The role of policy design in inducing technological change in the energy sector

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based on work with Leonore Hälg and Marius Wälchli

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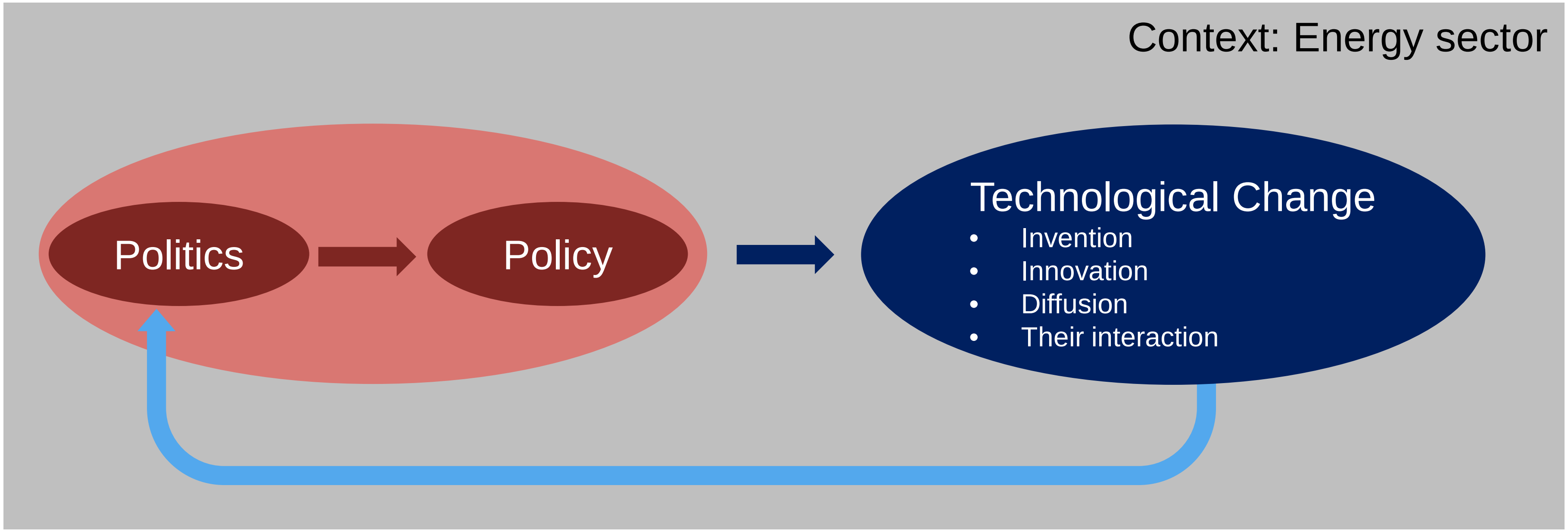
EPG's research framework

We analyze question related to the governance of technological change in the energy sector, particularly around the co-evolution of policy and technology



Our research stresses the role of path dependency in technological and policy change.

Source: www.epg.ethz.ch

Agenda

- **Background**
- Research Question, Approach, and Case
- Methods
- Results
- Discussion

The role of public policy in inducing technological change in the energy sector

- "Technological change is at once the most important and least understood feature driving the future cost of climate change mitigation" (Pizer and Popp, 2008, p. 2768).
- Technological change = invention, innovation, and diffusion of new technologies
- To avoid dangerous levels of climate change we need to accelerate and re-direct technological change in energy-related sectors (BAU rate & direction not enough)
- Several market/system failures involved in technological change in the energy sector: emission externality; knowledge spillovers from R&D and learning-by-doing/using; path dependency

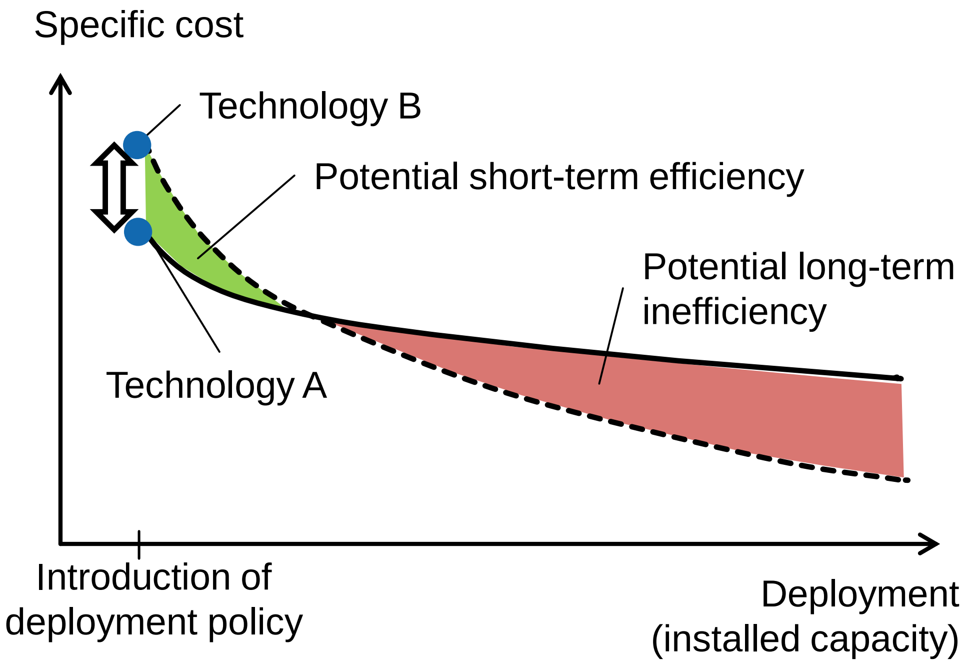
⇒ What is the most cost-effective policy (mix)?

