TECHNISCHE UNIVERSITÄT DRESDEN

Feed-in Tariffs for Photovoltaics: Learning by Doing in Germany?

Conference on the
"Economics of Energy Markets"

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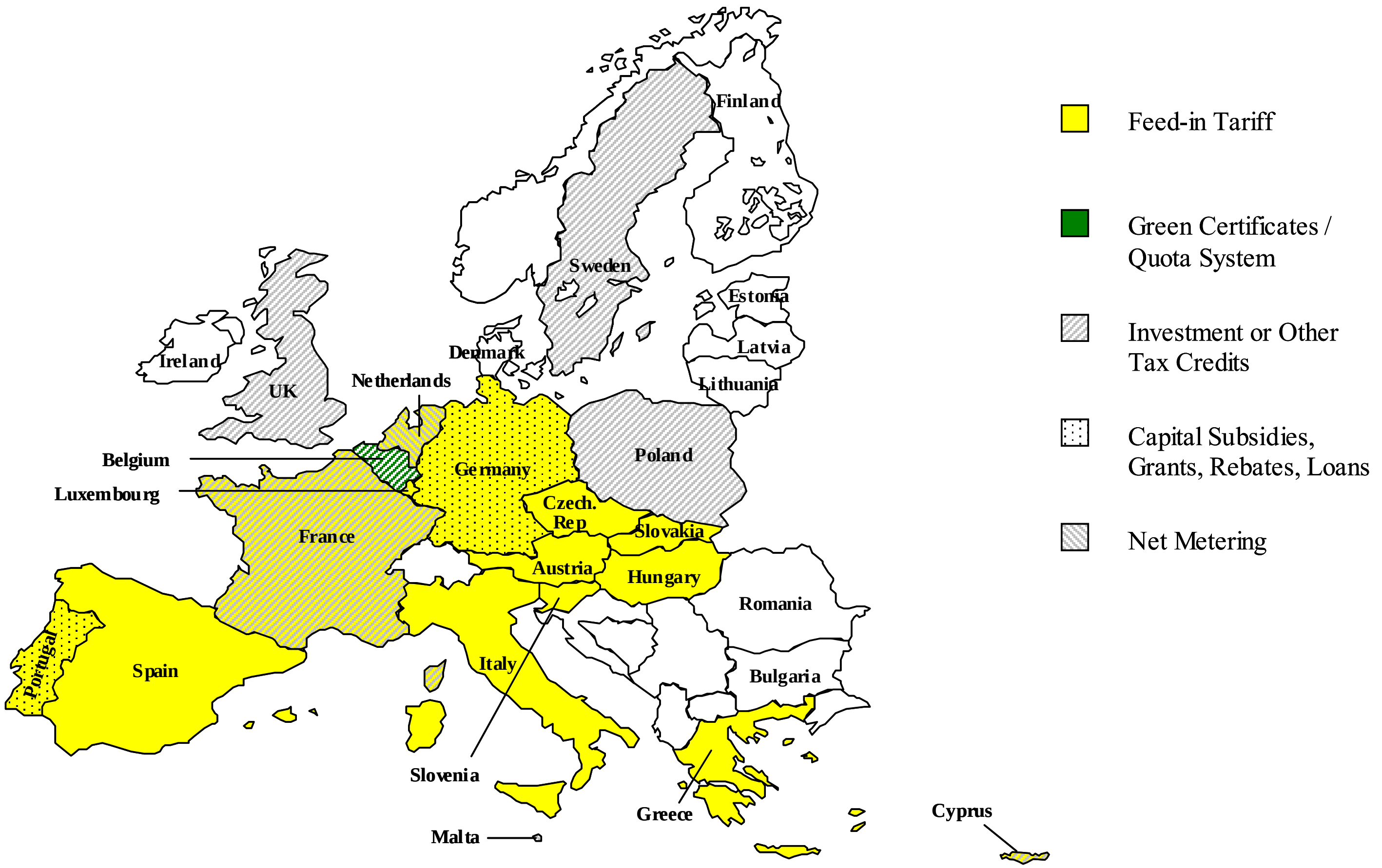
Robert Wand, **Florian Leuthold**

Chair of Energy Economics and Public Sector Management
Workgroup for Economic and Infrastructure Policy

Agenda

1. Introduction
2. The Model
3. Data and Parameterization
4. Base Case Results
5. Scenarios
6. Conclusions

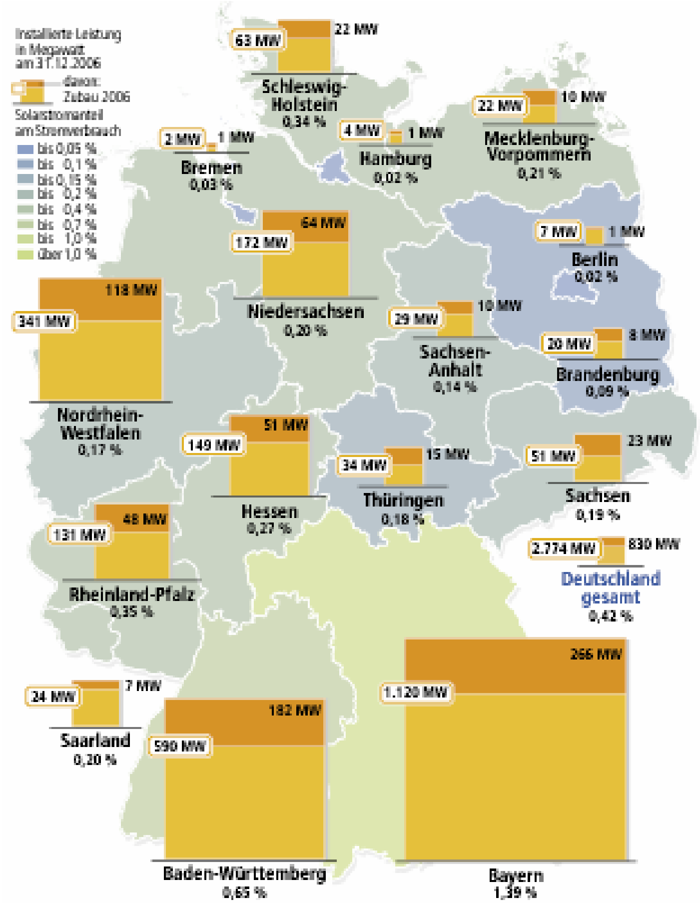
Energy Policy Instruments for Photovoltaic Power Generation



