Historical Case Studies of Energy Technology Innovation

CASE STUDY 14: RURAL SOLAR (KENYA).

SOLAR INNOVATION AND MARKET FEEDBACKS: SOLAR PHOTOVOLTAICS IN RURAL KENYA

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AUTHORS' SUMMARY

Until the recent explosion of solar PV deployment worldwide, the solar market in Kenya was one of the most dynamic per capita in the world. Up to 30,000 systems were sold each year, with much of this activity a result of unsubsidized, free market sale of household solar electric systems, which accounted for an estimated 75% of solar equipment sales in the country. Solar is the largest source of new electrical connections in rural Kenya.

Despite this undisputed commercial success, product quality has been a significant ongoing concern (Jacobson and Kammen, 2007). Quality problems first became clear with the variations in performance seem in amorphous silicon solar modules that entered the Kenyan market in the early 1990s. This situation created a serious problem in the market, as many potential solar customers were unable to determine which brands performed well and which did not. Through independent testing in 1999, underperforming suppliers and models were identified and consequently withdrawn from the market, but quality problems resurfaced after 2004.

In response, the Kenya Bureau of Standards (KBS) moved to formulate and enforce quality standards for both amorphous and crystalline silicon PV modules. Currently, the KBS requires that import companies secure a certificate that validates their product conforms to the respective Kenyan standards prior to bringing the modules into the country. This certificate of conformity must be issued by an accredited laboratory. No such facility exists in Kenya, so this testing needs to take place in laboratories in Europe, North America, and Asia.

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1 INTRODUCTION

The solar market in Kenya has been among the largest and most dynamic per capita among developing countries. Cumulative solar sales in Kenya since the mid-1980s are estimated to be in excess of 300,000 systems, and annual sales growth has regularly topped 15% over the past decade (Acker and Kammen, 1996; Jacobson, 2004). Much of this activity is related to the sale of household solar electric systems, which account for an estimated 75% of solar equipment sales in the country (ESDA, 2003). Solar is the largest source of new electrical connections in rural Kenya.

Despite this undisputed commercial success, product quality has been a significant concern in the Kenya market. The debate over solar module quality exploded publicly in May of 2004 in the form of a series of sensationalistic newspaper advertisements proclaiming that the low performance of a certain brand of amorphous silicon (a-Si) modules was a "solar panel scandal" (see Figure 1). The advertisements sparked a heated debate about quality, consumer rights, and the ethics of negative advertising. Within a short time, though, the focus shifted towards a search for solutions. The results and events presented in this case study represent a positive step towards resolving chronic quality problems that have plagued the Kenya solar market for more than a decade. The issues that emerged in Kenya, far from being an isolated case, were a precursor of what began to take place elsewhere due to the international character of the global solar industry, and the degree to which Kenya has for well over a decade been a leader in this rapidly expanding technology sector.

In a series of peer-reviewed publications (Acker and Kammen, 1996; Duke, Jacobson and Kammen, 2002; Jacobson and Kammen, 2007) and results reported in the local press, we present performance test results for five brands of small a-Si modules that were widely available in the Kenya market during 2004. Our results indicate that while three of the five brands perform at or near their advertised levels, two brands perform far below their nameplate power ratings. Both of the low performing "brands" were manufactured by the same company, although they were sold under different brand names in Kenya. They can therefore be considered to be a single line of modules.

The strong performance of the three leading brands supports previous evidence indicating that good quality a-Si PV modules can be excellent value for the money. At the same time, the very low performance of the two remaining brands is troubling, as many Kenyan consumers lack the information to distinguish among the various competing brands. There is, therefore, a need for market institutions that ensure the quality and performance of solar products sold in the Kenya market.