- Most research has focused on instrument type a vs b, but results often contradicting
- Some scholars argue that the policy design is more important than the instrument type
- One key design criterion is the *technology-specificity* of a policy

Policy interventions themselves can create lock-ins

4 determinants of technological path dependency:[1]
1. Large fix cost
2. Network effects
3. Shared expectations
4. **Learning effects**

- Assuming technological substitutes, costs are key adoption criterion[2]
- Cost differences at market introduction can determine technology selection by users (often found in energy sector)



Potential downsides of lock-in:
- Premature lock-in can lead to short term efficiency but long-term inefficiency[1]
- Systems with low diversity are less resilient to external shocks[3]

How to design deployment policies in order to avoid technological lock-in?

[1]Arthur, W., 1989. Competing technologies, increasing returns, and lock-in by historical events. The Economic Journal 99, 116–131.
[2]Abernathy, W.J., Clark, K.B., 1985. Innovation: Mapping the winds of creative destruction. Research Policy 14, 3 – 22.
[3]Stirling, A., 2007. A general framework for analysing diversity in science, technology and society. Journal of the Royal Society Interface 4, 707–719.

Source: Schmidt et al. (2016). Do deployment policies pick technologies by (not) picking applications? – A simulation of investment decisions in technologies with multiple applications. Research Policy 45, 1965-1983.

How to avoid lock-in through deployment policies?

Technology-specific policies school[1] argues…

- Markets select on short-term basis
- Risk and downsides of lock-ins too high

Þ (Complementary) technology specific instruments to level playing field

Technology-neutral policies school [2] argues…

- Policy decisions driven by political considerations, not market signals
- "Policy makers bad at picking winners"

Þ Technology-neutral instruments

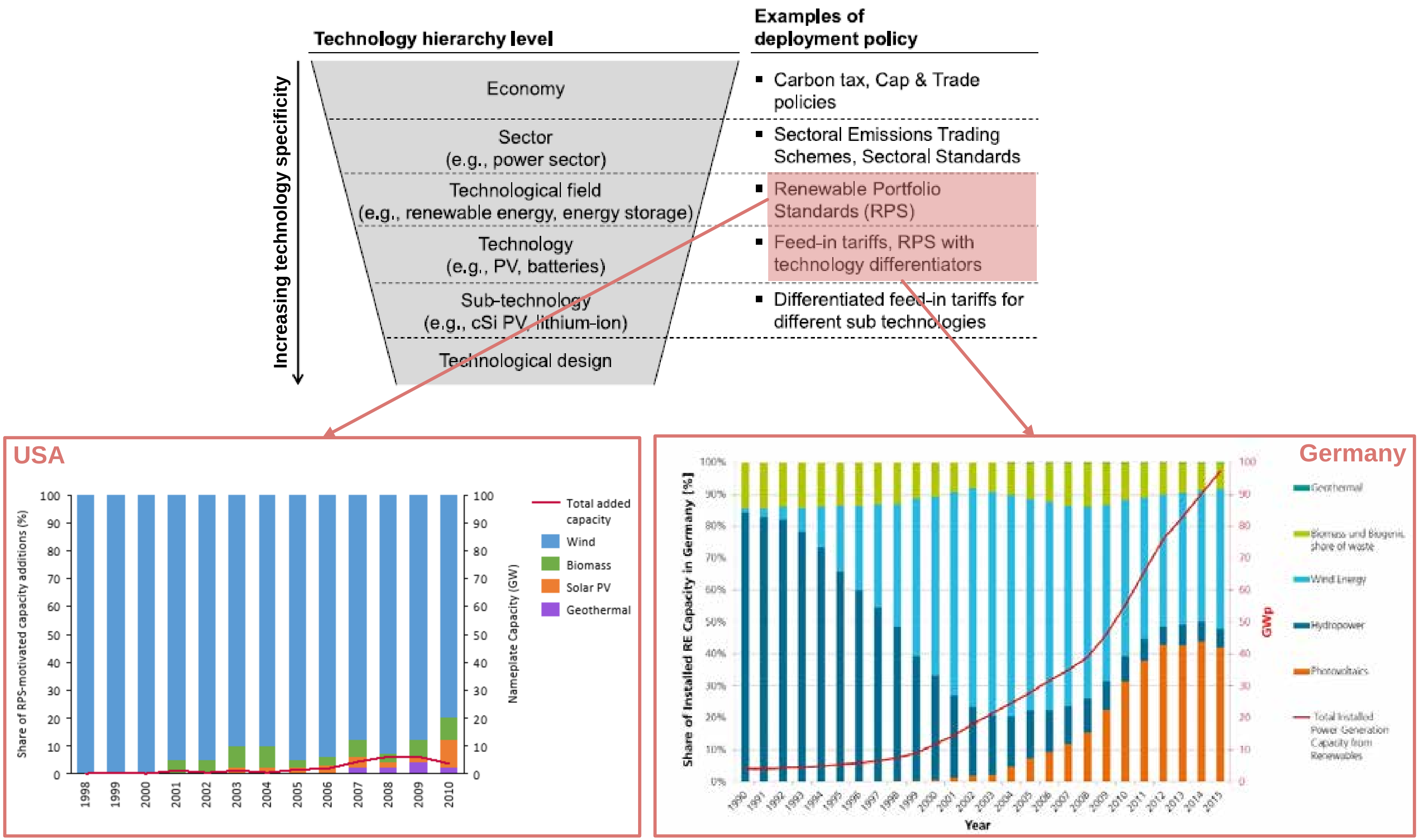
Overcoming the dichotomy:

- Technological change on different hierarchy levels[3]
- Policies can only be specific only on one hierarchy level [4]

[1] e.g., Aghion, P., David, P.A., Foray, D., 2009. Science , technology and innovation for economic growth: Linking policy research and practice in "STIG Systems." Res. Pol. 38
[2] e.g., Metcalf, G.E., 2009. Tax Policies for Low-Carbon Technologies. National Tax Journal 62
[3] Winskel, M., et al. 2013. Learning pathways for energy supply technologies: Bridging between innovation studies and learning rates. Tech. Forecast. & Soc. Change 81
[4] Azar, C., Sandén, B., 2011. The elusive quest for technology-neutral policies. Environmental Innovation and Societal Transitions 1, 135–139.

Source: Schmidt et al. (2016). Do deployment policies pick technologies by (not) picking applications? – A simulation of investment decisions in technologies with multiple applications. Research Policy 45, 1965-1983.

Deployment Policy Design for Renewable Energy Technologies (RET)



Sources: Schmidt et al. (2016). Do deployment policies pick technologies by (not) picking applications? – A simulation of investment decisions in technologies with multiple applications. Research Policy 45, 1965-1983.
USA: EPG (ETH Zürich) with data from Barbose, G. (2016). U.S. Renewables Portfolio Standard – 2016 Annual Report. Lawrence Berkeley National Laboratory, Berkely CA., Germany: Fraunhofer ISE, Photovoltaics Report, Germany. Freiburg im Breisgau.

Preliminary empirical results point to the technology-selection effect of policy mixes' technology-specificity

Regression of policy mixes' technology-specificity on technology diffusion

	Bioenergy	Wind	PV
IPA.Economy	0.002	-0.003	0.001
IPA.Sector	0.001	-0.009	0.005
IPA.Field	**0.009*****	0.010	-0.007
IPA.Tech.i	0.0004	**0.012*****	**0.014*****
IPA.Tech.1-i	0.001	0.002	0.003
Adjusted R sq	0.934	0.919	0.710

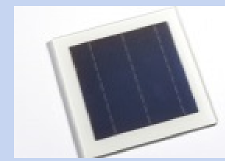
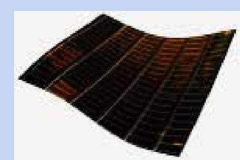
*p<0.1; **p<0.05; ***p<0.01

Background:

- Panel data of 9 countries' RE policies over 16 years: 562 policies intotal
- Each policy instrument is weighted by its intensity (see Schaffrin et al. 2015)
- Each policy instrument is coded with its technology-specificity
- Control variables included but not shown on slide
- Country fixed-effects

Source: Schmidt & Sewerin (working paper, 2017)

But policies might also target different applications (of the same technology)

German PV deployment policies	Applications	Technologies
• German 1’000 and 100’000-roofs programs *roof-top application* only		 Crystalline silicon (cSi)
• 2003: Feed-in tariff (FiT) additionally included *open-space applications* (market size and cost arguments)		 Crystalline silicon (cSi)  Thin film (CdTe)

[1]First Solar, 2011. Annual Report 2011. Tempe, AZ, United States.