Source: Illustration according to data from REN21 (2008), HEBE (2009), IEA (2008d)

Introduction and Motivation

Installed PV Capacities in Germany



Source: Photon (2007)

Motivation

- **Feed-in tariffs for 2009-2012**
- **Residential PV as costliest among the EEG-supported technologies**
- **Learning by doing (LBD) as expected benefit**
- **Recent studies:**
  - **Aggregated cost-benefit analyses for EEG** (BMU, 2008)
  - **PV-specific: orient to feed-in tariffs in the past** (Frondel et al., 2008)

The German Renewable Energy Sources Act (EEG)

- **Fixed feed-in tariff for 20 years**
- **Choice between feed-in tariff or bonus for self-supply**

Remuneration scheme for small-scale rooftop systems

Year	Installed Capacity x in Previous Year	Degression Rate	Feed-in Tariff
2009	irrelevant	8%	0.4301 €/kWh
2010	< 1000 MW 1000 MW ≤ x ≤ 1500 MW < 1500 MW	7% 8% 9%	0.4 €/kWh 0.396 €/kWh 0.3914 €/kWh
2011	< 1100 MW 1100 MW ≤ x ≤ 1700 MW < 1700 MW	8% 9% 10%	Depends on tariff in previous year
2012	< 1200 MW 1200 MW ≤ x ≤ 1900 MW < 1900 MW	8% 9% 10%	Depends on tariff in previous year

Source: Own illustration

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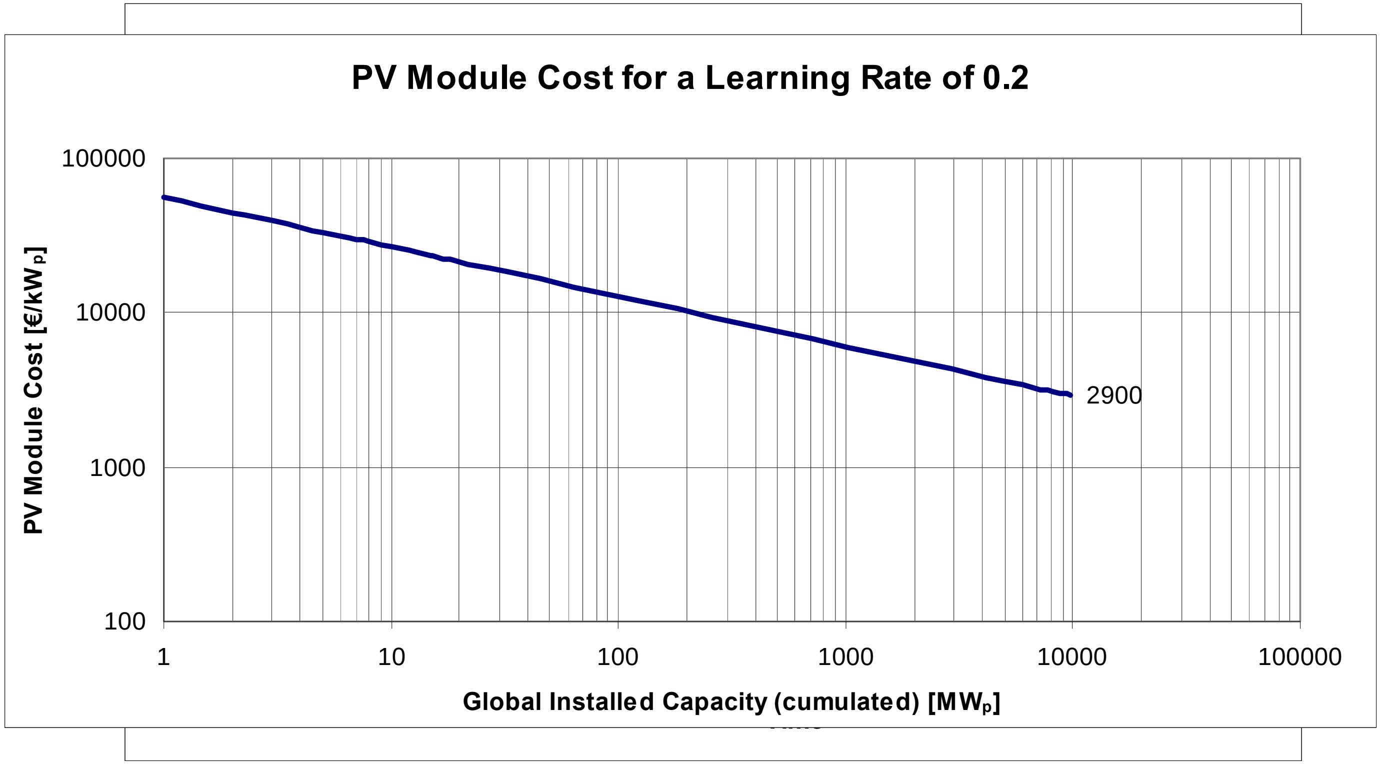
Technological Change

