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Environmental Energy Technologies Division

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DISCLAIMER

An Analysis of Residential PV System Price Differences Between the United States and Germany

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U.S. Department of Energy

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EXECUTIVE SUMMARY

Residential photovoltaic (PV) systems were twice as expensive in the United States as in Germany (median of $5.29/W vs. $2.59/W) in 2012. This price discrepancy stems primarily from differences in non-hardware or "soft" costs between the two countries, which can only in part be explained by differences in cumulative market size and associated learning. A survey of German PV installers was deployed to collect granular data on PV soft costs in Germany, and the results are compared to those of a similar survey of U.S. PV installers. Non-module hardware costs and all analyzed soft costs are lower in Germany, especially for customer acquisition, installation labor, and profit/overhead costs, but also for expenses related to permitting, interconnection, and inspection procedures. Additional costs occur in the United States due to state and local sales taxes, smaller average system sizes, and longer project-development times. To reduce the identified additional costs of residential PV systems, the United States could introduce policies that enable a robust and lasting market while minimizing market fragmentation. Regularly declining incentives offering a transparent and certain value proposition—combined with simple interconnection, permitting, and inspection requirements—might help accelerate PV cost reductions in the United States.

HIGHLIGHTS

- Residential PV system prices are twice as high in the USA than in Germany in 2012.
- Different cumulative national PV market sizes explain only 35% of price gap.
- Installer surveys show that price differences stem from non-module and soft costs.
- Largest cost differences stem from customer acquisition and installation labor.
- Incentives in the US are less effective in driving and following cost reductions.

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1. INTRODUCTION

Growing levels of greenhouse gases in Earth's atmosphere threaten the stability of global social, biological, and geophysical systems (Schneider et al., 2007) and require massive mitigation efforts (Betz et al., 2007). Photovoltaic (PV) technologies offer significant potential for decarbonizing the electricity industry, because direct solar energy is the most abundant of all energy resources (Arvizu et al., 2011). Although PV historically has contributed little to the electricity mix owing to its high cost relative to established generation technologies, technological improvements and robust industry growth have reduced global PV prices substantially over the past decade. Numerous sources document these price reductions, including the national survey reports under Task 1 of the International Energy Agency's "Co-operative program on PV systems" and subscription-based trade publications such as those produced by Bloomberg New Energy Finance, Greentech Media (GTM), Photon Consulting, Navigant, and EuPD Research.

In the academic literature, pricing analyses of PV modules and whole systems have been discussed primarily in the learning or experience curve literature (Maycock and Wakefield, 1975; Neij, 1997; Nemet, 2006; van der Zwaan and Rabl, 2003; Watanabe et al., 2000). Haas (2004) and Schaeffer et al. (2004) expanded the field by comparing pricing trends between countries and by distinguishing among prices for complete systems and costs of modules as well as hardware and "soft" (non-hardware) balance of system (BoS,) costs. Although PV system soft BoS costs were already examined 35 years ago (Rosenblum, 1978), they have received increased attention from the private and public sectors recently as their share of total system prices rose in conjunction with a decline in hardware component prices. Today, soft costs seem to be a major attribute for PV system price differences among various international mature markets.

The price difference is particularly stark for residential PV systems in Germany and the United States, averaging $14,000 for a 5-kW system in 2012. This article aims to explain the large residential system price differences between Germany and the United States to illuminate cost-reduction opportunities for U.S. PV systems. This research was conducted in the context of the U.S. Department of Energy's SunShot Initiative, which aims to make unsubsidized PV competitive with conventional generating technologies by 2020 (enabling PV system prices of $1/W for utility-scale applications and $1.50/W for residential applications) (U.S. Department of Energy, 2012).

2. OVERVIEW OF THE U.S. AND GERMAN PV MARKETS

While the United States was a global leader in PV deployment in the 1980s, the German PV market was significantly larger than the U.S. market from 2000 until 2012. Annual capacity additions (including residential, commercial, and utility-scale projects) accelerated in Germany since a reform of the German Renewable Energy Sources Act (EEG) in 2004, after which annual German PV installations were three to nine times higher than U.S. installations in terms of capacity. During 2010–2012, Germany added more than 7.4 GW per year, producing a cumulative installed capacity across all customer segments about four times greater (33.2 GW vs. 8.5 GW) than in the United States by the first quarter of 2013 (Figure 1) (Bundesnetzagentur, 2013; GTM Research and SEIA, 2011, 2012, 2013; Wissing, 2006, 2011) .

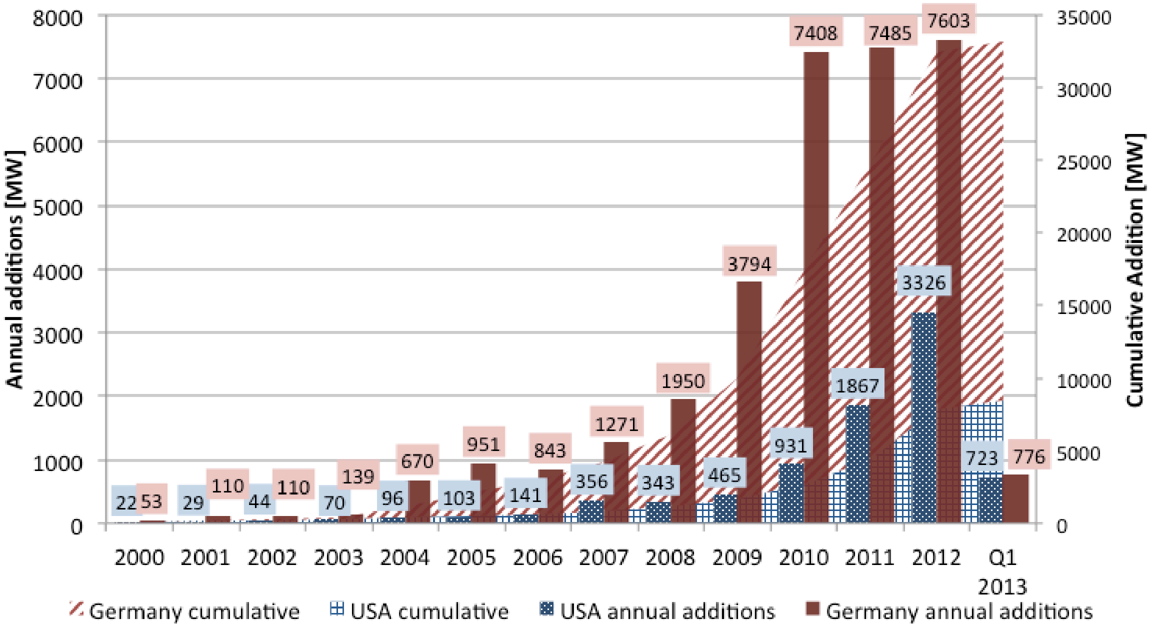

Figure 1: German and U.S. annual and cumulative PV capacity additions across all sectors

However, after the German Feed-in Tariff (FiT) was cut nearly 40% in 2012 and FiT degressions transitioned to a monthly schedule, German capacity additions slowed nearly to U.S. levels: 776 MW in Germany vs. 723 MW in the United States across all customer segments in the first quarter of 2013. Extrapolating from the first 6 months of 2013, German PV capacity additions would total about 3.6 GW in 2013, significantly lower than in previous years and close to the government target of 2.5–3.5 GW established in the 2010 EEG amendment.

