What about the long term? Using experience curves to describe the energy-efficiency improvement for selected energy-intensive products in Germany

Nils Brucker, Tobias Fleiter, Patrick Plötz
Fraunhofer Institute for Systems and Innovation Research, Karlsruhe

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Agenda

1. Objective and approach
2. Data used
3. The experience curve approach
4. Results
5. Conclusions

Objective and approach

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Objective and approach used

Objectives:

- What are the long-term energy efficiency trends in the German energy-intensive industry?
- Can experience curves be used to describe the energy efficiency progress in industrial production?

Approach in four steps:

1. Selection of products/industries: pulp and paper industry, production of crude steel, cement, clinker and primary aluminium
2. Gather time series data (~1950 to 2010) for energy efficiency (SEC in GJ/t] and experience indicator (production in t/a)
3. Linearize (log) and fit experience curve function to observations using OLS
4. Calculate learning rates and compare among products

Data used

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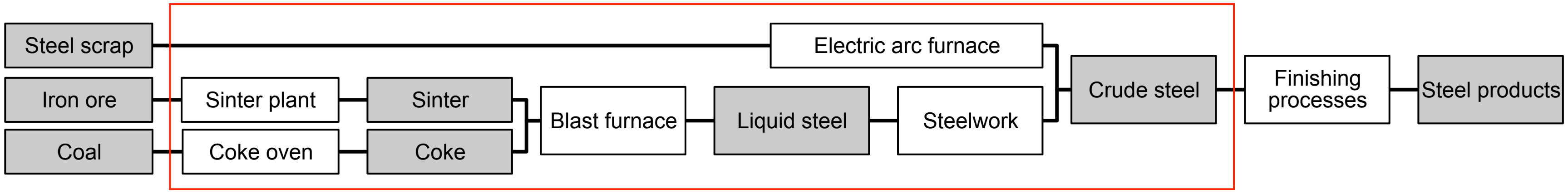
Overview of input data

Industry/product/process	Scope	Type of energy	Time period	No. of SEC data points
Pulp and paper industry	Sector	Final energy	1955-2008	4
		Electrical, thermal, final and primary energy	1973-2008	36
Cement	Product	Electrical, thermal, final and primary energy	1951-2012	59
Clinker	Product	Thermal energy	1951-2011	61
Crude steel	Product	Primary energy	1960-2011	52
Primary aluminium electrolysis	Process	Electrical energy	1947-2009	33

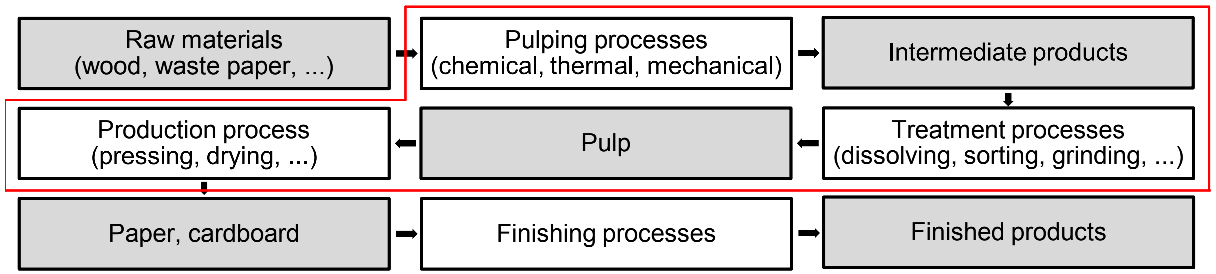
- The **scope** (system boundary) depends on the data availability (e.g. for crude steel a distinction in electric and oxygen steel was not possible)
- In some cases complete time series of **SEC data** were available (pulp and paper, steel), in other cases BAT data from various sources was used (primary aluminium)
- Distinguishing **electricity and thermal** energy was not possible in all cases (e.g. crude steel)
- Calculation of **primary energy** done by multiplying electricity consumption with three