Stages according to Schumpeter (1934):



Note: Exemplified illustrations

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The Model - Scope and Design

- **Partial cost-benefit model (does not consider PV's employment effects and security of energy supply)**
- **Model period: 2009 - 2030**
- **Grid-tied PV installations**
- **Residential PV-systems (<= 10 kWp)[1]**
  - **Historic data available**
  - **Relatively homogeneous investment conditions and technology (mSi, pSi)**
  - **Costliest sector**
  - **Considerable market share of approximately 40% of total German installed capacity (Staiß, 2007)**
- **EEG-bonus for domestic use not included (higher capital costs owing to fluctuating household electricity prices)**

[1] PV capacity is measured in kilo Watt peak (kWp), being defined as the power of a module under standard testing conditions (STC) of 1,000 Watt/m² of irradiance, at 25 degree centigrade cell junction temperature on a solar reference spectrum of air mass 1.5.

EE²

Objective Function

$$\max_{s_t} W = \sum_t \frac{q_t \cdot cap_{av}\left(\sum_{l=0}^{25} \frac{yield \cdot C_{ext}}{(1+r)^l} + CB_t - \left[\sum_{n=0}^{20} \frac{yield \cdot s_t \cdot p_{el,t}}{(1+r)^n}\right]_t\right)}{(1+r)^t}$$

$$s_t \geq 0$$

$$s_t = \frac{FIT_t - p_{el,t}}{p_{el,t}}$$

W	Welfare
Q_t	Demand in period t
cap_{av}	Average installation capacity
C_{ext}	Avoided external cost
$yield$	Annual electricity production per kWp
l	PV system lifetime periods
FIT_t	(Optimal) Feed-in tariff in period t
CB_t	Consumer benefit in period t
s_t	Subsidy in period t (as surplus on electricity price)
$p_{el,t}$	Electricity price in period t (net of taxes / charges)
r	Social discount rate
t	Period, year
n	Feed-in tariff periods

Learning-by-Doing and Consumer Benefit

$$C_t^{Invest} = C_0^{Panel} \cdot \left(Q_{2007}^G \cdot \left[1+g_{panel}\right]^t\right)^{-\beta_{panel}} + C_0^{BOS} \cdot \left(Q_{2007}^D + \sum_{1}^{t-1} q_t \cdot cap_{av}\right)^{-\beta_{BOS}}$$

Global learning (exogenous) — Regional learning (endogenous)

$$C_t^{Operation} = C_t^{Invest} \cdot \vartheta$$

$$CB_t = \left[C_t^{Invest}(0) - C_t^{Invest}(FIT_t)\right] + \sum_{l=0}^{25} \frac{C_t^{Operation}(0) - C_t^{Operation}(FIT_t)}{(1+r)^l}$$

C_t^{Invest}	Welfare
$C_t^{Operation}$	Demand in period t
Q_t	Demand in period t
G_{panel}	Global growth PV panel market (exogenous)
cap_{av}	Average installation capacity
0	No-policy case
β_{Panel}	Learning coefficient PV panels (global learning)
β_{BOS}	Learning coefficient Balance of System components (regional learning)
Q_{2007}^G	Global installed PV capacity in 2007
Q_{2007}^D	Installed PV capacity in Germany in 2007
ϑ	O&M cost coefficient
FIT_t	Optimal policy of feed-in tariffs

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Demand Specification

$$NPV_t = -C_t^{Invest} + \underbrace{\sum_{n=0}^{20} \frac{(1+s_t)\cdot p_{el,t}\cdot yield - C_t^{Operation}}{(1+i)^n}}_{\text{EEG remuneration periods}} + \underbrace{\sum_{m=21}^{25} \frac{p_{el,(t+m)}\cdot yield - C_t^{Operation}}{(1+i)^m}}_{\text{Post feed-in tariff periods}}$$

Demand specification according to Benthem et al. (2008):

$$q_t = \frac{a_t q_{\max}}{a_t + (q_{\max} - a_t)\cdot e^{-b*NPV_t}} + diff_t$$

$$diff_t = \gamma \cdot q_{t-1} \cdot \left(1 - \frac{q_{t-1}}{q_{\max}}\right)$$

$$a_t = a_{t-1} \cdot \left(\frac{q_{t-1} + diff_{t-1}}{q_{t-1}}\right)$$

$$s_t \geq 0$$

$$NPV_t \geq 0$$

NPV_t	Net present value in period t
C_t^{Invest}	Investment cost for residential solar system in period t
$C_t^{Operation}$	Operation and maintenance cost (annuity)
a_t	Parameter
b	Parameter
γ	Diffusion parameter
$diff$	Diffusion term
q_{max}	Maximum annual residential PV installations
s_t	Subsidy
i	Investor‘s discount rate for PV investment

