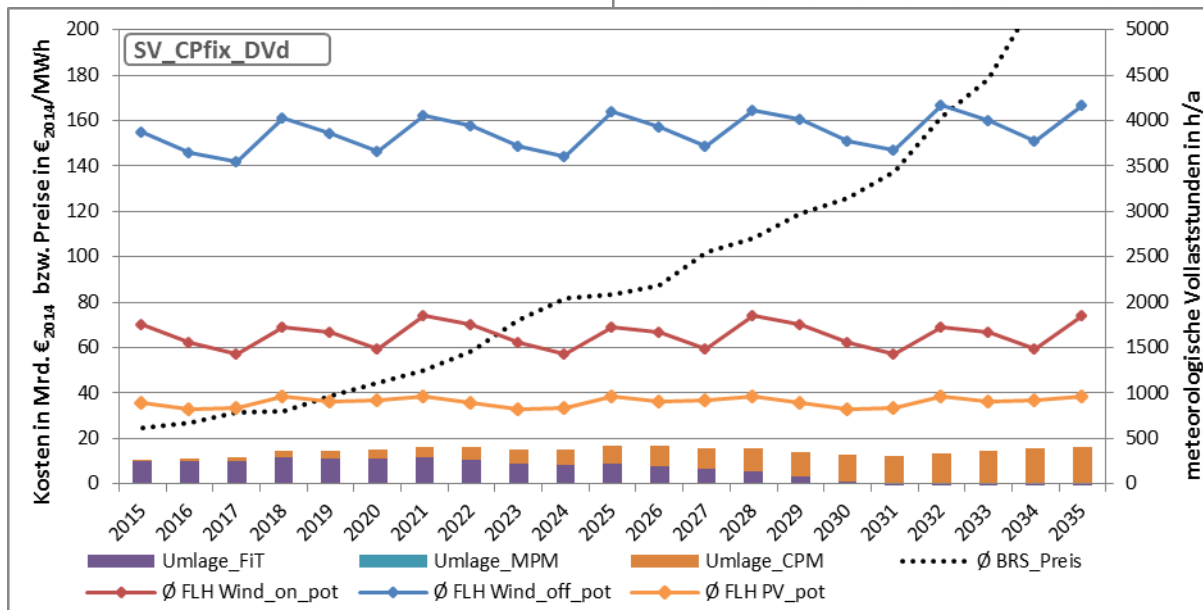
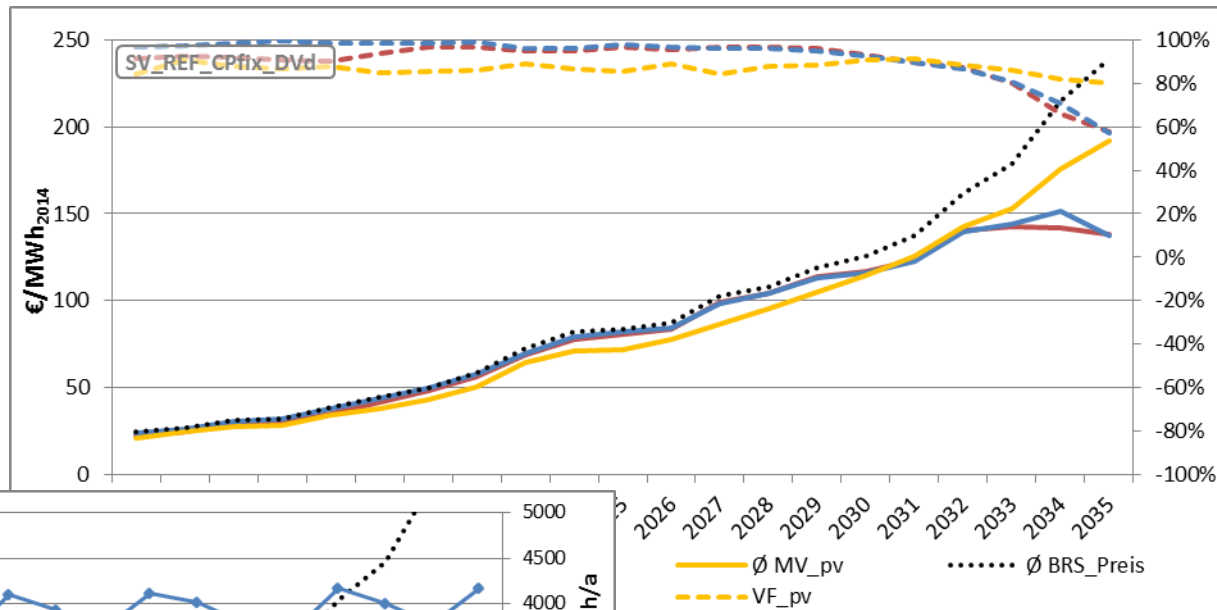


→ Fixe Prämie setzt kontraproduktive Investitionsanreize, das Anlagen an „guten“ Standorten extrem überfördert werden, und damit dem Marktwertverlust verstärken würden



Ergebnisse Marktwerte und Förderkosten des Laufs CP_fix (mit Abregelung)

- Anlange in der DV werden abgeregelt, sobald der Börsenpreis die variablen Kosten (O&M) unterschreitet

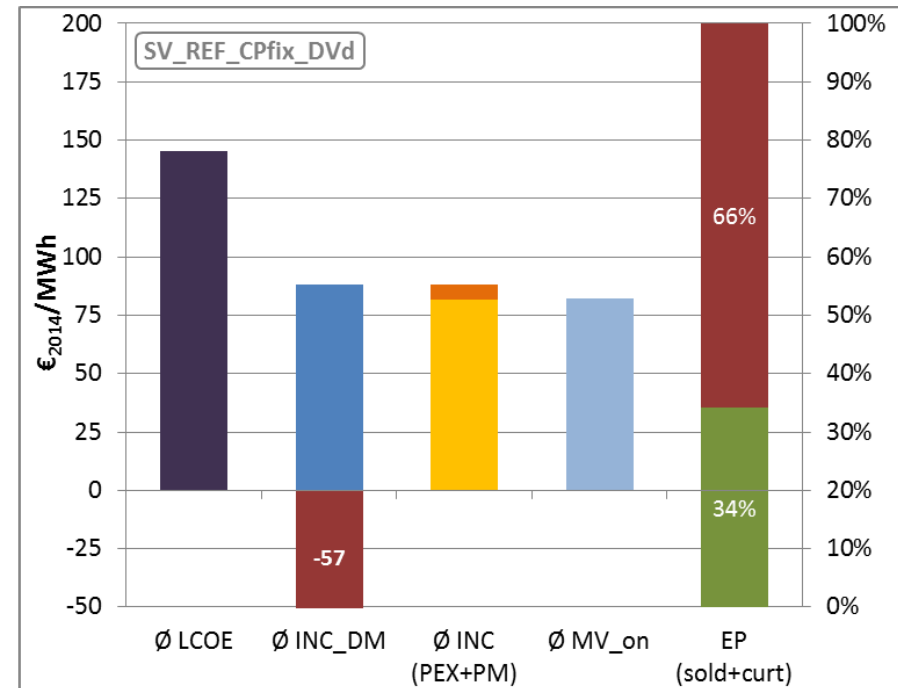
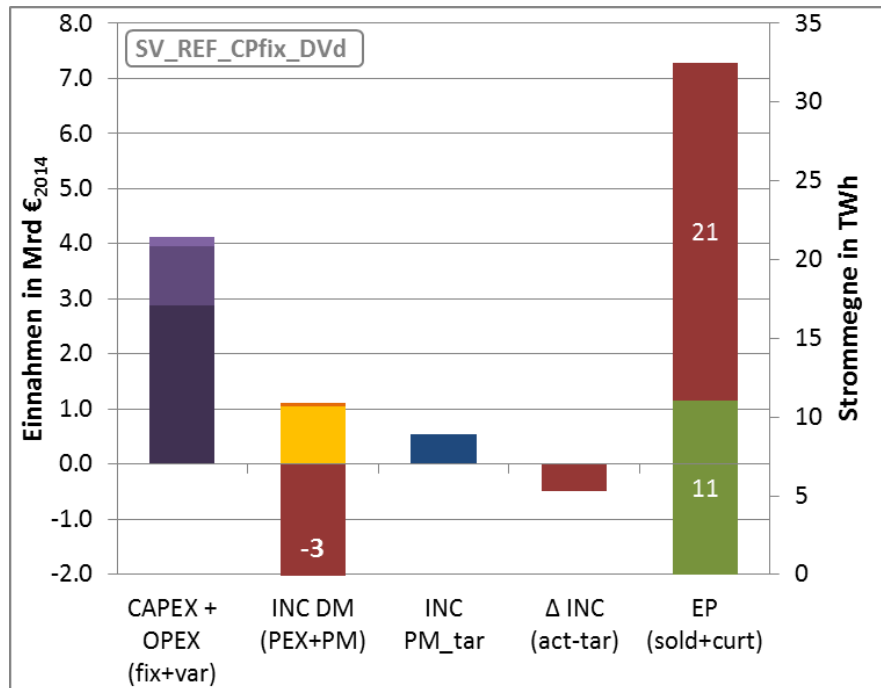