System boundaries by product

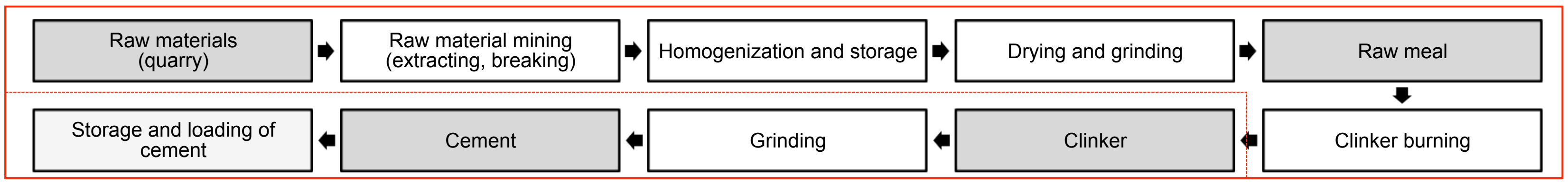
- Crude steel



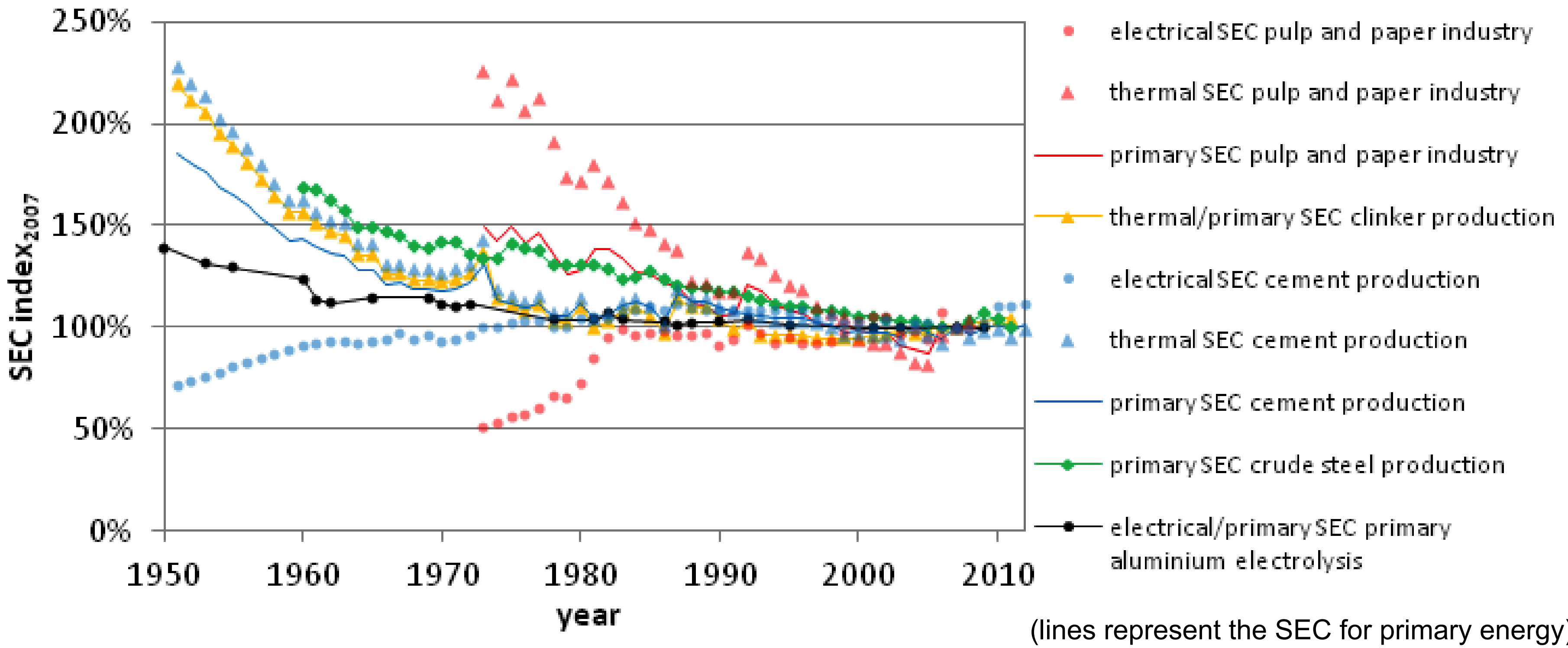
- Pulp and paper:



- Cement (clinker dotted line):



SEC over time



(lines represent the SEC for primary energy)

- Mostly decreasing SEC (except for electricity in paper and cement)
- Faster decrease at early stage, saturation after 2000

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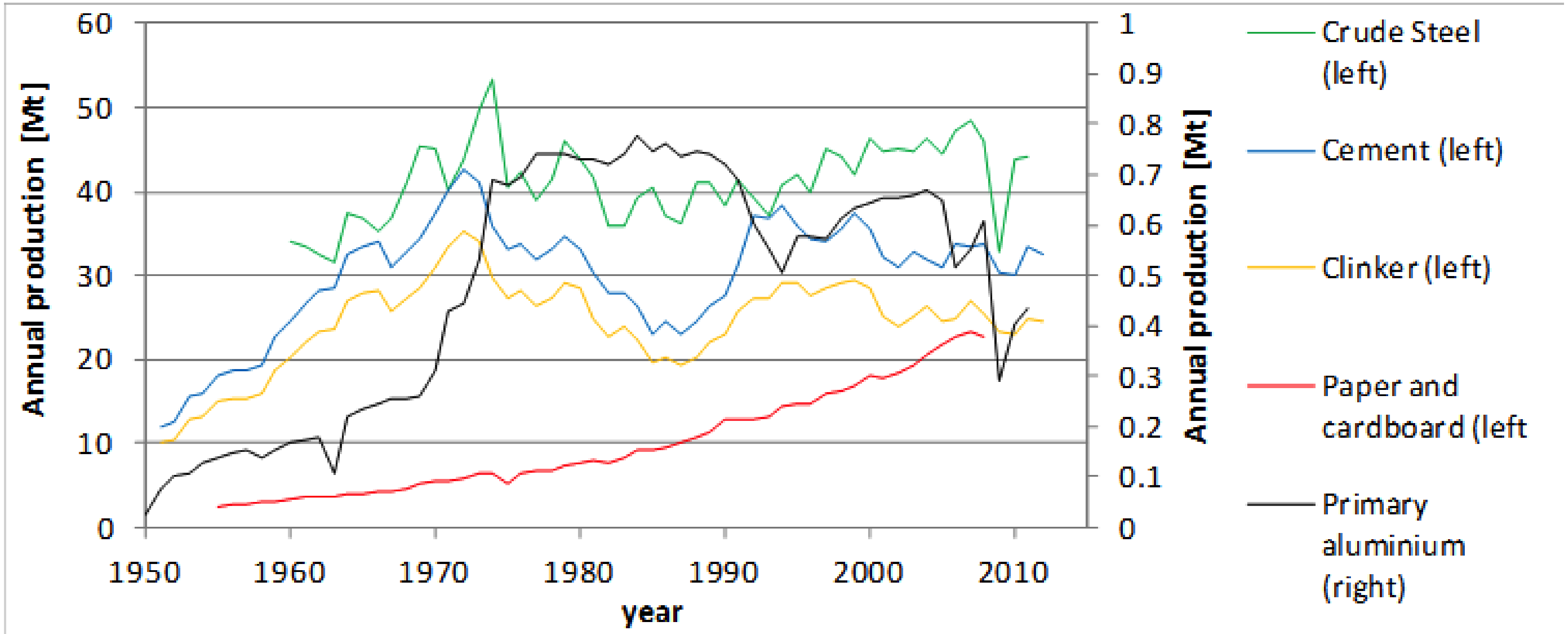
Production over time



- Crude steel, cement, clinker and primary aluminium experience a fast increase before 1970 and stagnation afterwards
- Only paper shows a continous increase until 2007

The experience curve approach

The experience curve approach

- **General Idea:** Tasks are conducted more efficiently, the more frequently they are performed -> „learning-by-doing“ or more general: „technology learning“
- **More specific:** Improvement in production efficiency depends on the (cumulative) experience gained
- **Past applications:**
  - Time and cost-efficiency in manufacturing processes
  - Decline of investment costs of energy supply technologies (IEA 2001, McDonald and Schrattenholzer 2001, Neji 2008)
  - Some authors look at energy-demand technologies (Weiss et al. 2010a and 2010b, Jardot et al. 2009, Jakob and Madlener 2010, Schall and Hirzel 2012)
  - Only one study found analyzing the progress in demand-side energy-efficiency: Ramírez and Worrell (2006) analyzing the global fertilizer industry