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Data and Parameterization

	Parameter	Denotation	Value	Unit	Data Source
Learning	Learning coefficient PV panels	β^{Panel}	0.322		Own calculations, using a LR of 0.2
	Learning coefficient BOS	β^{BOS}	0.234		Own calculations, using a LR of 0.15
	Investment cost for first production unit PV panels	C_0^{Panel}	57.2	€/Wp	Based on above LR and current module prices, PVXchange (2009b)
	Investment cost for first production unit BOS	C_0^{BOS}	7.9	€/Wp	Based on above LR, PVXchange (2009a), Photon (2008a)
Market Data	Cumulated residential PV capacity in in 2007	Q_{2007}^{D}	1196	MWp	Own calculation, based on BSW Solar (2009) and Transmission System Operator data
	Cumulated global crystal silicon PV capacity in 2007	Q_{2007}^{G}	10500	MWp	IEA (2008), Staiß (2007)
	German demand in 2007	q_{2007}	52.234	Thousand	Own calculations, BSW Solar (2009)
	German demand in 2008	q_{2008}	71.2	Thousand	Own estimation, BSW Solar (2009)
	Maximum annual German market size	q^{max}	277	Thousand	Own calculations, Kaltschmitt et al. (2002), Kaltschmitt and Fischedick (1995)
	Retail electricity price in 2008 (net of taxes and charges)	p_{2008}^{el}	0.12	€/kWh	Nitsch (2008), price path B
	Average growth global PV panel production 2009-2030	g^{Panel}	15	% p.a.	EPIA and Greenpeace (2008), Roland Berger Strategy Consultants (2007), Frost & Sullivan (2006)
Discount Factors	Social discount rate	r	3	% p.a.	Evans and Sezer (2005)
	Investor-specific discount rate (opportunity cost)	i	4.8	% p.a.	Deutsche Bundesbank (2009)
Demand	Demand function parameter	a_0	14.215		Own calculations, based on Transmission System Operator data
	Demand function parameter	b	0.384		Own calculations, based on Transmission System Operator data
	Diffusion parameter	γ	0.135		Own calculations, based on Transmission System Operator data
Other Parameters	Specific external cost	c^{ext}	0.034	€/kWh	Krewitt and Schlomann (2006), Dones et al. (2005), Klobasa et al. (2009)
	Specific electricity yield	$yield$	0.95	MWh/kWp	Solarenergie-Förderverein Deutschland (2009), Staffhorst (2006)
	O&M cost coefficient	ϑ	0.015		Staffhorst (2006), Dürschner (2009)
	Average PV system capacity	cap_{2008}^{av}	5.46	kWp	Own calculations, based on Transmission System Operator data