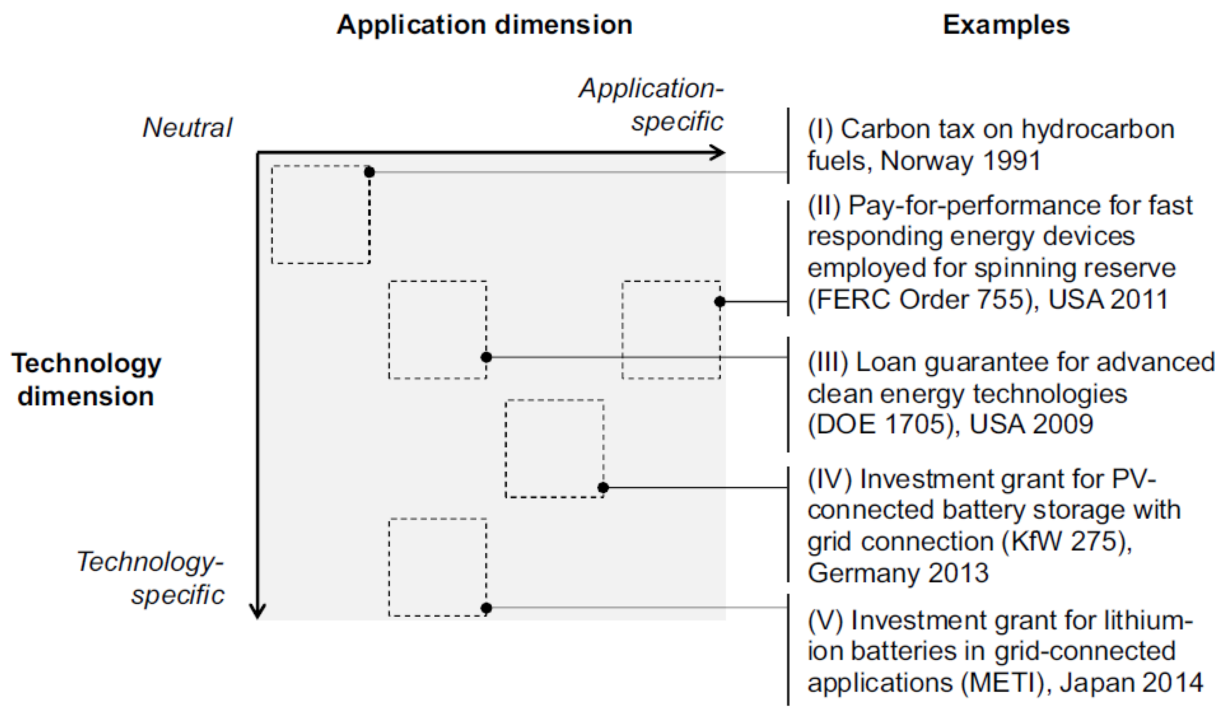
Source: Schmidt et al. (2016). Do deployment policies pick technologies by (not) picking applications? – A simulation of investment decisions in technologies with multiple applications. Research Policy 45, 1965-1983.

Deployment Policy Design for Renewable Energy Technologies (RET)

RET deployment policies may also be **application-specific**

An **application** may be differentiated based on, e.g., the **site** or **size** of an installation.

Technology- and application-specificity of battery deployment policies



LITERATURE GAP

Lack of understanding of the effect of deployment policy design on technology diffusion and lock-in

Source: Schmidt et al. (2016). Do deployment policies pick technologies by (not) picking applications? – A simulation of investment decisions in technologies with multiple applications. Research Policy 45, 1965-1983.

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Research Question and Approach

LITERATURE GAP	Lack of understanding of the effect of deployment policy design on technology diffusion and lock-in
RESEARCH QUESTION	*What is the effect of the deployment policy design on the diffusion and possible lock-in and lock-outs of different sub-technologies?*
CASE	German FIT and its effect on the diffusion of PV sub-technologies thin-film and c-Si along the applications open space and rooftop
APPROACH	Historically calibrated agent-based model simulating investment decisions

Case Selection: Solar Photovoltaics (PV) in Germany

GERMANY

Since 2000, **Renewable Energy Sources Act** (Erneuerbare-Energien-Gesetz) offering technology-specific feed-in tariffs

Germany has been the front-runner in RET and especially solar PV deployment with spendings of **47 bn EUR**[1] on solar PV between 2000 and 2015 **6%**[2] of the total **electricity production** from **solar PV** in 2015

SOLAR PV

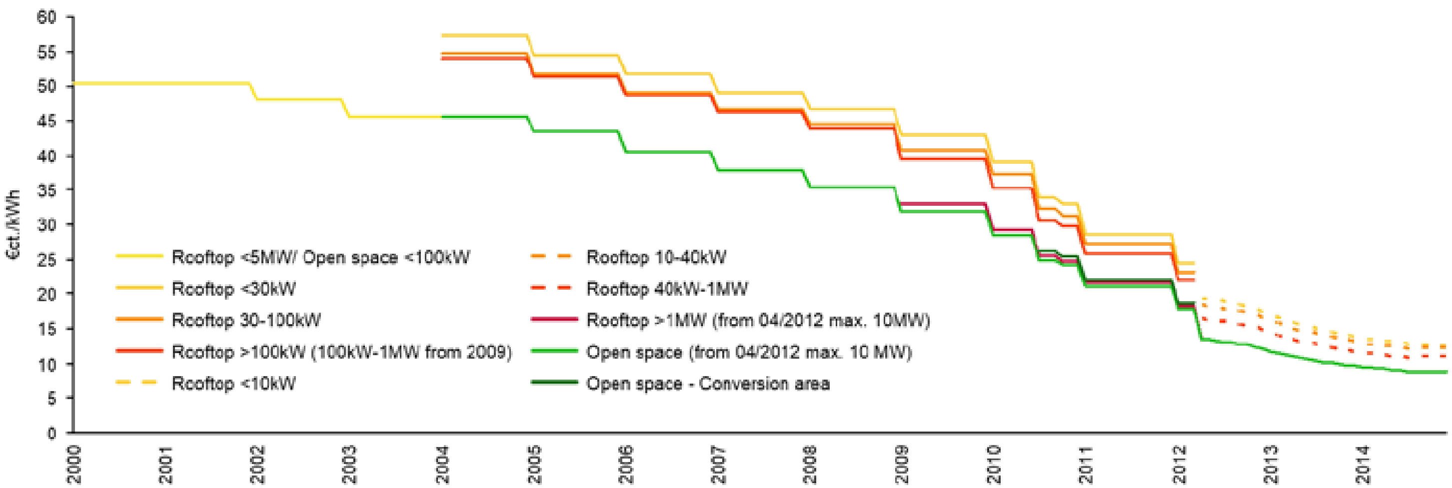
Two predominant technologies:

- Crystalline silicon (c-Si)
- Thin film

EEG differentiates between two main applications (starting in 2004):

- Rooftop (with size differentiation)
- Open space

FEED-IN TARIFFS



1 Bundesministerium für Wirtschaft und Energie (BMWi) (14.10.2016). EEG in Zahlen: Vergütungen, Differenzkosten und EEG-Umlage 2000 bis 2017; 2 Bundesministerium für Wirtschaft und Energie (BMWi) (2016). http://www.bmwi.de/DE/Themen/Energie/Erneuerbare-Energien/erneuerbare-energien-auf-einen-blick.html

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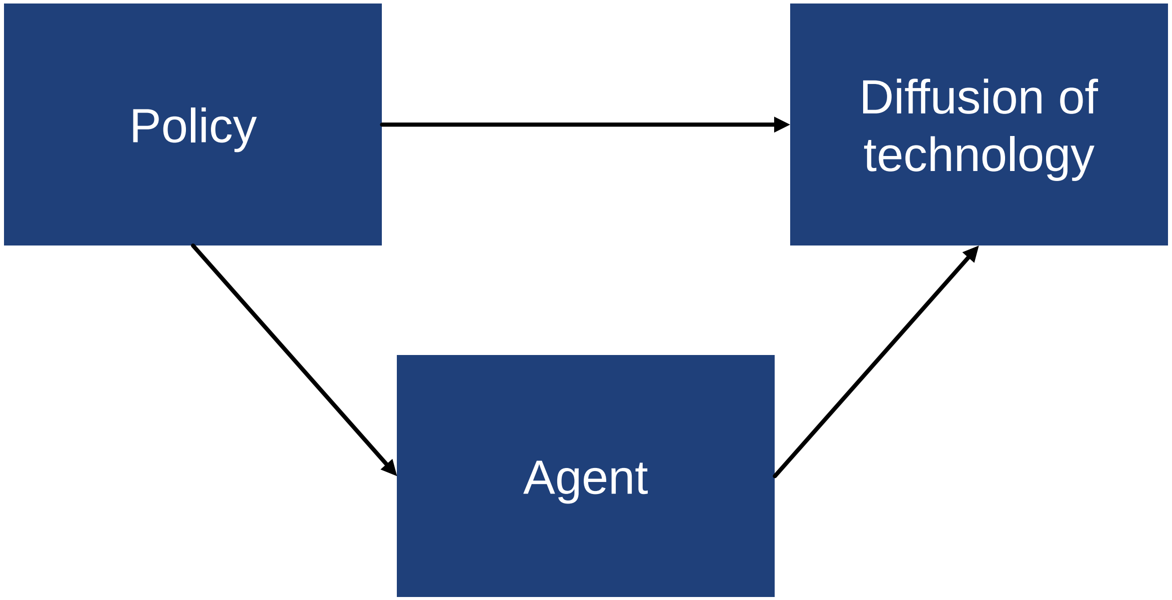
Method

	Activity	Goal
1	Literature review, data analysis	Provide rationales for model development and case selection, define alternative policy scenarios
2	Baseline model development and calibration	"Replay history": Obtain model fittings resulting in diffusion patterns similar to what really happened
3	Development of model for alternative policy scenarios	"Replay alternative history", evaluate the effect of policy design on diffusion patterns
4	Analysis of alternative policy scenarios	Derive implications for future deployment policy design

Agent-based model: Explaining “macro-level” outcomes by modelling “micro-level” decisions

“macro”

“micro”



Background on Modelling Technology Diffusion and Lock-In

Characteristics	Equation based, analytical, representative agents, deterministic	Probabilistic, algorithmic non-analytical	Heterogeneous agents, indirect interaction	Heterogeneous agents, indirect AND local interactions
Examples	Contagion diffusion model	Lock-in model with Polya process	History-friendly model	Agent-based model
	Bass, F. M. (1969), "A New Product Growth Model for Consumer Durables," Management Science , 15, 215–227.	Arthur, W. Brian. "Competing technologies, increasing returns, and lock-in by historical events." *The economic journal* 99.394 (1989): 116-131.	Malerba, Franco, et al. "'History-friendly'models of industry evolution: the computer industry." *Industrial and corporate change* 8.1 (1999): 3-40.	Palmer, Johannes, Giovanni Sorda, and Reinhard Madlener. "Modeling the diffusion of residential photovoltaic systems in italy: An agent-based simulation." *Technological Forecasting and Social Change* 99 (2015): 106-131.

Equation-based framework → Agent-based framework

Trade off: From general and simple/istic to specific and complex.

