# The 35th Annual IAEE International Conference
## 24-27 June 2012
## Perth, Western Australia
## Perth Convention and Exhibition Centre

### Conference Theme

Energy markets evolution under global carbon constraints: Assessing Kyoto and looking forward

### Objectives and Aims

The objective of the conference is to examine the dynamism of the world energy sectors in the context of what effect the Kyoto Process, which ends in 2012, had on the energy markets, technologies, and systems of the world. Also of interest is what technological and market developments occurred in spite of the Process? In other words, will the energy world of 2012 and beyond be purely the product of reactions to the Kyoto Protocol, or were there strong undercurrents of change that flowed throughout the period that would have occurred regardless? And from this examination, what may we reasonably expect for the near- to intermediate-future? Plenary sessions will examine these questions from industry, government, and academic perspectives.

### Overview

The conference will address the full range of energy issues that may be expected to be commanding the attention of academics, analysts, policy-makers, and industry participants in 2012, looking both forward and back. In addition to all major fields of energy economics and policy typically covered, other possible topics include:

- Greenhouse gas policy after Kyoto
- Energy supply and demand security
- A growing role for nuclear
- The role of unconventional energy resources
- Price volatility
- Renewable and alternative sources of energy
- Carbon capture and sequestration
- Policy consideration in a carbon constrained world
- Distributed generation
- Energy efficiency in primary commodity production
- Resources sector taxation policy
- Developments in LNG markets
- Harmonization of cross-border energy regulations
- Evolving geopolitics of oil and gas
- Emissions modelling
- Emission trading schemes
- The econometrics of oil and gas markets
- The economics of climate change
- Risk mitigation methodologies
- Reserves, production, and peaks
- Energy development and the environment

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## The Location: Perth, Western Australia

The conference will be hosted at the Perth Convention and Exhibition Centre. Visit the following website for a 3-minute online video of some of the wonders of Perth and the surrounding region: http://pcb.com.au/our-services/convention-tool-kit/destination-dvd.aspx. Come enjoy this beautiful part of the world, in one of the most dynamic energy development regions of the globe. We look forward to your company and active participation in the 35th IAEE International Conference in Perth, June 24-27, 2012.

## Call for Papers

We are pleased to announce the Call for Papers for the 35th International Association for Energy Economics conference to be held 24-27 June 2012 at the Perth Convention and Exhibition Centre in Perth, Australia. **The deadline for abstract submission is 13 January 2012.**

We will be accepting proposals for two different structures of conference presentations. We will have the typical concurrent session paper presentations, and we will augment these with a limited number of extended presentations with formal discussants. The typical sessions include up to five papers and presentations are limited to 15 minutes, including Q&A. The extended presentation sessions will include not more than three papers, with each allocated 30 minutes, including discussant and Q&A.

Paper abstracts for the typical concurrent sessions shall follow the format of the Abstract Template, which may be downloaded at www.business.curtin.edu.au/creme/AbstractTemplate.doc, (ticking the appropriate choice). The abstract should be one to two pages in length, and it must include: a) keywords, b) overview, c) methods, d) results, e) conclusions, and f) references. NOTE: All abstracts must conform to the abstract format presented in the abstract template. Authors will be notified by 16 March 2012 of the status of their papers. **We strongly encourage industry and government submission with economics and policy focus.**

The extended presentation paper proposals **require a near-final draft of the completed paper** on the 13 January 2012 deadline submission date. In addition to a complete paper, one author of each paper must commit to being a discussant of another extended paper. Use the AbstractTemplate as your cover page (ticking the appropriate box); completing just the title, author(s), and keywords sections.

Concurrent session abstracts and extended presentation papers should be in either Microsoft Word or PDF format and sent to IAEE.Perth.Abstracts@curtin.edu.au.

**Best Student Paper Award**: the IAEE is pleased to announce the continuation of its Best Student Paper Award program in 2012. The top energy economics paper award will receive US$1000, and the three runners-up will each receive US$500. All four students will also receive waivers for their conference registration. Complete information for this competition, including submission details, may be requested from David Williams at iaee@iaee.org, or found at Conferences link on www.business.curtin.edu.au/creme.

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**Conference registration fees** (all fees are in Australian dollars, inclusive of 10% GST)

| | **Early** (before 1 May 2012) | **Normal** (1 May 2012 & after) |
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| **Speakers/Chairs/ Discussants** (Members) | A$770 | A$855 |
| **Speakers/Chairs/ Discussants** (Non-members; includes membership) | A$850 | A$935 |
| **IAEE members** | A$855 | A$940 |
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| DATE TIME | MEETING ROOM | SESSION TITLE | PAPER TITLE | AUTHOR | CO-AUTHORS | INSTITUTE | SESSION CHAIR |
|---|---|---|---|---|---|---|---|
| Concurrent Sessions (2) Monday, 2.45pm - 4.15pm | 1 | Extended/Discussant I: Electricity: Contracts, Grids and Agents | Flicking the switch: Retail demand side response under alternative electricity pricing contracts. | **Rimvydas Baltaduonis** | Tihomir Ancev, Tim Capon, Taylor Smart | Gettysburg College / University of Sydney | **Harry Bloch** |
| | | | Ready or not, here comes the smart grid. | **Seth Blumsack** | | Penn State University | |
| | | | Can agent-based models forecast spot prices in electricity markets? Evidence from New Zealand. | **Stephen Poletti** | Oliver Browne, David Young | Electric Power Research Institute, Palo Alto | |
| | 2 | Energy Issues I | Future investment costs of renewable energy technologies at volatile energy and raw material prices – an econometric assessment. | **Christian Panzer** | | Energy Economics Group (EEG), Vienna University of Technology | **Gürkan Kumbaroğlu** |
| | | | Has liberalisation made European energy utility companies riskier? | **Ivan Diaz-Rainey** | Peter Moffatt, Daniel J. Tulloch | University of East Anglia, University of Otago | |
| | | | Adopting gasoline prices policy: Why is it easier for Brazil than China? | **Eduardo Roberto Zana** | | Petroleum, Natural Gas and Biofuels National Regulatory Agency | |
| | | | The impacts of carbon sequestration on oil production projects decision-making: A real option valuation approach on different oil prices volatility scenarios. | **Carlos A.C. Abreu** | | Federal University of Rio Grande do Norte State (UFRN) | |
| | 3 | Energy Markets | An integrated stochastic transport emissions policy model: Risks, opportunities and economics of U.S. greenhouse gas abatement in the near to mid term. | **Parisa Bastani** | John Heywood, Chris Hope | University of Cambridge and MIT | **Lars Bergman** |
| | | | Systematic risks and market changes in the Japanese electricity industry. | **Koichiro Tezuka** | Motokazu Ishizaka, Masahiro Ishii | Faculty of Education and Regional Studies, University of Fukui | |
| | | | International energy economics data: Sources, differences and their consequences. | **Nourah Abdul Rahman Al Yousef** | Carol A. Dahl | King Saud University | |
| | | | The influence of underlying fuels on electricity futures prices. | **Mehtap Kilic** | R. Huisman | Erasmus School of Economics, Erasmus University Rotterdam | |
| | 8 | Nuclear Energy in a Post Fukushima World | Taiwan's baseload power option analysis after the Fukushima nuclear accident. | **Fu-Kuang Ko** | Chin-Ho Cho | Institute of Nuclear Energy Research R.O.C | **Yukari Yamashita** |
| | | | Post Fukushima: Long-term role of the fusion power in Korea – a markal-times model approaches. | **Hansoo Chang** | Hyunsoo Tho, Wonjae Choi, Dong-yub Kang, Young-gu Park | National Fusion Research Institute, Korea | |
| | | | Consequences of the Fukushima Daiichi nuclear crisis on the future of energy provision: Evidence from coal, gas and renewable markets. | **Zhen Lei** | Anastasia Shcherbak | Penn State University | |
| | | | Kyoto, Fukushima and nuclear power. | **Ian J Duncan** | | Australian Academy Technological Sciences and Engineering | |
| | 9 | Oil Price | WTI and Brent crude oil markets: A dynamic analysis of the price differential. | **Julian Inchauspe** | Lurion De Mello | CREME, Curtin University, Australia | **Mine Yucel** |
| | | | The impact of oil prices in the process of financial integration in the GCC countries. | **Abdulfatah Alsameen** | | School of Economics and Finance, Curtin University | |
| | | | Determinants of crude oil prices between 1997-2011. | **Nourah AlYousef** | | Economics Department, King Saud University Riyadh, Saudi Arabia | |
| | | | Forecasting crude oil price using soft-computing methods and google insight for searcher. | **Imad Haidar** | Rodney C. Wolff | The University of Queensland, Australia | |
| | 11 | Energy Efficiency Writ Large | USA total energy demand and energy efficiency: A stochastic demand frontier approach. | **Massimo Filippini** | | Centre for Energy Policy and Economics (CEPE), ETH Zurich and Department of Economics, University of Lugano | **Luke Reedman** |
| | | | Portfolio optimization of new power plants with combinatorial auctions. | **Debora Yamazaki Lacorte** | | State University of Campinas/SP | |
| | | | Global and regional lifecycle energy efficiency of fossil-based primary energy sources: Trends and scenarios. | **Sonia Yeh** | Gouri Shankar Mishra, Geoff Morrison, Jacob Teter, Raul Quiceno | University of California at Davis | |
| | | | Disinvestment effect of electricity efficiency improvements in an economy with energy price control and imperfect markets. | **D. Manzoor** | I. Haqiqi, M. E. Aghababaei | Imam Sadiq University | |