Formulation of learning curve function

- Choice of **indicators** similar to Ramirez and Worrell (2006):
  - Performance indicator: SEC as measure of energy efficiency
  - Measure of cumulative experience: cumulative production
- **Learning curve function**:

$$SEC_t = SEC_0 * CP_t^b$$

SEC_t = Specific energy consumption in year t

CP_t = the cumulative production in year t

SEC_0 = SEC in the first year of production

b = experience index .

- **Linearized function:**

$$\log SEC_t = \log SEC_0 + b * \log CP_t$$

- **Learning rate**: decrease in SEC for each doubling in cumulative production:

$$LR = 1 - 2^b$$

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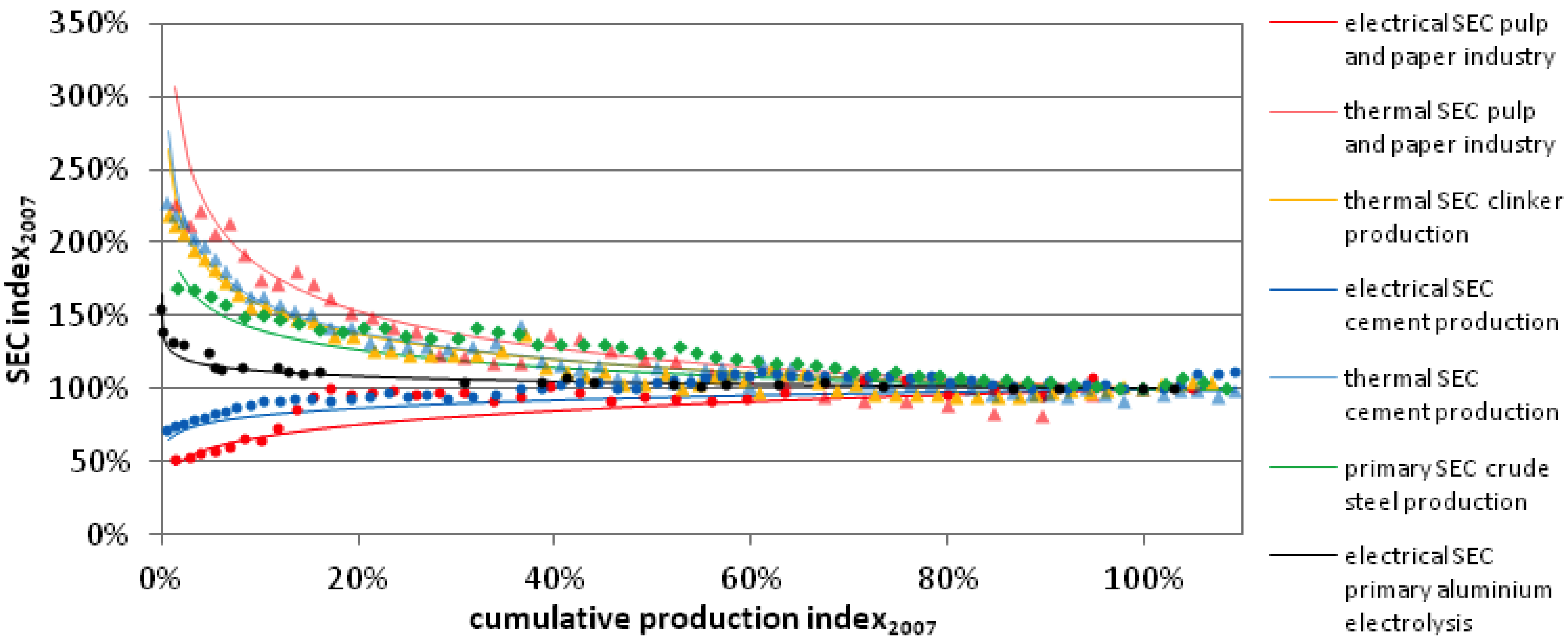
Results

