



The Solar Revolution – Who Made It Happen?

Felix Müsgens

@

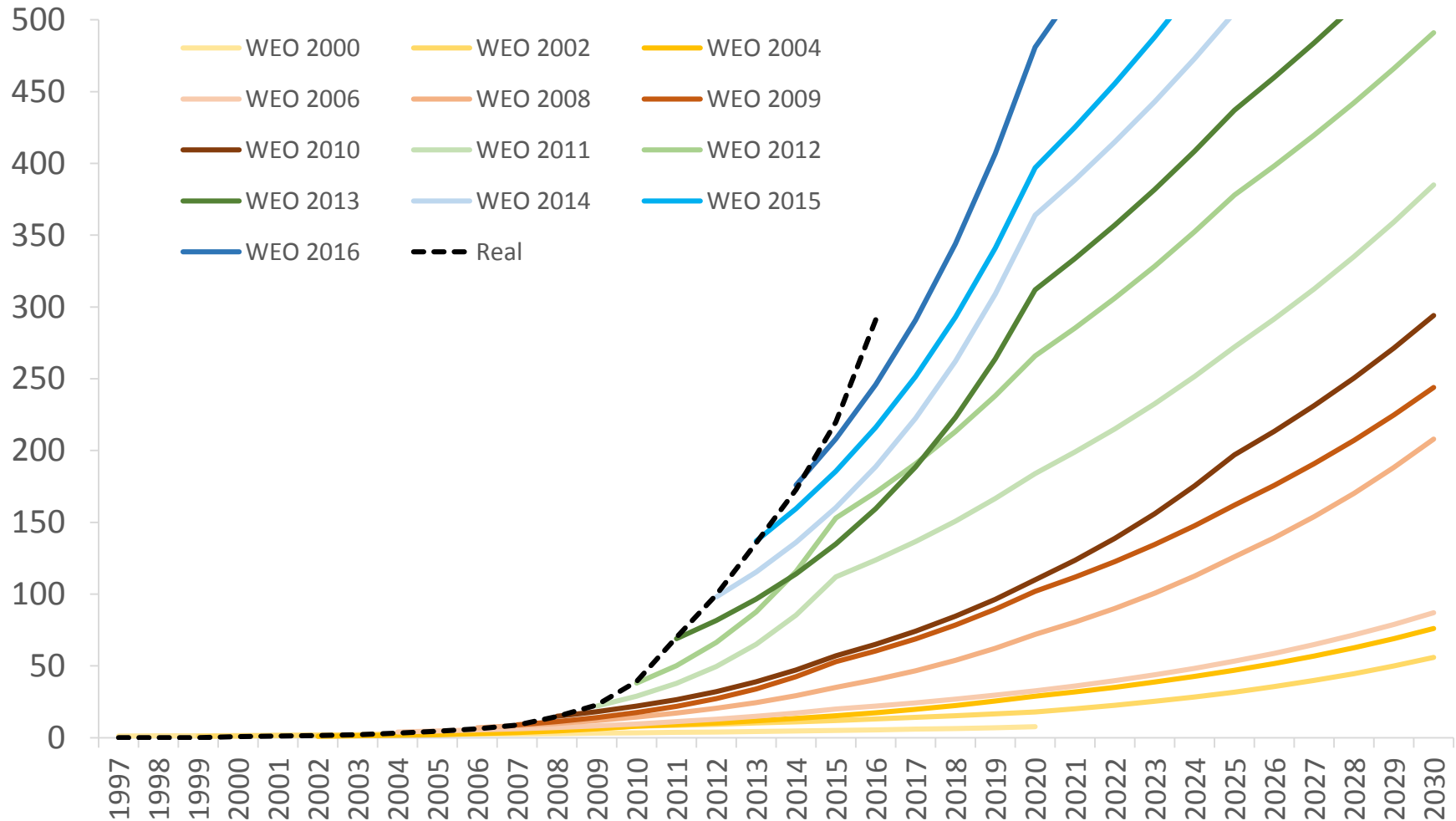
Research Seminar

EPRG Energy & Environment