This conclusion is strongly supported by a series of performance tests that we conducted on a-Si modules in Kenya dating back to 1999 (see Jacobson, et al., 2000a; 2000b; Duke, et al., 2000; Jacobson, et al., 2001; Jacobson, 2002; Duke, et al., 2002; and Jacobson and Kammen, 2004 for results, with papers also available online at http://rael.berkeley.edu/publications, and http://www.humboldt.edu/~aej1). The 1999 study played an important role in pressuring low performing brands of a-Si modules to improve or exit the market, while it also verified that high quality brands of a-Si modules performed well. The result was a stronger solar market and a better-served public. However, within a few years a new line of low performing a-Si modules entered the market. This confirms the need for vigilant quality monitoring. In other words, the mix of high and low performing brands identified in the recent 2004/05 tests is nothing new, and we should not expect performance problems to go away on a permanent basis even with the removal of the current low performing brands. Persistent problems require persistent solutions, and, in the absence of a vigilant and effective quality assurance program, performance related problems are likely to re-emerge in the future.

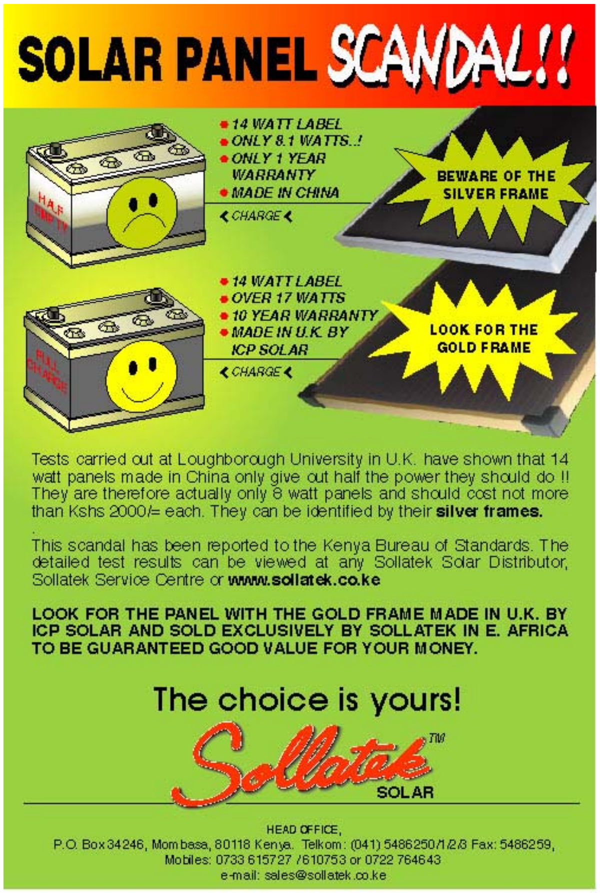

FIGURE 1. "SOLAR SCANDAL" ADVERTISEMENT IN THE DAILY NATION NEWSPAPER, MAY 2, 2004.

2 A BRIEF HISTORY OF A-SI TESTING IN KENYA

Amorphous silicon solar modules entered the Kenya market in 1989. Sales grew rapidly, and by the late 1990s a-Si modules had gained a significant share of the overall solar PV market in Kenya (see **Error! Reference source not found.**). Although the high sales figures indicate commercial success, a-Si technology has had a mixed reputation for quality in Kenya (e.g., Ochieng, 1999). The first generation of a-Si modules sold in Kenya were made by the Chronar Corporation, which went bankrupt in the mid-1990s in part due to quality related reputation problems (e.g., Crawford, 1997). Several of Chronar's successors made high performing a-Si modules, but low quality versions of the technology also continued to be sold. This situation created a serious problem in the market, as many potential solar customers were unable to determine which brands performed well and which did not (Duke, et al., 2002).

The debate about quality led to a study of a-Si module performance in 1999. This joint study was carried out by researchers (including the authors of this case study) from the University of California, Berkeley and Princeton University in collaboration with Energy Alternatives Africa (EAA) of Nairobi which has since changed its name to Energy for Sustainable Development, Africa (ESDA). In the context of this case study, we carried out a field study that included performance measurements of 130 a-Si modules and 17 crystalline modules at 145 homes in rural Kenya. We also purchased 14 new a-Si modules in Nairobi that we tested at outdoor testing facilities in the US and Kenya.