# Future investment costs of renewable energy technologies at volatile energy- and raw material prices – an econometric assessment

Christian Panzer[1]

***Keywords:*** Econometric modeling, investment capital, energy technologies, volatile markets

***JEL classification:*** C10; O33; Q42

## Abstract

The theoretical literature of dynamic energy technology investment cost modeling focuses mainly exclusively on technological learning by doing effects. More recent literature raises the question on a certain bias of the learning by doing effect caused by other exogenous effects. In this context, the impact of energy and raw material prices is revealed. Consequently, the core objective of this paper is to identify the impact of energy and raw material prices on the investment costs of energy technologies. Thus, the key drivers in terms of primary energy prices of most relevant raw material prices are quantified based on empiric evidence within econometric models. Furthermore, the simultaneous impact of these raw material prices and technological learning effects on energy technology investment costs is identified in econometric models too. This allows modeling the endogenous feedback from energy prices to the investment cost of energy generation technologies that are responsible for future energy prices.

Results depict a significant impact of coal and natural gas prices on steel and concrete prices. Silicon prices are largely depending on expenditures for electricity consumption. However, an important contribution of wind onshore investment costs is explained by steel prices, whereas offshore wind investment costs are additionally impacted by concrete prices. Steel and concrete price show an even slightly stronger impact on small-scale biomass CHP investment costs. In contrast silicon price only hold a marginal impact on Photovoltaic investment costs. Similar results are derived for small-scale hydro power investment costs, where energy and raw material prices do not explain their development significantly. In general, technological learning by doing effects are largely compensated by the impact of raw material prices in the case of wind and small-scale biomass CHP technologies.

In terms of electricity generation costs, the strong impact of energy and raw material prices on biomass CHP investment costs is partly compensated by the fuel costs. However, due to the technological similarity of biomass and coal fired CHP plants, conclusions highlight that even in times of increasing energy prices, wind energy generation

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costs can drop below conventional generation costs and Photovoltaic generation costs result in only slightly higher levels in 2030.

## Introduction

The global commitment towards a more sustainable future energy supply portfolio yields several technical, economical and political new challenges. Consequently in the year 2009, the European Commission published the Directive 2009/28/EC (European Commission, 2009) aiming for a 20 percent renewable energy target in the year 2020. In this context, fundamental contribution is expected from renewable energy sources in general and renewable electricity in particular (IEA, 2011). However, nowadays only a small share of renewable electricity generation already competes on international electricity markets whereas the rest is still incentivized by financial support schemes. Nevertheless, these implemented support schemes of renewable energy technologies must be strengthened towards more efficiency and effectiveness in order to meet the target by the year 2020. This is a necessary precondition in order to guarantee an enhanced future renewable energy development at moderate consumer expenditures, incentivizing this development.

Thus, necessary information for the design of efficient support options provides a precise forecast tool of future investment costs of renewable energy technologies. Main drivers of these investment costs must be identified and incorporate into energy models. Therefore, models deriving a future pathway of energy technology investment costs require new, additional methodological approaches. With respect to the status quo, most energy models only consider investment cost decreases caused by technological improvements, the learning by doing effect. The broad variety of known methodological approaches allows taking into account several important drivers and therefore deriving more precise estimations.

Recent market observations have shown that not solely technological learning by doing effects influence energy technology investment costs but volatile energy and raw material prices hold an even more significant impact (Chupka et al, 2007). Of high relevance in this respect is the pure impact of primary energy prices as well as steel, concrete and silicon prices on the investment costs of renewable electricity generation technologies. Furthermore the dynamic interaction between the different impact parameters gives an indication of the sensitivity of specific energy technology investment costs at volatile energy and raw material prices.

Consequently, this paper analyses the dynamic development of (renewable) energy technology investment costs. Specifically it assesses their key drivers in the historic and future context. Thus, the impact of technological learning and volatile energy and raw material prices is quantified. In particular the following research questions are addressed:

1. Which commodity prices are of key relevance for the investment costs of the selected energy technologies?
2. What are the main drivers of the identified commodity prices in terms of primary energy sources?
3. What is the quantitative relation between primary energy prices and commodity prices?
4. What is the quantitative relation between these commodity prices and energy technology investment costs?
5. What effect does learning by doing have on the investment cost in quantitative terms?
6. Are there any coherencies from renewable to conventional energy investment costs?
7. How robust are energy technology investment costs against energy price volatility?
8. What are the implications of the derived results for the electricity market?

Hence, an endogenous feedback from energy prices, forming the market where renewable energy technologies must compete, to the investment cost of renewable energy technologies is modeled within this paper.

## Method of approach

In a first step, the steel, concrete and silicon production processes are analyzed in order to indentify the components that hold major shares in terms of production costs. Obviously this differs strongly depending on the production type, however all three raw material are in common very energy intense in production and consequently impacting their prices.

$$CP = \delta + \vec{\varepsilon} * \mathrm{EP} + u_t \qquad \text{Eq. 1}$$

| | |
|---|---|
| CP | Commodity price |
| $\delta$ | Constant |
| $\vec{\varepsilon}$ | Matrix of weighting factors of considered primary energy prices |
| EP | Vector of considered primary energy prices |
| $u_t$ | Statistical disturbance term |

According to formula Eq. 1 the different commodity prices are derived by an econometric model (Greene, 2012), considering their main energy input prices, certain time lags and the standard disturbance term. In order to derive future forecasts of commodity costs, exogenous energy price assumptions (Capros et al, 2011) are taken into account.

Thus, derived commodity prices refer more to commodity costs, since others[2] than the energy related costs are neglected by estimating the commodity prices. Historic coal, coking coal, natural gas and electricity prices as well as their associated consumption time series are forming the basis of this linear regression model.

In a next step, the impact of the mentioned raw material prices on investment costs of the selected energy technologies is dynamically taken into account. Amongst others, Nordhaus (2008) discussed that, the problem of modeling technological learning appears in trying to separate learning by doing effects from technological change and consequently overestimating learning by doing effects. According to literature the most suitable approach is identified to be the multi factor impact modeling. Existing studies (Miketa et al, 2004; Yu et al, 2010 & Söderholm et al, 2007) have successfully applied this approach in order to consider effects as scale, R&D or partially raw material prices.

The ordinary learning by doing formula considers the dynamic investment cost development of renewable energy technologies depending on the cumulative capacity (see Neij, 1997 and Junginger, 2000). Consequently a certain learning progress in terms of reduced investment costs is achieved in every incremental point in time from t to t+1, whereby usually annual steps are taken into account. Therefore, extending the original learning by doing formula by an additional term allows considering multi factor impacts as R&D expenditures, scale effects as well as raw material impacts on top of learning by doing. However, this paper solely focuses in much detail on the impact of different raw material prices, either solely or as combination of various raw materials, depending on the relevant share of these commodities on the total investment costs. In this context, formula Eq. 2 is introduced to:

$$INV(t) = \left(\alpha + \vec{\beta}\ \mathrm{CP} + u_t\right) * \left(\frac{x_t}{x_0}\right)^m \qquad \text{Eq. 2}$$

| | |
|---|---|
| INV(t) | Investment cost in the year t |
| $\alpha$ | Constant |
| $\vec{\beta}$ | Vector of weighting factors of considered commodity prices |
| CP | Matrix of considered commodity prices |
| $u_t$ | Statistical disturbance term |

[2] World demand of raw materials, production capacities and local characteristics of different raw materials hold an additional impact on their prices.

$x_t$ Cumulative installed capacity in time t

$x_0$ Initial cumulative installed capacity

m Learning by doing impact

As addressed at the linear regression model of commodity costs, the model in formula Eq. 2 only considers raw material impacts and learning by doing effects[3]. Additionally, adding parameters of time lagged commodity costs as well as first derivations to the commodity price vector $\overrightarrow{CP}$ increase the quality of the regression model significantly. At the process of calculating the regressors in Eq. 2, real historic observation data is used. In comparison to the traditional multi factor learning curve approach (i.e. see Miketa et al, 2004), this research follows a separate identification approach of learning by doing effects and raw material impacts. Thus, considering a broad set of selected energy technologies, the limited data availability demands an independent calculation of these two impacts. A detailed assessment[4] of this approach is given in Panzer (2012).

