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IEWT 2013

Tagungsprogramm

Erneuerbare Energien: Überforderte Energiemärkte?

13. – 15. Februar 2013
Wien, Österreich

Tagungsort:
Technische Universität Wien
Karlsplatz 13
1040 Wien

Veranstalter:

Institut für Energiesysteme und
Elektrische Antriebe der TU Wien (ESEA)

Energy Economics Group (EEG)

Austrian Association for Energy Economics (AAEE)

- Patrick HANSEN (Forschungszentrum Jülich GmbH - IEK-STE): "Strategien zur Senkung der Energienachfrage der privaten Haushalte"

Session 3 F: **Förderung Erneuerbarer Energie**

Böcklsaal

- Johannes SCHMIDT, Georg LEHECKA, Viktoria GASS, Erwin SCHMID (Universität für Bodenkultur Wien): "Fixed feed-in tariff versus premium based feed-in tariff schemes: impacts on the spatial diversification of wind turbines"
- Dieter MAYR, Johannes SCHMIDT, Erwin SCHMID (Universität für Bodenkultur Wien): "Economic assessment of roof-top photovoltaic potentials: potential efficiency increases due to an auction based allocation policy"
- Michael HARTNER, Reinhard HAAS (TU Wien, Energy Economics Group): "Effects of the Austrian subsidy scheme for small scale PV-systems: empirical findings and suggestions for improvements"
- Mark ANDOR (Rheinisch-Westfälisches Institut für Wirtschaftsforschung), Kai FINKERBUSCH, Achim Voß (University of Münster): "Quantities vs. Capacities: Minimizing the Social Cost of Renewable Energy Promotion"

Session 3 G: **Technologien und Investitionen III**

HS 14A

- Mohammed HIJJO (Islamic University of Gaza), Imad IBRIK (An-Najah National University): "Techno-Economical Study Of Small-scale Renewable Energy Resources in Palestine"
- Christian PANZER (TU Wien, Energy Economics Group): "How fossil energy excess-reserves in the Middle East region can trigger renewable energy investments"
- Jürgen NEUBARTH (e3 consult): "Bewertung der Erlössituation von Wasserkraftprojekten am Beispiel der Neubauvorhaben Innervillgraten und Obere Isel"
- Markus BLIEM, Andrea KLINGLMAIR (IHS Kärnten): "Die Erschließung vorhandener Wasserkraftpotenziale in Österreich im Spannungsfeld von Energiepolitik und ökologischen Schutzzielen"

19.10: **Treffpunkt Haupteingang** - Abfahrt zum Heurigen mit Nostalgiestraßenbahn

20.00: **Heuriger**

Ort: Heuriger 10er Marie, Ottakringerstraße 222-224, 1160 Wien
Abfahrt von Karlsplatz mit Nostalgiestraßenbahn – Treffpunkt 19h10 bei TU Wien Haupteingang - Karlsplatz 13

How fossil energy excess-reserves in the Middle East region can trigger renewable energy investments

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Abstract

Nowadays two topics are on top of the agenda of global energy policy discussions. On the one hand, climate change issues and security of supply on the other hand, is addressed in detail. Therefore, strong emphases are put to diversified as well as sustainable energy supply portfolios. Additionally, the integration of renewable energy technologies faces different challenges depending on the energy sector. Therefore emphases are given to renewable electricity generation technologies in order to redirect fossil energy sources to other energy sectors which continue relying on these fuel types for a longer time period. An appropriate pathway offers the installation of concentrated solar power (CSP) plants in the Middle East region for domestic power generation. Consequently, the surpluses of domestic natural gas resource can be exported to other countries. Thereby, the additional income of gas exports covers the additional expenditures for CSP power generation.

Therefore, this paper analyzes potential additional incomes of GCC countries when replacing there fossil fuel fired power plants by CSP plants. In particular, the additional investment expenditures are compared in economic analyses to additional incomes of selling the displaced natural gas resources to different global gas markets. Finally, future scenarios take into account the dynamic investment cost development of CSP plants and discuss the consequences for selected GCC countries.

Qatar and in particular, Saudia Arabia show promising solar power generation potentials with high direct solar radiation areas. Additional, installing solar thermal storage facilities allows for electricity generation characteristics similar to gas-fired power plants. Current levelized electricity generation costs of CSP plants connected to a twelve hour solar storage facility are in the range of three to four times higher compared to the state-subsidized electricity generation costs of gas power plants. However, redirecting these natural gas resources via LNG to the Japanese gas market allocates sufficient additional incomes in order to run the CSP plants already under current investment cost levels without additional subsidies. Future cost reductions, respectively additional subsidies from CDM mechanisms enables to export the gas also to other gas markets like India, China or Europe.

Hence, the switch from gas power plants to CSP plants enables similar power supply characteristics in the GCC region at similar overall generation costs. With respect to decreasing

CSP investment costs and globally increasing gas price a remarkable, additional income for the GCC Member States can be achieved. In addition, CSP power generation prevents GCC countries[1] from becoming gas importing countries when their domestic electricity demand continues to increase as recently observed. Finally, besides the significant environmental benefit of avoided CO2 emissions, the additional export of natural gas to different global gas markets increases the security of supply of potential gas importing countries due to the opportunity of a more diversified gas supply portfolio.

[1] In the case of Saudia Arabia only 40 percent of its domestic gas resources are allocated to non-associated resources and therefore limits the availability of gas for power production, if crude oil exploitation is limited by OPEC regulations.

Introduction

In general, global energy policy discussions focus on security of supply patterns and sustainable energy supply portfolios. Therefore, in order to mitigate CO2 emissions, several different approaches are implemented in the different world regions. While industrial countries pursue direct financial incentives for an enhanced development of low carbon energy technologies, the rest builds on joint projects with other countries. Nevertheless, among the latter several regions hold significant fossil energy resources which are mostly exploitable at low to moderate cost levels. Therefore, power generation in these regions refers almost exclusively to conventional power generation technologies. In contrast, a high potential for renewable electricity generation is identified in these countries which is only rare exploited so far, caused by the significantly higher power generation costs, compared to conventional energy generators.

However, in technological terms renewable energy generation in the electricity sector is more mature than for other sectors, especially the transport sector. Thus, integrating renewable power plants in the GCC region and therefore replacing existing gas power plants may avoid global CO2 emission even more efficient, in technical and economical terms[2], than applying state-of-the-art renewable technologies in the transport sector within the EU. Subsequently, the displaced gas of the GCC region can be exported to global energy markets and be used, amongst others, in the transport sector.