A similar trend exists in the residential PV sector (defined here as any systems of 10 kW or smaller). Cumulative residential capacity in Germany was about 2.5 times greater (4,230 MW vs. 1,631 MW) than in the United States by the first quarter of 2013 (Figure 2) (Bundesnetzagentur, 2013; GTM Research and SEIA, 2011, 2012, 2013). However, German residential additions have slowed since the record year of 2011 and were for the first time smaller than U.S. residential additions in the first quarter of 2013 (136 MW vs. 164 MW). The recent residential growth in the United States has been spurred by new third-party-ownership business models, where either the system is leased to the site-host or the generation output is sold to the site-host under a power purchase agreement (quarterly market shares of third-party ownership range from 43% in Massachusetts to 91% in Arizona in Q4 2012) (GTM Research and SEIA, 2013). In contrast, third-party-ownership is uncommon in Germany.

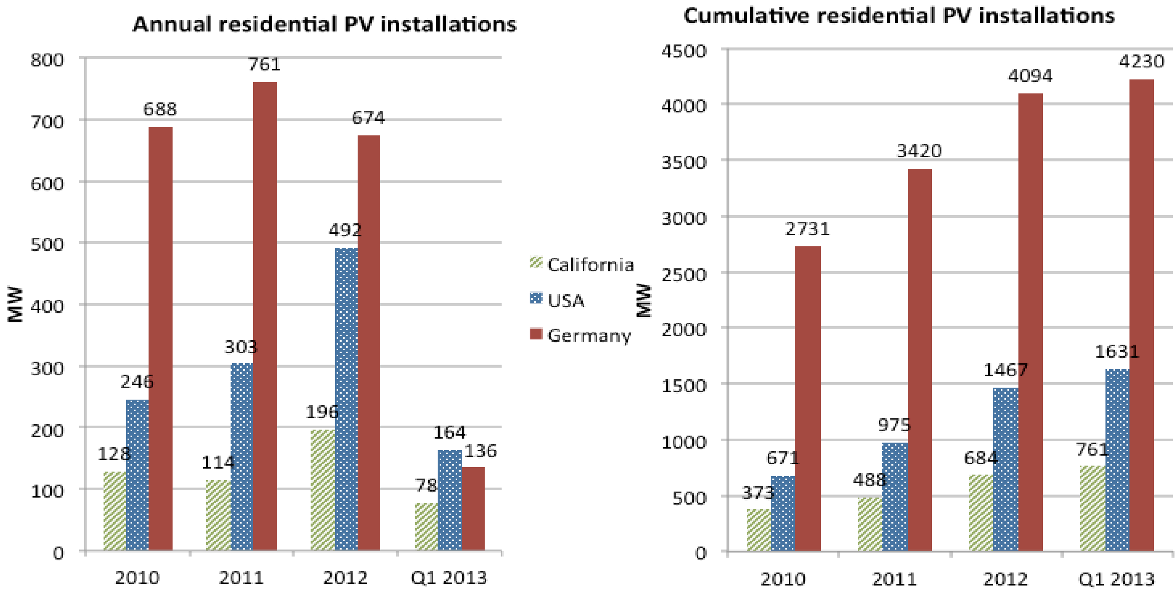

Figure 2: Residential annual and cumulative PV capacity additions: United States, Germany, and California

Despite this recent trend, residential PV systems remain much more ubiquitous in Germany than in the United States, especially in relation to each country's population; cumulative per capita residential PV capacity is 5 W in the United States, 20 W in California (the largest PV market in the United States), and 53 W in Germany in Q1 2013. This sizeable difference indicates that the German residential PV market is more mature than the growing U.S. residential PV market.

3. HISTORICAL RESIDENTIAL PV SYSTEM PRICING

3.1 Data Sources and Methodology

For this article, information for complete U.S. PV systems (but not individual soft-cost categories) and information on the country of origin of modules are derived from the database underlying the recent Lawrence Berkeley National Laboratory "Tracking the Sun VI" report, which reflects 70% of the U.S. PV capacity installed between 1998 and 2012 (Barbose et al., 2013). Systems larger than 10 kW and data entries with explicit information about non-residential use were excluded. It is important to note that the US data sample includes many third-party-owned projects. For systems installed by integrated companies (that both perform the installation and customer financing) the installed price data represents an appraised value, which was often significantly higher than prices of non-integrated installers between the years 2008 through 2011. The "appraised value prices" of many such systems stem from incentive applications that often utilize a "fair market value" methodology, which is based on a discounted cash flow from the project. This assessment can yield substantially higher values than the prices that would be paid under a cash-sale transaction of non-integrated installers. In order to avoid any bias that such data would otherwise introduce, projects for which reported installed prices were deemed likely to represent an appraised value – roughly 20,000 systems or 8% of the U.S. dataset – were removed from the sample to enable price comparisons with customer-owned residential systems in Germany. Unless otherwise noted, U.S. prices are reported as the statistical median from the Tracking the Sun dataset.

German system prices for 2001–2006 are arithmetic averages of data from the International Energy Agency's national PV survey reports (Wissing, 2011, 2006), the PV loan program of the German state bank Kreditanstalt für Wiederaufbau (KfW) (Oppermann, 2004, 2002), and a report comparing system prices between several European countries (Schaeffer et al., 2004). For 2007–2013, installed price averages for systems of 10 kW or smaller were obtained from quarterly surveys of 100 installers by the market research company EuPD for the German Solar Industry

Association (BSW) (Tepper, 2013). In addition, 6,542 German price quotes for systems of 10 kW or smaller were analyzed for price distributions and module brand market shares (EuPD, 2013).

Annual module prices reflect average sales prices for a blend of monocrystalline and polycrystalline silicon modules at the factory gate in a mix of representative geographic locations, based on data from Navigant (Mints, 2013, 2012). Quarterly module prices from 2010 to 2012 are a blend of UBS spot market prices for Chinese and non-Chinese modules (Meymandi et al., 2013), while quarterly residential inverter prices are based on the U.S. Solar Market Insights report series by Greentech Media (GTM Research and SEIA, 2013, 2012, 2011).

Throughout the analysis all prices are reported in average 2011 U.S. dollars (US$2011). German historical data were adjusted with German inflation data to average 2011 euros (€2011) and then translated to US$2011 by using the mean dollar-euro exchange rate for 2011 ($1.39/€).

Focusing only on the upfront installed price of a PV system (with the metric $/W) has inherent limitations. A range of important quality characteristics are not captured, such as longevity and degradation rates of the hardware components, module capabilities (e.g., efficiency under diffuse light in cloudy Germany), inverter power-quality-management capabilities (e.g. reactive power supply), and the ability to analyze generated and self-consumed electricity data remotely. In addition, the levelized cost of solar electricity (which matters most to consumers) depends not only on installed price, but also on factors such as system uptime and, more importantly, annual insolation. Nevertheless, capacity pricing in $/W (including sales tax if applicable) is a useful metric because it enables a direct comparison of residential PV system prices between the two countries at a granular level. It is used for the remainder of the analysis, with the exception of a brief comparison of PV electricity generation costs in the results section. Operation, maintenance, and financing costs are outside the scope of this research.

3.2 Results

Average residential PV system prices have fallen significantly over the past 11 years in both countries: about 75% in Germany (starting from $11.44/W in 2001) and about 50% in the United States (starting from $10.61/W). After initial fluctuation, prices became similar in each country by 2005 (around $8.6/W). In the following years, prices increasingly diverged; during a time of nearly constant module prices from 2005 to 2008, U.S. system prices decreased only to $8.03/W in 2009, while German non-module cost reductions yielded a system price of $4.82/W in 2009 (Figure 3).