Ergebnisse für Windanlagenbetreiber des Lauf CP_fix (mit Abregelung)

Beispiel Windanlagenbetreiber (WAB11):

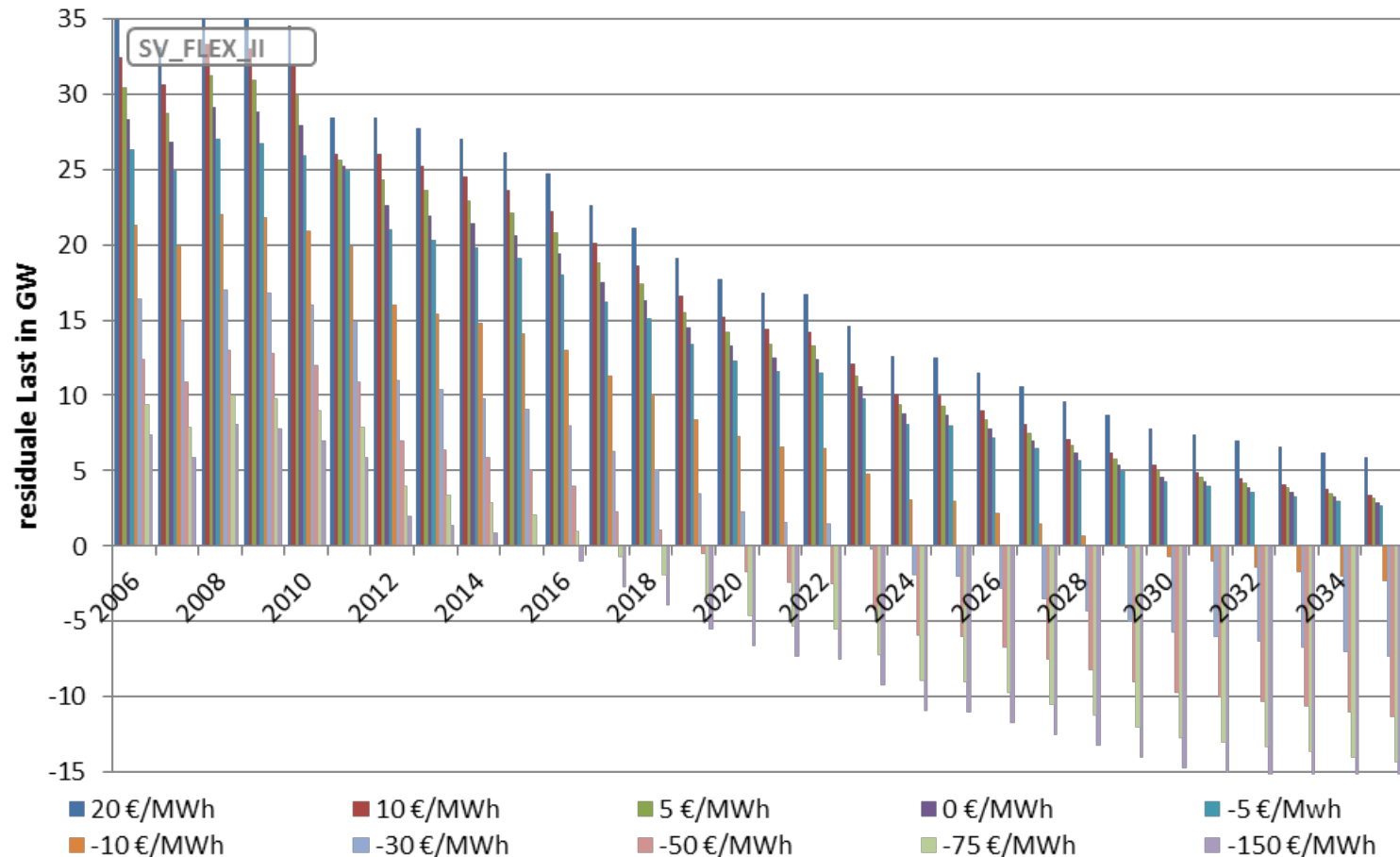
Investor: Privatperson

Standortgüte: schlecht (Süddeutschland)



Residuallast Intervalle beim Flex-Szenario

(SV-Flex = dynamische Sektorenkopplung, d.h. viele neue Verbraucher!)