Apart from the substantial environmental benefit, the security of power supply within the GCC countries becomes increasingly important. The Middle East faced a power demand increase of 56 percent during the last decade, caused by a strong demographic increase and representing four times the global power increase (The Economist, 2012). Taking into account that major shares of Saudia Arabian and especially Qatar's power generation is based on natural gas fired plants, the rapidly increasing power demand requires a disproportional share of their domestic natural gas resources in the future. Moreover, only 40 percent of, in particular, Saudia Arabian gas resources are allocated to non-associated[3] gas resources (Abi-Aad, 2012). Under current trends Saudia Arabia would therefore become an importer of natural gas within the next 20 years in order to meet their domestic power demand. Thus, renewable electricity opens the opportunity to supply

[2] CO2 abatement costs are lower in the electricity than in the transport sector (McKinsey&Company, 2007).
[3] Non-associated indicates the share of gas resources which can be independently exploited from the crude oil exploitation. Generally, OPEC Members cannot determine their oil production themselves but are restricted to the OPEC quota. This automatically limits the gas production of associated gas resources too.

electrical energy without depending on energy imports from neighboring countries even in times of an increasing domestic power demand.

Finally, in the third dimension renewable electricity generation also provides the opportunity of additional incomes in the short to long term due to the export of excess natural gas sources. In this context, on the one hand, natural gas prices are expect to increase and simultaneously, on the other hand renewable electricity generation costs are expected to decrease. Consequently, the opportunity costs of firing domestic natural gas sources in power plants might increase in future.

Method of approach

This paper compares levelized electricity generation costs of gas-fired CCGT power plants in Qatar and Saudia Arabia to levelized electricity generation costs of concentrated solar power (CSP) plants with thermal storage facilities. Subsequently, the additional expenditures for renewable power generation are compared to potential incomes from the export of the displaced natural gas resource to different global gas markets. Conclusion addresses the economic feasibility of renewable power generation in Qatar and Saudia Arabia.

First, a pre-assessment of the natural gas wholesale market in the GCC region – in particular, Saudia Arabia and Qatar – identifies the status quo of the gas price structure. Second, typical, regional annual direct normal irradiation values of solar light are quantified in order to derive the capacity factor of CSP plants. Thus, taking into account standard investment costs of CSP plants and their associated capacity factor (depending on the installed thermal storage capacity) delivers their levelized electricity production costs. The additional consideration of storage facilities for managing the produced heat allows generating renewable electricity also during nights and, therefore, comparing the fluctuating renewable electricity generation to ordinary gas power plant characteristics. In contrast, levelized electricity generation costs of gas-fired CCGT plants are derived, considering the domestic, subsidized gas price. Therefore, redirecting these financial subsidies of natural gas towards CSP plants determines the necessary natural gas price of the exported gas in order to operate CSP plants in the GCC region without additional financial subsidy. Sensitivities on different storage capacities respectively on optional emission fees complete the economic assessment. Future scenarios highlight the dynamic development of the economics of CSP plants.

Background assumptions

In terms of international gas markets strong regional price differences are observed. On the one hand, rather low prices are noted in gas producing countries whereas higher price are seen in gas importing countries. With respect to the latter, additionally a difference of almost 100 percent occurs between European and Japanese gas prices. This price difference is explained by the national value of security of energy supply. In consequence of the nuclear accident in Fukushima in March 2011 accompanied by the fact that Japan is only weakly connected by gas pipelines to the rest of Asia a voluntary higher gas price is paid to LNG exporting countries. An overview of regional landed[4] gas price, including the transport fee of 2 USD/MMBTU is given in Table 1.

Table 1 Overview of landed gas price of different international gas markets in USD2010/MMBTU in year 2012 (Source: Abi-Aad, 2012)

Region	Landed gas price [USD2010/MMBTU]
European Union	9-10
India	12-15
China	12-13
Japan	17

In contrast, natural gas prices in Qatar and Saudia Arabia are in the range of 1.1 USD/MMBTU. Generally, gas producing companies in these countries are state owned. This allows for subsidizing domestic gas prices and explains the very low domestic gas prices compared to international levels. Consequently, no future increase of gas prices in the Middle East is assumed within this paper. In contrast, gas price changes of international markets, above indicated in Table 1, are assumed to increase according to the IEA World Energy Outlook 2011 (IEA, 2011) assumptions. Thus, a gas price increase in Europe of about five percent is assumed for 2012 whereas this constantly declines to an increase of about one percent in 2030. In terms of Japan, a more moderate gas price increase is expected due to the already currently high gas price level. Japanese gas price are expected to increase by 2.5 percent in 2012 and the increase constantly decrease to 0.75 percent in 2030. For China and India a constant annual increase of two percent is assumed in this research.

[4] Landed gas prices refer to the energy price plus the liquefied, transport and re-gasification price.

Oppositional, the major impact on CSP power generation costs hold the direct normal irradiation (DNI) of the sun light. Several scientific studies have been conducted elaborating on optimal sites for CSP plants in the Middle East region (Ummel et al, 2008; Trieb et al, 2005 and Trieb et al, 2009). Consequently, this research builds on existing potential studies for CSP plants in Saudia Arabia and Qatar. The geographical distribution of the different DNI areas of these countries is addressed in Figure 1, whereas attention needs to be drawn to the different scales.

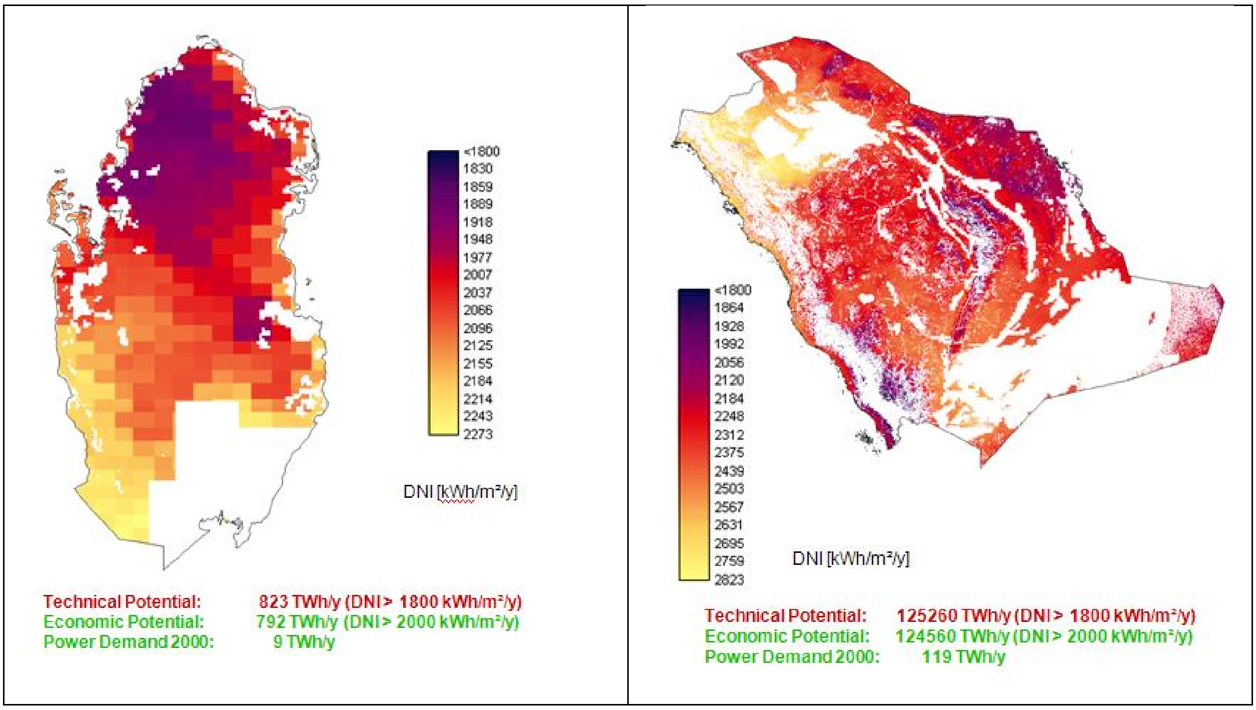


Figure 1 Direct normal irradiation (DNI) of the sun light in kWh/m²/y for Qatar (left side) and Saudia Arabia (right side) according to their latitude. Attention needs to be drawn to the different scales. Source: Trieb et al, 2005.