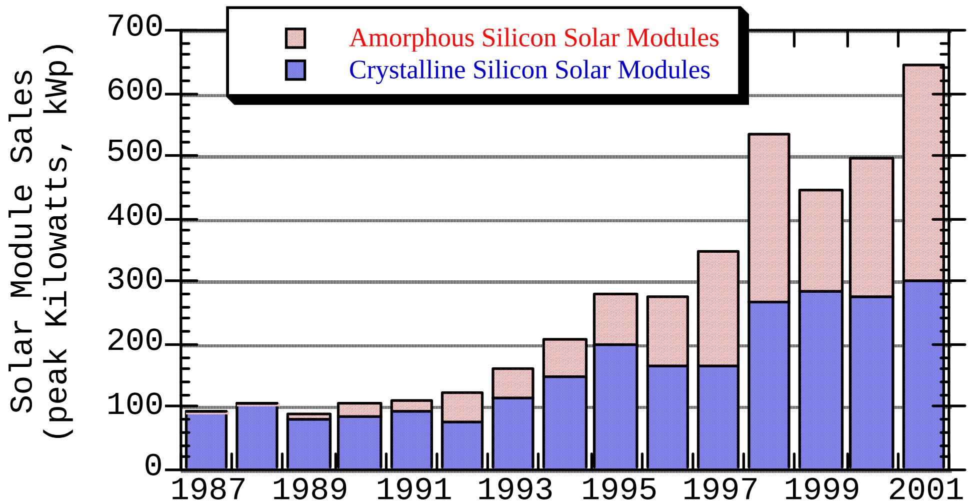

FIGURE 2. SOLAR MODULE SALES FROM 1987 TO 2001. SOURCES: HANKINS AND BESS, 1994; HANKINS, 2000; ESDA, 2003.

3 ASSURING PRODUCT QUALITY (1): PERFORMANCE TESTING IN 1999

3.1 Amorphous Silicon PV Performance Testing & Results - 1999

At the time of the 1999 study, the large majority of the a-Si modules sold in Kenya were manufactured by three competing companies. The results of the study are shown in **Error! Reference source not found.** and summarized in **Error! Reference source not found.**. They indicate that a-Si modules made by two of the three companies (Free Energy Europe and Koncar) performed reasonably well, while modules manufactured by the third company (Intersolar) performed well below their advertised levels. Free Energy Europe purchased the factory in France where its a-Si modules are manufactured from Neste Advanced Power Systems (NAPS) in 1998 (Duke, et al., 2000). Koncar modules are now sold in Kenya under the brand name “Solar Cells”. Intersolar was purchased by ICP-Solar in 2003 (Lane, 2003).

The performance testing showed that the high performing brands of a-Si modules were an effective, low cost alternative to crystalline PV. However, the poor performance of the low performing brand indicated a need for measures to ensure the high quality of all modules sold in the Kenya PV market. For more information about the study, see Jacobson, et al., 2000a, Jacobson, et al., 2000b, Duke, et al., 2000, Duke, et al., 2002, and Jacobson and Kammen, 2007.

TABLE 1. PERFORMANCE SUMMARY FOR A-SI PV PANELS TESTED IN KENYA DURING 1999.