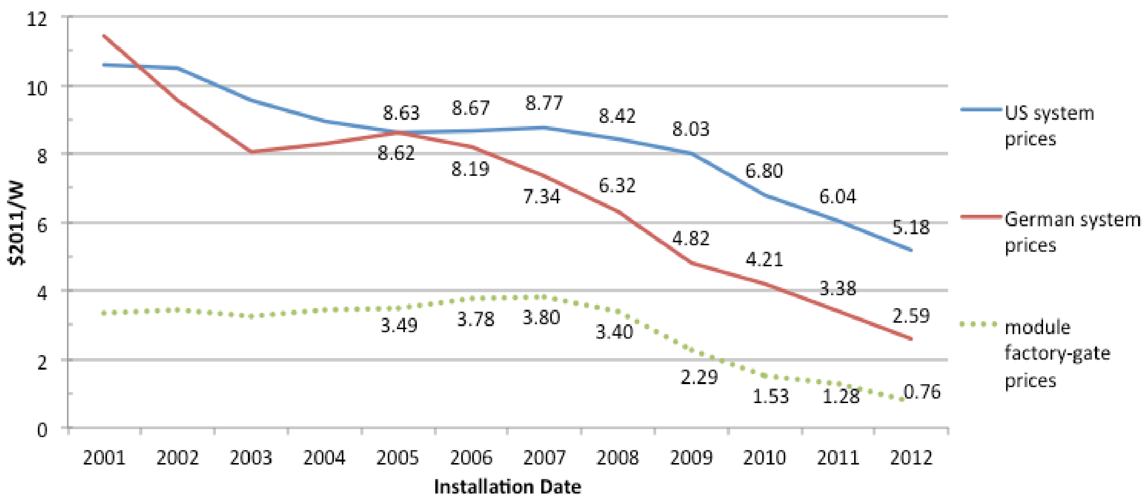

Figure 3: Median installed price of non-appraised PV systems <= 10 kW, 2001-2012

Median system prices decreased largely in parallel from 2010 through 2012, maintaining a price gap of about $2.8/W between residential systems installed in Germany and the United States. As shown in Figure 4, the price reductions in both countries were aided by a decline in module and inverter costs.

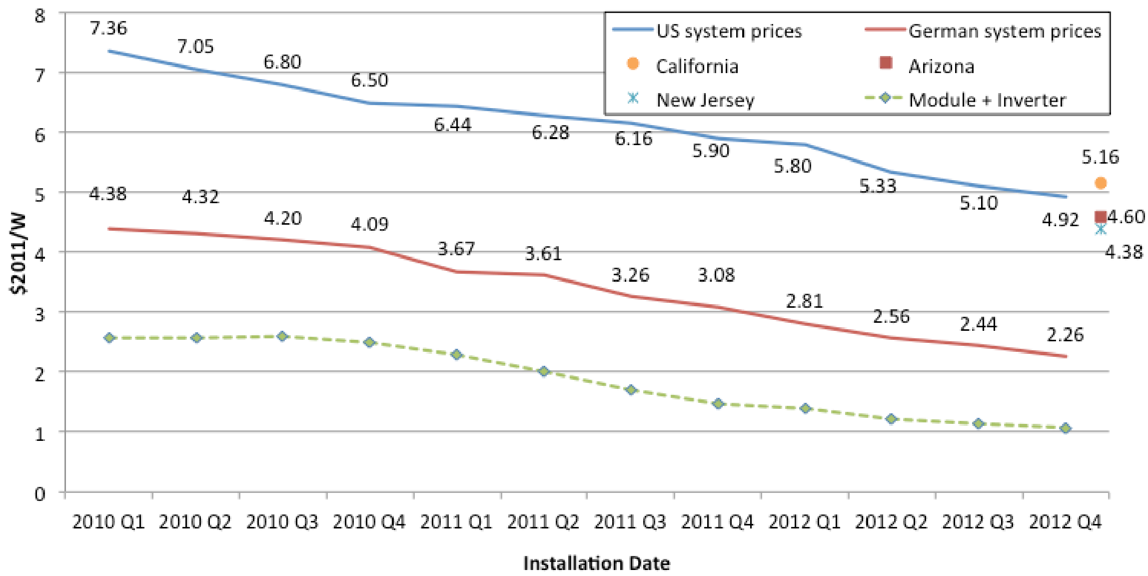

Figure 4: Median installed price of non-appraised PV systems <= 10 kW, 2010-2012

System-level prices are also much more heterogeneous in the United States than in Germany (Figure 5). For example, in 2012 the U.S. standard deviation was $1.54/W, compared with $0.45/W in Germany. Because of this wider spread of prices in the United States relative to Germany, the cheapest 15% of U.S. systems were installed at prices found among the more expensive systems in Germany.

The wider distribution can be explained in part by significant system price differences among individual U.S. states and the absence of clear price signals on the national level. For example, New Jersey (one of the lower-priced markets) had a median residential price of $4.38/W in the fourth quarter of 2012, compared with $5.16/W in California (one of the higher-priced markets and the largest U.S. PV market). This difference is partly due to varying business process costs (such as labor costs), but it also suggests the presence of value-based pricing and relatively fragmented markets across states and local jurisdictions. For example, the electricity costs avoided by net-metering agreements vary based on electricity rates and structures in different utility service territories and states, as do additional incentives.

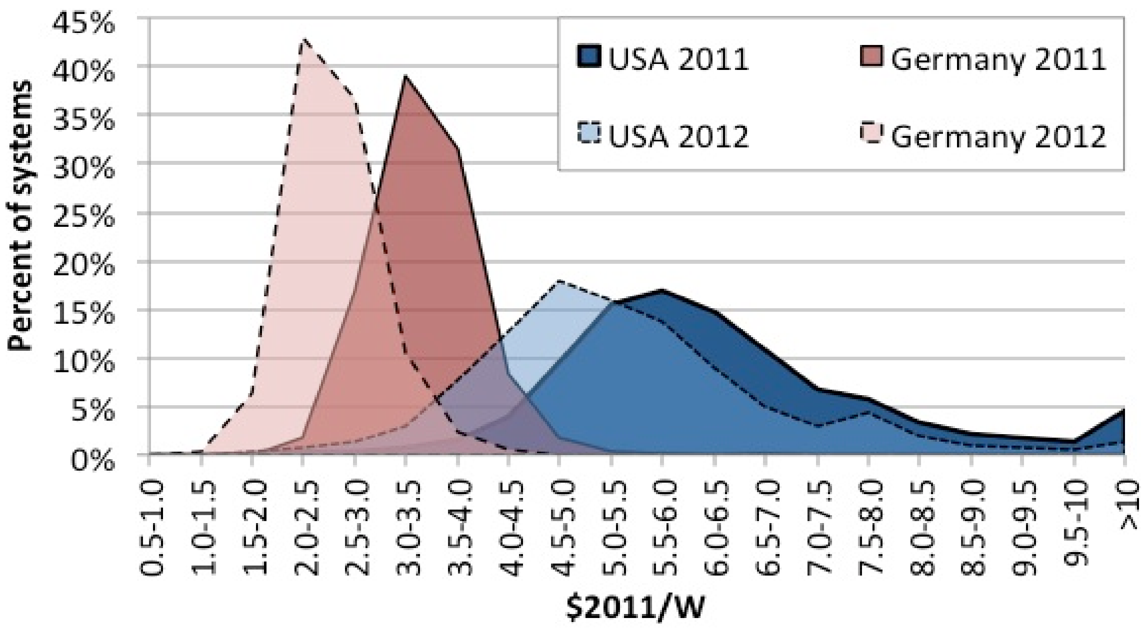

Figure 5: Price distribution of non-appraised PV systems <= 10 kW installed in the United States and Germany in 2011 and 2012

The system price differences between Germany and the United States affect the associated electricity generation costs, although they are partly offset by the different insolation resources. Germany's average insolation ranges between Alaska's and the State of Washington's, the least sunny areas of the United States (900–1,200 kWh/m^2 annual global horizontal irradiation averages). A levelized cost of electricity (LCoE) analysis based on the National Renewable Energy Laboratory's (NREL's) System Advisor Model showed that residential PV electricity generation costs at PV system prices from the fourth quarter of 2012 ($2.26/W in Germany and $4.92/W in the United States) in the cloudier parts of Germany were comparable to costs in sunny regions of the United States such as California.[1] If residential PV system prices in the United States decreased to German levels, electricity could be generated at very low costs in sunny areas in the United States. Figure 6 suggests that, with the 30% U.S. federal investment tax credit (ITC), achieving German PV system prices could reduce

[1] LCoE assumptions: 25-year life span, nominal discount rate of 4.5%, O&M $100/year, one inverter replacement over the system lifetime for $1,200, derate factor of 0.77, degradation rates of 0.5%/year.