Generally, Saudia Arabia achieves, in most areas, a higher solar radiation than Qatar. However, economical feasible areas for CSP power generation are identified in both countries. The economic potential assessment results in a 100 to 1,000 times greater potential compared to the electricity demand in year 2000. Therefore, even the strong electricity demand growth rate in the Middle East does not state a significant challenge for CSP plants to meet with domestic future electricity demand. Furthermore, according to Trieb et al (2009) the direct normal irradiation is transformed to CSP plant full-load hours[5]. Hereby, the extension of the power unit by one or more thermal storage units of similar capacity increase the full-load hours significantly.

[5] Full-load hours indicate the adequacy of hours per year, the power unit works on full capacity.

Regarding the economic assumptions of gas power plants in the Middle East region, on the one hand, and CSP plants, on the other hand, overnight investment costs, operation and maintenance costs (O&M) and fuel costs are considered as well as electrical efficiency rates, lifetime[6], interest rate and full-load hours. An overview of the assumption is given in Table 2.

Table 2 Economic parameters of gas power and CSP plants (Source: Huber, 2012 and Scholz, 2010)

USD of 2010	Gas power plant (CCGT)	CSP plant
Investment cost	1200 USD/kW	Solar field: 2260 USD/kW Power unit: 1525 USD/kW Storage unit: 70 USD/kWh
O&M costs	23.2 USD/kW	Solar field: 21.2 USD/kW Power unit: 38.5 USD/kW Storage unit: 1.7 USD/kWh
Fuel costs	1.1 USD/MMBTU	-
Electrical efficiency	54%	Storage unit: 95%
Depreciation time	25 years	25 years
Interest rate	7%	7%
Full-load hours	6132h	Depending on country and storage units between 1800h and 7552h

Additionally, CSP investment costs are expected to decrease over time due to technological learning (Panzer, 2012). Thereby, investment costs constantly decline with each doubling of globally cumulative installed CSP capacity by ten percent (see Annex I). In contrast, gas power plants do not show any learning effects and are rather expected to increase due to raw material price increases. However, within this study gas power investment costs are assumed to be constant throughout the considered time period.

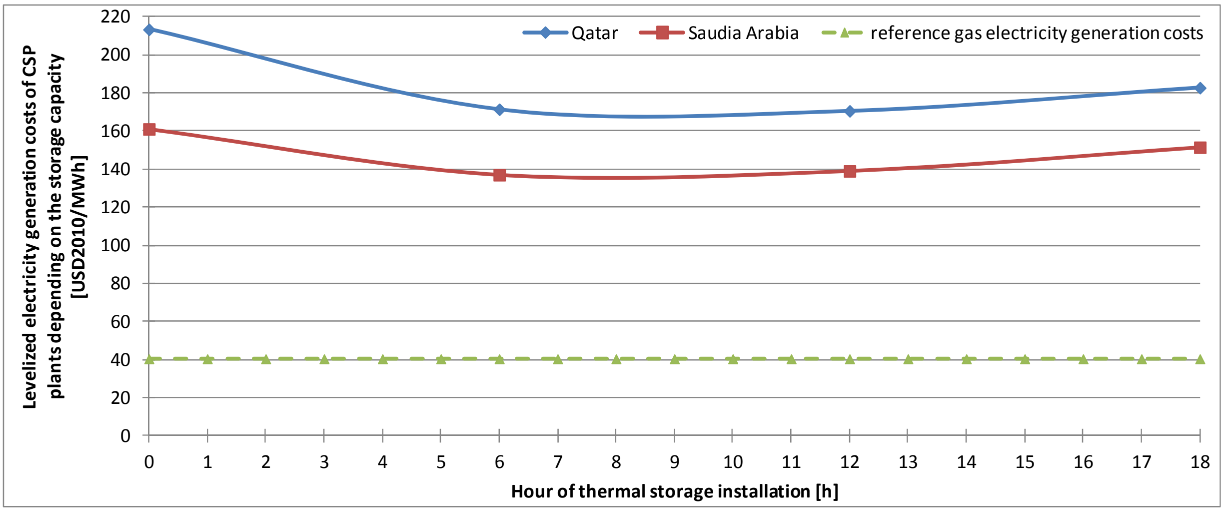
Economics of power generation in the Middle East

First, gas power generation costs are taken into account. In the context of the assumption indicated in Table 2, electricity generation costs are about 27.5 USD/kWh to 92.4 USD/kWh depending on assumed emission fees. Generally, modern gas power plants emit about 350 g/kWh

[6] The depreciation time is assumed to be the technical lifetime for CSP and CCGT plants.

CO_2 per produced electricity unit (D'haeseleer et al, 2007). However, up to now no emission fees are introduced neither in Qatar nor in Saudia Arabia. Nevertheless, such additional surcharges might be installed either in the form of global emission reducing targets or in form of discounted CDM[7] prices. This research considers additional charges between 0 USD/t_{CO2} and 100 USD/t_{CO2} with a default value of 20 USD/t_{CO2}.

Second, in terms of CSP plants electricity generation costs are highly sensitive to their full-load hours. A standard CSP plant without a thermal storage unit achieves around 2,000 full-load hours a year. Adding a thermal storage unit of 6, 12 or 18 hours storage capacity at simultaneously keeping the solar unit at similar capacity allows operating the power unit also in times of no direct solar irradiation. In literature it is referred to solar multiples (SM). A power unit without storage facilities is considered as a SM1 plant. A power unit and a similar sized storage capacity and a doubled solar unit refers to an SM2 plant, implying a six hours thermal storage. Furthermore, a power unit, a doubled storage unit and a tripled solar unit implies a 12 hour storage facility and is called a SM3 plant. Since, storage units do not only increase the full-load hours and therefore cause a constant power generation, free from the fluctuations of sunlight availability, but also cause higher investment costs, CSP plants are maximal considered as SM4 types. The economic breakeven point of additional thermal storage units and higher electricity generation costs is addressed in Figure 2.