Finally, future scenarios of renewable energy investment costs are derived based on the developed model in Eq. 2. In contrast to the identification of the regressors, where the real historic observed commodity price information is used, the scenario calculation builds on derived commodity costs of Eq. 1. This allows for an endogenous feedback from energy prices to future investment costs of (renewable) energy technologies, serving as basis for simulation models of investment decisions as well as policy recommendations.

## Commodity prices – impacts and drivers

First the steel price development is analyzed. In the focus of primary energy consumption of steel production it needs to be distinguished between the different technical production processes. In principal, three major technologies are in operation nowadays. On the one hand, the Basic Oxygen Furnace (BOF) technology mainly builds on iron ore and coking coal inputs. Hereby the coking coal plays an important role in the context of energy input as well as for forming the physical structure of the steel product. On the other hand, the Electric Arc Furnace process produces steel only from steel scrap inputs. Therefore, the required energy input and consequently CO2 emissions are

[3] Research and Development expenditures, Strategic pricing, opportunity costs of investors, market power of suppliers are not taken into account in this research. Economies of scale are only considered indirectly, since input data of renewable energy investments has been filtered according to the scale of the plant.

[4] According to different technology cost indexes (Vatavuk, 2002), energy technology investment costs did not show any impact of raw material prices before the year 2000 whereby the pure technological learning rate could be defined. Building on constant technological learning rate, this allows for the quantification of pure raw material prices impacts in the time period beyond the year 2000.

significantly reduced. Finally, the Direct Reduced Iron (DRI) process has been developed in recent years. The DRI process starts from natural gas or coal which is then passed over the iron ore to produce sponge iron. The sponge iron needs then to be fed into an EAF process in order to produce steel (Wooders et al, 2009). In total steel production by the DRI process followed by EAF system causes about the half of the CO2 emissions than the BOF system and neither depends on steel scrap. However, about two third of the current steel production refers to BOF system whereas coal prices play a key role in steel production. Therefore, an in-depth modeling assessment is carried out in order to quantify the impact of coal prices on steel prices. Formula Eq. 3 depicts the derived model specifications.

$$\frac{\Delta c_{\mathrm{steel}}}{\Delta \mathrm{t}} = c + DIFFCOAL * \frac{\Delta c_{coal}}{\Delta \mathrm{t}} + DIFFCOAL(-1) * \frac{\Delta c_{\mathrm{coal}}}{\Delta(\mathrm{t}-1)} + u(t) \qquad \text{Eq. 3}$$

| | |
|---|---|
| $\frac{\Delta c_{\mathrm{steel}}}{\Delta \mathrm{t}}$ | Annual steel price growth rate |
| c | Constant parameter |
| $\frac{\Delta c_{\mathrm{coal}}}{\Delta \mathrm{t}}$ | Annual coal price growth rate |
| $\frac{\Delta c_{\mathrm{coal}}}{\Delta(\mathrm{t}-1)}$ | Annual coal price growth rate of previous year |
| u(t) | Statistical disturbance term |
| DIFFCOAL<br>DIFFCOAL(-1) | Constant parameter of regression of the impact of annual coal price growth rates |

The model in Eq. 3 describes the annual change rate of the steel price development in dependence on a constant term, the annual change rate of the coal price, the annual change rate of the coal price of the previous year and the statistical disturbance term. In general, the constant term represents a floor price. Moreover, the impact of the coal price growth rate indicates the high share of coal products in steel production. In contrast the coal price growth rate of the previous year represents the coal price impact on coke production used in steel-making processes. However, major impact of delayed coal prices occur due to the fact that high volumes of coal are traded on long term contracts (Adams, 2006).

Figure 1 compares the historically realized steel price development to the derived steel prices based on energy price impacts. Besides the deviations of the model based steel price from real the observation around the year 2000 generally a slightly lower steel price is calculated fitting the overall trend very well. Generally, a steel price increase of 35 percent between the year 2000 and 2005 is calculated, whereas the coal price increased by 139 percent in the same time period – having an impact of about 25 percent on the steel price development. Nevertheless, future forecast scenarios based on econometric analyses have to be interpreted carefully, especially in the long term horizon up to the year 2030.

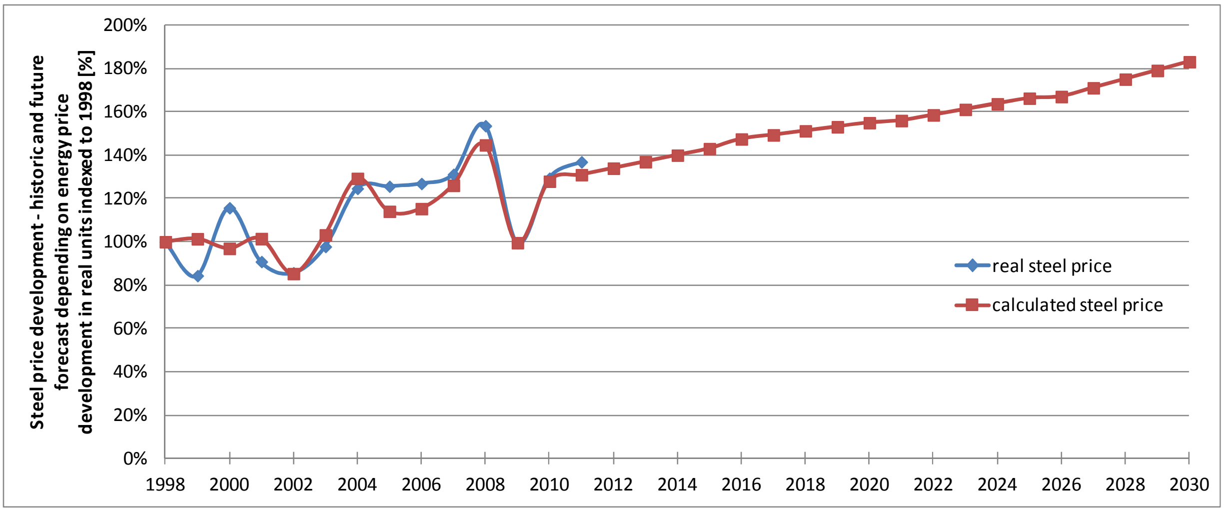


Figure 1 Future forecast scenario of the steel price development according to coal price assumptions (Capros et al, 2011) in real units indexed to the year 1998 and comparison to historical observations. Source: own calculations

Next, silicon prices are taken into account. Starting from raw materials in a first step metallurgical silicon is produced in a carbonthermic reduction. Hereby Electric Arc Furnaces are applied in order to reduce the quartz sand with coal. Due to the high electricity consumption of this process, the economic behavior is strongly influenced by the electricity price of the region. Therefore countries with high shares of hydro power generation are large producers of metallurgical silicon (Jungbluth et al, 2008). Furthermore, based on the metallurgical silicon, electronic grade silicon respectively nowadays also solar grade silicon is produced. In particular, the metallurgical silicon is first converted into a gas and subsequently this gas is purified by means of distillation. Finally, by adding hydrogen in a deposition reactor, the Siemens reactor, the gas is decomposed onto a surface of electrically heated silicon rods (Jungbluth et al, 2009). According to these steps electronic grade silicon is produced in the so called Standard Siemens route. The total silicon production is strongly dominated by electricity consumption, both in the production of the required metallurgical silicon as well as in the final stage of deriving electronic grade silicon. According to the identification of major input materials in silicon production an econometric model is established allowing for modeling pathways of silicon prices depending on electricity expenditures.

$$\ln c_{silicon}^{*}(t) = \mathrm{c} * \mathrm{k}^{*} + SI\_ECL * \ln c_{ele}^{*}(t) + SI\_ECL(-1) * \ln c_{ele}^{*}(t-1) + u(t) \qquad \text{Eq. 4}$$

$$c_{silicon}^{*}(t) = c_{silicon}(t) - \rho * c_{silicon}(t-1) \qquad \text{Eq. 5}$$

$$c_{ele}^{*}(t) = c_{ele}(t) - \rho * c_{ele}(t-1) \qquad \text{Eq. 6}$$

$$k^{*} = 1 - \rho \qquad \text{Eq. 7}$$

| | |
|---|---|
| $c_{silicon}(t)$ | Silicon price in the year t |
| $c_{ele}(t)$ | Electricity expenditures for silicon production in year t |
| c | Constant parameter |
| ρ | Cochrane-Orcutt parameter |
| u(t) | Statistical disturbance term |
| SI_ECL<br>SI_ECL(-1) | Constant parameter of regression of the impact of electricity expenditures for silicon production |

The model in Eq. 4 indicates that the silicon price is a function of a constant term, the electricity expenditures and the one year time lagged electricity expenditures plus a statistical error term. In order to linearize the relation the natural logarithmic has been introduced to the model. Moreover, all parameters of the regression have been transformed by the Cochrane-Orcutt factor (ρ=0.968) according to formulas Eq. 5 to Eq. 7. Hence, the overall regression estimation is corrected for first order serial correlation of the error term and thus fulfills the Gauss-Markov Theorem (Greene, 2012). Generally, the silicon price is depending on the electricity expenditures of the same year as well as of the previous year. The feedback of the previous year implies that technology development is a constant development different silicon production facilities only replace their production equipment by time. Consequently, different energy consumption characteristics occur, having an impact on silicon prices.