with In Search of 'Good' Energy
Policy

Cambridge, November 6th, 2018

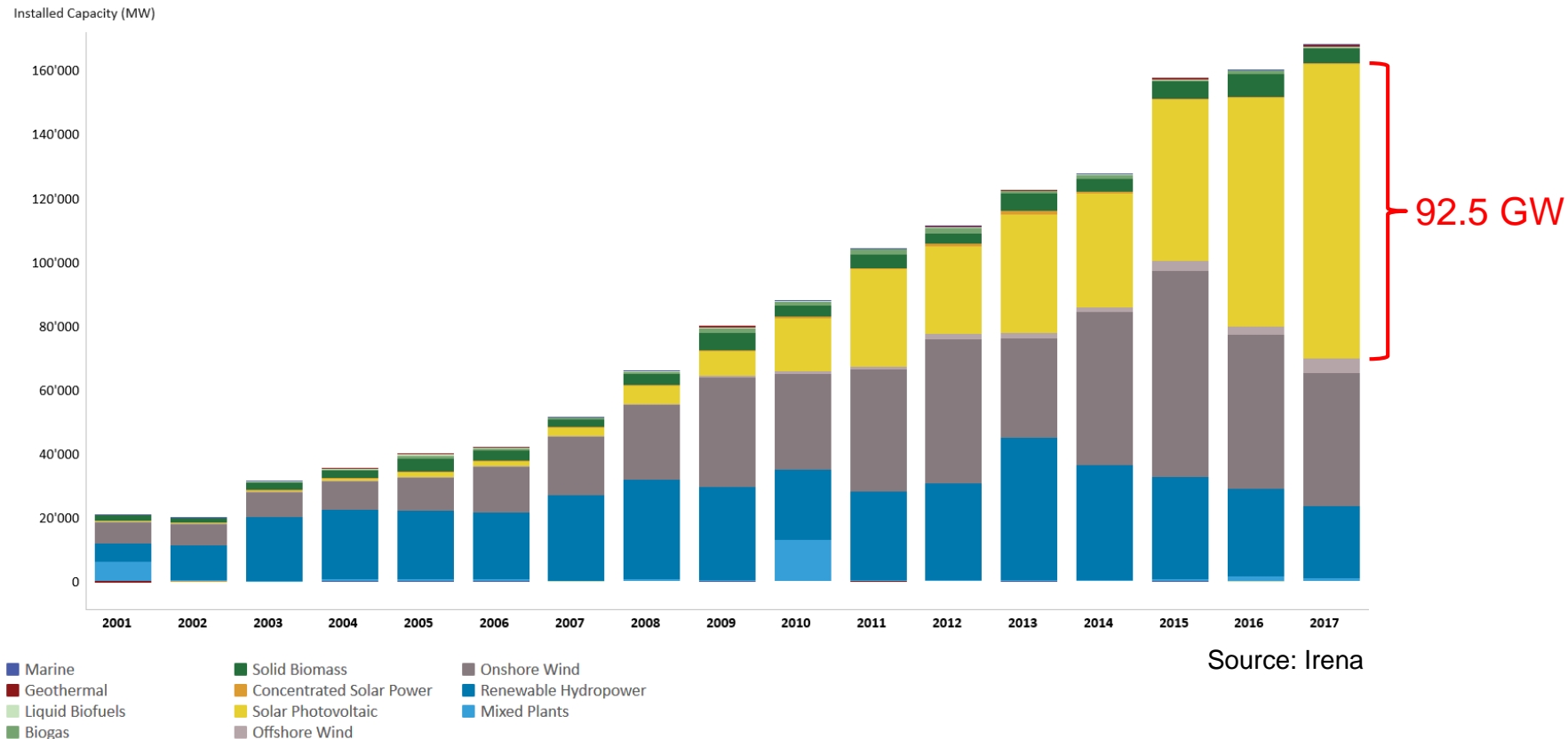
Global installed PV capacity (in Gigawatt)