[7] The Clean Development Mechanism (CDM) principally allows Annex1 countries to support low-carbon technologies in countries that have not ratified the emission saving target. Generally, the additional expenditures of a low-carbon technology to the otherwise installed conventional power technology is covered by the Annex1 country. Generally, these additional expenditures are covered in a lump-sum. Within this research, this lump-sum is considered discounted on the avoided CO2 emissions.

Figure 2 Levelized CSP electricity generation costs depending on the capacity of the connected thermal storage unit in Qatar and Saudia Arabia in year 2010. Additionally, the reference price of a gas power plant in this region is indicated. Source: Own calculations

On the one hand, Figure 2 indicates that CSP electricity generation costs are generally higher in Qatar than in Saudia Arabia. This is caused by the higher solar radiation in Saudia Arabia, resulting in higher full-load hours. On the other hand, connecting a six hours storage unit (SM2 type) decrease the electricity generation costs and results in a less volatile electricity output. Doubling the storage unit (SM3 type) hardly shows any impact on the electricity generation costs but results in an almost constant power output. In terms of full-load hours, and therefore availability, the CSP – SM3 type is competitive to gas power plants in the Middle East region. An additional increase of storage capacity (SM4 type) increases the generation costs slightly and does not contribute to a constant power output as strong as the increase from a SM2 to a SM3 type. Regardless the CSP type, electricity generation costs are above gas power generation costs.

Furthermore, the direct normal irradiation (DNI) and the latitude of the site of the CSP plant impact their full-load hours significantly too. As Figure 1 above has shown, suitable areas of CSP plants in Saudia Arabia provide on average a DNI of 2,500 kWh/m²/y whereas Qatar provides on average only 2,000 kWh/m²/y. Consequently, Table 3 indicates the derived full-load-hours of CSP plants in Qatar and Saudia Arabia depending on their solar multiple (SM) type.

Table 3 Full-load hours of CSP plants depending on the storage capacity in Qatar and Saudia Arabia. Source: Trieb et al, 2009

	Qatar	Saudia Arabia
SM1 type [kWh/kW]	1801	2386
SM2 type [kWh/kW]	3719	4653
SM3 type [kWh/kW]	5223	6406
SM4 type [kWh/kW]	6260	7552

Taking into account the dynamic development of CSP plants, results in constant cost reductions of their investment costs. Therefore, the approach of learning by doing[8] is applied in order to

[8] Learning by doing refers to a constant cost reduction with each doubling of cumulative installed capacity.

forecast future CSP investment costs and thus levelized electricity generation costs. However, different learning rates are identified for the solar field, the power unit and the storage capacity. In this respect, it assumed that the solar field learns by 10 percent, the power unit only by 3 percent and the storage capacity by 14 percent due to the several new storage concepts. Moreover, a different global development in terms of installed capacity is considered, since solar fields are only applied in CSP plants whereas steam turbines in the power unit are also installed for other electricity generation types. As a result, levelized electricity generation costs of CSP plants connected with a 12 hour thermal storage (SM3 type) are depicted in Figure 3 for Saudia Arabia and Qatar. Due to the expected, reduced investment costs of CSP and storage units in 2030, levelized electricity generation costs in Qatar are getting closer to Saudia Arabian conditions and close the gap by a third. Nevertheless, electricity generation costs of CSP plants keep above gas power generation costs in both countries, amounting to slightly more than the doubled generation costs in 2030 in the best case.

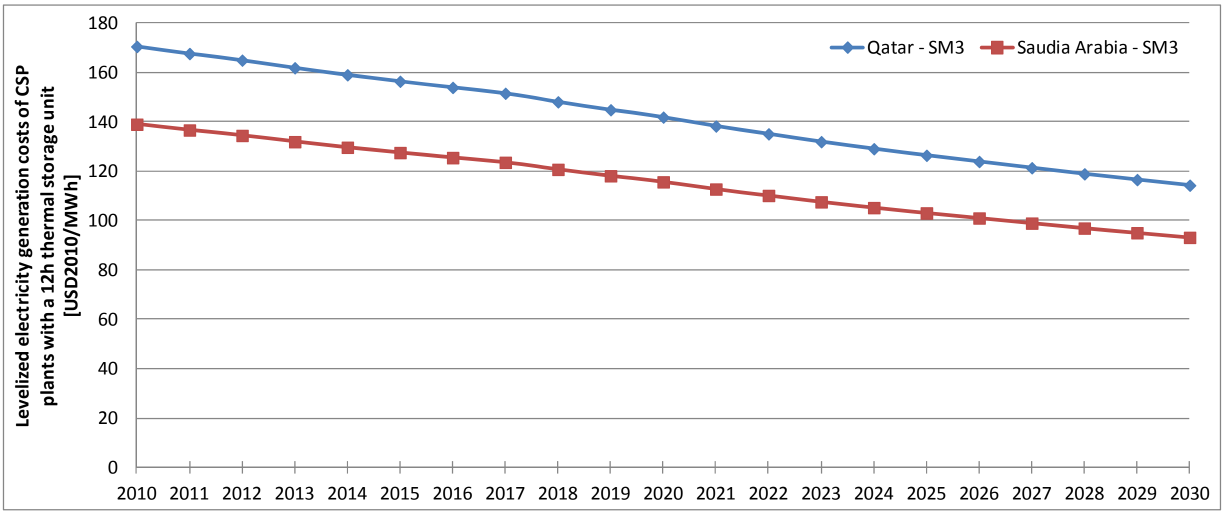


Figure 3 Levelized electricity generation costs of CSP plants connected with a 12 hour thermal storage unit (SM3 type). Costs are indicated in USD2010/MWh. Source: Own calculations.

Cost competiveness analysis of CSP plants in the Middle East

In order to bring renewable electricity generators to market competiveness with fossil-fired conventional power generators different mechanisms are introduced (Ragwitz et al, 2011). However, especially for countries those one the one hand, show significant renewable electricity potentials and, on the other hand, are rich in fossil energy resources, also different options for competitive CSP plant operations occur. This is the case for Saudia Arabia and Qatar. The opportunity costs of using the domestic gas resource for power production might even exceed the

CSP power generation costs. Especially, in Saudia Arabia where 60 percent of the domestic natural gas resources are allocated to associated gas, CSP power generation opens the opportunity for additional incomes due to gas export. Similar in the case of Qatar, which limits itself its annual gas exploitation quantity, due to a national referendum of some years ago. Therefore, reducing the domestic gas resources for power production shows high opportunity costs in terms of selling it on international gas markets.

Thus, in a first step, the required difference in monetary terms between CSP and gas power generation costs are quantified. Additionally, the electrical efficiency rate of gas power plants transfers the difference in electricity generation costs to required gas prices. Generally, gas prices for domestic use in the Middle East are subsidized by the state. Therefore, these subsides are assumed to be re-directed towards CSP power generators and are implicitly reflected in the required costs of gas exports. An overview of the required export gas prices for covering the higher CSP electricity generation costs indicates Figure 4.