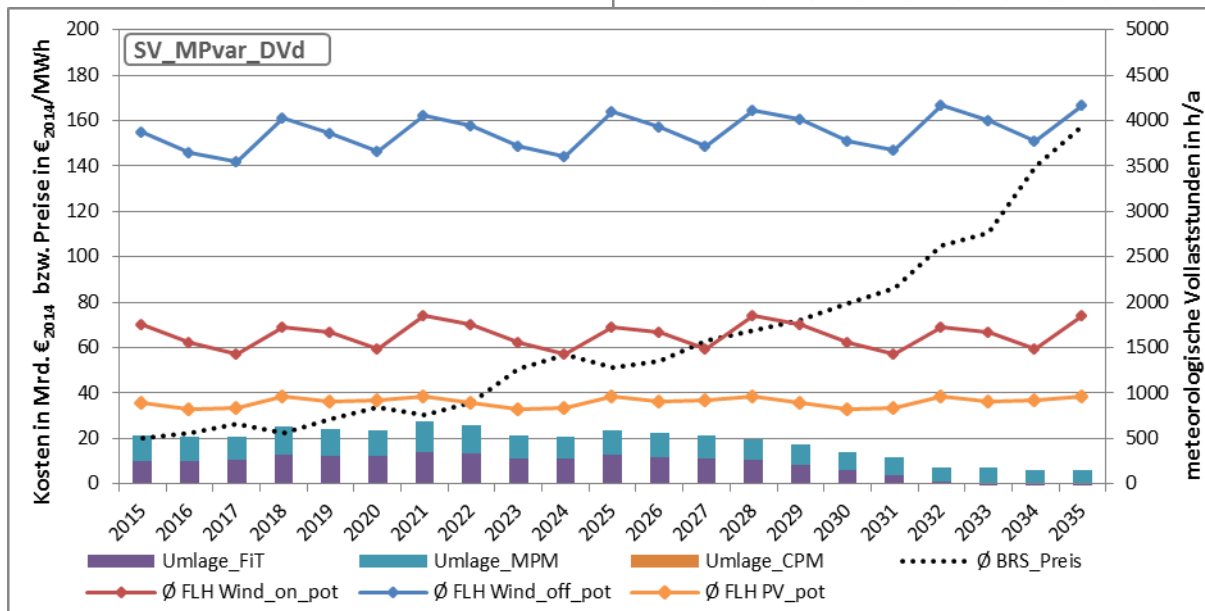
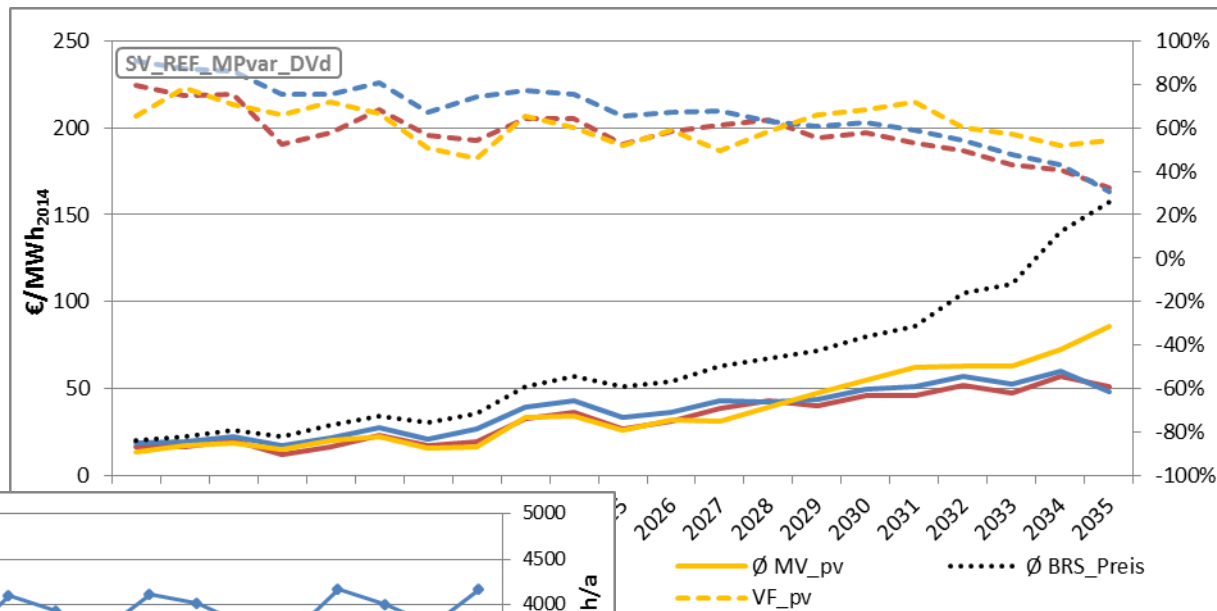


→ Die Residuallastintervalle bestimmen im Merit-Order-Modell, ab wann extrem niedrige bzw. negative Preise auftreten



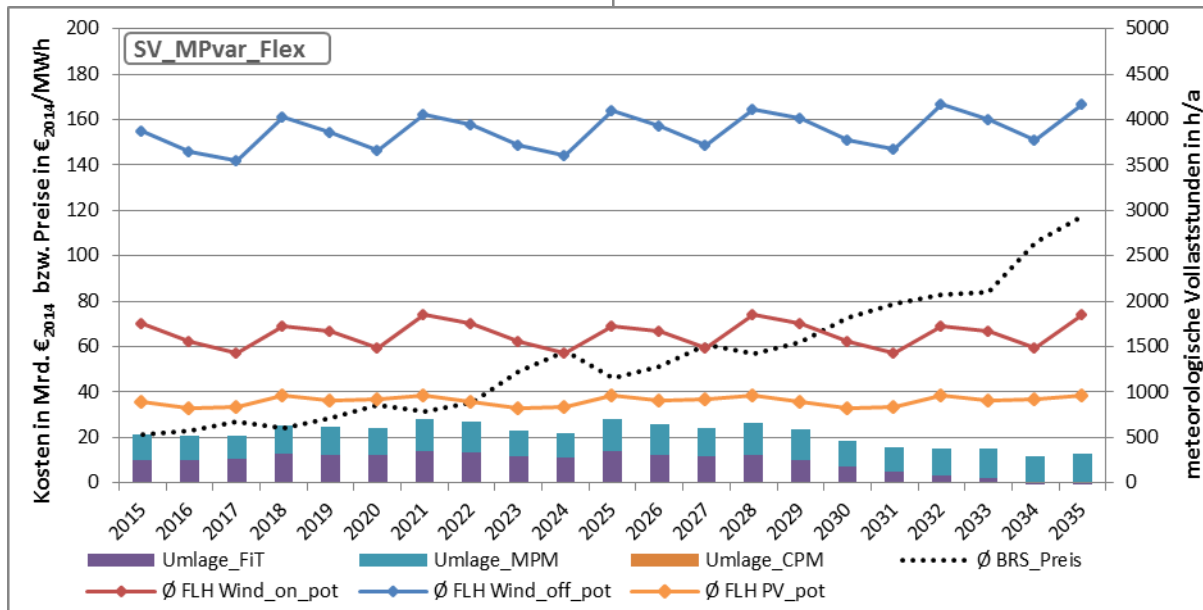
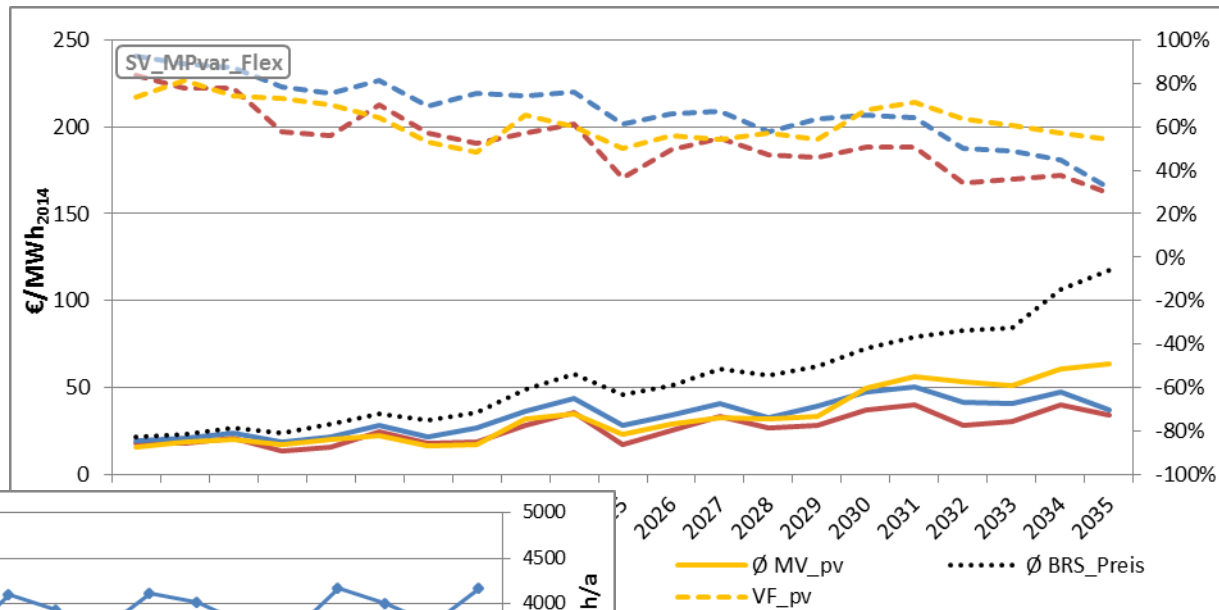
Ergebnisse Marktwerte und Förderkosten des Lauf MP_var (ohne Flex-Opt für Vergleich)