PV electricity generation cost to $0.06/kWh for residential installations in Los Angeles.

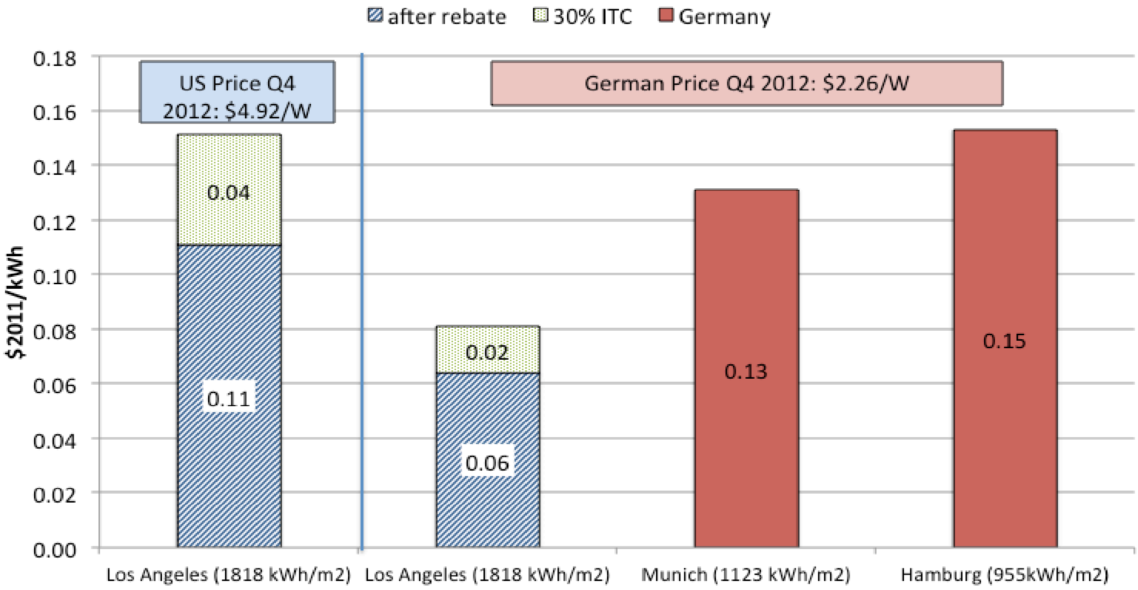

Figure 6: Levelized cost of electricity estimates for residential PV systems at varying global horizontal annual insolation rates in Q4 2012

4. NON-MODULE COSTS AS PRIMARY DRIVER OF PRICE DIFFERENCES

With the significant growth and internationalization of PV module manufacturing, modules increasingly have become a global commodity that can be purchased at very similar prices in the large and mature PV markets around the world. Previous analyses have shown very little recent pricing discrepancy for PV modules between Germany and the United States (Goodrich et al., 2012). Further, lower-cost Chinese and Taiwanese module brands penetrated the residential markets of both countries similarly in 2012 (increasing from 23% to 39% in Germany and from 32% to 40% in the United States from 2010 to 2012), even though German brands were more popular in Germany (56% of all systems in 2010 declining to 46% in 2012 (EuPD, 2013)) than were American brands in the United States (relatively stable around 20% (Barbose et al., 2013))[2]. This leaves non-module costs as the primary driver of system price differences.

Non-module costs can be divided into two general categories: inverter and other BoS hardware costs and non-hardware costs, which are also called “business process costs” or “soft (BoS) costs.” Since the strong decline in module prices starting in 2008, increasing attention has been devoted to BoS costs and soft costs for further price reductions. The U.S. Department of Energy has dedicated significant consideration to these costs in the context of the SunShot Initiative (Ardani et al., 2012; U.S. Department of Energy, 2012, 2010). Other public entities on both sides of the Atlantic (e.g., Bony et al., 2010 with an initial evaluation of U.S. soft costs; Persem et al., 2011; Sonvilla et al., 2013 with an evaluation soft costs in Germany and the EU), private industry (e.g., GTM Research, 2011), and academic researchers have taken on this subject increasingly as well (Ringbeck and Sutterlueti, 2013 focusing on commercial installations; Schaeffer et al., 2004 as one of the first international comparisons of soft cost categories; and Shrimali and Jenner, 2012 using soft costs as dependent variable in the context of their larger regression analysis). Our analysis complements that literature by providing an in-depth comparison of soft-BoS cost

[2] Information is based on the country of the headquarter of the 25 most ubiquitous module brands in the U.S., derived from 106,472 systems installed in 20 different U.S. states between 2010 and 2012.

components in Germany and the United States, that was derived from one consistent survey instrument distributed to a larger number of respondents and resulting in more granular soft-BoS cost categories than previously available. These survey results, which are more recent then what has previously been available in the literature, are then aggregated in complete bottom-up cost models for both countries. The survey data is also contextualized with additional statistical analyses of the largest U.S. PV system database (Barbose et al., 2013), and a complete database of interconnected German PV systems (Bundesnetzagentur, 2013) to discern influences of system sizes and system development times on soft costs. At last we highlight best practices and associated BoS cost-reduction opportunities for both the United States and Germany.

4.1 Introduction to Soft-Cost Survey and Methodology

More detailed information on the composition of soft costs was needed to identify the sources of the significant residential PV system price gap between the United States and Germany. Building on a bottom-up benchmarking analysis of the U.S. residential PV market in 2010 (Ardani et al., 2012), we adapted a survey developed by NREL to collect granular data on soft costs for residential PV systems in Germany and to enable direct comparisons between the two countries. The survey instrument inquired about German residential systems installed in 2011. It was distributed in early 2012 to more than 300 German residential PV installers in Microsoft Excel format and as an online survey on the platform www.photovoltaikstudie.de. The survey asked either for total annual expenditures for a given business process, translated into $/W based on each installer's annual installation volume, or for labor-hour requirements per installation for individual business process tasks, which were multiplied by a survey-derived, task-specific, fully burdened wage rate to estimate $/W costs.

The German survey respondent sample consisted of 24 installers that completed 2,056 residential systems in 2011, yielding a residential capacity of 17.9 MW. This is roughly half the sample size of the corresponding U.S. survey.

Due to surprisingly low reported installation labor hours in the German survey (likely because of a misunderstanding of the term “man-hours”), a follow-up survey was fielded in October 2012 focusing solely on installation labor requirements during the preceding 12 months. Forty-one German installers participated in this second survey, collectively representing 1,842 residential systems installed over the previous year, with a capacity of 11.9 MW.

The median reported residential system size was 8 kW, which is close to the median system size of all grid-connected PV systems of 10 kW or smaller in Germany in 2011 (6.8 kW) (Bundesnetzagentur, 2013). In both German surveys, most respondents were relatively small-volume installers, completing fewer than 50 residential systems per year (median: 25 in 2011, 26 in 2012). These German firm sizes are generally comparable to the installer firm sizes of the U.S. survey (median of 30 residential installations per year), although two U.S. firms installed more than 1000 systems per year, a threshold not reached by a single German company in the survey. Survey responses were weighted by the installed residential capacity of each installer, giving a stronger emphasis to larger companies.