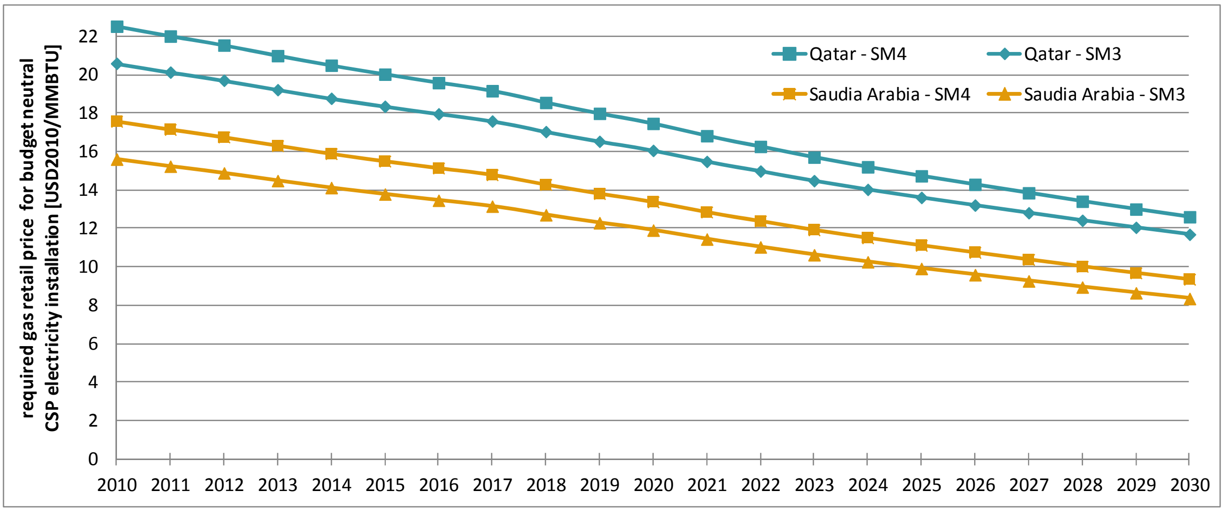


Figure 4 Annual development of the required gas retail price in order to meet the higher CSP power generation costs compared to gas-fired conventional power generators; depicted in real USD/MMBTU of 2010. Source: Own calculation.

Apparently, Figure 4 points out that CSP power generation in Saudia Arabia requires lower gas export prices than it is the case in Qatar. Moreover, for both countries generation costs of a CSP power plant with 12 hour capacity storage (SM3 type) and 18 hour capacity storage unit (SM4) are presented. Although CSP plants of the SM4 type require higher gas export prices they are able to generate electricity at higher availability. However, since a CSP plant of a SM3 type show a similar characteristic as gas power plants in this region and additionally require lower gas export prices, this CSP type is selected for further research. With respect to the required, in absolute terms, high gas export price a high flexibility of directing export gas towards the most profitable international gas markets is needed. Therefore, mainly liquefied natural gas (LNG) transport is used. Thus, the price of liquefying, transporting and re-gasification need to be adduced in addition to the required export gas price.

Consequently, next the required export gas prices are compared to international gas market prices already reduced for the LNG transport fee. Due to the required flexibility of gas export, on the one hand, and due to the issue that gas producing countries do not export gas via others than their own pipelines, on the other hand, only gas importing markets are selected offering LNG import possibilities. Figure 5 illustrates the described gas price development of the Japanese, Indian, Chinese and European gas market as well as the required export prices of CSP plants (SM3 type) in Qatar and Saudia Arabia.

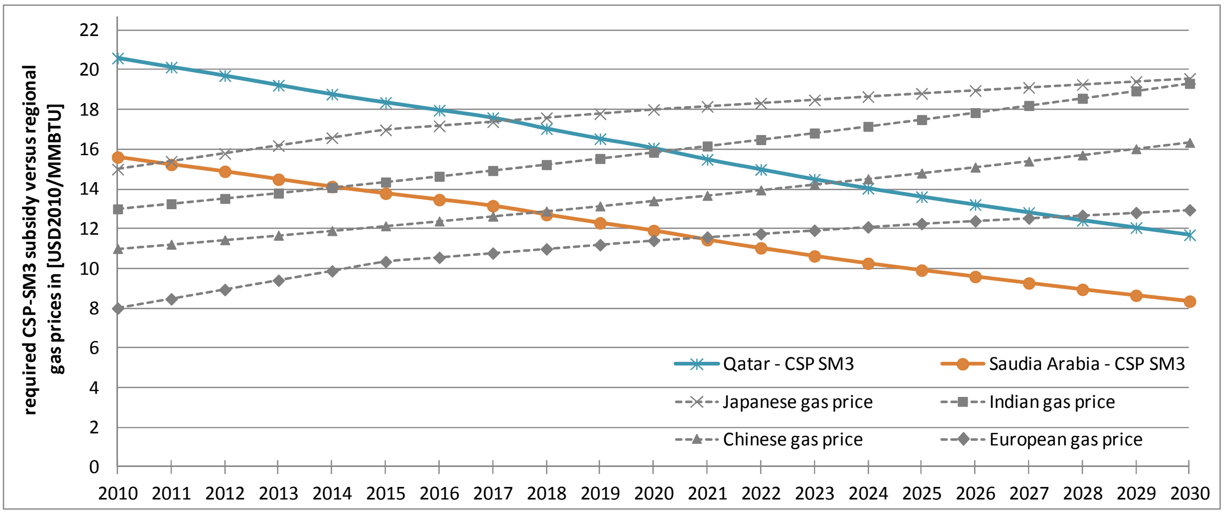


Figure 5 Annual development of the required gas retail price in order to meet the higher CSP power generation costs (connected to a 12 hour capacity storage (SM3)) compared to gas-fired conventional power generators. Highlighted in front of international gas market prices; depicted in real USD/MMBTU of 2010. Source: Own calculation.

In consequence of the stronger solar radiation in Saudia Arabia, CSP power generation is already cost competitive since year 2011 if the excess gas is transported to Japan via LNG tankers. However, no other markets would currently offer such high revenues of the Saudia Arabian gas exports in order to operate a CSP (SM3 type) plant without any additional subsidy[9]. In the case of Qatar, cost competiveness of CSP power generation is still expected in 5 years from now. Taking into account the planning and installation phase as well as the market penetration of new energy technologies it is already now the time to introduce CSP plants to Middle Eastern electricity

[9] An emission fee of 20 USD/t_{CO2} is considered in the gas power generation costs, coming from CDM projects.

supply portfolios. In the same time period (five years from now) Saudia Arabia can select between three major gas importing markets where to direct their gas exports, to in order to run their domestic power production without additional financial support9. In ten years from now, even European gas prices are expected to be sufficient for supporting CSP electricity generation in Saudia Arabia. However, historically natural gas prices showed strong volatility which might distort the results slightly and, therefore, CSP plants might become cost neutral even in prior or slightly delayed.