- Anlange in der DV werden abgeregelt, sobald der Betrag des neg. Börsenpreises die antizipierte Prämienhöhe übersteigt



Ergebnisse Marktwerte und Förderkosten des Lauf MPvar (SV_Flex)

- Anlange in der DV werden abgeregelt, sobald der Betrag des neg. Börsenpreises die antizipierte Prämienhöhe übersteigt

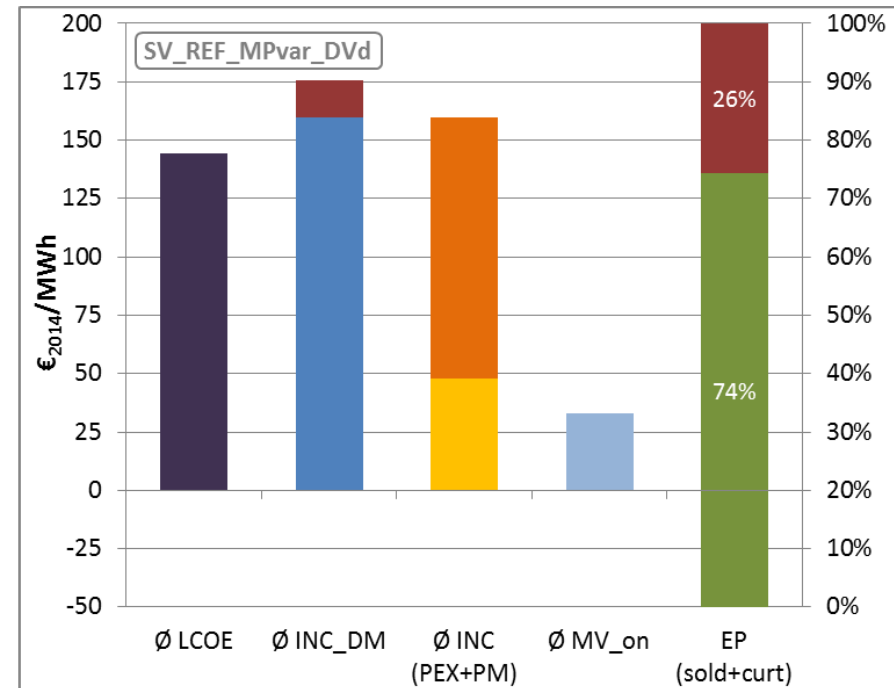
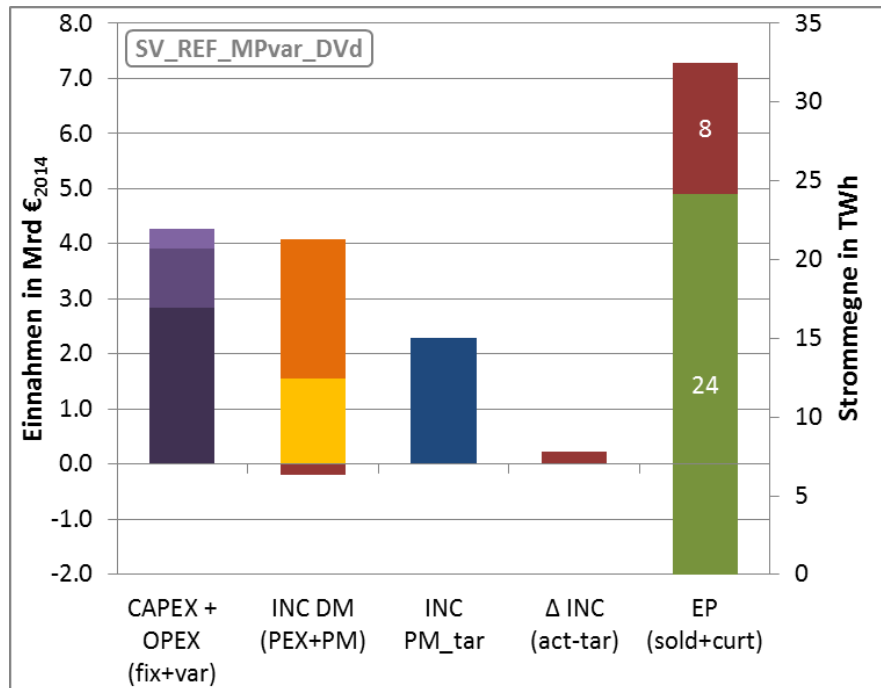


Ergebnisse für Windanlagenbetreiber des Lauf MP_var (ohne Flex-Opt für Vergleich)

Beispiel Windanlagenbetreiber (WAB11):

Investor: Privatperson

Standortgüte: schlecht (Süddeutschland)