Baseline and Alternative Policy Scenario (APS) Models

AGENT-BASED MODELS

- Heterogeneous agents (investors) with bounded rationality
- Indirect interactions between agents via price curve
- Direct interactions through peer effect (at installer and individual level)

INVESTMENT DECISION MODULE

Select installation (application, size) with different boundary conditions

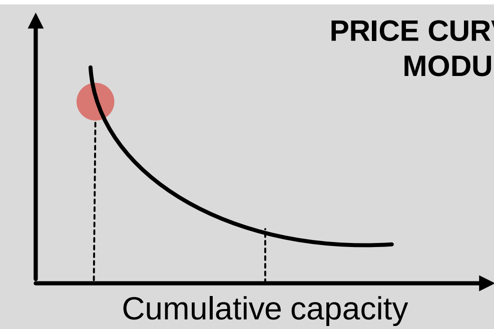
Calculate NPV for both technologies (given different policy designs)

Take investment decision
- No invest
- Invest in Tech1
- Invest in Tech2

Baseline: Historical installation
APS: Distribution based on historical installations

Number of iterations per year
Baseline: Historical installations
APS: Number of investment decisions from calibration

PRICE CURVE MODULE



Source: Working paper, Haelg, Waelchli, Schmidt (2017)

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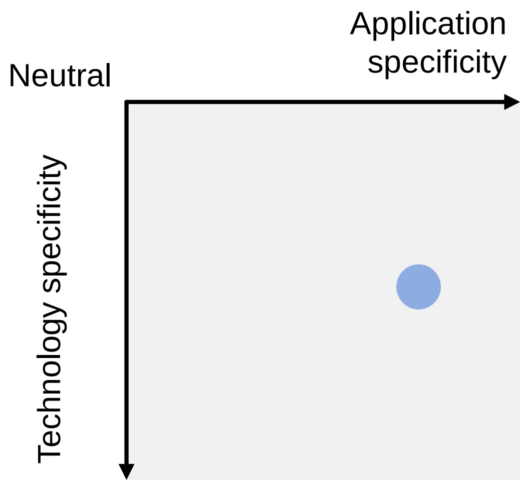
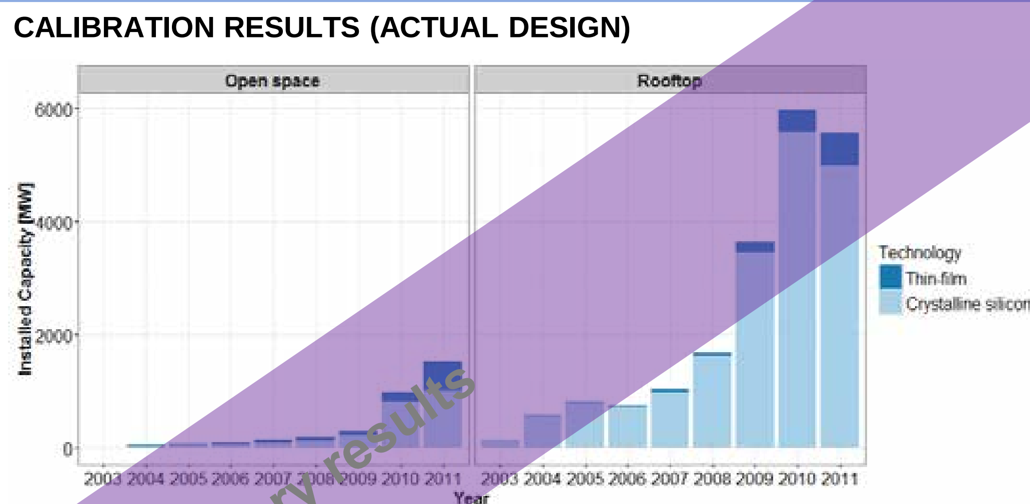
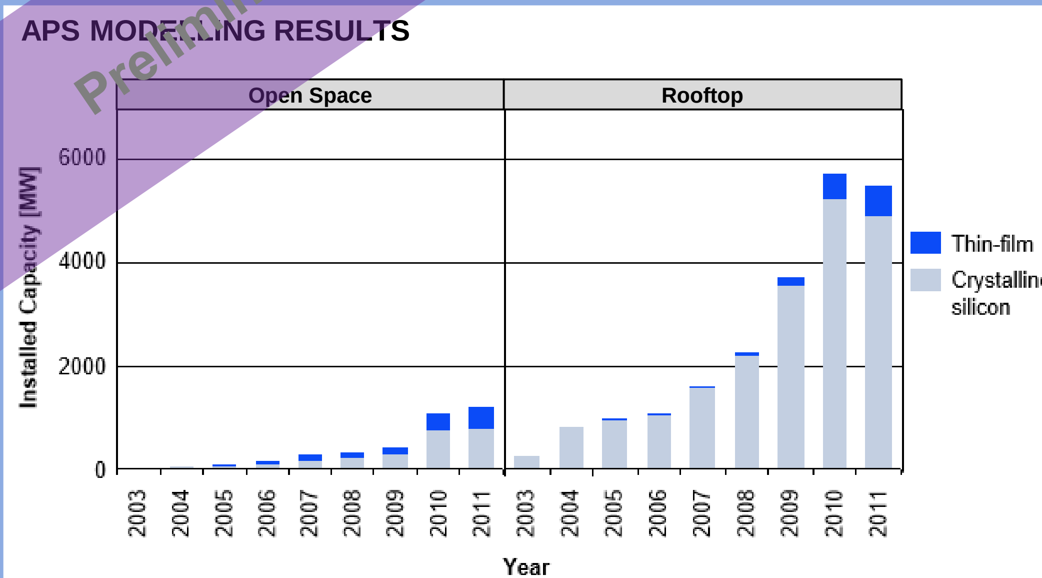
Alternative Policy Scenarios – Historical FiT