Sensitivities on emission fees for gas power plants and their implications

As discussed above, additional support schemes could be introduced for the abatement of CO2 emissions due to power generation by CSP plants. Therefore, a price per ton of CO2 emissions is taken into account at the electricity generation costs of gas power plants. This price of CO2 abatement can either be implemented in form of a national/regional CO2 tax or as a subsidy from Annex1 countries (Nordhaus et al, 1999) in the context of the CDM mechanism. Figure 6 discusses the sensitivity of CO2 prices on the competiveness of CSP plants in Qatar.

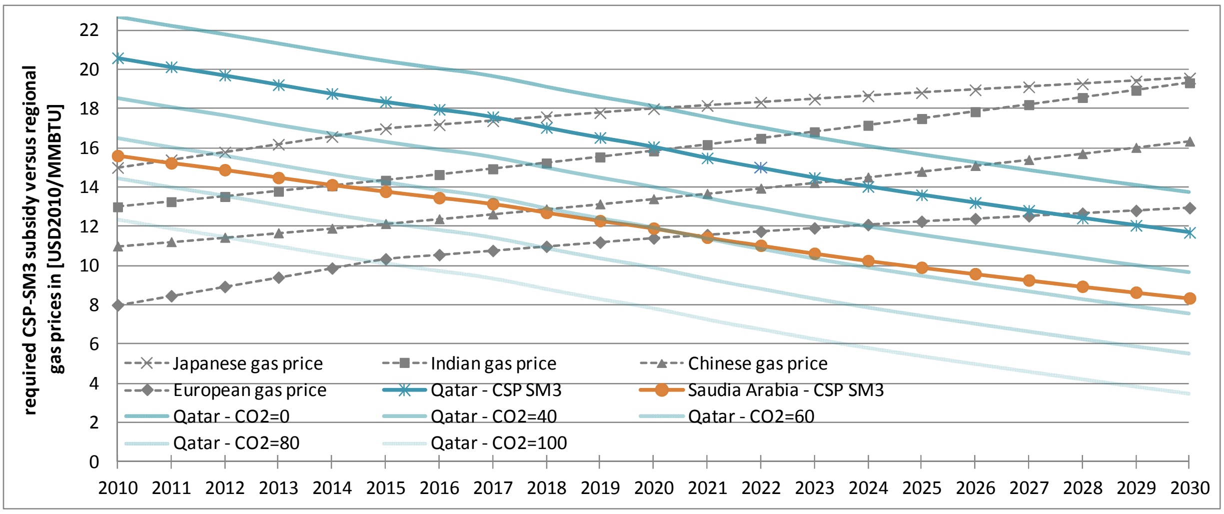


Figure 6 Annual development of the required gas retail price in order to meet the higher CSP power generation costs (connected to a 12 hour capacity storage (SM3)) compared to gas-fired conventional power generators. Emission fees in the case of Qatar point out their sensitivity. Source: Own calculation.

In comparison to the default results, derived earlier, an ignoring of CO2 prices delays the cost competiveness of CSP (SM3 type) in Qatar by about three years. However, in ten years CSP power generation costs can be covered from the revenues of exporting gas even to India and additional incomes could be gained on the Japanese gas market. An increase of CO2 prices to 60 USD/t_{CO2} would decrease the required export gas prices to the level of Saudia Arabian conditions. Thus, cost competiveness of CSP plants would already be achieved nowadays when exporting the excess gas to Japan and by year 2020 the flexibility to export gas to all considered international markets would be achieved. A further increase of CO2 prices significantly lowers the required revenues of exported excess gas, and increase potential additional incomes for Qatar.

Introducing a CO2 price on gas power generation in Saudia Arabia, results in similar implications for CSP plants as in Qatar. Figure 7 depicts these opportunities for Saudia Arabia in detail.

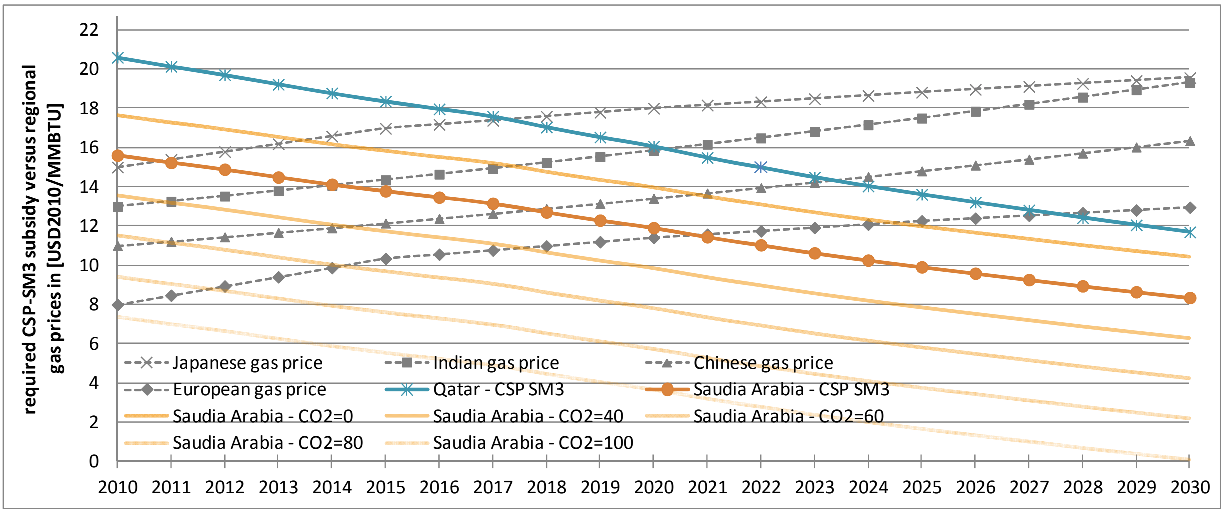


Figure 7 Annual development of the required gas retail price in order to meet the higher CSP power generation costs (connected to a 12 hour capacity storage (SM3)) compared to gas-fired conventional power generators. Emission fees in the case of Saudia Arabia point out their sensitivity. Source: Own calculation.

Thus, neglecting the CO2 price apparently delays the cost competiveness of CSP plants by two years. However, this implies that CSP (SM3 type) could be operated already in 2013 without any additional support if the excess gas is exported to Japan. Moreover, although the negligence of a CO2 price for gas power production in Saudia Arabia increases the required level of revenues from exporting the excess gas, it does not exceed the default value of Qatar. In contrast, at a CO2 price of 60 USD/t_{CO2} CSP plants would be profitable at all selected international gas market price levels already in two years from now. Taking into account the planning and installation time, this would require action already by today.