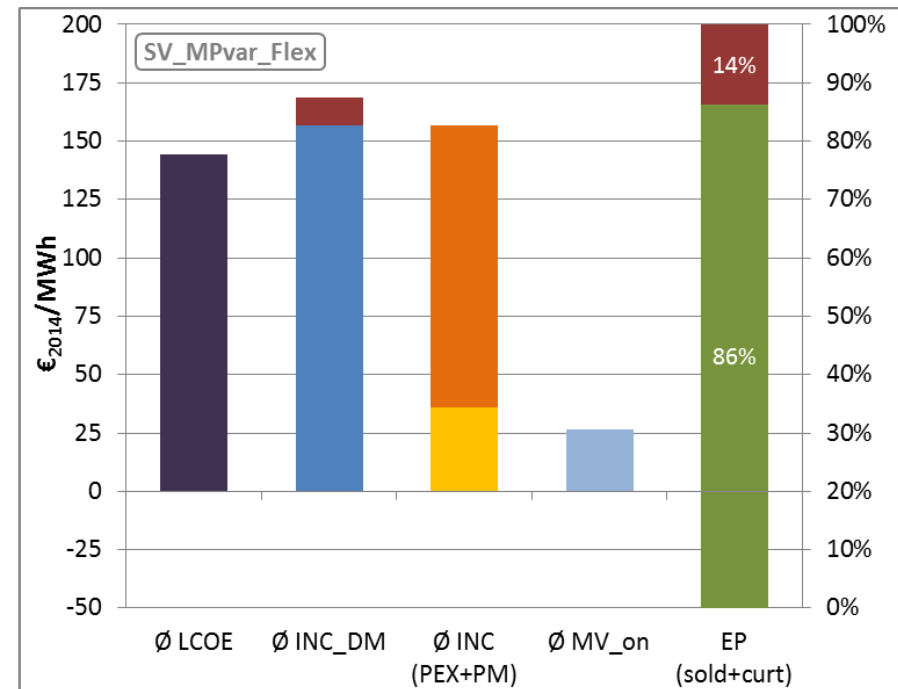
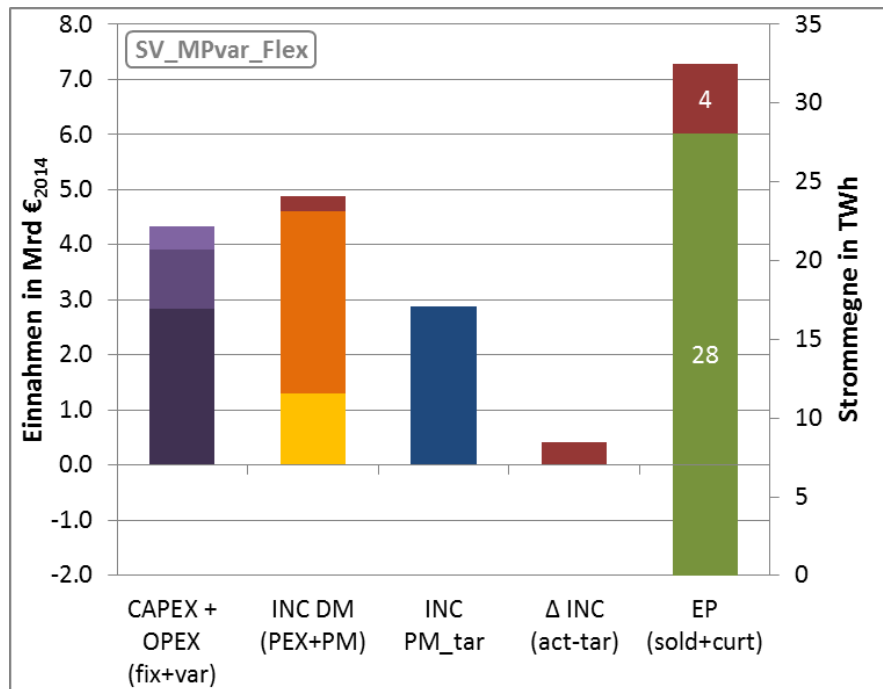


Ergebnisse für Windanlagenbetreiber des Lauf MPvar (SV_Flex)

Beispiel Windanlagenbetreiber (WAB11):

Investor: Privatperson

Standortgüte: schlecht (Süddeutschland)



Zusammenfassung und Fazit

- Steigende Komplexität des Systems erfordert neue Analysemethoden → ABM als Methode zur Analyse von Systemdynamiken
- aktuelle Marktbedingungen sind nicht für eine gute EE Integration geeignet
- Refinanzierung der FEE auch bei wettbewerblichen Kosten zu konv. KW unwahrscheinlich
- Schon kleine Änderungen im Förderdesign können gravierende Auswirkungen auf die Ausbaudynamik haben (LCOE, Förderkosten, Über-/ Unterförderung, Marktwerte)
- Höhere Mengen- u. Preisrisiken bei den FEE führen zu deutlich höheren Kapitalkosten
- Höhere Kapitalkosten bei EE müssen durch Effizienzgewinne bei der Integration „erwirtschaftet“ werden → zentrale Vermarktung effizienter als dezentrale?
- ohne entsprechende Flexibilität im zukünftigen System kann die EE-Integration sehr teuer werden



Thank you very much for your Attention!!!

Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)

German Aerospace Center

Institute of Engineering Thermodynamics | Systems Analysis and Technology Assessment