Panel Type	Rated Max. Power (Watts)	Average Measured Max. Power (Watts)	Percentage of Rated Output	Average Age of Modules (years)	# Modules Tested
Koncar (Solar Cells)	12	10.0	83%	2.8	31
NAPS	11	9.7	88%	3.1	31
Free Energy Europe	12	10.6	89%	0.9	32
Intersolar "Phoenix"	11	6.8	61%	2.4	5
Intersolar "Phoenix Gold"	14	7.7	55%	1.5	12
APS	25	22.5	90%	5.0	1
Chronar	10	7.2	72%	5.9	4

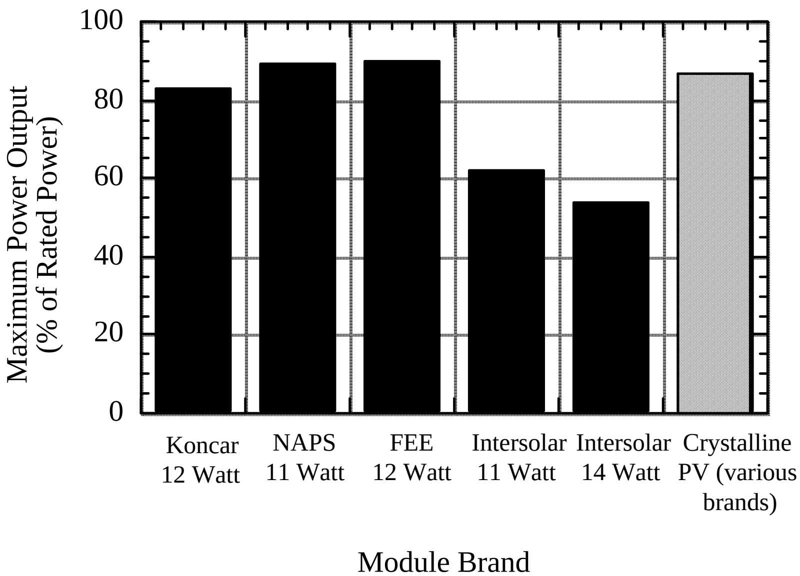

FIGURE 3. AVERAGE PERFORMANCE FOR SOLAR PV MODULES TESTED IN 1999.

3.2 Response to Solar PV Quality in Kenya following the 1999 Study

Intersolar made considerable investments to improve the performance of its a-Si products in the years following the 1999 study. These investments resulted in improved performance over time, as documented in **Error! Reference source not found.**. These results include tests carried out by Jacobson in 2000 and 2001 at UC Berkeley, as well as performance results from the 2004/05 study that we report in greater detail below. The tests from 2000 and 2001 were based on samples of four modules each that were sent by Intersolar to UC Berkeley for testing. The 2004/05 performance was based on a randomly selected sample of modules purchased from retail shops in Kenya.

These results represent a significant success story, as the low performing Intersolar modules of the 1990s have been replaced with the current generation of high performing ICP-Solar a-Si modules.

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However, while the improvements made by Intersolar and ICP-Solar are very encouraging, these gains did not, as we explain below, eliminate the quality problems with a-Si technology in the Kenya solar market.