Finally, Figure 2 presents the historic and future development of the silicon price in dependence on electricity expenditures. Obviously moderate deviations occur in comparison to historic observations in some years, whereas the trend of the development can be acceptable explained by only taking into account energy prices. The lack of silicon production in 2004 and therefore associated additional energy demand in silicon production in these years led to an increase in silicon prices.

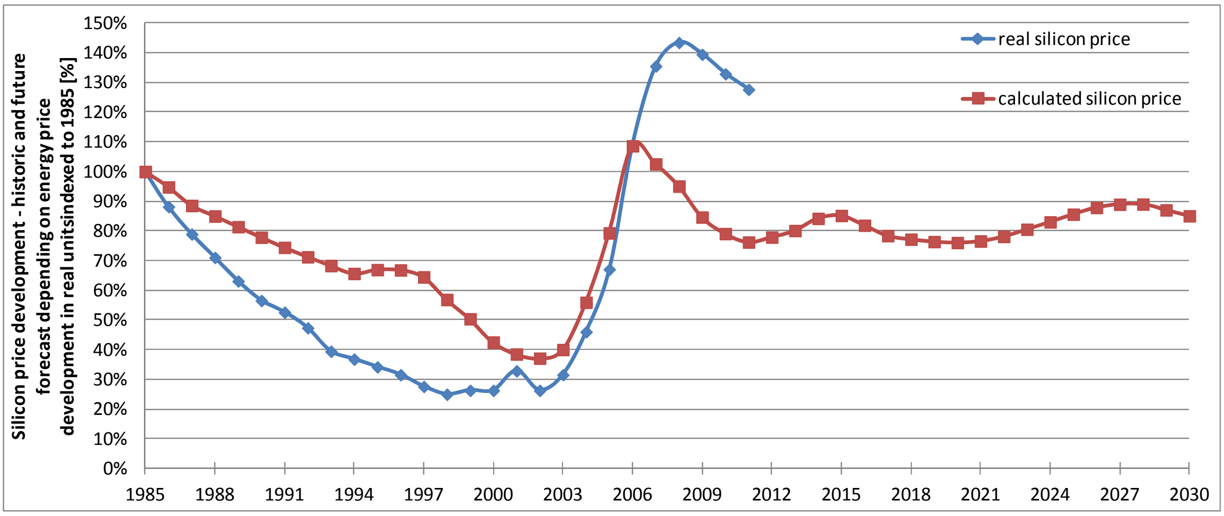


Figure 2 Future forecast scenario of the silicon price development according to electricity expenditures (Huber et al, 2004) in real units indexed to the year 1985 and comparison to historical observations. Source: own calculations

Regarding the long term future forecasts, attention has to be drawn to the model which cannot consider other than historical observed, technological changes in silicon production and therefore the long term silicon price forecast is uncertain.

Finally, with respect to the concrete price development the impact of historic primary energy prices is analyzed. In consequence of the comparatively energy intensive production of cement in contrast to the concrete production, the energy inputs and associated prices in the cement industry are considered as the relevant drivers of the concrete price. Generally three production steps are distinguished: The mining and preparation of raw materials, the clinker burning and the finish grinding. As the first step is a rather electricity intensive process  the clinker burning is the overall most energy intensive production step, accounting for about 90 percent of the total energy use. However, the total energy consumption depends very much on the moisture content of the raw materials. In contrast, the last production step only requires about five percent of the total energy consumption (Worrell et al, 2000). According to the different moisture content of the raw materials different technologies are selected. Starting at wet rotary kilns using raw materials containing up to 38 percent water to dry kilns with pre-heater with much less energy consumption are installed nowadays. Additionally, semi-wet and semi-dry kilns are in operation with reduced moisture content and consequently energy consumption compared to the wet rotary kiln (Szabó et al, 2003). Almost two thirds of the total energy consumption refers to coal and coke. Natural gas holds an increasing share due to its lower emissions but is currently mainly used in on-site electricity production. Moreover, alternative fuels as biomass energy are used in the cement industry. However, the biomass products used are dominated by rubber tires and sewage sludge. Therefore, the concrete price model is characterized through formula Eq. 8 below.

$$c_{concrete}(t) = c + COAL * c_{coal}(t) + COAL(-1) * c_{coal}(t-1) + GAS(-2) * c_{gas}(t-2) + u(t) \quad \text{Eq. 8}$$

| | |
|---|---|
| $c_{concrete}(t)$ | Concrete price in the year t |
| $c_{coal}(t)$ | Coal price in year t |
| $c_{gas}(t)$ | Natural gas price in the year t |
| C | Constant parameter |
| u(t) | Statistical disturbance term |
| COAL<br>COAL(-1) | Constant parameter of regression of the impact of coal prices and the impact of the previous year coal price |
| GAS(-2) | Constant parameter of regression of the impact of gas prices |

Generally, the present concrete price is explained by a constant term, the present coal price, the previous year coal price and the natural gas price of two years ago. In the model of Eq. 8, the impact of the present coal price reflects energy use for heat production in clinker burning. Additionally, the time lagged impact of the coal price results from the pre-preparation of coking coal where coal plays a determining role. With respect to the gas price, highest impacts are identified for two year time lagged prices. On the one hand, high volumes of gas are traded on long term contracts and on the other hand small on-site storages facilities lag the impact of gas prices additionally. Moreover, the discrete representation of the continuous technology development in the model, leads to additional time lagged influences of the primary energy prices.

Figure 3 illustrates the concrete price development indexed to the year 1985 and compares it to real historic observation. Apart from the deviation in the year 2002, caused by strong increasing natural gas prices a well acceptable approximation is explained through the primary energy price development. However, with respect to the future scenarios a significant decrease of concrete prices in the first year of simulation is recognized. Responsible therefore is the switch from historic statistics of natural gas prices to the general energy price assumptions (Capros et al, 2011) in this paper which are far below historic records. By trend a leveling off, of concrete prices is expected beyond the year 2020 when energy prices are expected to grow moderately too.

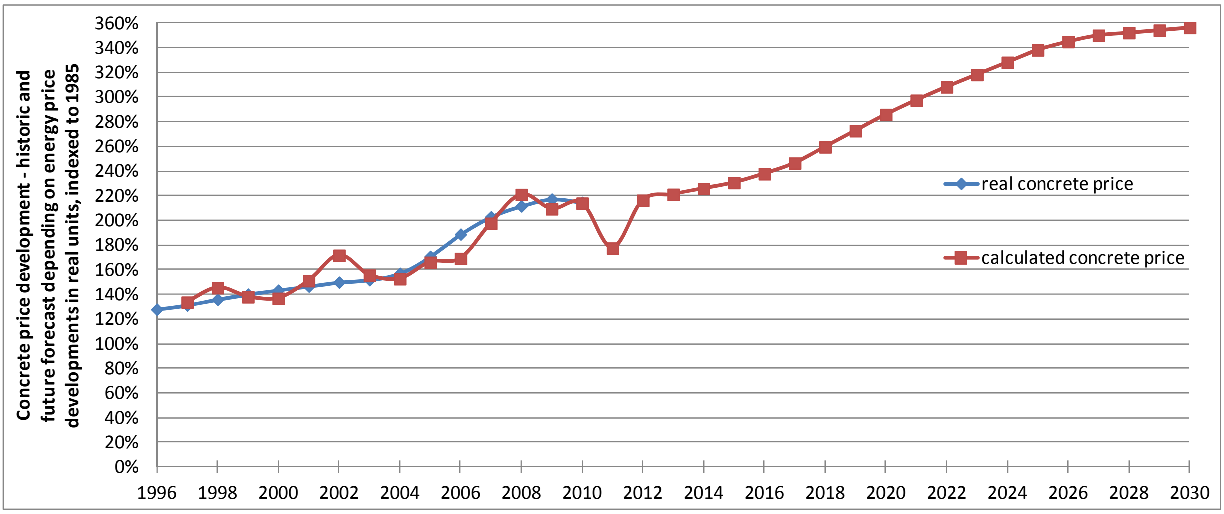


Figure 3 Future forecast scenario of the concrete price development according to coal and natural gas prices (Capros et al, 2011) in real units indexed to the year 1985 and comparison to historical observations. Source: own calculations.