In contrast to the earlier reporting of median prices, capacity-weighted means are more meaningful in a bottom-up cost analysis and thus are used for the survey results. The capacity-weighted mean price for U.S. residential systems was slightly higher than the median price in 2011 ($6.19/W vs. $6.04/W).

4.2. Survey Findings

The capacity-weighted mean price for German residential systems reported in the survey for 2011 was $3.00/W, slightly lower than the BSW estimate for 2011 of $3.38/W (Tepper, 2013, reported earlier in Fig. 3). Total non-hardware costs (including margin) were much lower in Germany, accounting in 2011 for only $0.62/W (21% of system price) versus $3.34/W in the United States (54%).

A comparison of fully burdened wages between the two countries reveals that installation labor was cheaper in Germany but that wages of system design engineers, sales representatives, and administrative workers were higher in Germany (Table 1).

Table 1: Fully burdened wages at PV installation companies [$/h]

	Electrician Installation	Non-electrician Installation	System Design Engineer	Sales Representative	Administrative Labor
United States	62	42	35	32	20
Germany	48	38	47	53	42

The wage data includes taxes and welfare contributions but excludes employment-related overhead costs incurred by human resources departments. Data for Germany was derived from the fielded survey, while U.S. wage data was utilized that had been previously used in U.S. soft cost analyses by the U.S. National Renewable Energy Laboratory (RSMeans, 2010). Some of the German wage data derived from the survey are higher than estimates by the German federal statistical agency (Destatis), especially for sales labor. This discrepancy can be explained by the fact that many German residential installers are small businesses and local craftsmen—where the business owner is often involved in the sales process—while the Destatis numbers are not specific to the PV industry and represent sales labor wages in larger companies.

Of the three specific soft cost categories examined, the largest difference between the United States and Germany was associated with **customer acquisition costs** (a difference of $0.62/W).

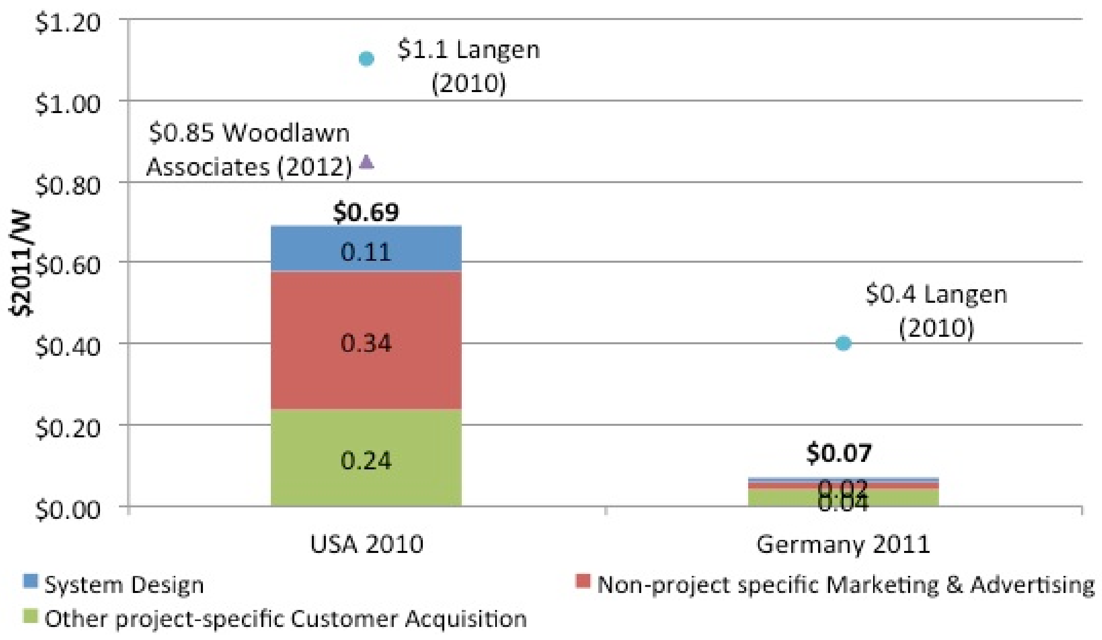

Figure 7: Average customer acquisition costs in the United States and Germany

In Figure 7, *"Non-project-specific Marketing & Advertising"* includes expenses such as online and magazine ad campaigns, while *"Other project-specific Customer Acquisition"* includes categories such as sales calls, site visits, travel time, bid preparation, and contract negotiation (averaging about $400 for a German installation). Previous analyses confirmed a similar degree of expense differences between the two countries for 2010 and similar levels of U.S. customer acquisition costs in 2012 (Woodlawn Associates, 2012). *"Non-project-specific Marketing and Advertising"* costs average about $200 for a residential installation in Germany, although one third of the respondents reported no expenses for such broad advertising activities for their businesses. *"Other project-specific Customer Acquisition"* expenses are in comparison both more substantial (averaging about $400 per installation) and more ubiquitous (only two respondents reporting no costs for this category).

Customer acquisition costs may be lower in Germany because of partnerships between installers and both equipment manufacturers and lead-aggregation websites, where potential customers are quickly linked to three to five installers in their zip code areas. German residential PV installers also have a higher bid success rate, which lowers per-customer acquisition costs: 40% of leads translate into final contracts in Germany compared to 30% in the United States.

In addition, the large German market has transformed residential PV systems from an early-adopter product into a more mainstream product, and new customers are recruited primarily by word of mouth. Peer effects in the diffusion of PV (Bollinger and Gillingham, 2012), therefore, further explain the relatively low customer acquisition costs in the more mature German market; about 1 of 32 German households owned PV systems in the first quarter of 2013 compared with 1 of 83 California households and 1 of 323 U.S. households. As explained later, the relatively straightforward value proposition of PV systems under the FiT in Germany may further facilitate the sales process and contribute to lower customer acquisition costs compared to the United States.

The second-largest soft cost difference ($0.36/W) stems from the **physical installation process** (Figure 8). According to the follow-up survey, German companies installed residential PV systems in 39 man-hours, on average, while U.S. installers required about twice as many labor hours (75 man-hours per residential system). One possible contributor to the difference in installation labor hour requirements is the prevalence of roof penetrations. Most surveyed German installers either never or only rarely install residential systems requiring rooftop penetration;

this share is likely higher in the United States due to differences in roofing materials and climatic requirements.[3] Other studies have reported even shorter installation times for Germany (Bromley, 2012; PV Grid, 2012).

A recent field study by the Rocky Mountain Institute—using a time and motion methodology for residential PV installations in both countries—confirmed our findings and provided further details on differences in installation practices that highlight remaining optimization opportunities for U.S. installers (Morris et al., 2013). The required installation labor hours for German installations are not strongly positively correlated with the installed system size, suggesting further economies of scale for the slightly larger German residential PV systems in comparison to U.S. residential systems. The standard deviation in reported total installation labor hours is only 12h for German systems, and even the 90th percentile of German labor hours (55h) is significantly less than what their American counterparts reported for the year 2010.

In Germany, the bulk of installation labor consisted of cheaper non-electrician labor (77% of total man-hours), whereas non-electrician labor represented only 65% of total installation labor hours for U.S. residential systems. Fully burdened wages were also slightly lower in Germany than in the United States. As a result of this combination of factors (fewer total installation labor hours, greater reliance on non-electrician labor, and lower overall wage rates), installation labor costs averaged \$0.23/W in Germany compared to \$0.59/W in the United States (Figure 8).