SEC related to cumulative production



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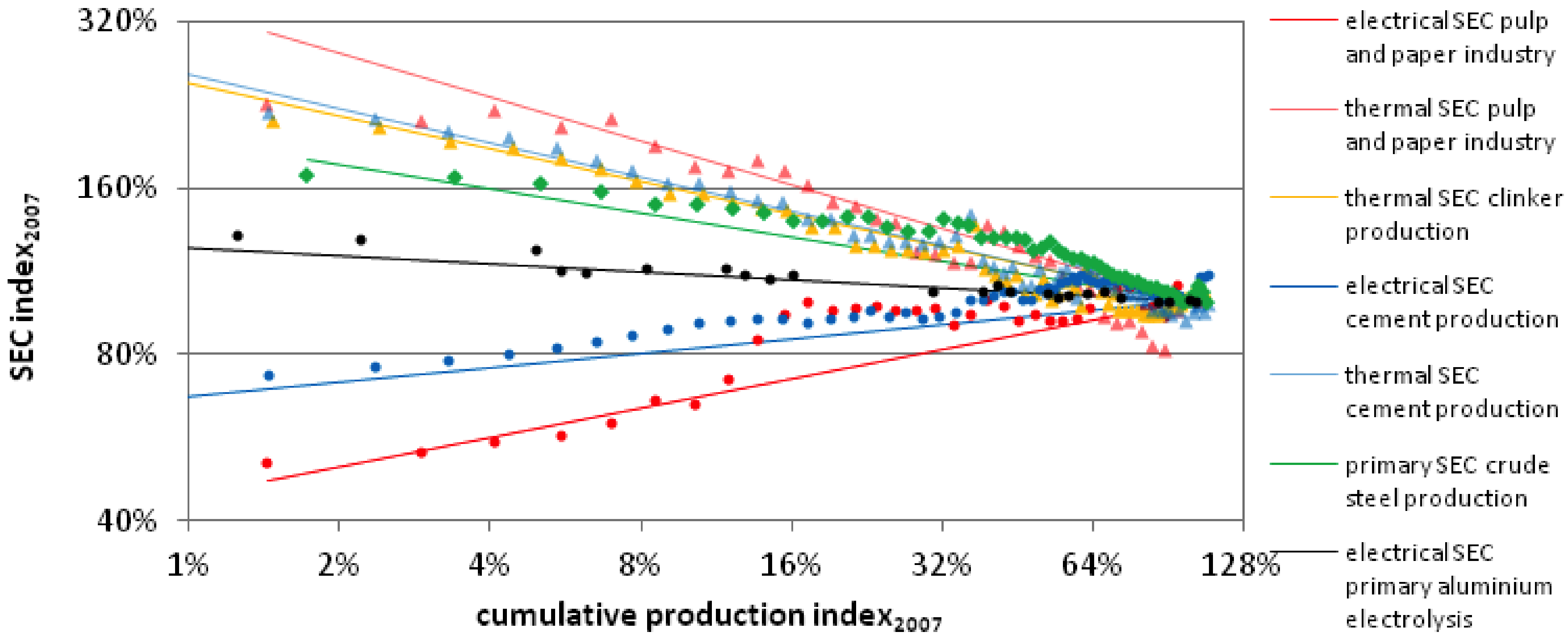
SEC related to cumulative production in log scale for electricity and thermal energy