Forecasts International Energy Agency vs. Realisations



Global net renewable capacity additions

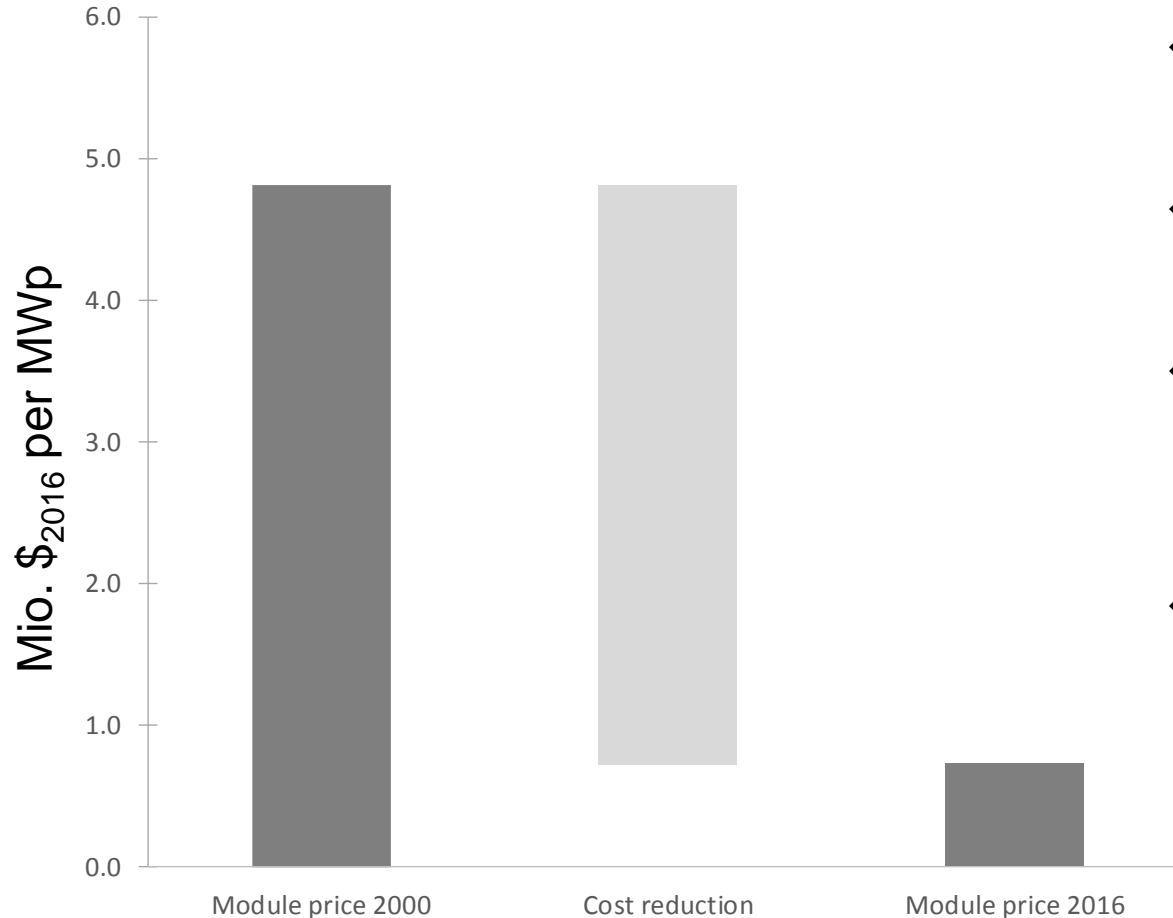
Trends in Renewable Energy



© IRENA

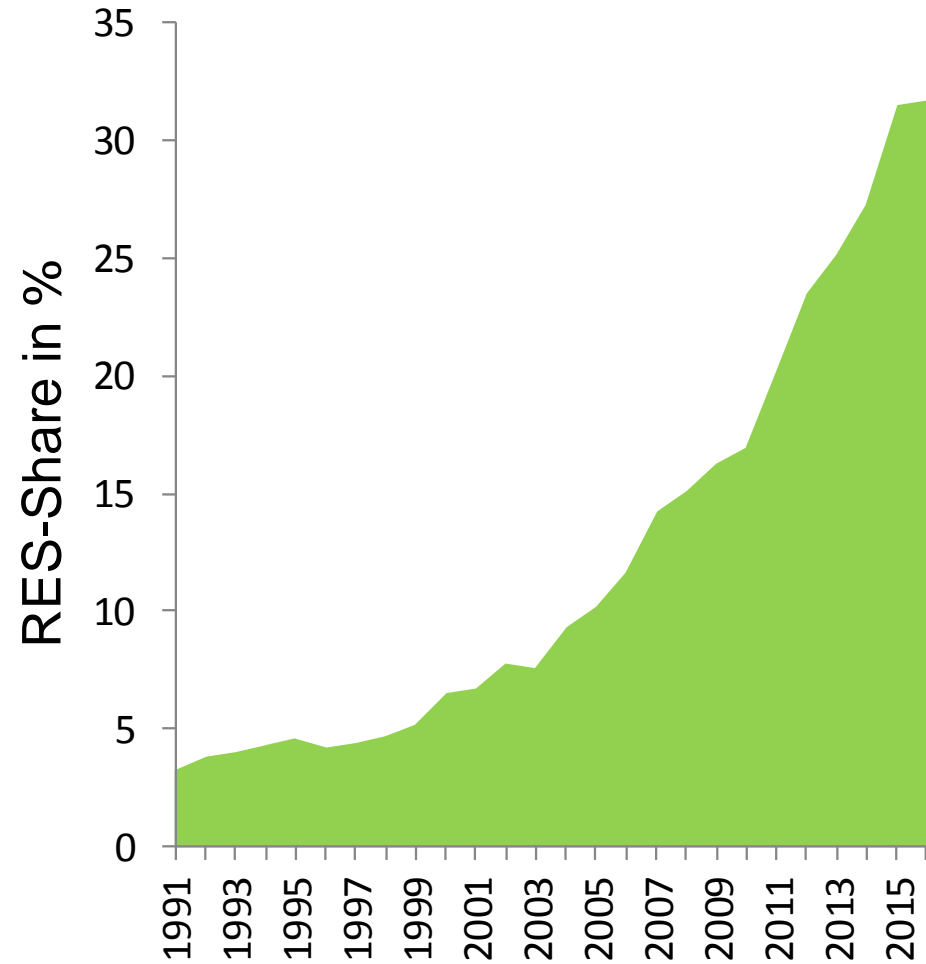
Net Capacity Additions in 2017:
 PV 92.5 GW > hardcoal + lignite + natural gas + nuclear 70 GW