[3] Additional hypotheses about faster German installations due to less use of an extra conduit for wiring or much faster grounding practices could not be confirmed.

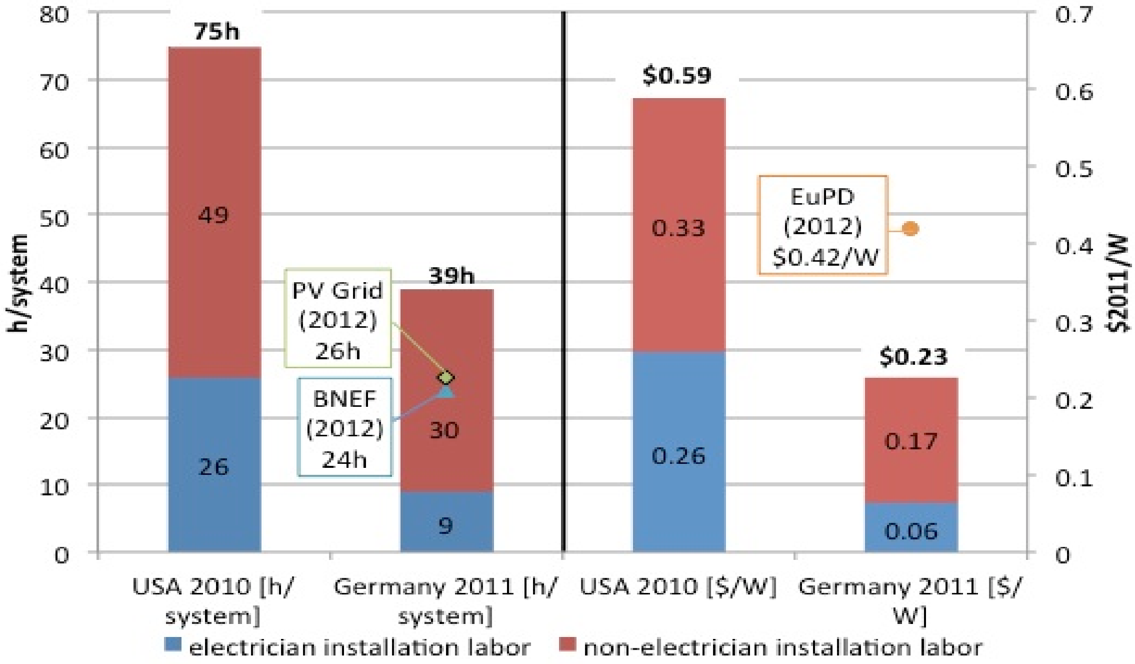

Figure 8: Installation labor hours and costs in the United States and Germany

Costs associated with **permitting, interconnection, inspection** (PII) have been discussed widely in the United States. As shown in Figure 9, our survey indicated PII costs (including incentive application processes) were $0.21/W lower in Germany than in the United States. This difference is mostly due to lower PII labor hour requirements in Germany (5.2 h vs. 22.6 h). In Germany, local permits (structural, electrical, aesthetic) and inspection by county officials are not required for the construction of residential PV systems. Incentive applications are done quickly online on one unified national platform - all respondents of the German survey reported zero labor hours for this activity, suggesting that this is done by the owner of the PV system and no facilitation of the installer is required. In addition, no permit fee is required in Germany, while residential permitting fees in the United States average $0.09/W. As result, the only sizable PII activity in Germany is the actual interconnection process to the distribution grid (the respondents are very consistent in their reports of 2h -3.5h) and an associated notification to the local utility (20% of the respondents stating that 0h are required for this activity, while 12% report time budgets of 3.5h-4h).

These survey results are very similar to other estimates of permit time requirements and total PII costs (Tong, 2012; PV Grid, 2012; Sprague, 2011; Dong and Wiser, 2013). Since the assessment of U.S. permitting time requirements in 2010 (Ardani et al., 2012), substantial efforts have been made across many U.S. jurisdictions to streamline processes and make reporting requirements more transparent. Among the initiatives are online databases such as www.solarpermit.org, the U.S. Department of Energy's "Rooftop Solar Challenge" with best practices shared in an online resource center, and state legislation limiting permit fees in Vermont, Colorado, and California.

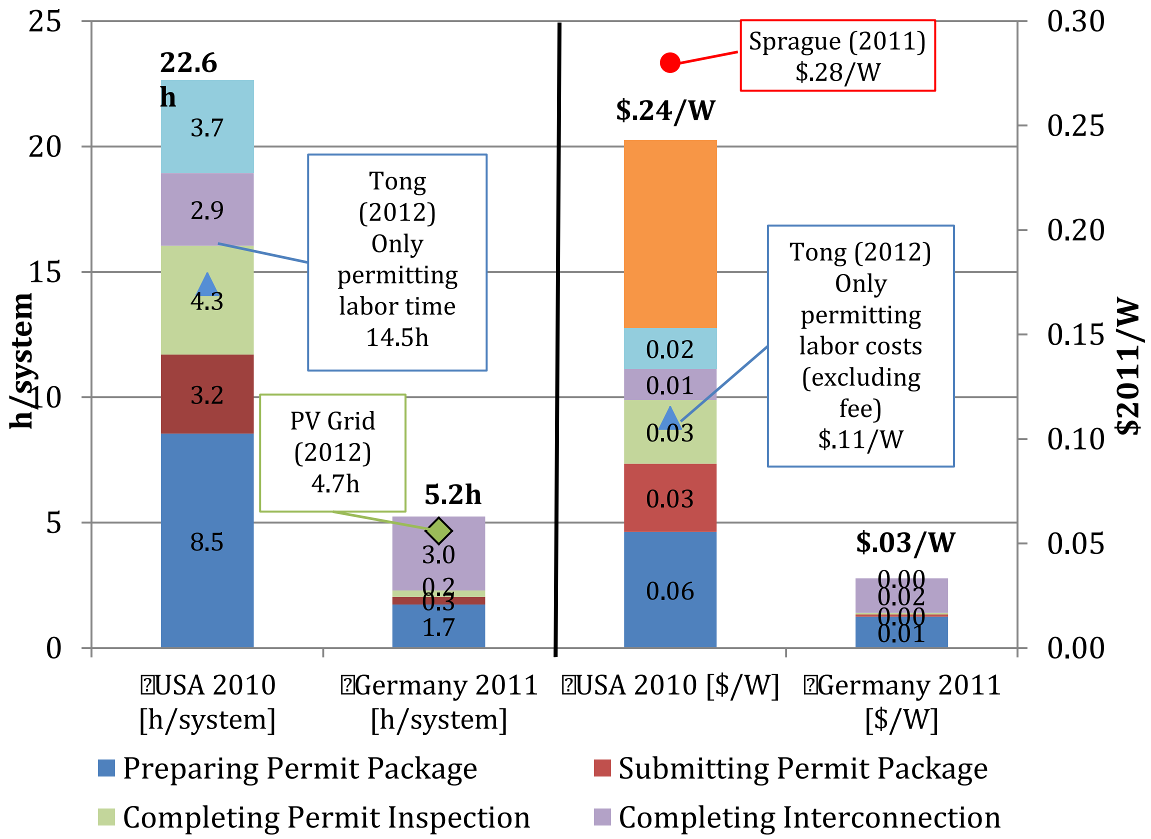

Figure 9: Permitting, interconnection, inspection, and incentive application hours and costs in the United States and Germany

In addition to the soft cost categories explored through the survey, sales taxes are another reason for the divergence between residential PV system prices in the United States and Germany. German PV systems are effectively exempt from sales and value-added taxes (usually 19%) either due to the "Kleinunternehmer" or "Vorsteuererstattungs" clause (Bundesverband Solarwirtschaft (BSW-Solar), 2012). In the United States, 23 states assess sales taxes on residential PV systems, usually ranging between 4% and 8% of the hardware costs. In addition, local sales taxes are often levied (The Tax Foundation, 2013). Given the spatial distribution of PV systems in the United States (Barbose et al., 2013), and accounting for PV sales tax exemptions in some states (DSIRE, 2012), state and local sales taxes added according to our analysis approximately $0.21/W to the median price of U.S. residential PV systems in 2011.