Historical feed-in tariff in Germany

- Application-specific
- Technology neutral (subtechnology)

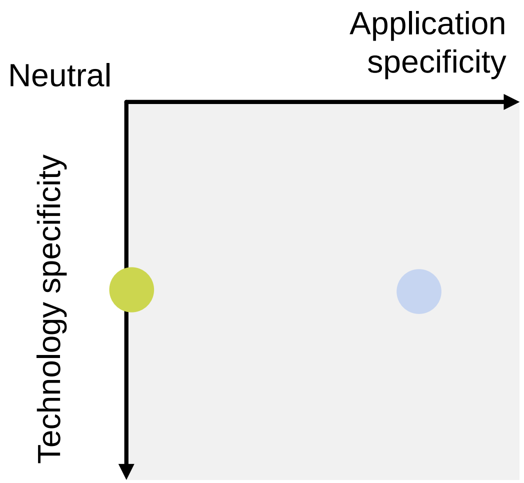


Very **similar results** even though the models use different boundary conditions

Validity of APS model is given

Source: Working paper, Haelg, Waelchli, Schmidt (2017)

Alternative Policy Scenarios – Technology/Application Neutrality



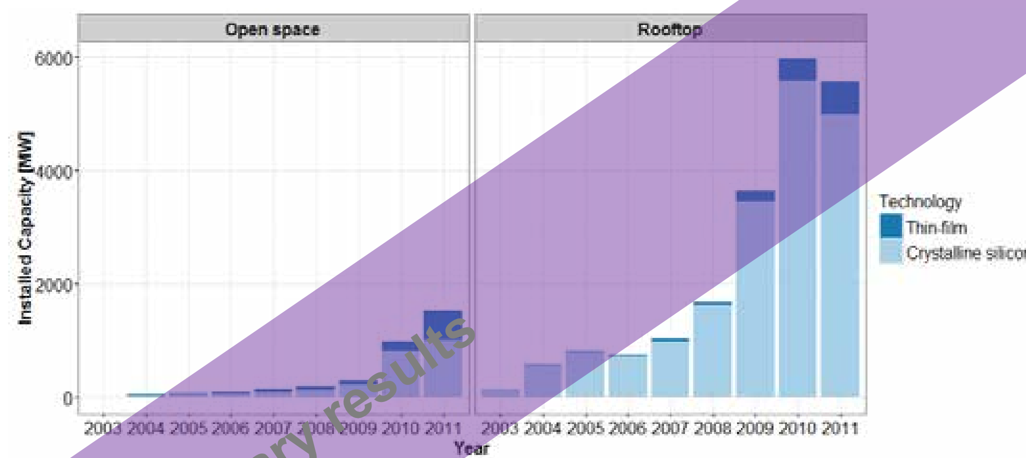
APS 1

- Application neutral
- Technology neutral
- **Historical open space FiT for all applications**

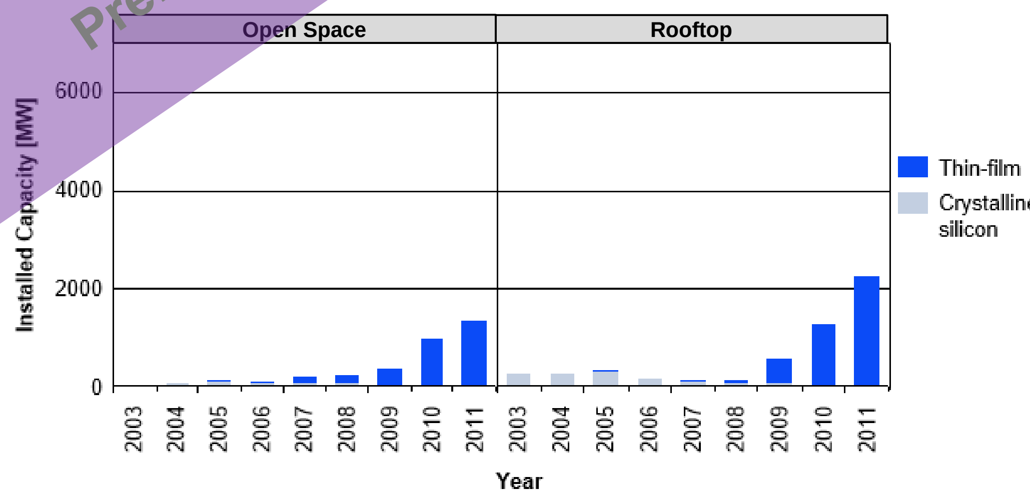
Lower overall diffusion (especially rooftop application)