Module prices decreased 85% between 2000 and 2016

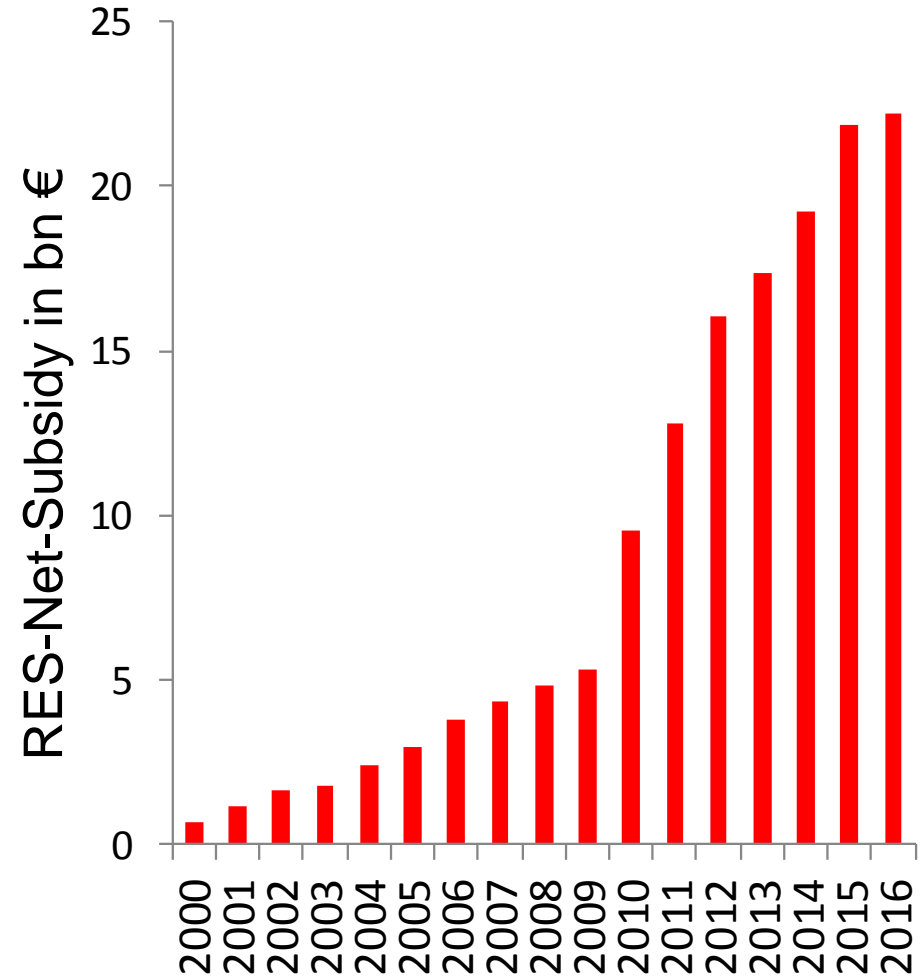


- ◆ Module price 2000:
4,82 Mio. \$₂₀₁₆ per MWp
- ◆ Module price 2016:
0,72 Mio. \$₂₀₁₆ per MWp
- ◆ Cost reduction in real terms:
4,1 Mio. \$₂₀₁₆ per MWp
- ◆ To what extent is this resulting from individual countries' renewable support schemes?

Status-Quo: Renewable Energy Shares and Net-Subsidies in Germany



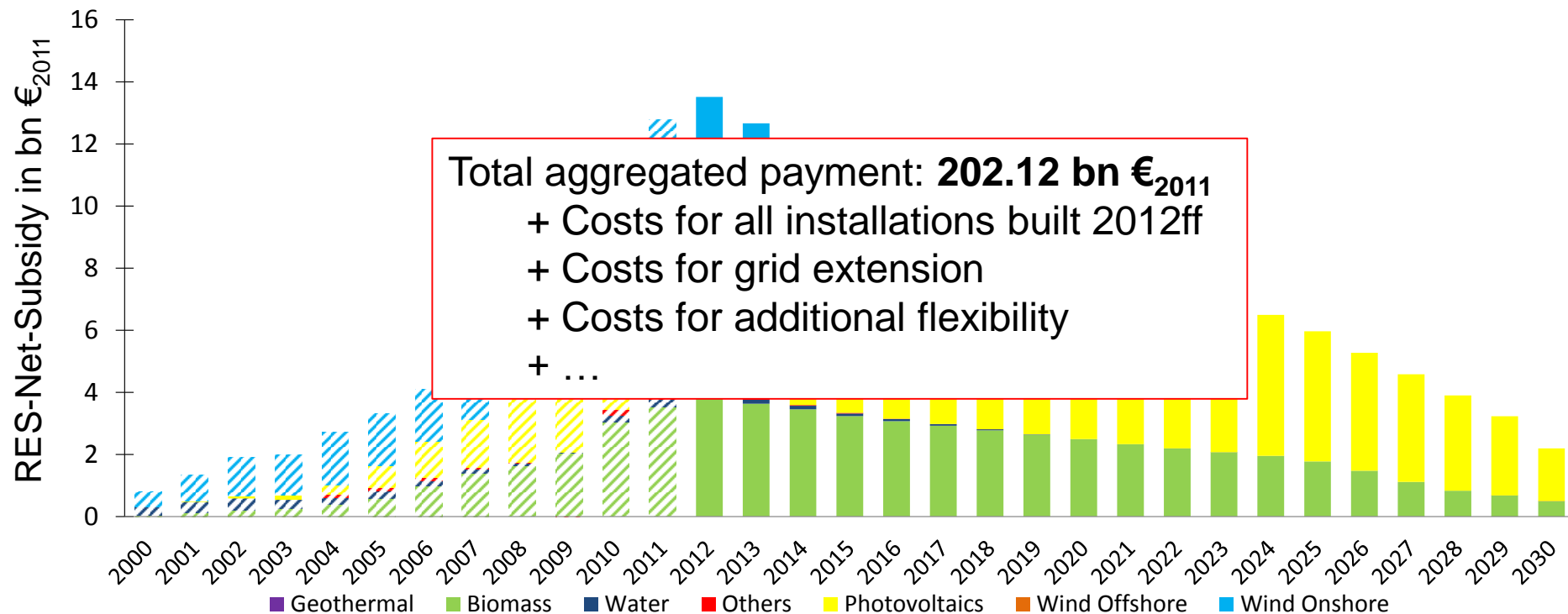
Source: AGEB



Source: Bundesregierung

Total Net Costs for German Renewable Energy Sources installed before 31/12/2011

- ◆ The German “EEG” (RES-Act) specified that all RES installations receive feed-in tariffs for 20 years (plus year of installation).
- ◆ Below are estimates for the future cost burden for all RES plants built before the end of 2011 (again, only net costs are shown, market value for electricity has been subtracted):