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www.DLR.de



References

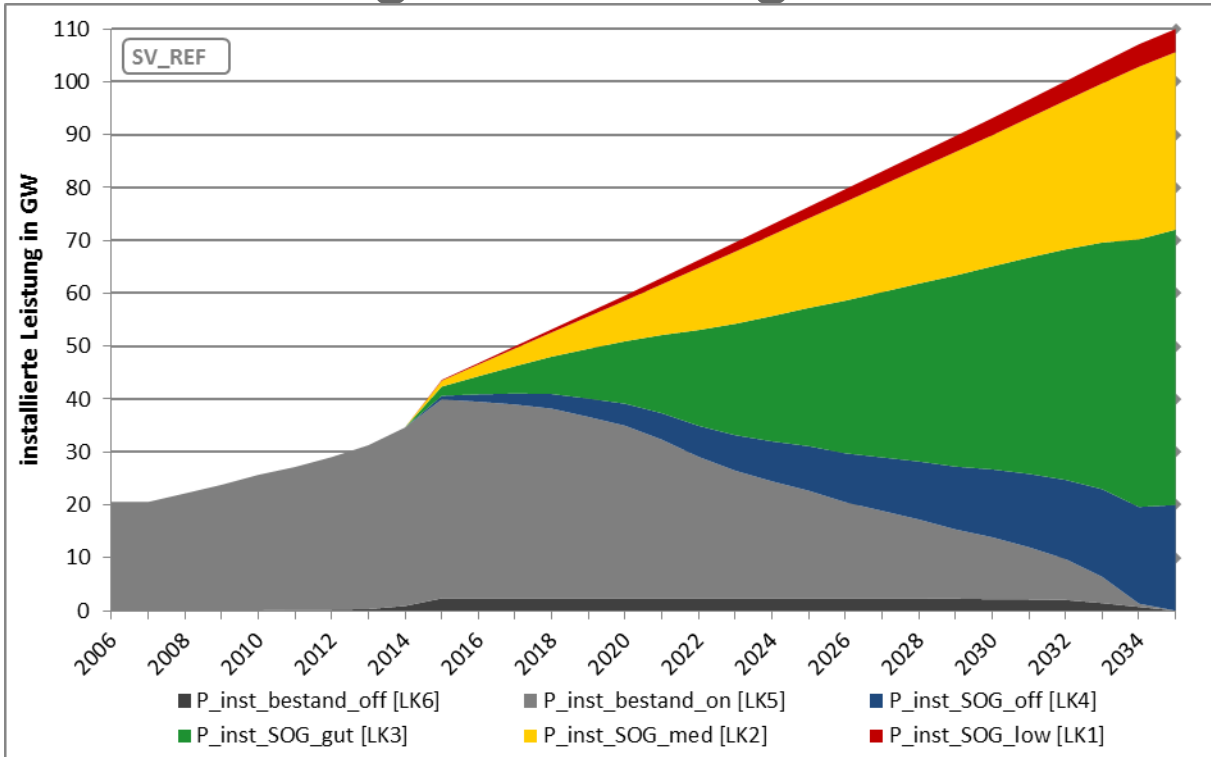
- van der Brugge and Van Raak (2007): Facing the adaptive management challenge: insights from transition management. *Ecology and Society* 12(2): 33.
- Sondejker, Geurts, Rotmans and Tukker (2006): Imagining sustainability: the added value of transition scenarios in transition management. *Foresight* 8(5):15-30.
- Quist (2007): *Backcasting for a sustainable future: the impact after 10 years*. Eburon, Delft, Netherlands.
- Rotmans, Kemp and van Asselt (2001): More evolution than revolution: transition management in public policy. *Foresight* 3(1):15-31.
- Hoogma, Kemp, Schot Truffer (2002): *Experimenting for sustainable transport: the approach of strategic niche management*. Spon Press, London, UK.
- Smith and Kern (2009): The transitions storyline in Dutch environmental policy. *Environmental Politics* 18(1):78-99.
- Smith, Stirling and Berkhout (2005): The governance of sustainable sociotechnical transitions. *Research Policy* 34:1491-1510.
- Shove and Walker (2007): CAUTION! Transitions ahead: politics, practice and sustainable transition management. *Environment and Planning A* 39(4):763-770
- Grundwald 2015: Strategisches Wissen für Nachhaltige Entwicklung. Symposium „Zukunftsfähige Entwicklung und Generative Organisationskulturen“ der FH Bochum, 12. Februar 2015.
- Smith and Stirling (2010): The politics of social-ecological resilience and sustainable socio-technical transitions. *Ecology and Society* 15(1): 11
- Geels (2002): Technological transitions as evolutionary reconfiguration processes: a multilevel perspective and a case-study. *Research Policy* 31, pp. 1257-1274.
- Geels (2004): From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. *Research Policy* 33, pp. 897-920.
- Arthur (2005): *Out of Equilibrium Economics and Agent-Based Modeling*. In: Handbook of Computational Economics, Vol. 2, K. Judd and L. Tesfatsion (eds.), Elsevier/ North-Holland, 2005
- Holland, Holyoak, Nisbett and Thagard (1986): *Induction - Processes of Inference, Learning, and Discovery*. MIT Press.
- Sargent (1994): *Bounded Rationality in Macroeconomics*. Clarendon Press, Oxford.
- Wooldridge, M. (2002): *An Introduction to Multi-Agent Systems*. John Wiley & Sons, Chichester.
- Schmidt, B. (2000): *Die Modellierung menschlichen Verhaltens*. SCS – European Publishing House, Delft.
- Focken et al. (2002) A statistical analysis of the reduction of the wind power prediction error by spatial smoothing effects. *Journal of Wind Engineering and Industrial Aerodynamics* 90:3, p. 231–246
- Nitsch et al. (2012) Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global. DLR, IWES, IfNE im Auftrag des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit (BMU).
- Scholz et al. (2014) Möglichkeiten und Grenzen des Lastausgleichs durch Energiespeicher, verschiebbare Lasten und stromgeführte KWK bei hohem Anteil fluktuierender erneuerbarer Stromerzeugung. Gefördert durch das Bundesministerium für Wirtschaft und Energie (BMWi)