## Energy technology investment costs – drivers and impacts

Generally, renewable energy technology investment costs are taken into account, whereas some arguments are carried out for conventional coal plants as well. In particular wind on- and offshore, Photovoltaic and small-scale biomass CHP investment costs are analyzed.

First wind onshore investment costs are addressed. On the one hand, technological improvements steadily decreased the investment costs of onshore wind turbines. On the other hand, different exogenous effects rather have an increasing effect. Particularly, steel prices hold a significant impact on the investment costs of onshore wind turbines. In terms of wind onshore investment costs, about 42 percent up to 58 percent, depending on the scale of the wind energy turbine, are caused by steel inputs (Ancona et al, 2003 and Krohn et al, 2009). Consequently, this section elaborates on the impact of steel prices on the investment costs of onshore wind energy technologies. Thus, an econometric model is developed in order to quantify the impact. Moreover, the simultaneous effect of technological learning by doing is taken into account in the model of formula Eq. 9.

$$\ln INV_{WI-ON}\,(t) = c + LSTEEL * \ln c_{steel}(t) + LSTEEL(-1) * \ln c_{steel}(t-1) + u(t) \qquad \text{Eq. 9}$$

| | |
|---|---|
| $INV_{WI-ON}(t)$ | Investment cost of onshore wind in the year t corrected for technological learning effects |
| $c_{steel}(t)$ | Steel price in the year t |
| $c_{steel}(t-1)$ | Steel price of the previous year t-1 |
| c | Constant parameter |
| u(t) | Statistical disturbance term |
| LSTEEL<br>LSTEEL(-1) | Constant parameter of the regression of the direct and time lagged impact of steel prices |

Generally, in order to meet the preconditions for estimating the wind onshore investment costs with the discussed OLS method, the Gauss Markov Theorem must be fulfilled. Therefore the natural logarithmic is used in order to linearize the model in Eq. 9. Moreover, the disturbance term does not contain any information by definition. On the one hand, a direct impact of current steel prices is identified in the model. On the other hand, also a direct impact of the previous year's steel price is recognized. The time lagged impact occurs from long term contracts of steel supply for wind technology manufactures but also the long time period of admission procedures is responsible for the delayed impact

Thus, Figure 4 compares the historically realized wind onshore investment costs to the modeling results. On the one hand the traditional learning by doing result is indicated showing a constant price decrease. On the other hand, the additional impact of steel prices describes the volatile character as it has been observed in the recent past.

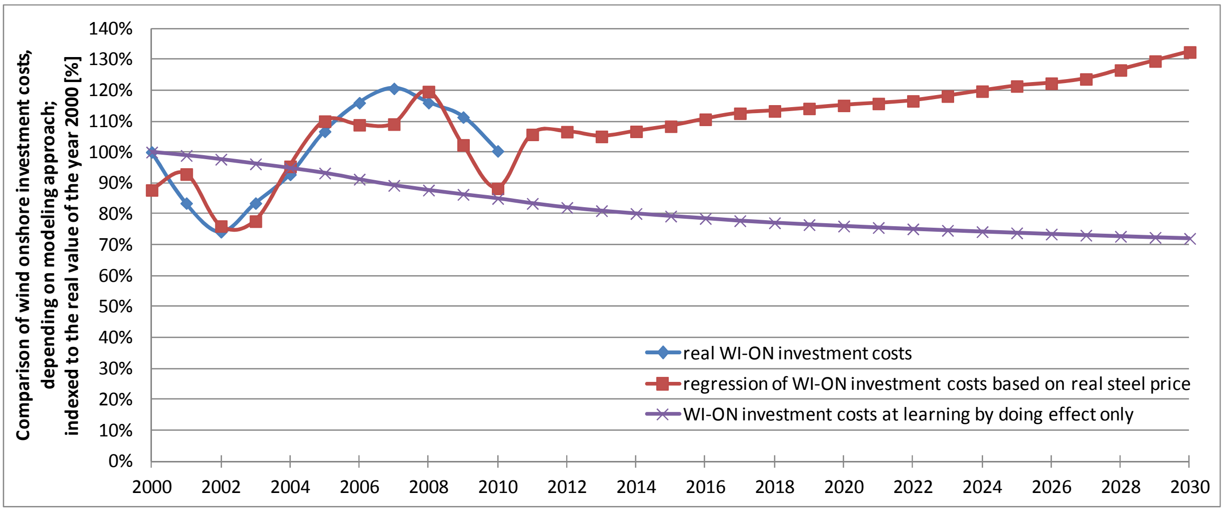


Figure 4 Future forecast scenarios of onshore wind energy investment costs, on the one hand based on technological learning effects (LR=7%) only and on the other hand additionally considering the steel price impact too. Source: Own calculations.

Generally, estimations based on steel price assumptions are slightly below realized investment costs, apart the year 2008 when high market steel prices were noticed but wind investment costs stabilized. Although a future forecast based on historic evidence requires attention[5] in terms of interpretation a clearly more precise estimation is given compared to neglecting the impact of steel prices. Otherwise, in times of decreasing steel prices wind onshore investment costs would be overestimated at neglecting steel prices in investment cost estimations and vice versa. However, Figure 4 depicts, that the technological learning effect would be completely compensated by the impact of steel prices and consequently wind onshore investment costs would increase by about 25 percent until 2030 compared to nowadays (2011). Perceivable in both scenarios is the decreasing effect of technological learning beyond the year 2020 observable when a doubling of cumulative, global installation takes longer than nowadays.

A slightly different approach is carried out for wind offshore investment costs. However, with respect to their input materials, similar commodities are used (Smit et al, 2007). In contrast, the foundation of offshore wind energy converters differs significantly from onshore technologies. Consequently, this research focuses on the dynamic development of investment costs of the additional equipment of offshore wind energy plants compared to onshore. Previous research (Junginger et al, 2004) highlighted an impact of commodity prices on foundations of wind offshore turbines of 45 to 55 percent in terms of investment costs. Thus, the impact of technological learning, steel and

[5] Technological relation and input parameters are assumed to be constant in the considered time period. Energy prices are exogenously assumed and therefore the scenario has a normative character, showing a potential future development in case of the assumed input parameters.

concrete prices on foundation, platform and grid connection of offshore wind plants is derived in the following. The model of the investment costs of the additional equipment of offshore wind turbines is discussed in formula Eq. 10.

$$\ln INV^{*}_{WI-OFF}(t) = c * k^{*} + STEEL * \ln c^{*}_{steel}(t) + CONCRETE * \ln c^{*}_{concrete}(t-1) + u(t) \qquad \text{Eq. 10}$$

$$INV^{*}_{WI-OFF}(t) = INV_{WI-OFF}(t) - \rho * INV_{WI-OFF}(t-1) \qquad \text{Eq. 11}$$

$$c^{*}_{steel}(t) = c_{steel}(t) - \rho * c_{steel}(t-1) \qquad \text{Eq. 12}$$

$$c^{*}_{concrete}(t-1) = c_{concrete}(t-1) - \rho * c_{concrete}(t-2) \qquad \text{Eq. 13}$$

$$k^{*} = 1 - \rho \qquad \text{Eq. 14}$$

| | |
|---|---|
| $INV_{WI-OFF}(t)$ | Investment costs of the additional equipment of offshore wind installation, corrected for learning effects in the year t |
| $c_{steel}(t)$ | Steel price in year t |
| $c_{concrete}(t-1)$ | Concrete price in the previous year (t-1) |
| c | Constant parameter |
| ρ | Cochrane-Orcutt parameter |
| u(t) | Statistical disturbance term |
| STEEL CONCRETE | Constant parameter of regression of the impact of steel and concrete prices |

The model in Eq. 10 indicates that the investment costs of the additional equipment of wind offshore installations are a function of a constant term, the steel price and the one year delayed concrete price plus a statistical error term. In order to linearize the relation the natural logarithmic has been introduced to the model. Moreover, all parameters of the regression have been transformed by the Cochrane-Orcutt factor ($\rho$=0.3348) according to formulas Eq. 11 to Eq. 14. Hence, the overall regression estimation is corrected for first order serial correlation of the error term and thus fulfills the Gauss-Markov Theorem. Generally, a direct impact of the steel price is identified whereas the concrete price influences the investment costs one year delayed. Among others, this issue is caused by the fact that wind offshore installations usually require a longer planning and admission procedure. Therefore, one year delayed concrete prices are taken into account in actual installations but steel price are mostly considered in real times.