Source: Kreuz, S., Müsgens, F. (2018): Measuring the cost of renewable energy in Germany, The Electricity Journal 31, May 2018, 29-33

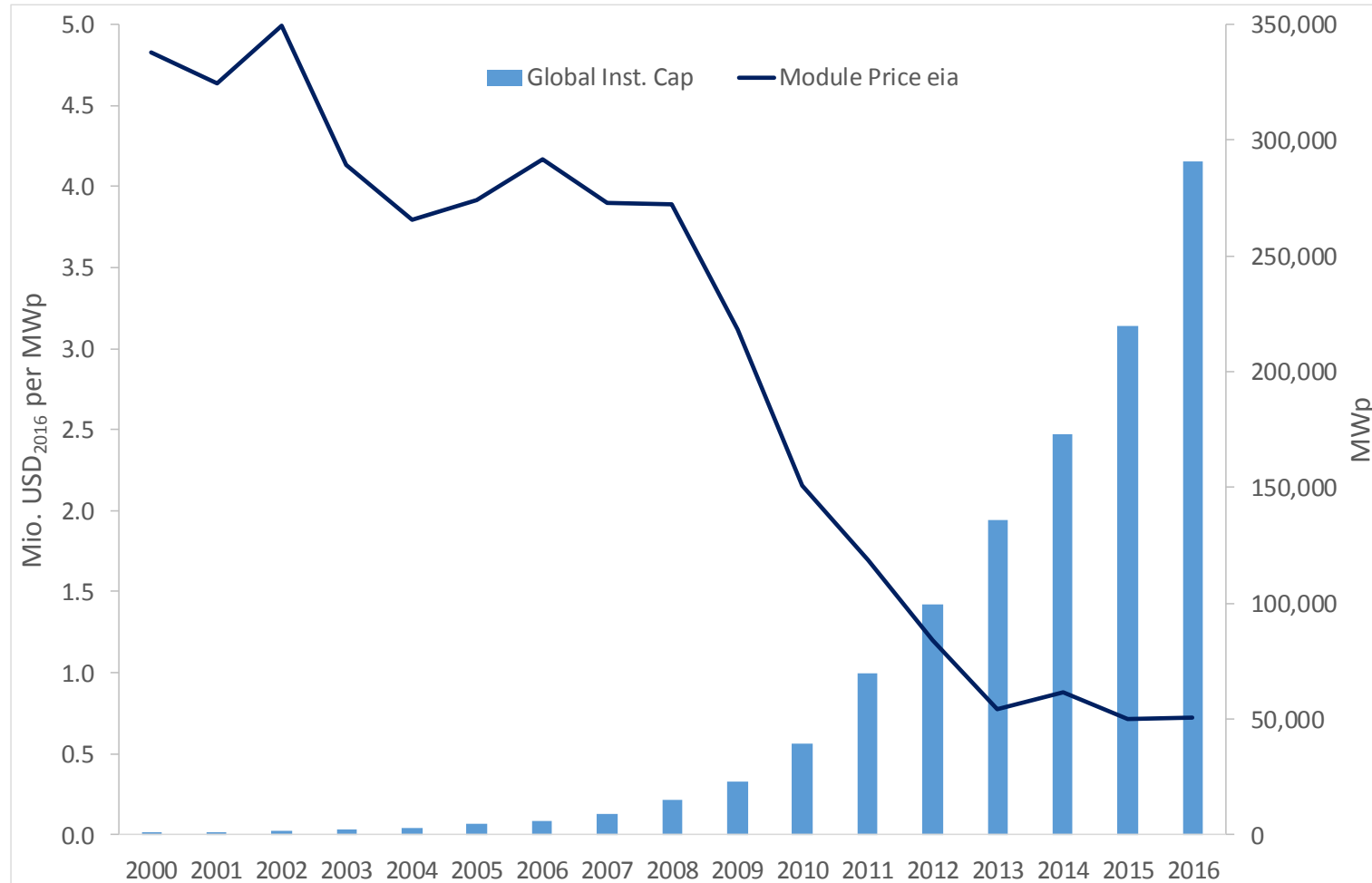
Benefits of RES-Promotion

- ◆ Low carbon technology
- ◆ Correction of R&D externalities (i.e. market participants invest too little in renewables for fear of other companies copying advances)
- ◆ Correction of externalities related to fossil fuels
 - Particulate matters (respirable dust)
 - NO_x, SO₂, ...
- ◆ „Green Growth“
 - Jobs in economically weak regions (North and East Germany)
 - Know-How for Exports
- ◆ Reduction of fossil fuel imports
- ◆ Making green technologies available for world wide expansion

These advantages have often been discussed...

... but rarely quantified.