We devised a bottom-up cost model for U.S. systems using hardware cost estimates for 2011 (GTM Research and SEIA, 2012; Goodrich et al., 2012) and soft cost benchmarks for 2010 (Ardani et al., 2012). Figure 10 summarizes the identified sources for the price difference of $3.19/W between U.S. and German residential systems installed in 2011. Besides the residual costs, the largest difference in soft costs stems from customer acquisition costs, followed by installation labor costs, sales taxes, and PII costs.

To our knowledge, no detailed national data are available on additional overhead costs (e.g., property-related expenses, inventory-related costs, insurance, fees, and general administrative costs) and net profit margins of U.S. residential installers. The additional category "overhead, profit, and other residual costs" in Figure 10, therefore, accounts for the difference between the system prices (Barbose et al., 2012) and the bottom-up cost estimates. German installers reported $0.29/W for overhead costs and profits, while the U.S. residual was $1.61/W (a difference of $1.32/W). Additional research is needed to understand the source of this large difference.

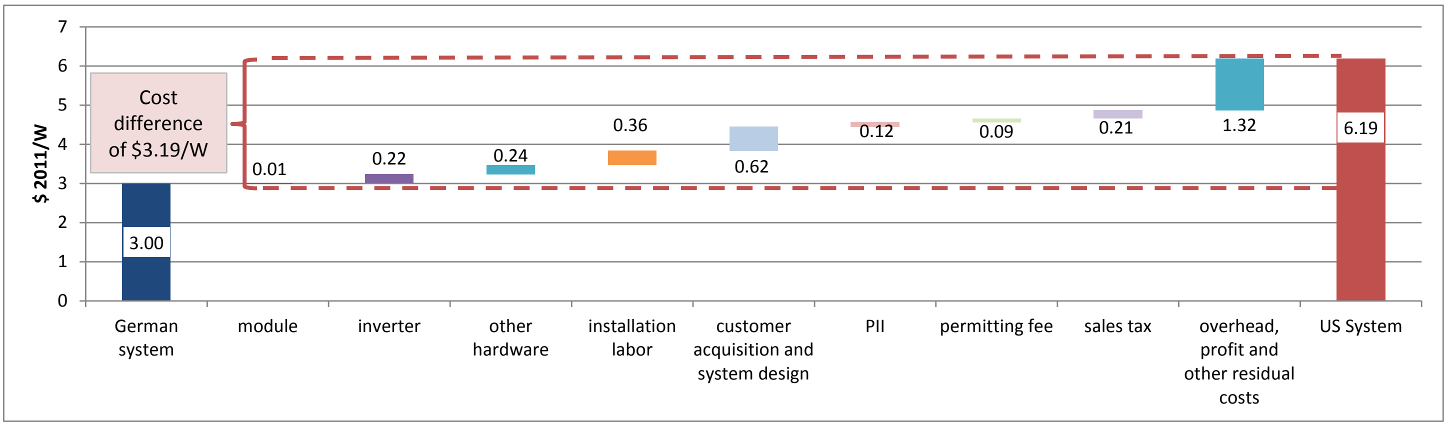

Figure 10: Components of cost difference between German and the U.S. residential PV systems in 2011

Two additional hypotheses may explain in part why residential PV prices are higher in the United States, even though they do not add directly to the numbers already represented in the bottom-up cost model: implications of longer development times and the effect of differences in system sizes on final system prices.

According to the survey, German residential PV installers require on average 35 days between first contact with a potential customer and the completion of the PV system installation and interconnection. System development times are substantially longer in the United States, where the average time between the first application date for a future specific PV installation and the reported system completion is 126 days. This substantially longer period of nearly 3 months impacts an installer's financing costs for purchased materials, the volume of annual installations, and the associated relative burden of general business overhead costs per installation. It also influences the installer's ability to pass down material price reductions to the final customer in a timely manner. For example, prices for systems completed in the fourth quarter of 2012 may have been negotiated in that quarter in Germany but in the third quarter of 2012 in the United States. The effects of these temporal misalignments vary with pricing dynamics in both countries over time. In the fourth quarter of 2012, they may explain $0.18/W of the system price difference (the price difference between the third and fourth quarters of 2012 in Germany).

An analysis of German PV interconnection data (Bundesnetzagentur, 2013) for systems of 10 kW or smaller shows that systems in Germany are also slightly larger than those in the United States, with respective medians of 6.80 kW and 4.95 kW in 2011. Although the mode is in the 5–6 kW bin in both countries, the German distribution of system sizes is positively skewed, while the U.S. distribution is negatively skewed. This difference can be explained by the fact that German residential system sizes historically have been constrained only by available roof area and the customers' willingness to pay for larger system sizes, because the FiT payments are not system-size dependent within each FiT bin (0–30 kW until April 2012, 0–10 kW since then). Because PV systems exhibit economies of scale, larger systems result in a higher rate of return, providing an incentive for larger systems. In the United States, by contrast, PV customers size their systems predominantly according to their own electricity consumption, because excess generation is not compensated favorably under most net-metering agreements (Darghouth et al., 2011). Thus, owing to economies of scale, the larger German systems have lower average system prices than the smaller U.S. systems. Applying the German system size distribution to the U.S. system price distribution quantifies this price advantage at $0.15/W for systems installed in 2011.

5. DISCUSSION OF FINDINGS

Our preceding empirical analysis shows that the primary sources of price differences between U.S. and German residential PV systems are non-module costs, primarily soft costs such as business process costs and “overhead costs and profit.” The following discussion section contextualizes our quantitative results with a few general hypotheses that are not exclusively linked to individual business process cost categories, but that may explain differences in the broader market characteristics between the two countries. As the observed price disparities are likely of multi-causal origin, we first turn to structural market differences including market size and the degree of market fragmentation. In a second step we examine differences in the economic valuation of the generated electricity of PV systems to illuminate possible consequences on system pricing by installers and the customers’ willingness to pay. We recognize however that the postulated hypotheses are by no means exhaustive and that a further analysis of market differences between both countries provides an excellent field for future research.

At first, some of the price discrepancy between the United States and Germany may be in part attributable to the smaller size of both annual the residential PV market in the United States compared with Germany as well as a significantly lower amount of cumulative installations. In general one would suppose that a larger market gives installers more experience, enabling them, for example, to streamline workflows during the physical installation process.

The transferability of the German experience to the Unites States may be limited due to a number of structural differences between the two markets that are unlikely to change: Germany has a higher population density, leading to lower transportation costs and travel times, while climatic differences such as higher wind loads and roofs not designed to withstand large snow masses may require a higher degree of scrutiny during the structural design process for PV systems in the United States.

Some of the market fragmentation in the United States—particularly fragmented permitting processes among states, utility service territories, and cities—is politically induced and originates in the substantial regulatory role that state and local governments assume. In contrast, the national Renewable Energy Sources Act and the German Energy Act primarily govern Germany's renewable energy policy, which provides the country with a national incentive structure and one unified PV market with few PII requirements. One may postulate the hypothesis that four aspects of the German PV market seem to work more effectively than in the U.S. and enable thus a quicker project flow and lower customer acquisition costs: the relative simplicity of the German regulatory framework, a large potential customer base that holds strong environmental values, bandwagon and diffusion effects among customers, and a very competitive PV market.