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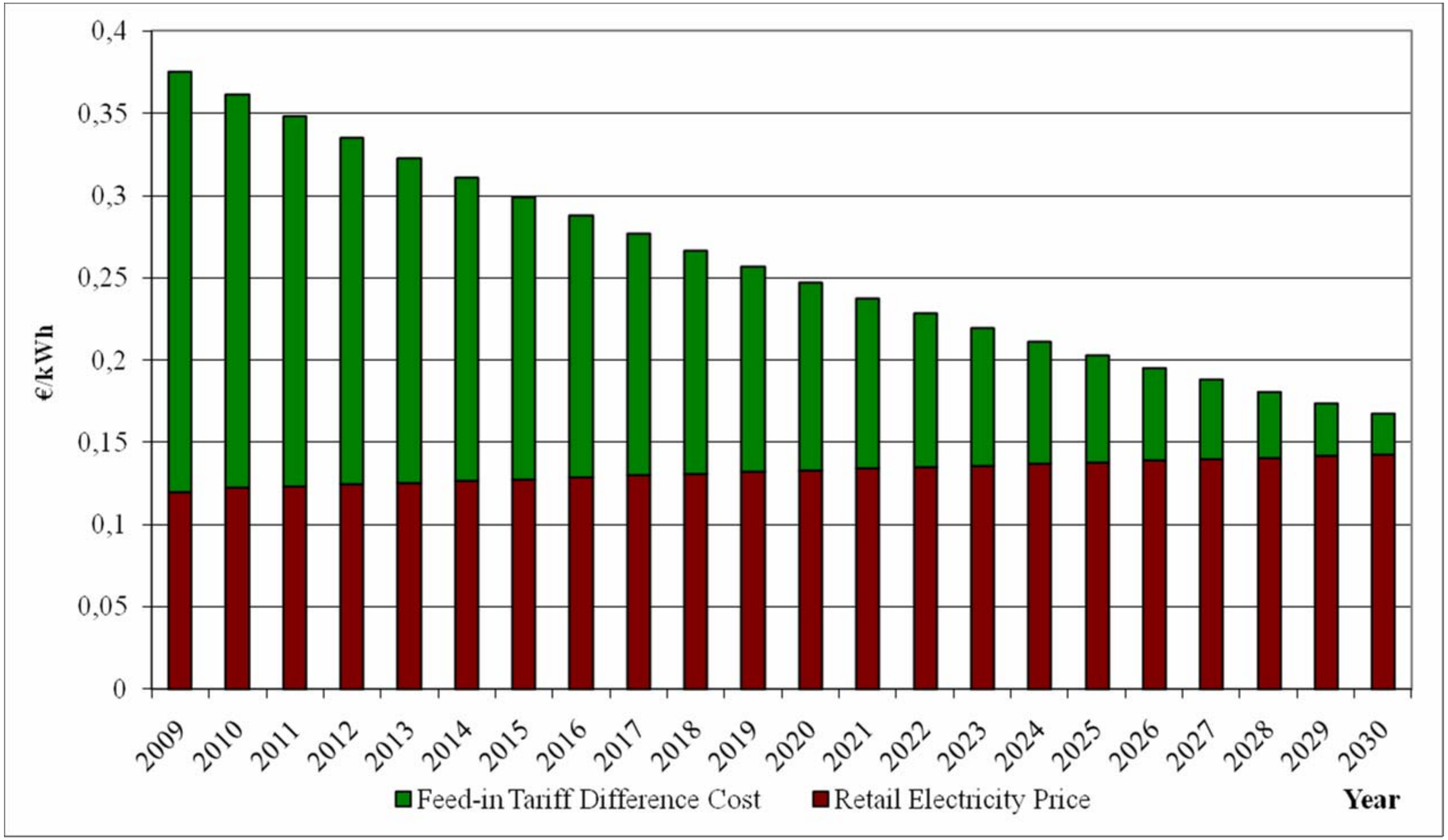
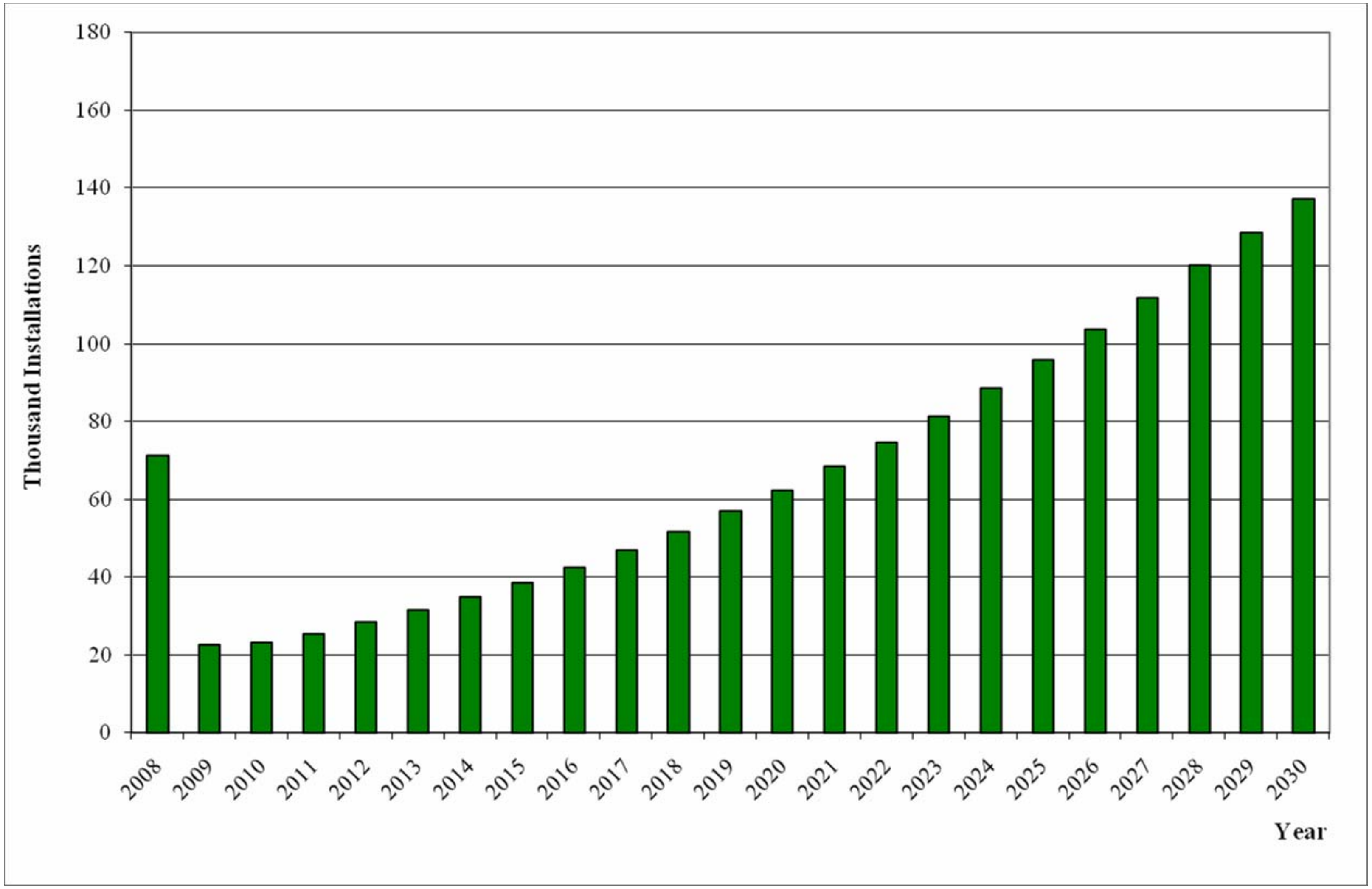
Feed-in Tariffs (Base Case)