Module prices (left axis) and global installed capacity (right axis)



Assumptions

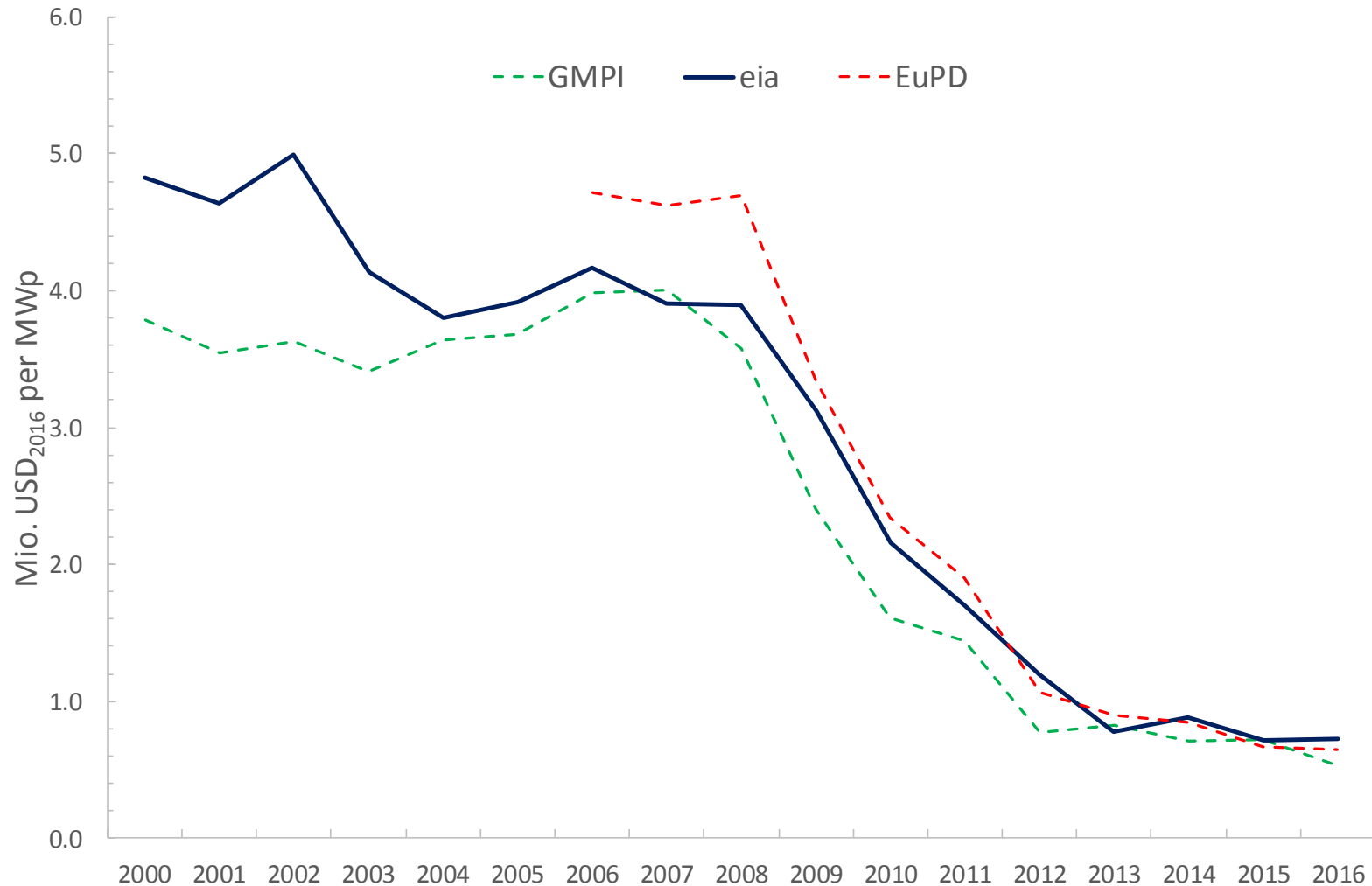
- ◆ Cost reductions correlate with output (due to learning)
- ◆ Rubin et al. even argue: „[...] by far the most common model used in the energy literature to forecast changes in technology cost is the ‘*one-factor learning curve*’ (or ‘experience curve’).“
- ◆ Hence, we assume in the following:
 - Cost reductions can be attributed exclusively to installed capacity
 - Prices are a proxy for costs
 - Learning is global (→ Restrict analysis to module manufacturing.)
 - Every MW of installed capacity (in a year) contributes symmetrically to cost reduction (in that year)
- ◆ Key contribution:
Assess country specific contributions to module cost reductions

Aggregated Installed Capacities (in MWp)