Generally, the historic realized investment cost data refers to explicit case studies and therefore holds high volatility depending on the site specific circumstances. Nevertheless a reasonable estimation of the trend of total wind offshore investment cost is derived in the model. However, the strong deviations from 2001 to 2003 are due to underestimated onshore wind investment costs which are partly considered as offshore turbine investment costs too. In this time period, decreasing steel prices significantly reduced onshore investment costs but offshore investment cost rather increased based on additional technical requirements compensating the decreasing input price impacts. A rough calculation of average offshore wind energy investment costs (EWEA, 2010) indicates a similar trend as the model result in Figure 5 below. With respect to future forecasts, the pure learning by doing approach expects a decrease in investment costs to about 60 percent of the year 2000 level in 2030. In contrast, additionally taking into account steel and concrete prices, drive future investment costs up to about 114 percent of the year 2000 level in 2030. Therefore, increasing steel and concrete prices are expected to increase wind offshore investment costs significantly and totally compensate the learning effect.

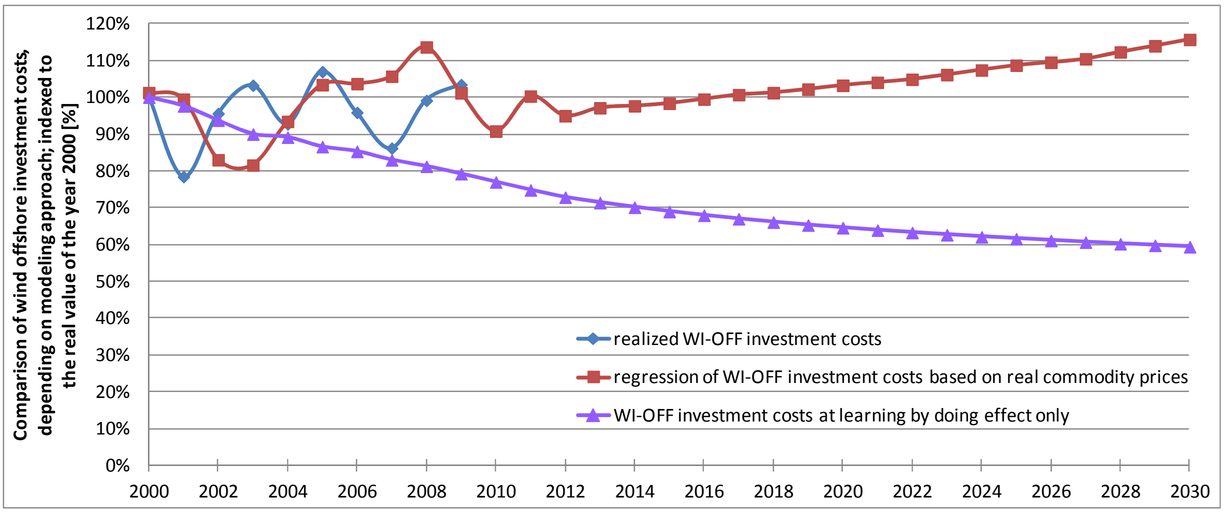


Figure 5 Future forecast scenarios of offshore wind energy investment costs, on the one hand based on technological learning effects (additional equipment: LR=10%) only, and on the other hand considering the steel and concrete price impact too. Source: Own calculation.

Next, Photovoltaic investment costs are analyzed with respect to their energy and raw material price impact. Generally, it is distinguished between crystalline silicon and thinfilm Photovoltaic modules[6] whereas crystalline modules have a market share of about 87 percent (EPIA, 2008). Thus, this paper concentrates on investment costs of

[6] Additional, amorphous and CIS Photovoltaic modules exist, but do not have significant market shares.

crystalline silicon installations. Therein silicon prices are responsible for about 13 to 27 percent of the total investment costs of Photovoltaic installation (Sinke et al, 2009 and Nemet, 2006). Consequently an econometric model is derived focusing on the impact of silicon prices and technological learning effects on investment costs of Photovoltaic installations.

$$\ln INV_{PV}^{*}(t) = c * k^{*} + PV * \ln c_{silicon}^{*}(t) + PV(-3) * \ln c_{silicon}^{*}(t-3) + u(t) \qquad \text{Eq. 15}$$

$$INV_{PV}^{*}(t) = INV_{PV}(t) - \rho * INV_{PV}(t-1) \qquad \text{Eq. 16}$$

$$INV_{PV}^{*}(t) = INV_{PV}(t) - \rho * INV_{PV}(t-1) \qquad \text{Eq. 17}$$

$$c_{silicon}^{*}(t-3) = c_{silicon}(t-3) - \rho * c_{silicon}(t-4) \qquad \text{Eq. 18}$$

$$k^{*} = 1 - \rho \qquad \text{Eq. 19}$$

| | |
|---|---|
| $INV_{PV}(t)$ | Investment costs of Photovoltaic installation, corrected for learning effects in the year t |
| $c_{silicon}(t)$ | Silicon price in year t |
| $c_{silicon}(t-1)$ | Silicon price three years ago, year (t-3) |
| C | Constant parameter |
| ρ | Cochrane-Orcutt parameter |
| u(t) | Statistical disturbance term |
| PV<br>PV(-3) | Constant parameter of regression of the impact of silicon on three years delayed silicon price |

The model in Eq. 15 indicates that the Photovoltaic investment costs, adjusted for technological learning effects, are a function of a constant term, the silicon price and the three years delayed silicon price plus a statistical error term. In order to linearize the relation the natural logarithmic has been introduced to the model. Moreover, all parameters of the regression have been transformed by the Cochrane-Orcutt factor ($\rho$=0.2927) according to formulas Eq. 16 to Eq. 19. Generally, a direct impact of silicon prices on the investment costs of Photovoltaic installations is identified, whereas an additionally delayed impact of the silicon price of three years ago has important influences too. Historically silicon from the electronic industry has been used in the Photovoltaic industry and therefore no delay of the silicon supply for Photovoltaic production has occurred. In contrast, the production shortage of silicon in peak time of Photovoltaic demand reduced the actual silicon supply and enforced a delayed silicon price impact.

With respect to the investment costs of Photovoltaic installations, a remarkable learning by doing effect is realized at a learning rate of LR=20%. Considering their rapid market penetration according to IEA (2008) significantly impacts the Photovoltaic investment costs. Combining the material price impact and the technological learning effect illustrates the dynamic development in Figure 6.

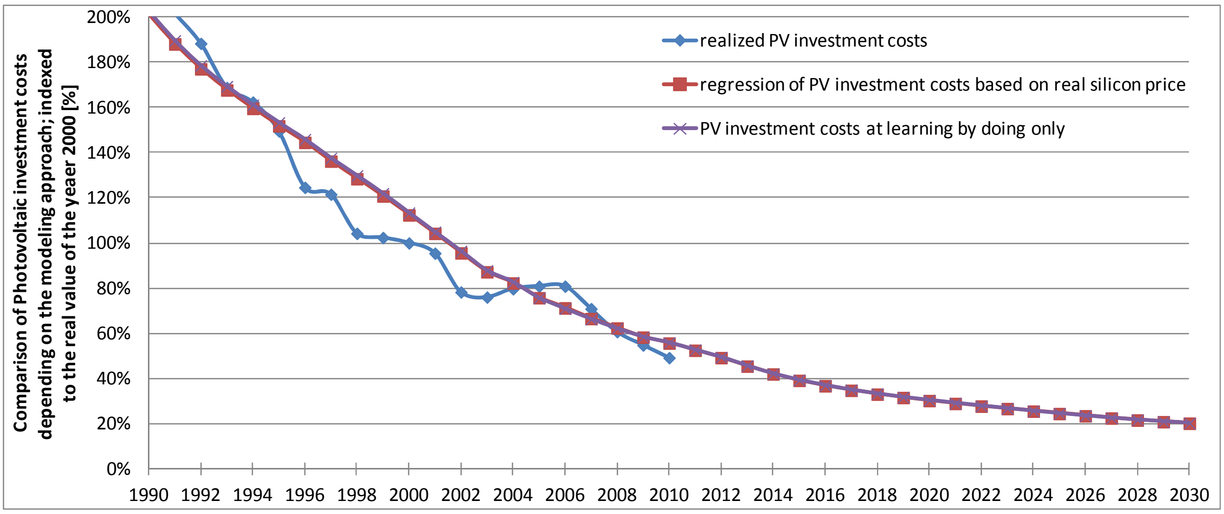


Figure 6 Future forecast scenarios of Photovoltaic investment costs, on the one hand based on technological learning effects (LR=20%) only and on the other hand additionally considering the silicon price impact. Source: Own calculations.