Conclusions

Generally, on the one hand, Qatar and Saudia Arabia are facing a high demographic increase in recent years, leading to a disproportional raising electricity demand. On the other hand, power generation in these countries is largely dominated by gas power plants. Consequently, domestic gas demand is expected to increase significantly. However, a major share of Saudia Arabian gas resources refer to associated gas and the limiting exploitation referendum in Qatar restricts its annual gas production too. Saudia Arabia might even become an importer in gas within the next 20 years if the current share of gas power plants in the domestic power supply portfolio does not change and domestic demand increase continues. In order to avoid energy imports and the associated costs of these imports, renewable solar power production is an economical and technical feasible remedy. Exporting the natural gas, originally used in gas power plants, covers the additional generation costs of CSP plants. In later years even additional incomes could be gained instead of occurring costs for gas imports to meet the domestic power demand. In more detail, research has shown that CSP plants connected to a thermal storage unit shows less power fluctuations and reduce the overall power generation costs of CSP plants. Due to higher solar radiation in Saudia Arabia cost competiveness of CSP plants, accompanied with gas export revenues, to gas power generation is already given nowadays.

In this context, action is required already today. Planning, permission and installation time periods need to be taken into account when adding CSP and storage capacities to the electricity supply portfolios. Consequently, even in cases when CSP is only cost competitive to gas power plants when exporting the natural gas to Japan, first steps of CSP installations are required nowadays. Moreover, a constant development of CSP technology additional drives down their investment costs (technological learning). In contrast, in order to hold flexibility to export excess gas to the most profitable international markets, LNG transport capacities are already very well developed.

Furthermore, research has shown that CSP (SM3 type) plants are in both countries cost competitive when exporting the excess gas to international markets, without any additional support. However, CO_2 prices in terms of CO_2 taxes or as CDM subsidies accelerate their cost-competiveness significantly, especially in the case of Qatar. Moreover, a CO_2 price enables to export gas to different markets and therefore become independent of single gas market developments.

Nevertheless, further research needs to be done with respect to the technical restrictions of CSP plant integrations. Although CSP plants connected to a thermal storage unit (SM3 type) show similar characteristics as gas power generators, a focus on required balancing power needs to be laid. Additionally, the existing grid infrastructure system needs to be considered when identifying most suitable sites for CSP plant installations.

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Annex I – drivers of future solar energy technology investment costs

Solar energy currently shows a comparatively low market penetration in terms of energy generation, but therefore holds the strongest annual growth rates among all renewable energy sources. With respect to its specific investment costs, solar energy technology is still more expensive than most other renewable electricity generation but shows significant cost decrease over time, especially in recent years.

Principally, solar energy technologies are impacted by energy- and raw material prices as well as technological learning effects. In order to assess these impacts in a quantitative manner, first, the technological learning by doing rate is identified in a time period when no impacts of energy and raw material prices have been noticed in real terms. This time period is identified from year 1980 to year 2002. Since the technological learning rate is assumed to be constant over time it allows for a pre-adjustment of solar energy investment costs for the technological learning by doing effects and therefore quantifying the pure impact of energy and raw material prices. An econometric model, estimating solar energy investment costs, is depicted in the formulas Eq. 1 to Eq. 5.

$$\ln INV^{*}_{solar}(t) = c * k^{*} + EP * \ln p^{*}_{energy}(t) + EP\_LAG3 * \ln p^{*}_{energy}(t-3) + u(t) \quad \textbf{Eq. 1}$$

$$INV^{*}_{solar}(t) = INV_{solar}(t) - \rho * INV_{solar}(t-1) \quad \textbf{Eq. 2}$$

$$p^{*}_{energy}(t) = p_{energy}(t) - \rho * p_{energy}(t-1) \quad \textbf{Eq. 3}$$

$$p^{*}_{energy}(t-3) = p_{energy}(t-3) - \rho * p_{energy}(t-4) \quad \textbf{Eq. 4}$$

$$k^{*} = 1 - \rho \quad \textbf{Eq. 5}$$

$INV_{solar}(t)$	Investment costs of solar energy installation, corrected for learning effects in the year t
$p_{energy}(t)$	Energy and raw material price in year t
$p_{energy}(t-1)$	Energy and raw material price three years ago, year (t-3)
c	Constant parameter
ρ	Cochrane-Orcutt parameter
u(t)	Statistical disturbance term
EP	Constant parameter of regression of the impact of energy

EP_LAG3 prices and three years delayed energy price

The model in Eq. 1 indicates that the solar energy technology investment costs, adjusted for technological learning effects, are a function of a constant term, the energy price and the three years delayed energy 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 (ρ=0.2927) according to formulas Eq. 2 to Eq. 5. Hence, the overall regression estimation is corrected for first order serial correlation of the error term and thus fulfills the Gauss-Markov Theorem.

A comparison of the realized solar energy investment costs, corrected for the identified technological learning effects, to the estimation of the model is discussed in Figure 8. Learning corrected solar energy investment costs historically developed constant with some volatility at a very low scale. According to the model result, energy price are not responsible for this volatility. In contrast, stronger investment costs changes beyond the year 2000 are very well explained by the model purely considering energy and raw material price prices. Nevertheless very minor deviations between the two time-series appear which are not explainable by energy related impacts but rather by exogenous market effects. Generally, a significant contribution of energy and raw material prices on learning by doing corrected investment costs of solar energy technologies is noted in Figure 8.

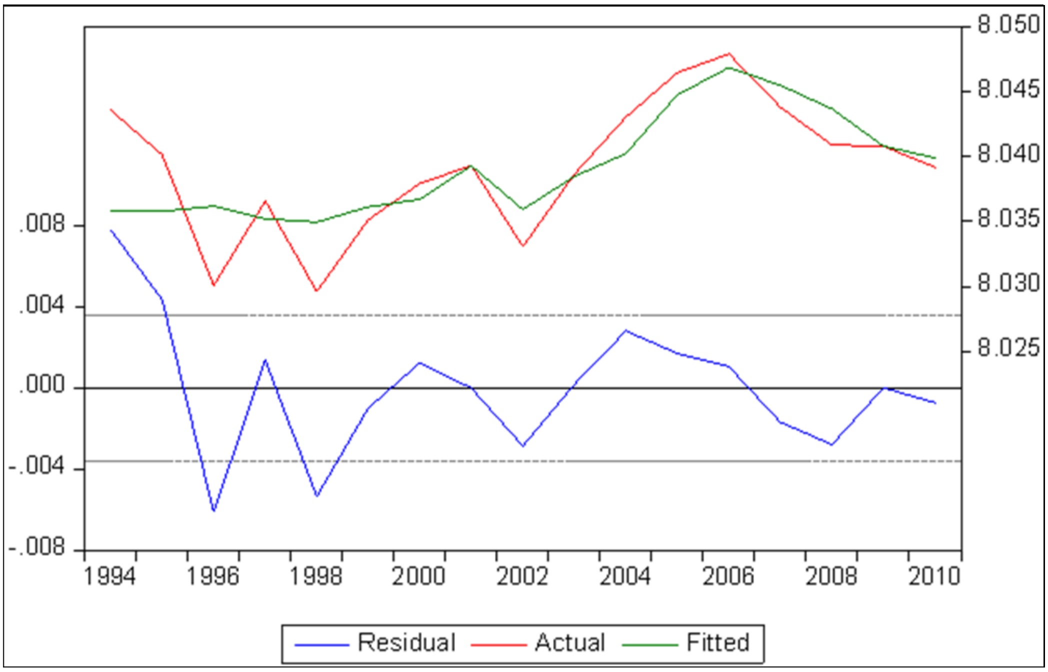

Figure 8 Comparison of historical observed solar energy technology investment costs to estimated investment costs according to the model without consideration of technological learning by doing effect. Additional, the residual of the estimation is plotted at the left scale. Source: Own calculations

With respect to the investment costs of solar energy installations, a remarkable learning by doing effect is realized at a learning rate. Considering their rapid market penetration according to IEA (2011) significantly impacts the solar energy investment costs. Combining the material price impact and the technological learning effect illustrates the dynamic development based on the model. Thus, Figure 9 addresses the total solar energy technology investment costs within the last three decades.