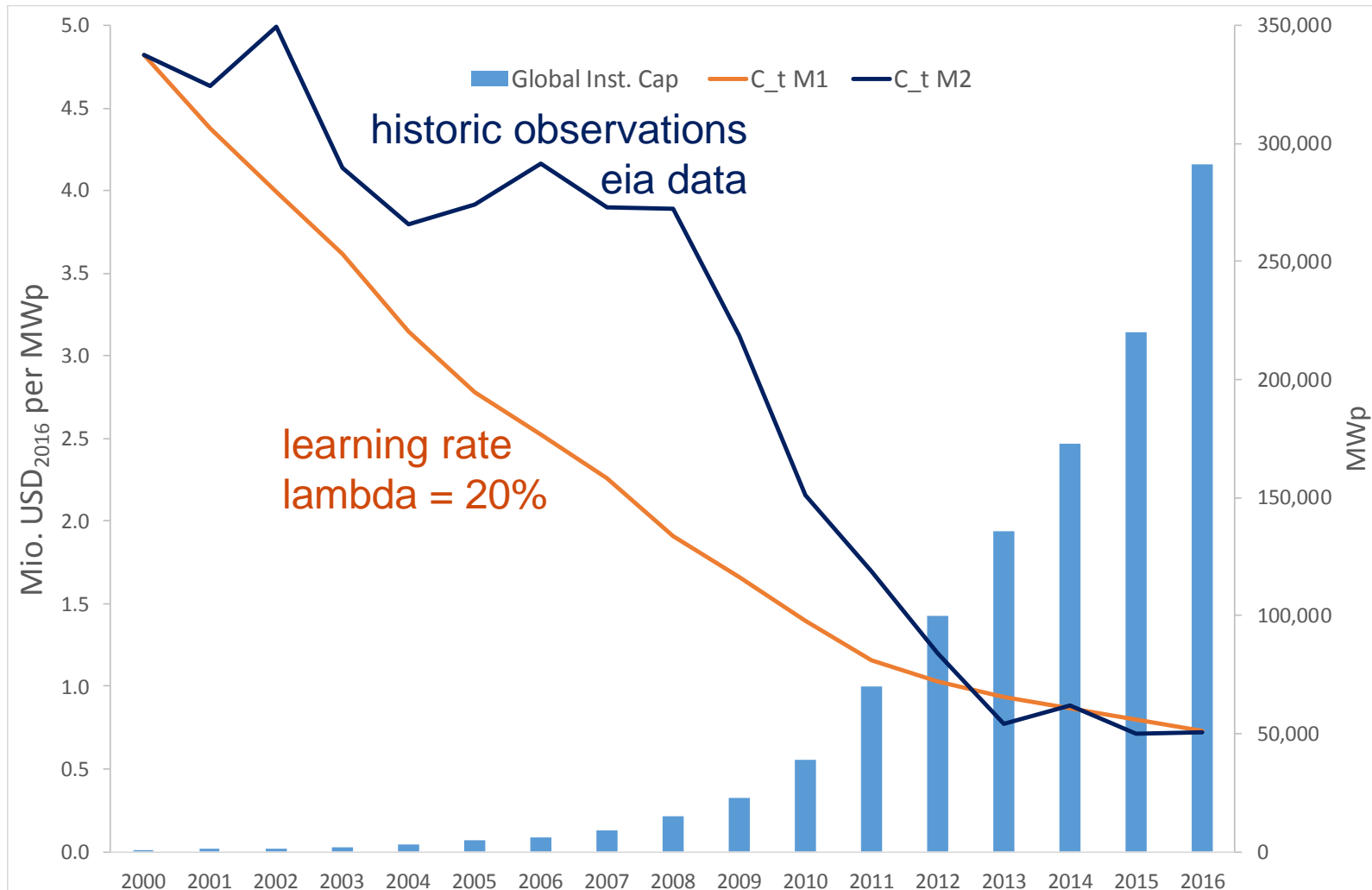
	World	China	Japan	Germany	USA	Italy	Spain	All Other
2000	830	42	330	114	176	19	12	137
2001	1,118	51	453	195	213	20	16	170
2002	1,488	88	637	260	255	22	20	206
2003	2,029	108	860	435	293	26	27	280
2004	3,128	127	1,132	1,105	363	31	37	333
2005	4,589	141	1,422	2,056	493	34	60	383
2006	6,178	160	1,708	2,899	698	45	169	499
2007	8,781	198	1,919	4,170	974	110	739	671
2008	14,771	253	2,144	6,120	1,153	483	3,389	1,229
2009	22,720	431	2,627	10,564	1,614	1,264	3,488	2,732
2010	39,119	958	3,618	17,552	2,909	3,592	3,921	6,570
2011	69,955	3,478	4,914	25,037	5,172	13,131	4,352	13,872
2012	99,608	7,018	6,632	32,641	8,137	16,785	4,646	23,749
2013	135,758	17,748	13,599	36,335	11,759	18,185	4,785	33,347
2014	172,794	28,388	23,339	38,234	14,878	18,594	4,787	44,574
2015	219,868	43,538	33,300	39,786	21,684	18,892	4,856	57,812
2016	291,064	77,788	41,600	40,986	32,954	19,245	4,871	73,621