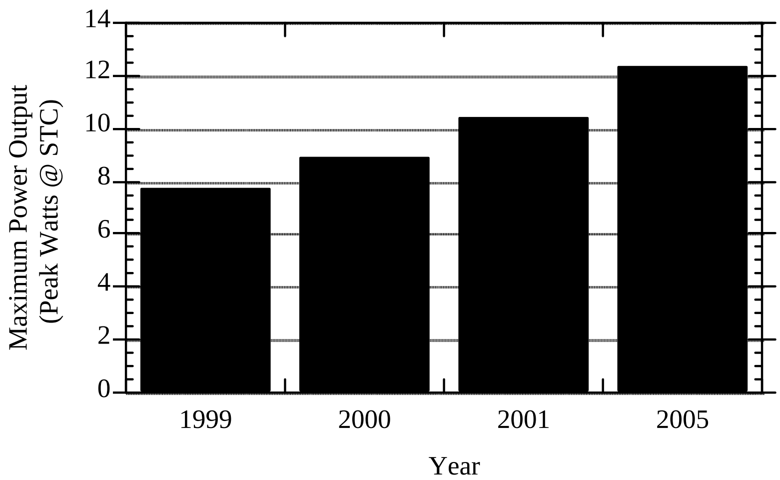

FIGURE 4. PERFORMANCE TREND FOR 14 WATT RATED INTERSOLAR / ICP-SOLAR MODULES FROM 1999 TO 2005.
NOTES: THE PERFORMANCE DATA FOR 1999 ARE FROM FIELD TESTS OF THE 12 INTERSOLAR "PHOENIX GOLD" MODULES INCLUDED IN THE BERKELEY-PRINCETON-EAA STUDY. THE 2000 AND 2001 RESULTS ARE BASED ON MEASUREMENTS OF TWO SEPARATE BATCHES OF FOUR "PHOENIX GOLD" MODULES BY JACOBSON AT UC BERKELEY. THE 2005 RESULTS ARE BASED ON THE PERFORMANCE OF THE FOUR ICP-SOLAR MODULE INCLUDED IN THE CURRENT STUDY.

Several years after the 1999 study, a new line of low performing a-Si modules began to enter the Kenya solar market in significant quantities. The presence of these modules eventually led to the tensions described above that came to a head in the first half of 2004. The re-emergence of quality problems in the Kenya market confirm that the issue cannot be solved decisively by one time testing efforts, nor by focusing on the improvement of individual low performing brands. Rather, institutional solutions that persistently require high performance for all brands are needed to ensure quality.

In the years following the 1999 study, the Kenya Bureau of Standards (KBS) worked in collaboration with the Kenya Renewable Energy Association (KEREA) to draft performance standards for a range of solar products, including but not limited to amorphous silicon solar modules. By 2003, the committee in charge of drafting the standards had approved a set of performance standards for both amorphous and crystalline PV modules that drew heavily from the respective codes established by the International Electrotechnical Commission (IEC). The relevant IEC standard for crystalline silicon PV modules is IEC 61215, while the standard for amorphous modules is IEC 61646. The corresponding Kenyan standards are KS 1674 and KS 1675.

The KBS did not, however, have access to the necessary equipment or technical capacity to carry out the specified tests, and the standards, while adopted, remained largely un-enforced. Thus, while the move to draft and adopt performance standards may have represented a positive step towards an institutionalized approach to quality assurance, the adoption of un-enforced standards did little to protect the interests of Kenyan consumers.

4 ASSURING PRODUCT QUALITY (2): PERFORMANCE TESTING IN 2004/5

4.1 Amorphous Silicon PV Performance Testing - 2004/5

The results presented here are based on tests of five different brands of a-Si solar PV modules sold in Kenya (see Table 2 for details). These tests were carried out at Humboldt State University and the University of California at Berkeley between September of 2004 and March of 2005. In implementing this project, we worked in conjunction with the Kenyan Renewable Energy Association (KEREA), as well as Kenyan based import companies who sell the various brands of amorphous silicon (a-Si) modules included in the study. In particular, KEREA coordinated a series of discussions within the Kenyan solar energy industry about solar module quality, while the solar import companies contributed funds to cover the costs of buying the modules and shipping them to the USA. The university researchers coordinated all of the field activities related to selecting and purchasing the solar modules from retail shops in Kenya.

TABLE 2. BRANDS OF A-SI SOLAR MODULES INCLUDED IN THE 2004/05 STUDY.

a-Si Module Brand	Kenyan Import Company	Country of Origin
Free Energy Europe	Chloride Exide, Telesales	France
ICP-Solar	Sollatek	U.K. (Wales)
Shenzhen Topray #1 (eSolar)*	Kenital	China
Shenzhen Topray #2 (SunLink)*	Electric Link	China
Solar Cells	Bhatt Electronics	Croatia

* Topray #1 modules were imported by Kenital from the Shenzhen Topray Solar Company and sold in Kenya under the "eSolar" brand name. Topray #2 modules were imported by Electric Link from the Shenzhen Topray Solar Company and sold in Kenya under at least two brand names in Kenya, including "SunLink" and "SunSolar."