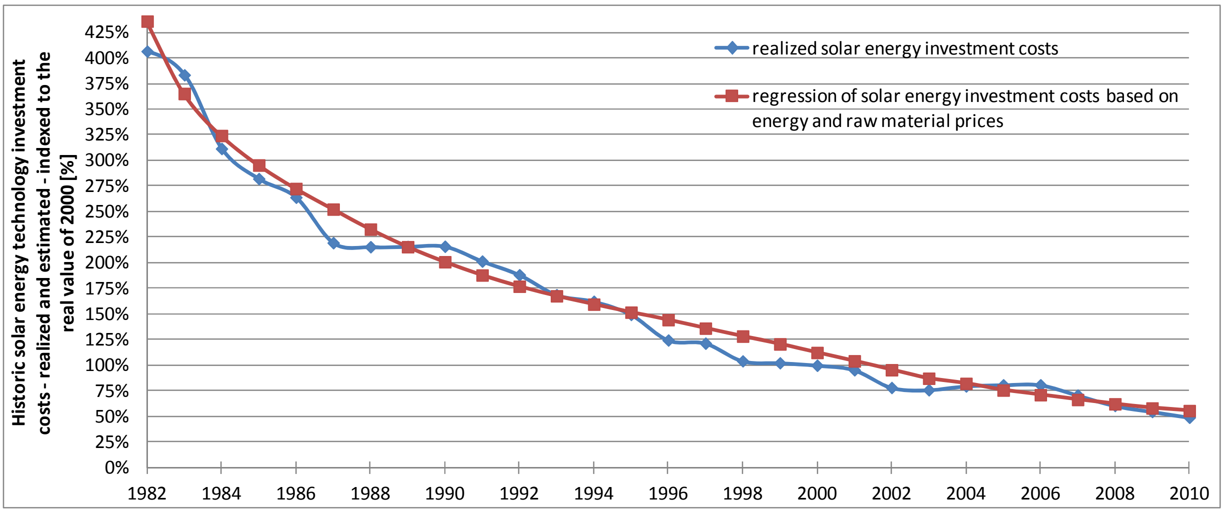

Figure 9 Comparison of realized historical solar energy technology investment costs to the estimation according to the econometric model considering the impact of energy and raw material price and the technological learning effect. Source: Own calculation.

Generally, fast decreasing investment costs of solar energy technologies are observed since the early eighties. Additionally, only light fluctuations occurred in this time period. Taking into account the estimation of solar energy technology investment costs based on the energy and raw material price development and adding the technological learning effect results in a well acceptable approximation. However, as previously indicated in Figure 8 the significant impact of energy and raw material prices around the year 2004 is compensated by technological learning effects. Hence, energy and raw material prices have indeed an impact on solar energy costs but with respect to their investment costs they are hardly recognizable.

Finally, forecast scenarios of solar energy investment costs are derived according to two different approaches. On the one hand, a pure consideration of the learning by doing effect represents the ordinary dynamic modeling approach. On the other hand, technological learning effects and the impact of energy and raw material prices is combined according to the model derived above. The results of these two future scenarios until the year 2030 is again compared to historical observations and illustrated in Figure 10. Generally, solar energy 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. Thus technological learning effects have a much stronger impact on solar energy technology investment costs than energy and raw material prices do. Therefore, hardly any difference between the two modeling approaches is recognized in Figure 10.

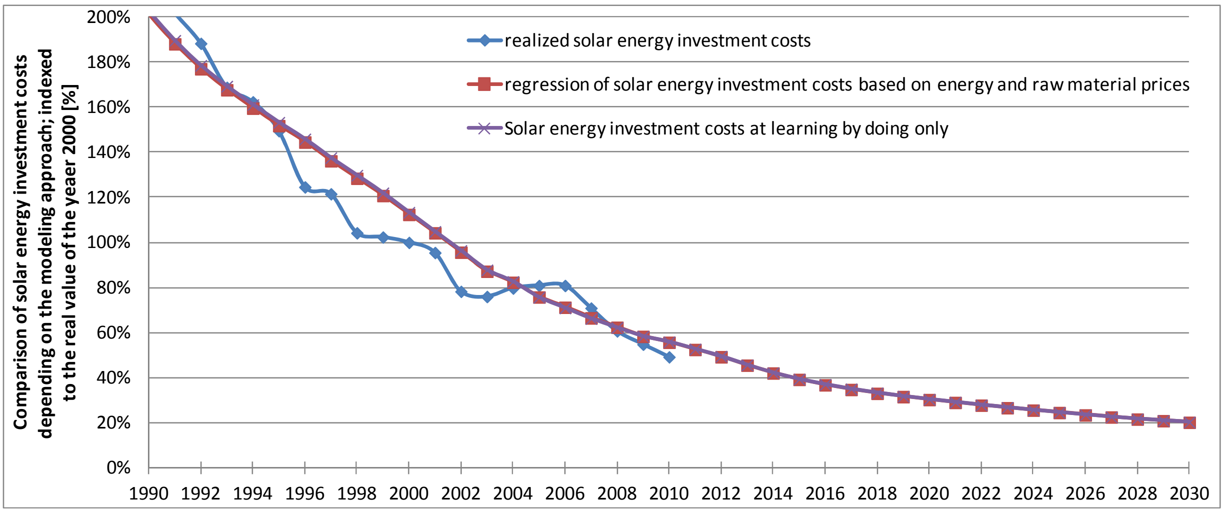

Figure 10 Future forecast scenarios of Photovoltaic investment costs, on the one hand based on technological learning effects (LR = 20 %) only and on the other hand additionally considering the silicon price impact. Source: Own calculations.

In conclusion, technological learning effects based on cumulative production dominate over the energy and raw material price impact in terms of solar energy technology investment costs. The novel approach of solar energy technologies enforces a high learning rate. Additionally, the strong development of this electricity generation technology show high learning effects. Thus, this paper focuses on learning by doing effects solely and neglects other impacts on investment costs. Further scientific research shows that energy and raw material price hold significant impacts on different energy generation technologies (Panzer, 2012). However, a technology specific assessment of the key drivers of investment costs is required, especially in order to assess the future performance of gas power generators in more detail.