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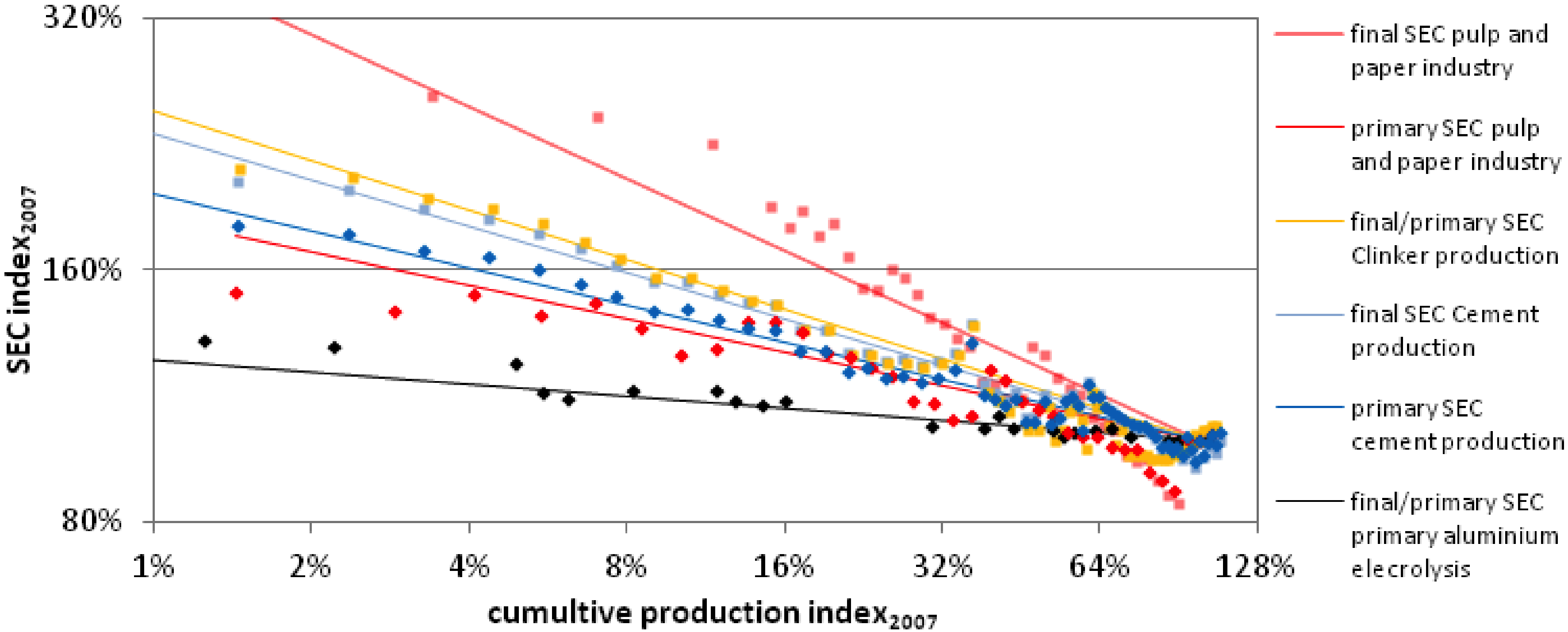
SEC related to cumulative production in log scale for primary and final energy



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Learning rates and goodness of fit

Industry/product/process	Electricity		Thermal energy		Final energy		Primary energy	
	LR ± $2\sigma_{LR}$	R^2	LR ± $2\sigma_{LR}$	R^2	LR ± $2\sigma_{LR}$	R^2	LR ± $2\sigma_{LR}$	R^2
Pulp and paper industry*	-13.0 ± 2.0 %	0.79	16.5 ± 3.0 %	0.90	13.0 ± 2.0 %	0.86	9.0 ± 1.5 %	0.84
Clinker			12.5 ± 1.0 %	0.93	*12.5 ± 2.0 %*		*12.5 ± 3.0 %*	
Cement	-6.0 ± 1.0 %	0.85	13.5 ± 2.0 %	0.94	12.0 ± 2.0 %	0.94	9.5 ± 2.0 %	0.93
Crude steel							9.5 ± 1.5 %	0.80
Primary aluminium electrolysis	3.5 ± 0.5 %	0.93			*3.5 ± 1.0 %*		*3.5 ± 1.0 %*	

- For final and primary energy all learning rates are positive (including standard deviation)
- For paper and cement, learning rates for electricity are negative
- Relatively high goodness of fit (coefficient of performance $R^2 > 0.79$)
- Highest goodness of fit for thermal energy use (and electricity for primary aluminium)