4.2 Performance Test Results

The final, stabilized average maximum power output for each of the brands is given in **Error! Reference source not found.**. These results indicate that the performance of three of the brands (Free Energy Europe, Solar Cells, and ICP-Solar) is consistent with what one would expect from high performing 12 Watt solar PV modules. The performance of the remaining two brands (eSolar and SunLink), both of which are purchased from the same manufacturer in China, is well below their advertised level of performance.

It is notable that that the final performance of all three of these brands is close to 12 Watts despite the differences in their initial performance, as it confirms that the rate of efficiency decline over the first months of operation (so-called 'Staebler-Wronski degradation') differs from brand to brand. In this study, the average performance of the four ICP-Solar modules dropped by 29% prior to stabilization, compared to 21% for the Free Energy Europe modules and 20% for the Solar Cells modules. This highlights the importance of basing comparisons of relative performance on the final stabilized performance rather than on the initial power output.

It is also important to note that the relative performance of all three of these brands is statistically identical. In other words, although the average performance of the four ICP-Solar modules tested in the study (12.3 Watts) was slightly higher than the performance of the Solar Cells (12.1 Watts) and the Free Energy Europe (11.8 Watts) modules, these differences are well within the margin of error of the measurements methods used in the study. The 95% confidence intervals for average stabilized performance for Free Energy Europe modules are 10.7 - 12.9 Watts, for Solar Cells modules are 11.2 - 13.0 Watts, and for ICP-Solar modules are 10.3 - 14.3 Watts. A larger sample size for each module type would be required to determine differences in the relative performance of the respective brands.

One additional significant point is that, while the maximum power output of a solar module under standard test conditions is a key indicator of performance, other performance parameters such as durability and longevity are also important. In this area, Free Energy Europe is noteworthy for the high performance of its "C-version" a-Si module, which has passed the rigorous set of tests required for IEC certification (based on the IEC 61646 standard).

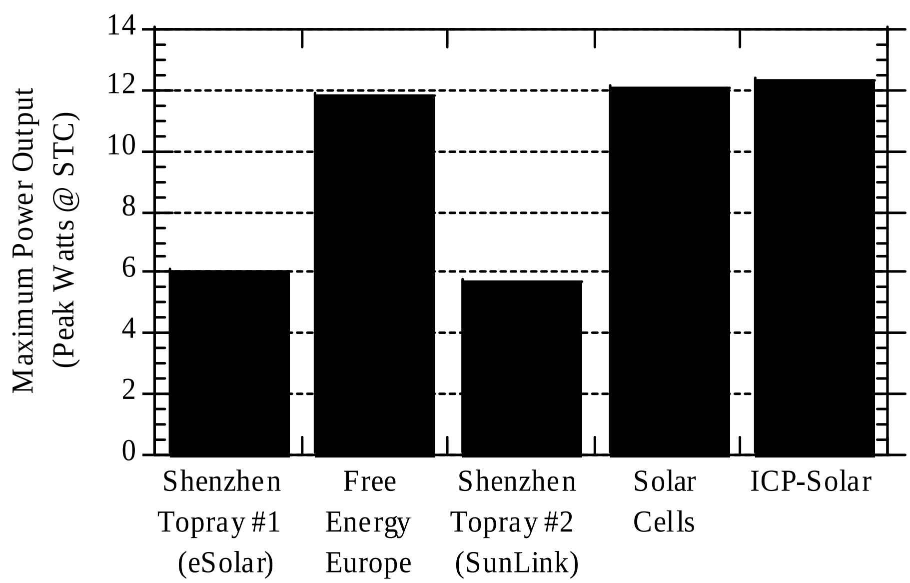

FIGURE 5. AVERAGE STABILIZED MAXIMUM POWER OUTPUT FOR FIVE BRANDS OF AMORPHOUS SILICON SOLAR MODULES SOLD IN KENYA. NOTES: MAXIMUM POWER AT STANDARD TEST CONDITIONS (STC) OF 1000 W/M2 AND 25°C.