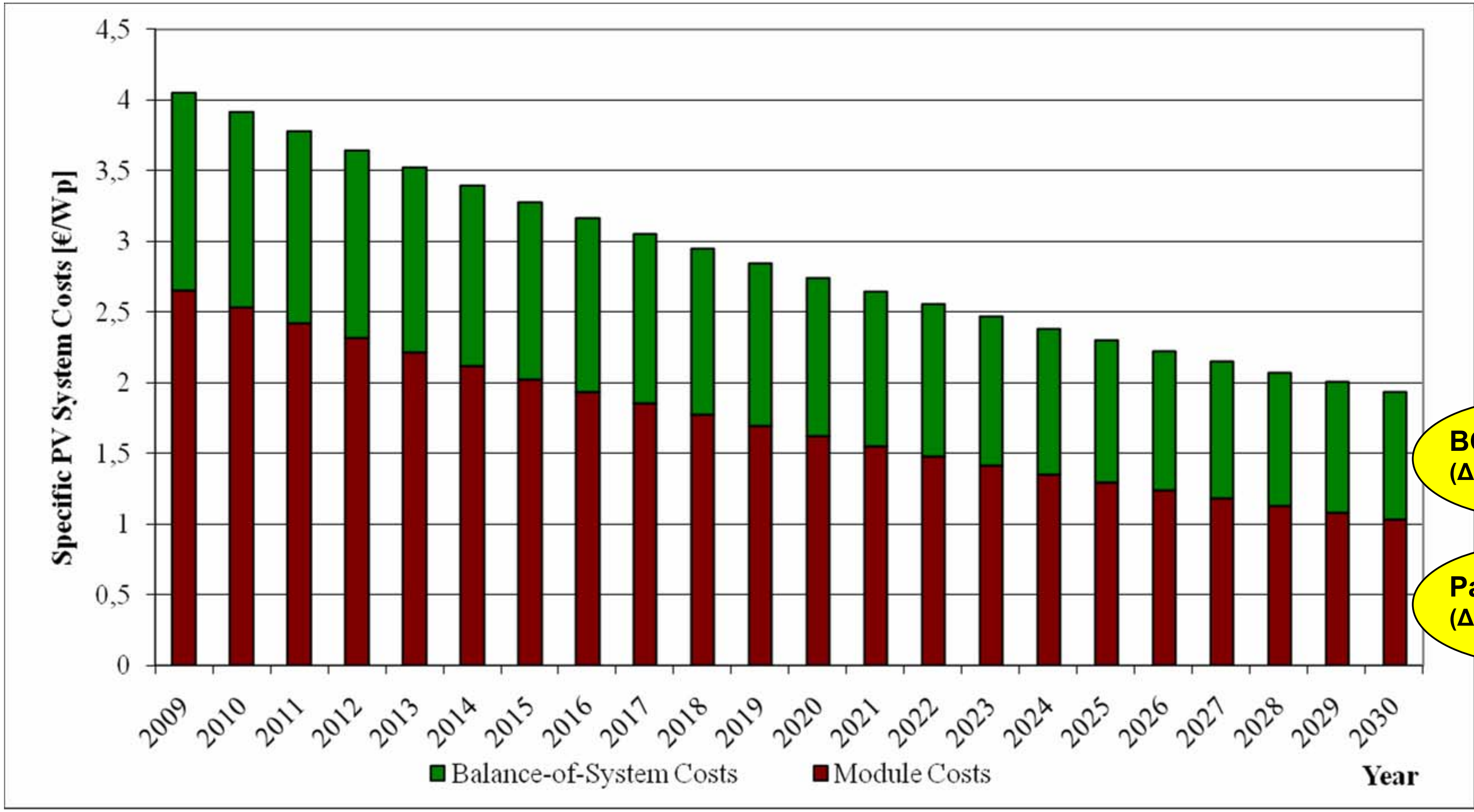


- **Feed-in tariff in 2009: 0.375 €/kWh → reduction against 2008: 19.8%**
  → 12.8% below EEG level

Demand (Base Case)



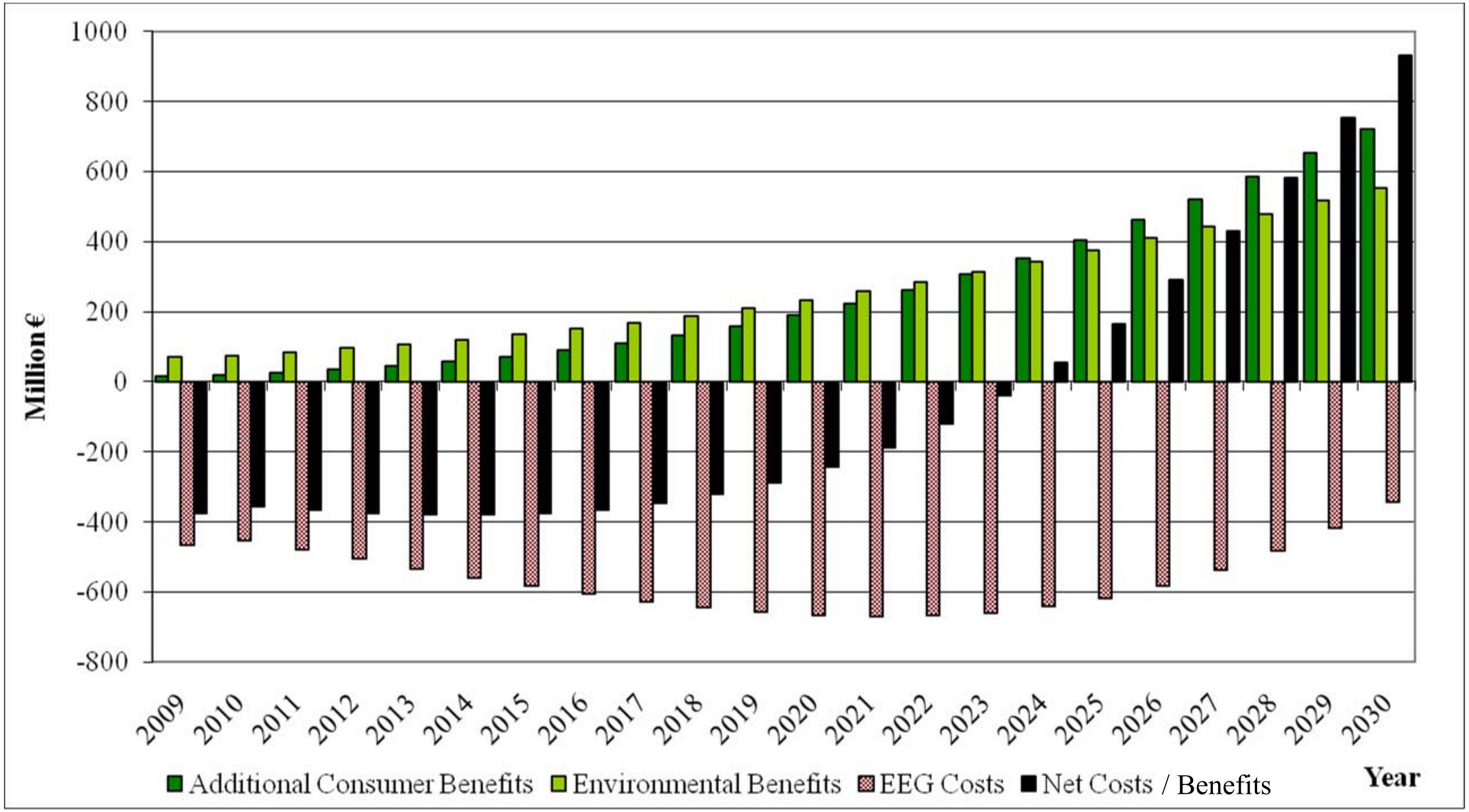
PV System Costs (Base Case)