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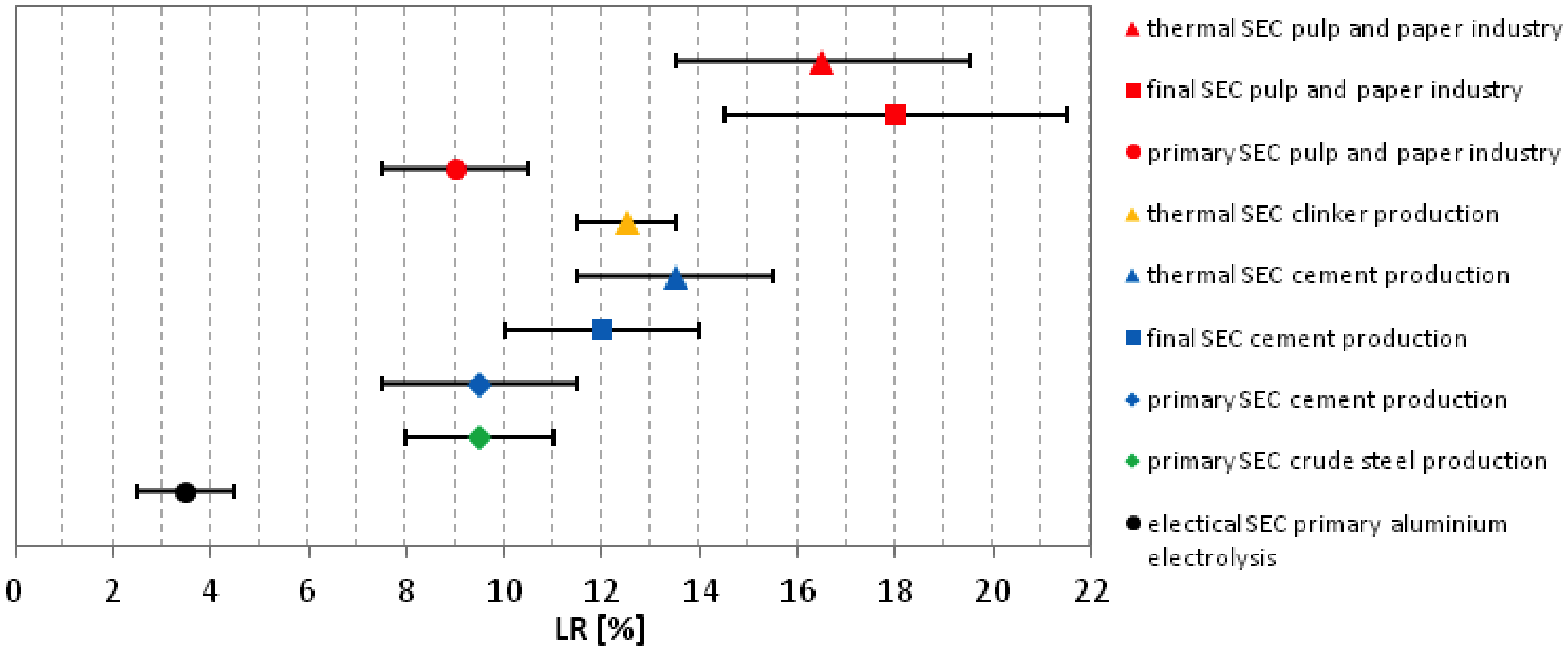
Comparison of learning rates



- Some indication: Increasing LR with increasing system boundary

Conclusions

Conclusions

Main findings

- Learning curve approach applicable to describe the development of SEC of industrial processes over time
- Indication that learning rates are higher when system boundaries are broader -> policy instruments should be designed with a broad scope in order to allow process substitution
- Policy recommendation misleading? The approach suggests that ..
  - … as long as (cumulative) production increases there will be energy efficiency improvement
  - … (cumulative) production is the only determinant of energy efficiency

Challenges

- The time period considered affects the results (and often data is not available back to the process introduction) -> select time series as long as possible
- Using production output in Germany neglects learning in other countries

Further research

- More analyses of additional products and countries are required in order to arrive at robust conclusions (So far only one study using a similar approach (Ramirez and Worrell 2006))
- Include additional determinants (see two-factor learning curve)
- Use approach to simulate technological change in long-term models

Contact

Tobias Fleiter
Fraunhofer Institute for Systems and Innovation Research
Breslauer Str. 48
76139 Karlsruhe, Germany
Tobias.Fleiter@isi.fhg.de
+49 721 6809-208

Thank you for your attention!