German PV market growth and rapidly falling prices also may have been facilitated by the regularly adjusted FiT, which has provided a simpler, more certain, and more lasting value proposition to the final customer (e.g. Haas et al., 2011; Klessmann et al., 2013; Mendonca, 2009) compared to U.S. policies consisting of a combination of tax credits, local incentives, and net-metering policies.

It is relatively easy to calculate the value of the FiT-payments revenue stream in Germany; its decline for new systems is shown in Figure 11 (blue line in $/kWh, right axis), along with its corresponding net present value (NPV) in $/W. The modeled NPV accounts for module degradation and inflation but excludes additional operation and maintenance costs—the FiT NPV should thus be higher than corresponding system prices to allow for cost recuperation and the earning of a return on the investment. Because the NPV for a given FiT level is determined primarily by local insolation, a representative system for the sunny regions in the German south (generating roughly 860 kWh/kW each year, light green dotted line, left axis) and one for the less sunny northern regions (generating roughly 730 kWh/kW each year, dark green dotted line, left axis) are modeled in Figure 11.

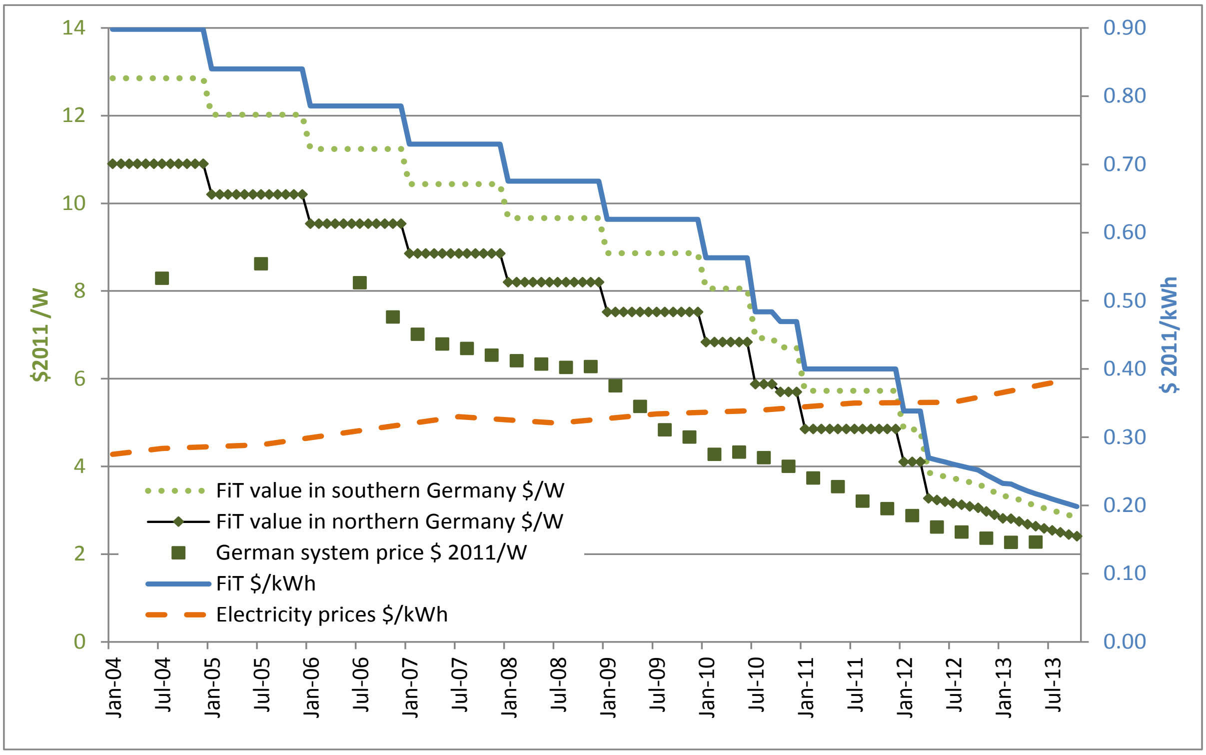

Figure 11: German residential PV system prices and the value of FiT payments in high (southern) and low (northern) irradiation regions in Germany

This policy mechanism of regular incentive reductions has forced residential installers to lower system prices (even in times of stable module prices before 2008) to offer their customers attractive rates of return. In 2012, however, the FiT for German residential PV systems reached “grid parity” as the remuneration amount was less than average residential electricity prices for the first time. Since then, the FiT has continued to decline while retail electricity prices have risen (orange dashed line, right axis in Figure 11) (Haller et al., 2013), leading to a difference of $0.17/kWh in July 2013. This spread has motivated new German PV customers increasingly to displace electricity purchased from the utility with self-generated electricity from the PV system. In contrast to most U.S. net-metering policies, this displacement must occur on an instantaneous basis and not on a net basis over a longer period (typically a year), which historically has limited the attractiveness of this option for German customers. However, a new federal subsidy program for batteries (30% of the battery price up to a cap of 2€ per Watt PV capacity for new residential installations) and the growing value discrepancy between the purchase price of retail electricity and the set sales price of the FiT may overcome these hurdles. The overall price-decreasing pressure of the degressing FiT could thus become less effective over the coming years should German residential PV customers rely increasingly on the higher value of the self-consumption option. That and a stagnation of module prices may explain the increase in German system prices in the second quarter of 2013, the first rise compared to the previous quarter since the second quarter of 2010. German customers have not yet responded, however, to these new value propositions by optimizing PV systems for self-consumption; size distributions between the first quarter of 2010 (pre-FiT-grid parity) and the first quarter of 2013 (post-FiT-grid parity) show no change in either shape or average values (Bundesnetzagentur, 2013).

Similar pressures to reduce system prices may not exist to the same degree in the United States. Even though state-level incentives (such as upfront rebates and performance-based incentives) have declined over time, they have done so with less consistency than the German FiT, while the largest national incentive (the federal Investment Tax Credit) has remained stable at 30% of the total system price, at least until 2016. Furthermore, significant variation in PV customer bill savings can occur in the United States due to complicated rate structures, such as changing marginal electricity prices for different consumption tiers in California (Darghouth et al., 2011; Mills et al., 2008), which make the true value proposition of the PV system less transparent to the average consumer. In addition, the NPV associated with electricity cost savings from net-metering agreements does not fall regularly and may even increase with rising electricity prices over time (similar to the new reality in Germany after 2012). These facts may explain higher customer acquisition costs and the potentially more prevalent above-cost, value-based pricing of PV systems. Only a very competitive installer market and the motivation to capture a higher market share may drive installers to price their systems more aggressively.

One subject still insufficiently understood is the composition of overhead costs and margins among U.S. residential PV installers. Studies analyzing pricing decisions—such as the degree of value-based-pricing—and competition between installers would fill an important gap in the current literature and help determine whether structural differences in incentive policies can explain the sizable price gap between German and U.S. residential PV systems.

6. CONCLUSION

Residential PV systems in the United States were nearly twice as expensive as those in Germany in 2011 - recent price differences of about $2.8/W continued through 2012 and then declined slightly over the first half of 2013. Most of these differences originated in high business process and overhead costs in the United States and cannot be explained by mere differences in national market size. To reduce these costs, actors in the United States could consider policy reforms that enable a larger residential PV market with a stable growth trajectory while minimizing market fragmentation. Simpler PII requirements and regularly decreasing incentives, which drive and follow price reductions and offer a transparent and certain value proposition, might help accelerate residential PV price reductions in the United States.

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