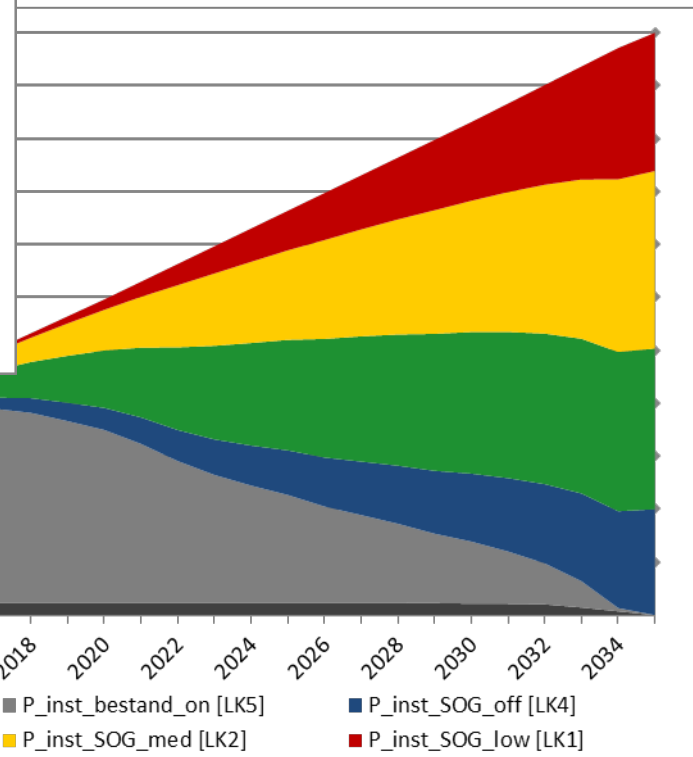
Back-Up Slides



Windanlagenverteilung beim Wind-Szenario



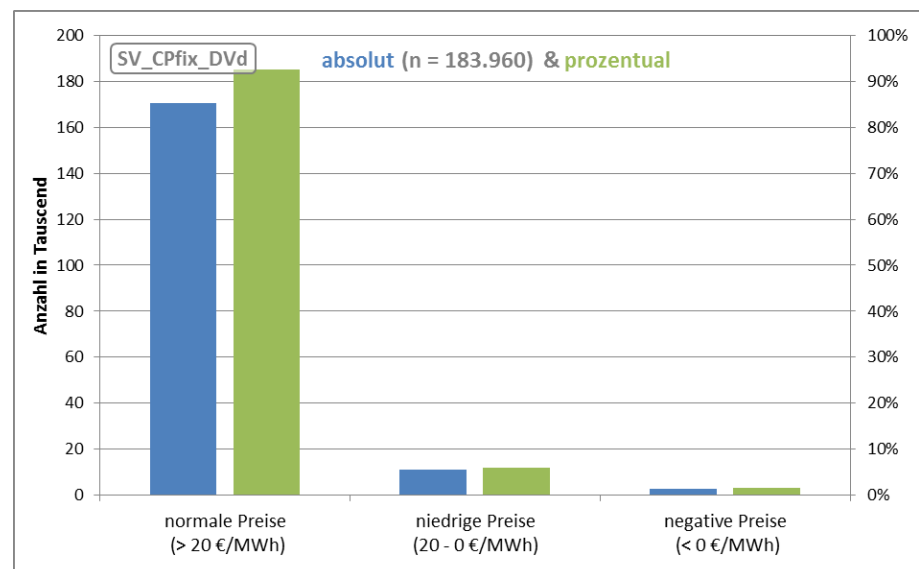
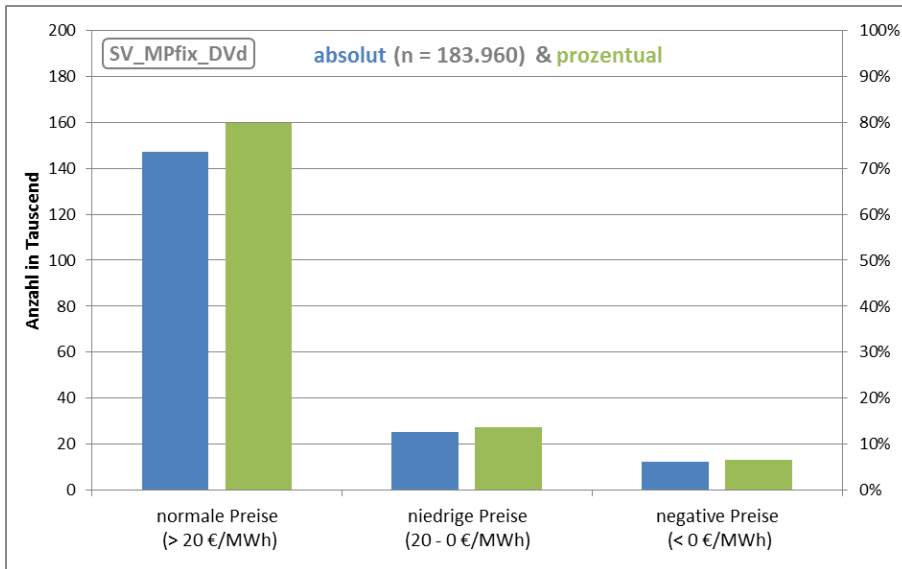
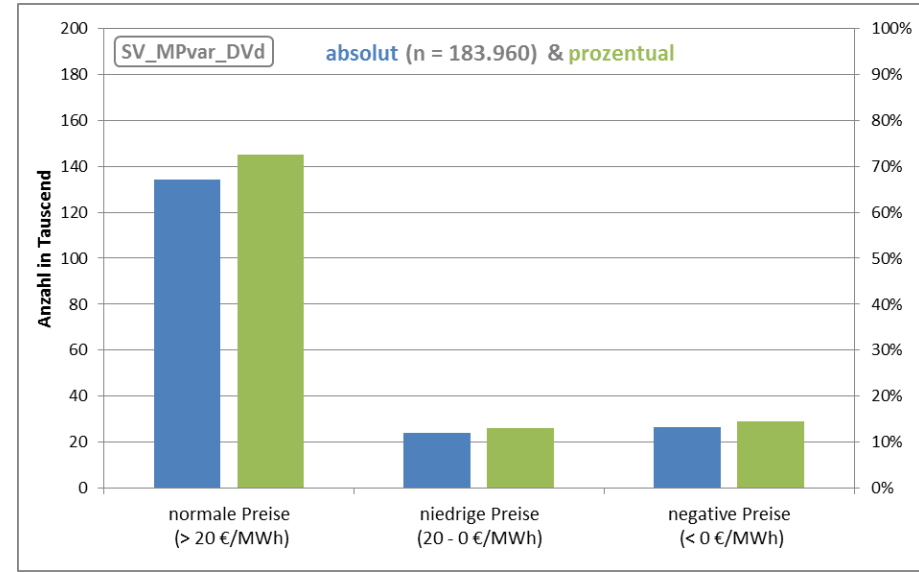
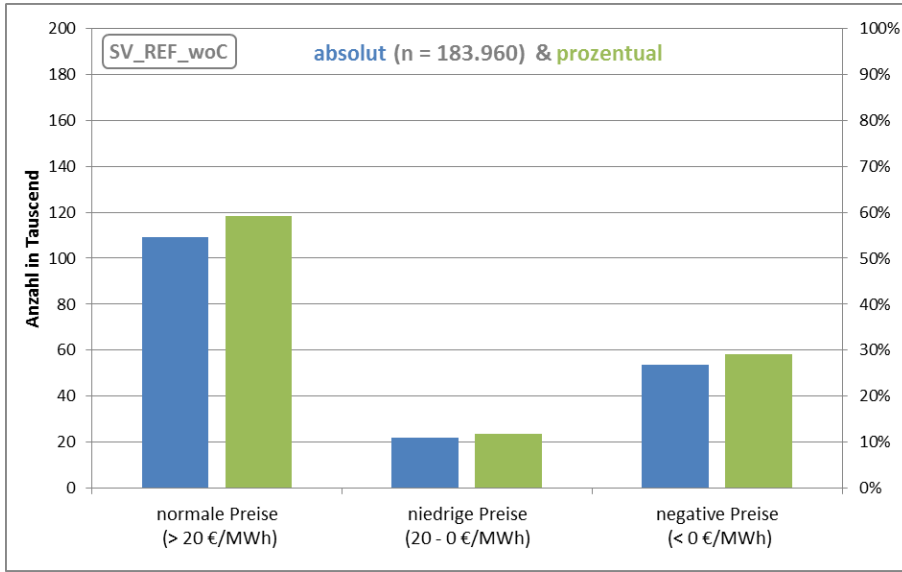
← SV_REF:
Fortsetzung des
historischen Verlaufs
des Ausbaus



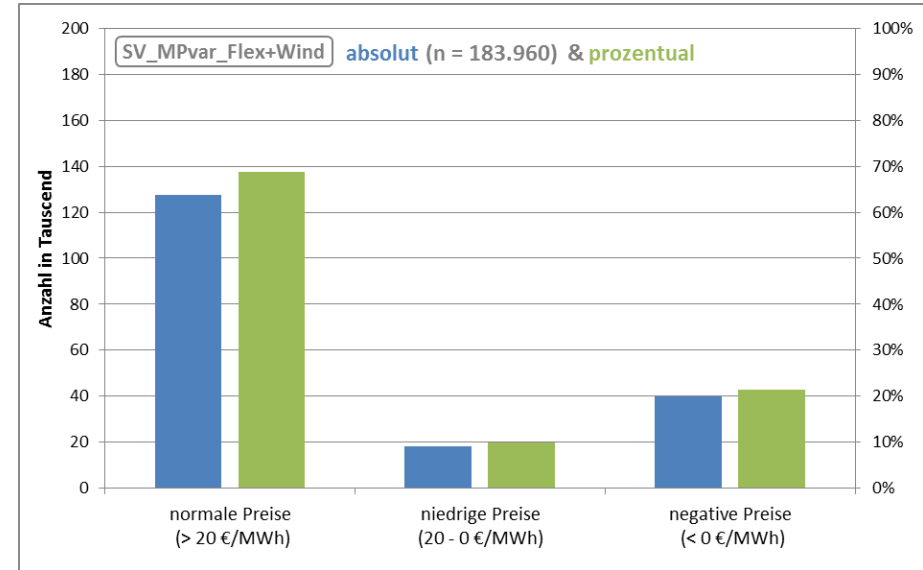
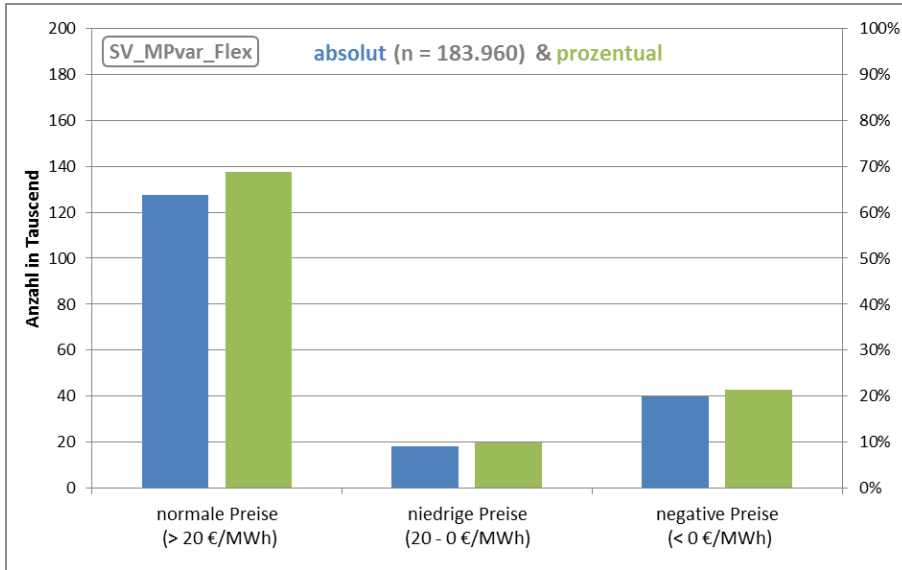
Sv_Wind →
Umkehrung des
historischen Verlaufs des
Ausbaus