However, the significant impact of silicon prices on the investment costs determined at the model of formula Eq. 15 around the year 2004 is compensated by technological learning effects. Hence, silicon price have indeed an impact of Photovoltaic costs but with respect to their investment costs they are hardly recognizable. Generally, Photovoltaic investment costs are expected to further decrease by about 35 percent within the next twenty years. However, this decrease is mainly driven by technological learning effects too, although a slower decrease is expected than historical observed due to the longer time it takes for doubling the installed capacity.

Finally, small-scale biomass CHP investment costs are discussed. Generally, in terms of the combustion process significant similarities of the technological equipment exist to the conventional energy sector with slight adoptions in the case of biomass energy use (Kleijn et al, 2011). The largest components in terms of costs are the boiler, up to 82 percent, the fuel handling, up to 23 percent and the steam turbine up to 15 percent (Koornneef et al, 2007). With respect to commodity prices, steel and concrete prices hold a relevant impact on the investment costs of small-scale biomass CHP plants. According to manufactures (Polytechnik, 2011) the impact of steel prices on the overall investment costs is identified on average at about 20 percent. Additionally, an important impact of commodity prices is identified in the biomass feedstock preparation process. An econometric model quantifies the impact of these commodity costs in a mathematical context and moreover the results are interpreted in an energy related context. Technological learning by doing effects, simultaneously influencing the investment costs are considered too. The model is depicted in formula Eq. 20 below.

$$INV_{BM-CHP}(t) = c + CONCRETE(-1) * c_{concrete}(t-1) + STEEL(-1) * c_{steel}(t-1) + u(t) \quad \text{Eq. 20}$$

| | |
|---|---|
| $INV_{BM-CHP}(t)$ | Investment costs of small-scale biomass CHP plants, corrected for learning effects in the year t |
| $c_{concrete}(t-1)$ | Concrete price of the previous year (t-1) |
| $c_{steel}(t-1)$ | Steel price of the previous year (t-1) |
| c | Constant parameter |
| u(t) | Statistical disturbance term |
| CONCRETE(-1) STEEL(-1) | Constant parameter of regression of the impact of the one year delayed concrete and steel price |

The model indicates that small-scale biomass CHP investment costs, corrected for technological learning effect, are explained by a constant term, the one year time lagged concrete and steel price as well as an error term. Due to the moderate volatility of the time series no linearization need to be taken into account. The one year delayed impact of both commodity prices is caused by the fact that the planning procedure mostly requires a longer time period. The constant term represents the part of the investment costs being independent of energy and raw material prices. Furthermore, the statistical error term do not contain any information of investment costs but solely indicates the random difference between the real and estimated investment costs.

Consequently, Figure 7 depicts the historically realized biomass CHP investment costs as well as the estimations based on technological learning effects and the additional consideration of commodity price impacts. Similar to the historic observation of offshore wind investment costs, small-scale biomass CHP investment costs refer to specific case studies rather than to annual averages and therefore show a higher volatility.

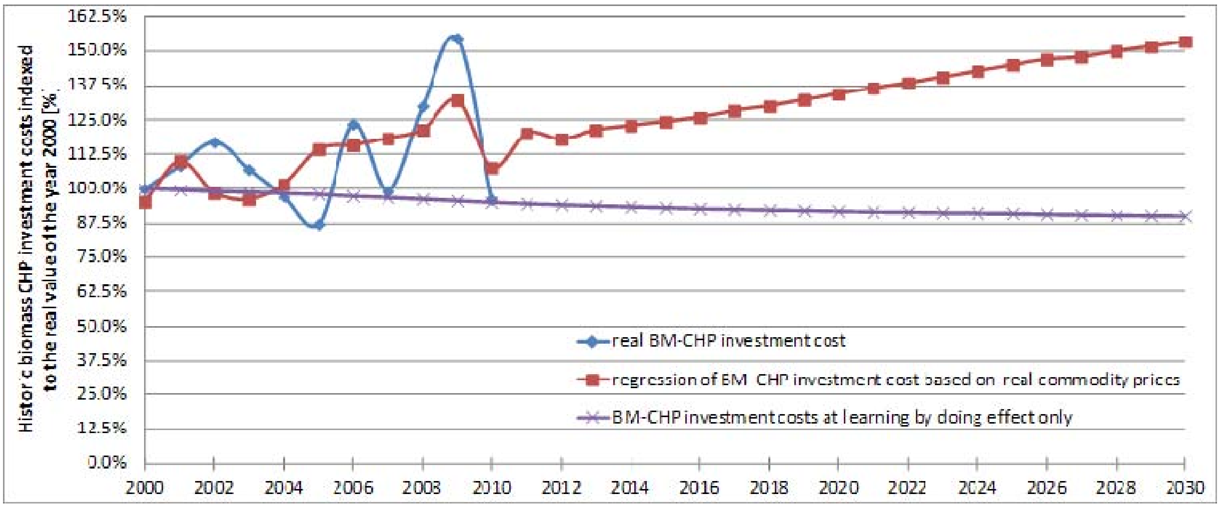


Figure 7 Future scenario of small-scale biomass CHP investment cost, on the one hand based on technological learning effects (LR=5%) only and on the other hand additionally taking into account steel and concrete price impacts. Source: Own calculations.

However, decreasing investment costs in the time period 2001 and 2004 are caused by the impact of concrete and steel prices. Furthermore, an increasing effect on biomass CHP investment costs is noticed in the period from 2005 to 2009 when commodity prices peaked. The derived model estimations show an impact from steel and concrete price of about 20 to 28 percent which is confirmed by biomass CHP manufactures (Polytechnik, 2011). In the context of future forecasts, the pure learning by doing effect expects an investment cost decrease by four percent up to 2030 compared to nowadays (2012). In contrast the additional consideration of concrete and steel prices results in an investment cost increase 38 percent in the same time period. Nevertheless, the future investment cost development strongly depends on the underlying assumptions on the primary energy price development.

With respect to small-scale hydropower plants, research has shown that their investment costs depend on many different technical and environmental aspects and are therefore difficult to compare. Generally, about half of the investment costs are used in the planning and admission procedure whereas the rest is divided into turbines, electrical equipment, construction and building (EREC, 2010). This share on investment cost supposes that concrete and steel prices are the major drivers in terms of commodity prices of small-scale hydropower investment costs. However, in literature only impacts of five percent each of steel- as well as construction costs on the total investment costs are discussed (Bard, 2006). Since, neither research (Panzer, 2012) has identified any significant contribution of energy and raw material prices to the explanation of the investment cost development, a high robustness can be concluded.

## Conclusions and implications

Summarizing the discussed results it can be clearly stated that with respect to the historical time period the dynamic investment cost development is characterized by the impact of energy and raw material prices. Moreover, apart from Photovoltaic investment costs an increasing trend is noted. In general the investment cost approximations deviate only slightly from the historical observed values. Nevertheless, these slight deviations vary strongly over time, depending on the effect of other exogenous impacts, not considered herein. Thus, in times of a strong technology demand, investment costs increased additionally but the model does not react directly, leading to an underestimation of the discussed investment costs. Some significant deviations appear especially in the case of small-scale biomass CHP investment costs, mainly caused by the site specific historic data. Moreover, the deviations differ between technologies. With respect to onshore wind investment costs a slight overestimation in 2001 and 2002 is noticed when real investment costs decreased significantly. Beyond 2005 a slight underestimation is caused by investment cost drivers related to market characteristics besides the impact of energy and raw material prices. In terms of Photovoltaic, the moderate stagnation of investment costs between 2002 and 2006 caused some deviations in investment cost estimations. Principally, the model allows for a precise approximation of investment costs and a dynamic reaction on energy and raw material price changes.

In terms of future scenarios, a continuous increase of wind on- and offshore as well as biomass CHP investment costs is expected. Basically, the more mature a technology is, the more are technological learning effects compensated by energy and raw material price impacts. Consequently, wind offshore investment costs are expected to increase to 116 percent compared to 2000 whereas wind onshore investment costs are about 32 percent higher than 2000 and biomass CHP investment costs even by 54 percent. In contrast, Photovoltaic investment costs show hardly any impact of energy and raw material prices but therefore show strong technological learning effects. Thus, investment costs are expected to decrease continuously to about 20 percent in 2030 compared to the year 2000.

Regarding the impact of energy and raw material prices on investment costs a sensitivity analysis points out their robustness of the selected energy technologies. Figure 8 addresses the relative investment cost change at a relative primary energy price variation of up to plus minus 30 percent.