Source: Irena

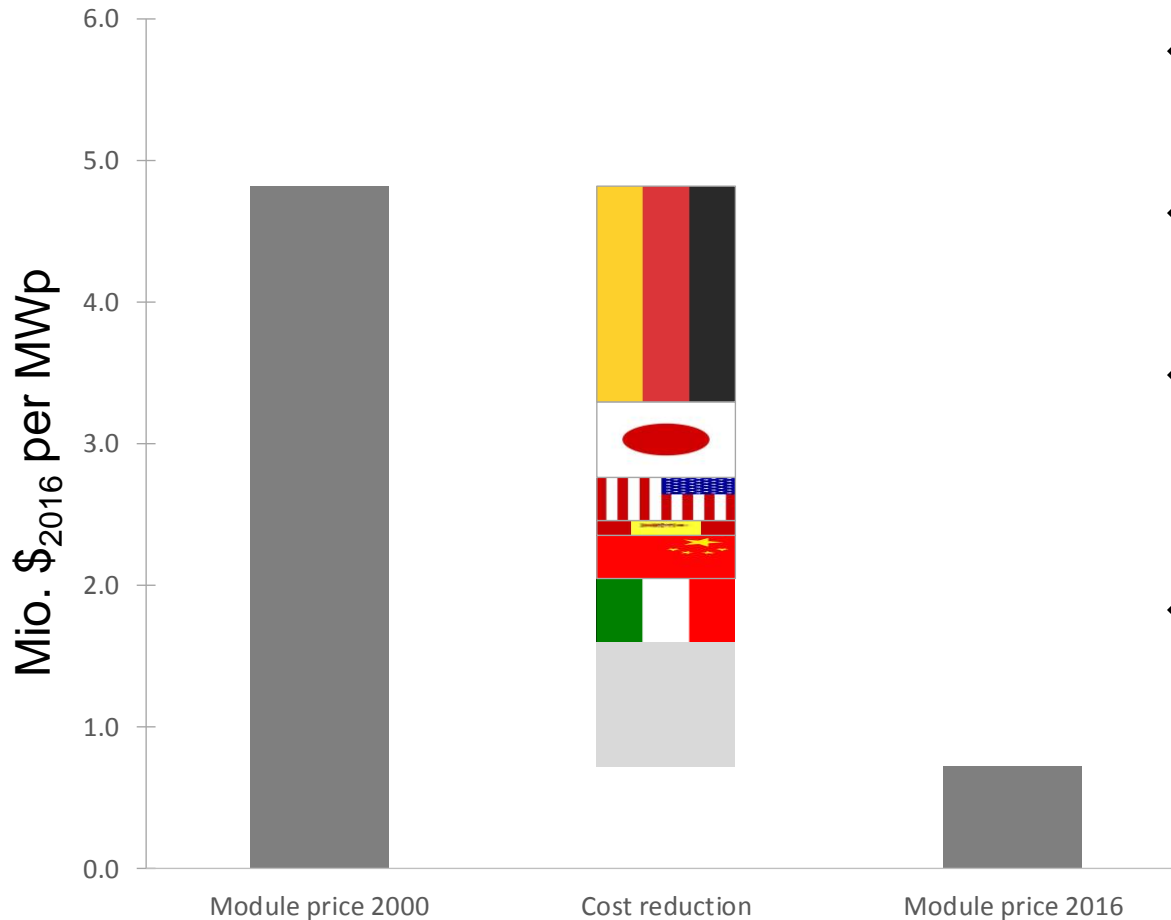
Module prices - comparison of available price data



Module prices - used in analysis



Module prices decreased 85% between 2000 and 2016 (Results from model 2)



- ◆ Module price 2000:
4,82 Mio. \$₂₀₁₆ per MWp
- ◆ Module price 2016:
0,72 Mio. \$₂₀₁₆ per MWp
- ◆ Cost reduction in real terms:
4,1 Mio. \$₂₀₁₆ per MWp
- ◆ To what extent is this resulting from individual countries' renewable support schemes?

Preliminary Results I

	Cost Delta	China	Japan	Germany	USA	Italy	Spain	Other	
Model 1									
AC: Absolut Cont	4.09	0.24	0.91	1.58	0.36	0.20	0.27	0.53	Mio. \$ ₂₀₁₆ per MWp
RC: Relative Cont	100.0%	5.9%	22.3%	38.5%	8.9%	4.8%	6.6%	13.0%	
Av. Price paid									Mio. \$ ₂₀₁₆ per MWp
Model 2									
AC: Absolut Cont	4.10	0.30	0.53	1.52	0.31	0.44	0.10	0.89	Mio. \$ ₂₀₁₆ per MWp
RC: Relative Cont	100.0%	7.3%	13.0%	37.0%	7.6%	10.8%	2.6%	21.7%	
Av. Price paid									Mio. \$ ₂₀₁₆ per MWp

Preliminary Results II

	Cost Delta	China	Japan	Germany	USA	Italy	Spain	Other	
Model 1									
AC: Absolut Cont	4.09	0.24	0.91	1.58	0.36	0.20	0.27	0.53	Mio. \$ ₂₀₁₆ per MWp
RC: Relative Cont	100.0%	5.9%	22.3%	38.5%	8.9%	4.8%	6.6%	13.0%	
Av. Price paid		0.83	0.96	1.36	0.93	1.17	1.76	0.95	Mio. \$ ₂₀₁₆ per MWp
Model 2									
AC: Absolut Cont	4.10	0.30	0.53	1.52	0.31	0.44	0.10	0.89	Mio. \$ ₂₀₁₆ per MWp
RC: Relative Cont	100.0%	7.3%	13.0%	37.0%	7.6%	10.8%	2.6%	21.7%	
Av. Price paid		0.83	1.03	1.98	1.04	1.65	3.23	1.09	Mio. \$ ₂₀₁₆ per MWp

Thank you for your attention!

Brandenburg University of Technology

Prof. Dr. Felix Müsgens

Chair of Energy Economics

<https://www.b-tu.de/energiewirtschaft/>