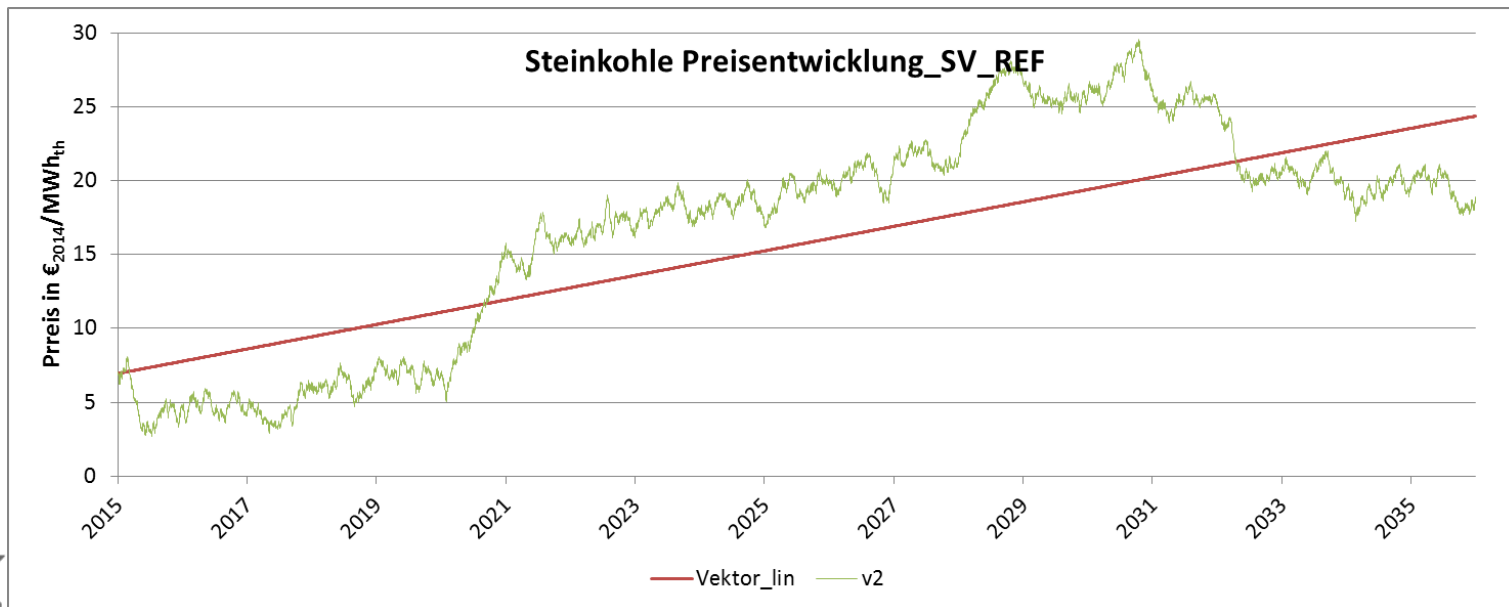
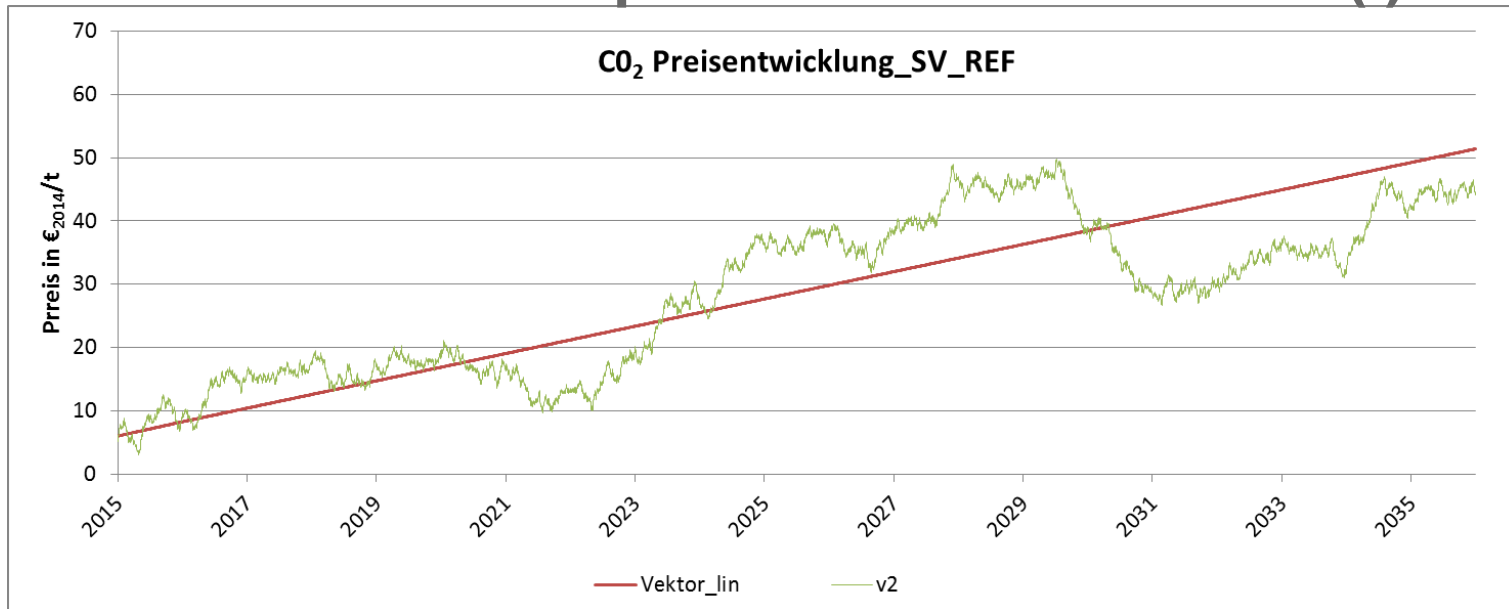
Börsenpreise in den Szenarien (I)



Börsenpreise in den Szenarien (II)



CO₂ und Brennstoffpreise in den Szenarien (I)



CO2 und Brennstoffpreise in den Szenarien (II)