BOS: -35%
(Δ=0.49 €/Wp)

Panel: -61%
(Δ=1.62 €/Wp)

Social Costs and Benefits (Base Case)



NPV of residential PV promotion's net social costs (2009-2030): - 2.014 bn €

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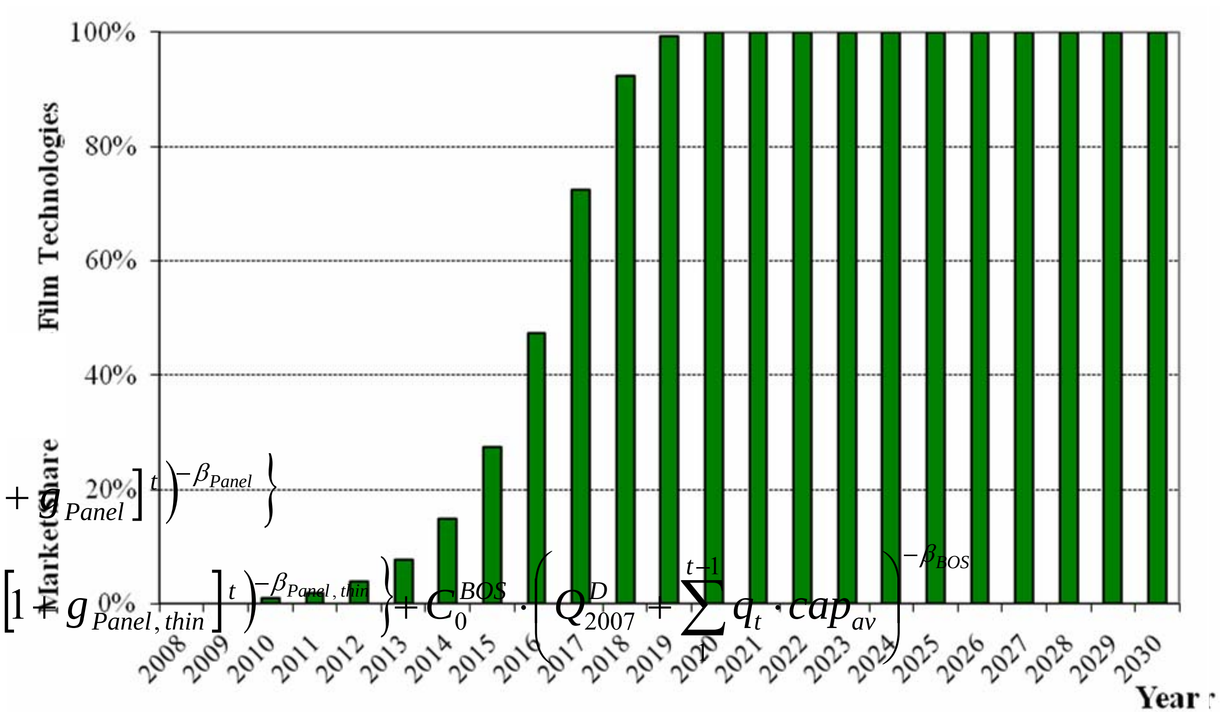
Scenario Description (I/II)

- **Scenario 1: "Economic Growth"**

Input Parameter	Scenario 1	Base Case (BAU)
Investor-specific discount rate i	5.8% p.a.	4.8% p.a.
Retail electricity price $p_{el,t}$	Growth rate of 3% p.a.	Nitsch (2008), price path B (moderate)
Annual market growth for crystalline PV panels g_{Panel}	20% p.a.	15% p.a.
Avoided external cost C_{ext}	0.05 €/kWh	0.034 €/kWh

Scenario Description (II/II)