As noted above, the performance of the two low performing brands is well below their advertised nameplate ratings. The average stabilized performance for both lines of Shenzhen Topray a-Si modules was approximately 6 Watts, which is well below acceptable levels for 14 Watt rated modules. The low performance of these modules may be caused by impurities introduced during production and/or other quality control problems in the manufacturing process.

In addition to low power output, we observed problems with module failure for both lines of Shenzhen Topray a-Si modules. In the case of the modules sold under the eSolar brand name, three of the four modules failed completely during their first few months on the test rack. One of the four modules sold under the SunLink brand name also failed during this time period. These failures appear to be caused by water intrusion that led to delamination of the active material of the a-Si modules (see **Error! Reference source not found.**).

FIGURE 6. WATER INTRUSION RELATED DELAMINATION IN A SHENZHEN TOPRAY A-SI SOLAR MODULE. PHOTO: ARNE JACOBSON.

4.3 Response to Amorphous Silicon Performance Results from the 2004/05 Study

Kenital, the company that marketed the Shenzhen Topray amorphous silicon modules under its eSolar brand name, responded to the results of this study by discontinuing sales of these low performing modules. Upon learning of the test results, Kenital began importing and distributing the Croatian made "Solar Cells" a-Si modules.

Electric Link, the other company that had been importing Shenzhen Topray modules, continued to sell the product for a number of months after being informed of its low performance. The Kenya Bureau of Standards (KBS) moved to enforce its existing quality standards for both amorphous and crystalline silicon PV modules in the month following the public release of the results of this study in Kenya. It was only at this point that Electric Link discontinued sales of the low performing Shenzhen Topray modules.

5 DISCUSSION & IMPLICATIONS

The history of solar PV in Kenya, focusing on the importance of quality control and the role of performance testing, highlights the importance of an institutional and enforceable approach to quality assurance. Currently, the KBS requires that import companies secure a certificate that validates that their product conforms to the respective Kenyan standards prior to bringing the modules into the country. This certificate of conformity must be issued by an accredited laboratory. No such facility exists in Kenya, so this testing takes place in laboratories in Europe, North America, and Asia (see www.worldbank.org/astae/qpp/PVGAP/App8.pdf for a list of qualified facilities). This means that potential market feedbacks between end-users and suppliers of energy technologies may be weakened (with the testing stations only available overseas).

This approach represents a promising step towards an institutionalized approach to quality assurance for the Kenya solar market. While it is perhaps too early to draw conclusions about the long term significance of these recent events, several solar manufacturers have already sought and obtained IEC certification as the result of this new requirement for participation in the Kenya market. At the same time, the lower performing brands appear to have been forced from the market.

6 CONCLUSIONS

The evolution and both national and international support of renewable energy markets has become a topic of international concern (IPCC, 2011). The findings presented here are important not only for Kenya, but also for solar markets elsewhere in Africa and in developing markets worldwide. One of the barriers to the regulatory approach that is currently being implemented in Kenya had been a dearth of small, low cost, certified solar PV modules. In many African countries the solar markets remain too small to provide the government with sufficient leverage to induce solar manufacturers to pursue certification for the purpose of selling products in that country alone. The Kenya market, however, appears to have grown to a size where it can now successfully provoke such a response. Now that Kenya has taken this step, it should be easier for countries with smaller solar markets to follow suit. This suggests the possibility for significant spillover benefits from Kenya to solar markets elsewhere on the continent and beyond.

On a global stage, the recent growth of on-grid and off-grid renewable energy deployment has raised issues of product quality, testing procedures, and the value of certification and of industry standards. The experience in Kenya is particularly important in efforts to resolve these issues because avenues to address product testing, consumer and industry feedback are all weak in the solar industry generally. These issues are exacerbated in developing nations. More broadly, the Kenya solar story involves a holistic, or 'systems' approach to integrating scientific, engineering, industry standards, and adaptive, or 'organic' regulation of a fast-growing element of the energy sector.

7 FURTHER READING

IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. v. Stechow (eds.)] (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA).

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