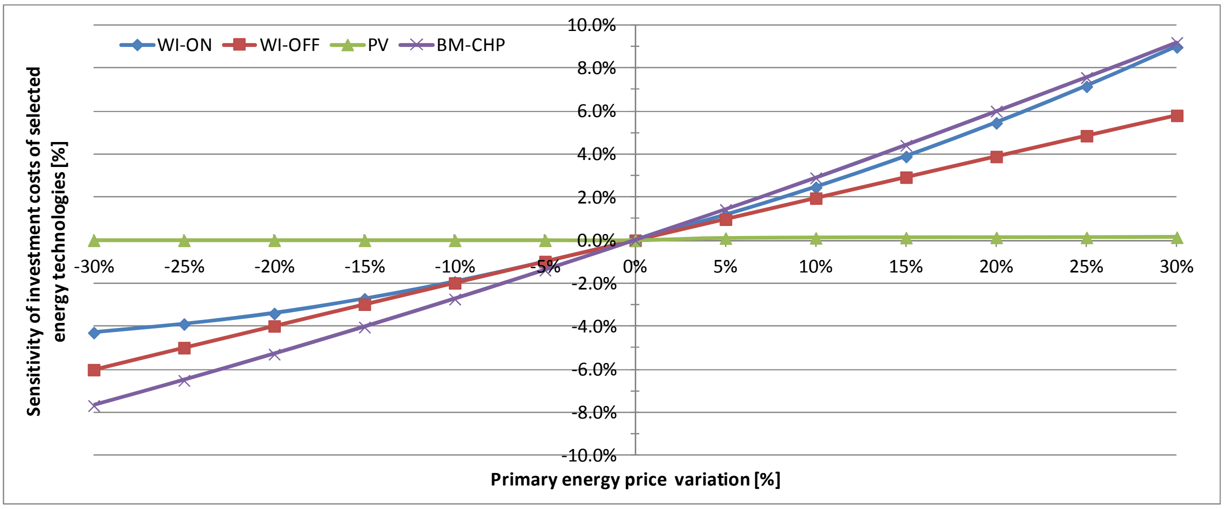


Figure 8 Sensitivity analysis of selected energy technology investment costs depending on primary energy price variations of plus minus 30 percent. Source: Own calculations.

Generally, only a marginal impact of increasing energy prices on Photovoltaic investment costs is determined whereas biomass CHP and onshore wind investment costs react with an investment cost increase of nine percent on a 30 percent energy price increase. Wind offshore investment costs are still sensitive but less than onshore due to the stronger learning effects compensating the price increases partly. In contrast, declining energy prices do not reduce wind onshore investment costs in the same magnitude. A similar but weaker effect is observed for small-scale biomass CHP investment costs. Generally, novel technologies are holding strong future market growth potentials and therefore show stronger learning effects. This learning effect partly compensates the impact of volatile energy and raw material prices and therefore these technologies are more robust against energy price impacts. Additionally, the high robustness of small-scale hydropower investment cost against energy and raw material price variations has been mentioned, caused by the low share of these costs on total investment costs.

However, generally this paper considers renewable energy technologies for electricity production which in principally show electricity generation costs above current market prices (Resch et al, 2009). On the one hand, increasing energy price might therefore lower the gap between market prices and renewable electricity generation costs. On the other hand, increasing energy prices impact the selected energy investment costs differently and might therefore distort the merit order of the energy technologies. In order to address the implications of the completed results on electricity market rough estimations of investment costs of conventional coal fired CHP plants are conducted. Basically, in terms of the technological process a biomass fired CHP plant applies a very similar approach like a coal fired CHP plant (Overend, 2006) whereby similar trends of the investment cost development can be assumed.

A pure consideration of the economics of the electricity market allows deriving some implications of the endogenous impact of volatile investment costs on the electricity market. However, important technical challenges in terms of grid stability, intermittency and market balancing are not considered within this assessment. Consequently, electricity generation costs of selected electricity technologies up to the year 2030 are discussed, representing the costs of new installations in the specific years, see Figure 9[7]. Therefore, the investment cost development is taken into account according to model approximation under consideration of technological learning effects and the impact of energy and raw material prices.

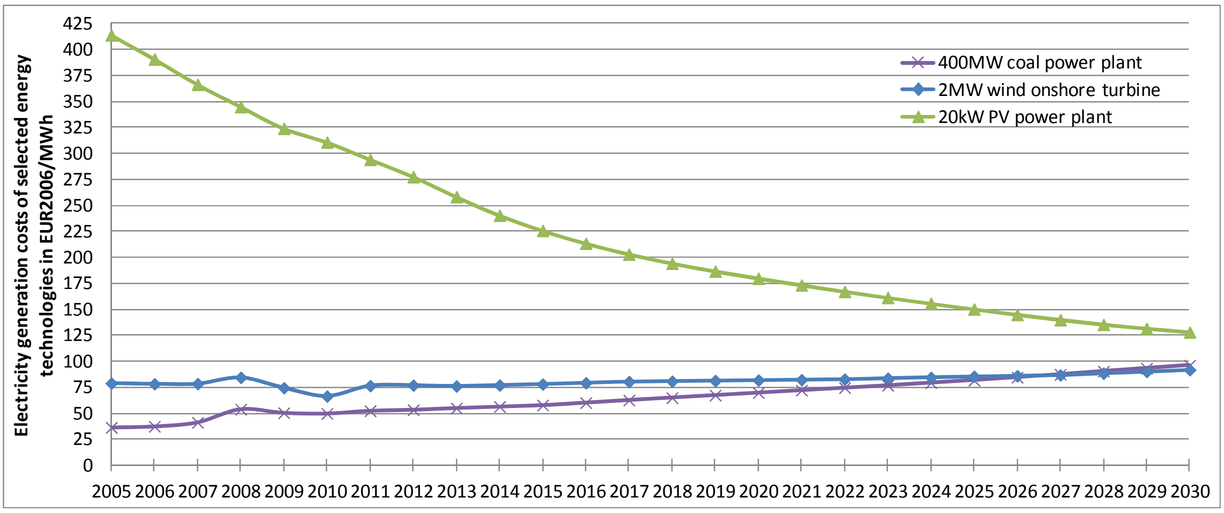


Figure 9 Levelized annual electricity generations costs in EUR2006/MWh, considering the impact of energy and raw material price on investment costs of selected energy technologies. Economic assumptions based on footnote 7. Source: Own calculation

Figure 9 indicates significantly increasing coal power electricity generation costs up to the year 2030. This increase is driven by 50 percent of raising fuel prices, 30 percent CO2 price increases and the rest is caused by investment cost increases. With respect to the year 2008, the peak of the energy and raw material price impact is significantly

[7] Thereby, standard assumptions are taken into account with respect to weighted average cost of capital (WACC=6.5%) and a depreciation time of 30 years for coal plant and 15 years for renewable plants. Moreover investment costs in 2005, operation and maintenance costs and full-load hours of coal plants refer to a 400 MW plant cited in literature (D'haeseleer et al, 2007). Additional CO2 emissions and CO2 prices are considered in the calculation. Hereby an average CO2 intensity of a current coal power plant is considered with 743gCO2/kWh (Schiffer, 2011) and CO2 price development according to Capros et al (2011). With respect to the selected renewable energy sources the corresponding data is taken from the updated Green-X database (Huber et al, 2004).

noticed with a relaxing period beyond. Moreover, wind onshore electricity generation costs show an almost constant development until 2015 with slight fluctuations in the period 2008 to 2011. Beyond 2015 a moderate increase is expected. According to this scenario, in the year 2025 wind onshore generation costs reach the breakeven point to coal fired electricity generation costs. In contrast Photovoltaic electricity generation costs are expected to decrease in same magnitude as historically observed until 2020. The slower decline in generation costs beyond 2020 is caused by the strong market penetration in that time and the therefore slower doubling of cumulative installations. According to this scenario grid parity[8] of Photovoltaic installations is achieved around the year 2016 but its generation costs will not decline to the level of conventional plants until 2030.

Generally, the derived methodology results in a very supportive approach at the estimation of energy technology investment costs. However, specific technological characteristics control the quality of the analyses significantly. Nevertheless, on the one hand, estimations of selected energy technology investment costs have been derived for the recent historic development. In this context, the volatile character of recent historic investment costs is very precisely described by the derived models. In particular, good approximations are achieved in the case of wind and Photovoltaic energy investment costs whereas for solid biomass CHP investment costs only moderately acceptable results are achieved. In the case of small-scale hydropower investment costs no significant impact of energy and raw material prices has been identified. On the other hand, future forecast scenarios are calculated by the model quantifying potential future pathways of the investment costs depending on energy price assumptions up to the year 2030.

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[8] Grid parity represents the point in time, when Photovoltaic electricity generation costs are in the range of household electricity prices (EPIA, 2011) – in Austria about 200 EUR/MWh.

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