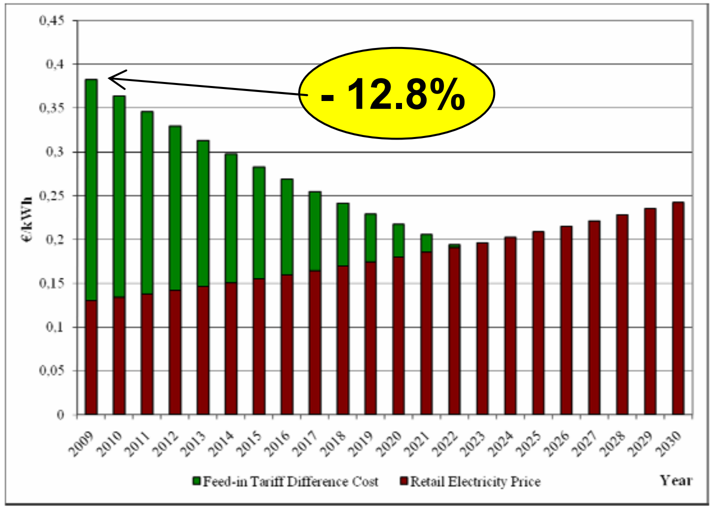
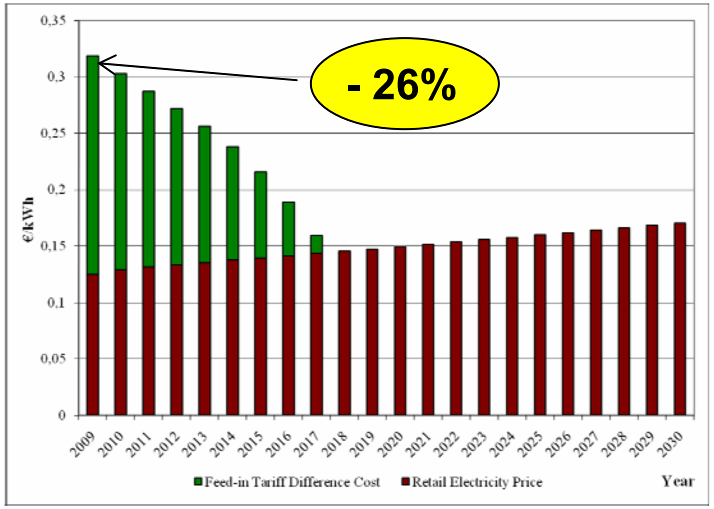
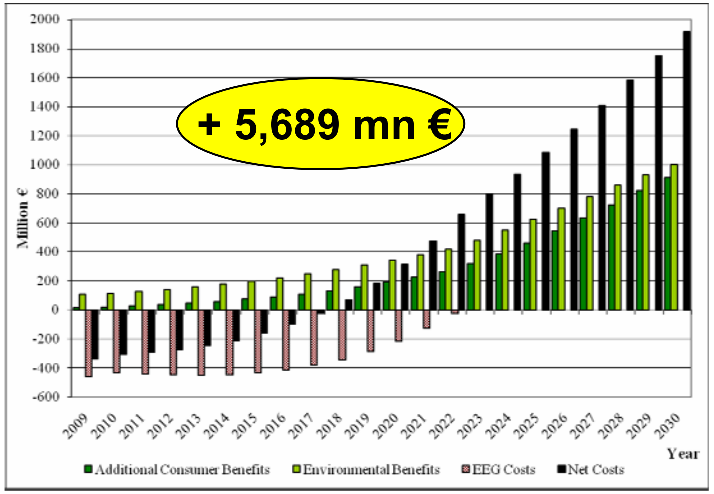
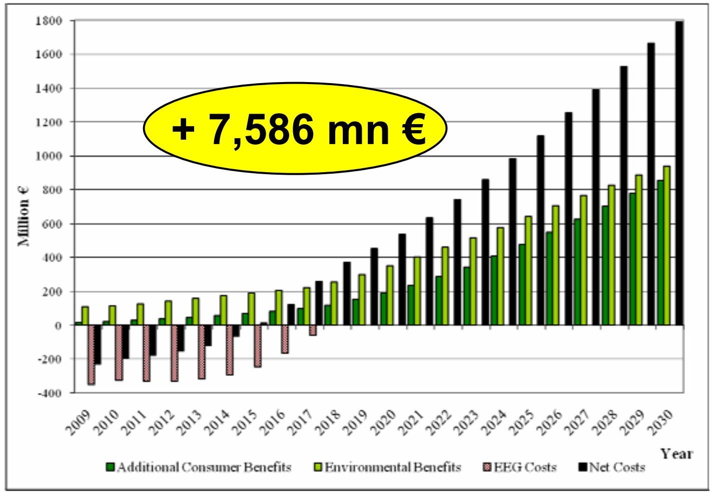
- Scenario 2: "A Bright Future for PV"
  - Favorable environment for PV as a fledgling technology (cost competitiveness in high solar irradiation regions)
  - Thin-film technologies penetrate into the market for residential PV installations
  - Higher progress ratio for thin-film technologies (PR=0.7)
  - Lower discount rate (3% p.a.) and increased external costs (cf. scenario 1)



- Adjusted learning curve:

$$C_t^{Invest} = (1-ms_t)\left\{C_0^{Panel}\cdot\left(Q_{2007}^{G}\cdot[1+g_{Panel}]^{t}\right)^{-\beta_{Panel}}\right\} + ms_t\left\{C_{0\,thin}^{Panel}\cdot\left(Q_{2007}^{G,thin}\cdot[1+g_{Panel,thin}]^{t}\right)^{-\beta_{Panel,thin}}\right\} + C_0^{BOS}\cdot\left(Q_{2007}^{D}+\sum^{t-1} q_t\cdot cap_{av}\right)^{-\beta_{BOS}}$$

Scenario Results

	Scenario 1 ("Economic Growth")	Scenario 2 ("Bright Future")
Feed-in Tariffs		
Social Costs and Benefits		

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Results show that the EEG's current feed-in tariffs for residential PV are too high

Results (contd.)

- PV's welfare effect strongly depends on the chosen scenario
- In the positive scenarios, residential PV reaches grid-parity until 2030
- Sensitivity Analysis:
  - Welfare effects are primarily influenced by
    - Learning effects
    - Discount rates
  - Demand is primarily influenced by
    - Demand parameter calibration

Conclusions

- Residential PV's current promotion scheme in Germany according to the EEG should be reconsidered
- Induced regional learning effects in PV equipment production are limited
- Employment effects and aspects of security of energy supply have not been taken into account
- Real options approach: accumulation of knowledge and value of PV as strategic technology deployment?

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TU berlin

Thank you very much for your attention!
Questions or comments are highly appreciated.

Robert Wand: rw@wip.tu-berlin.de
Florian Leuthold: florian.leuthold@tu-dresden.de

Chair of Energy Economics and Public Sector Management
Workgroup for Economic and Infrastructure Policy

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