Lock-in to thin film

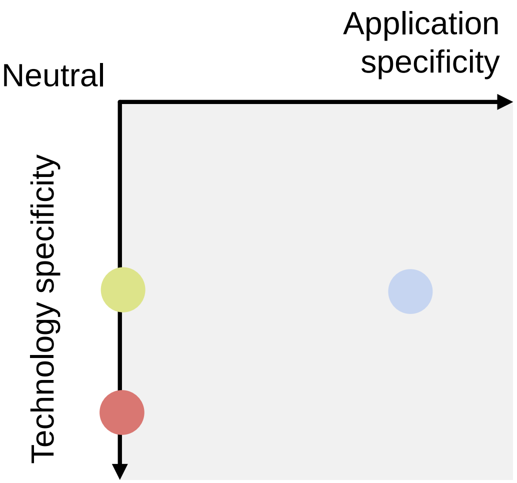
CALIBRATION RESULTS (ACTUAL DESIGN)



APS MODELLING RESULTS



Alternative Policy Scenarios – Technology Specificity



APS 2.1

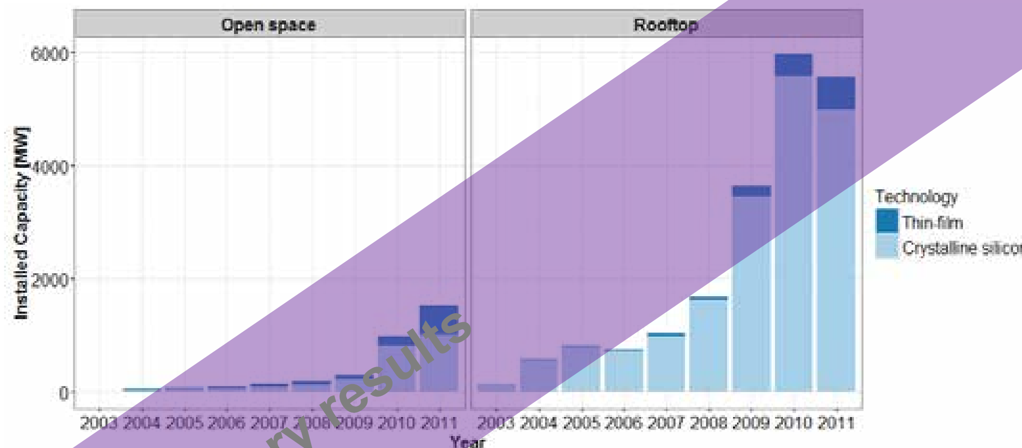
- Application neutral
- Technology-specific
- **+5% FiT for c-Si**

Higher overall diffusion (esp. rooftop) than for APS 1

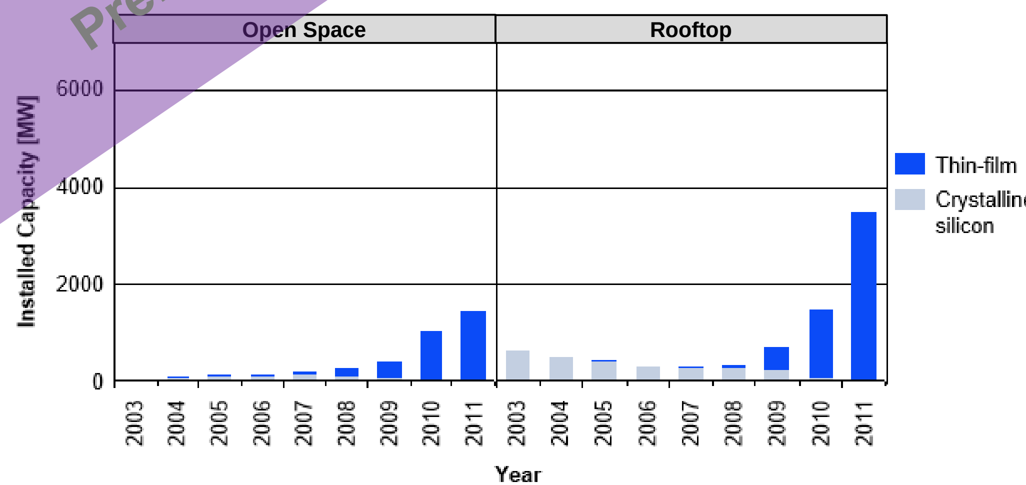
Higher initial diffusion of c-Si, then **lock-in to thin film**

Spillovers from c-Si to thin film in terms of BOS cost

CALIBRATION RESULTS (ACTUAL DESIGN)



APS MODELLING RESULTS



Source: Working paper, Haelg, Waelchli, Schmidt (2017)

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Discussion and Policy Implications

Technology and application neutrality

- leads to low overall diffusion
- leads to lock-in to one technology

Technology specificity

- adds to overall diffusion
- leads to lock-in to one technology

Application specificity

- adds to overall diffusion
- may prevent lock-in to one technology

Policy design has a big impact on and may, even unintendedly, lead to technology selection

Application-specific policies may open **niches** for technologies to mature

Changes in the technology selection happen **gradually** and leave space for policy makers to **adapt the policy design**

Source: Working paper, Haelg, Waelchli, Schmidt (2017)

Thank you for your attention!

For more information and publications,
please visit: www.epg.ethz.ch