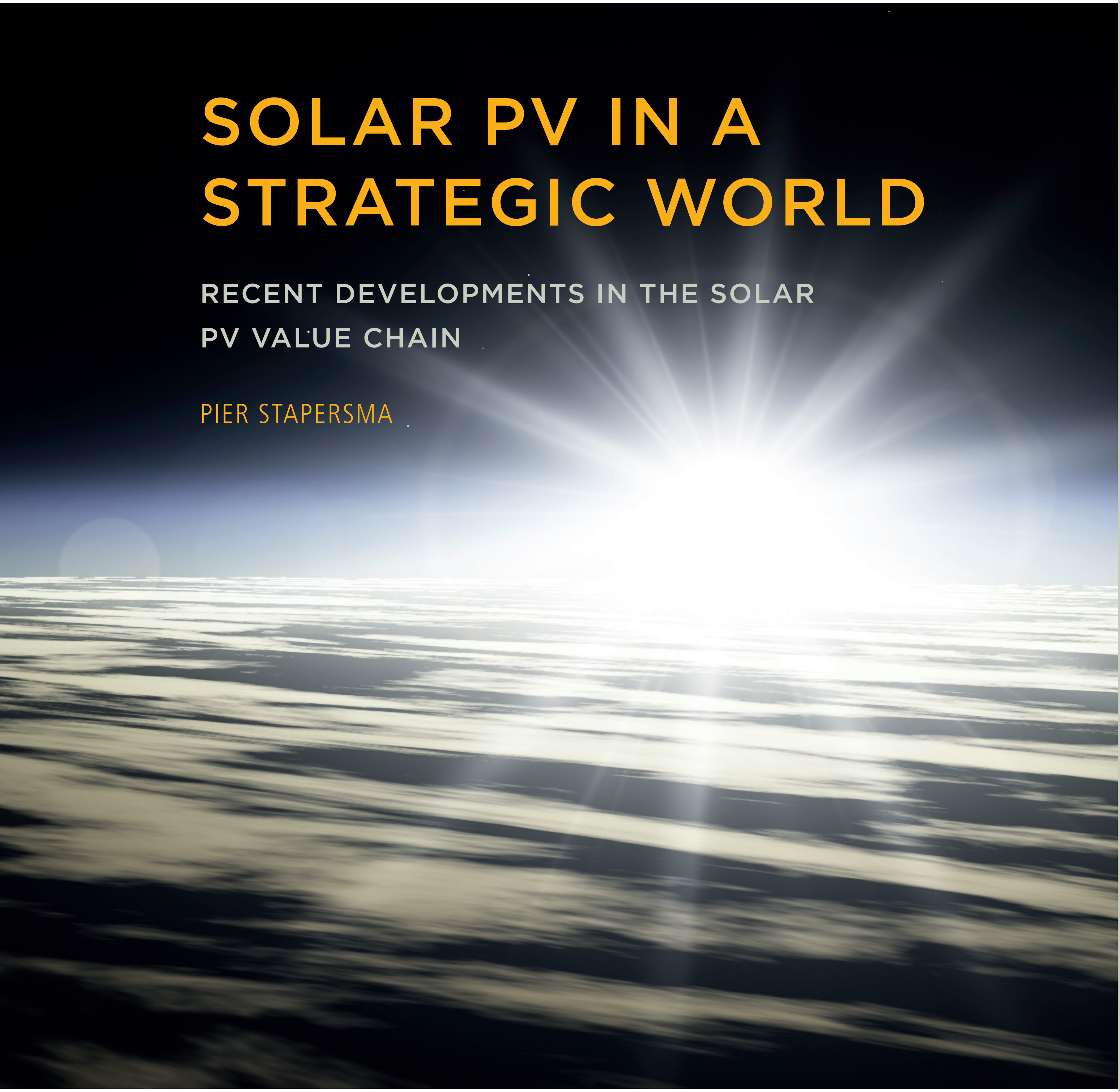
CLINGENDAEL
INTERNATIONAL
ENERGY
PROGRAMME
CIEP



SOLAR PV IN A STRATEGIC WORLD

RECENT DEVELOPMENTS IN THE SOLAR PV VALUE CHAIN

PIER STAPERSMA

CIEP PAPER 2015 | 04

CLINGENDAEL
INTERNATIONAL
ENERGY
PROGRAMME
CIEP

CIEP is affiliated to the Netherlands Institute of International Relations 'Clingendael'. CIEP acts as an independent forum for governments, non-governmental organizations, the private sector, media, politicians and all others interested in changes and developments in the energy sector.

CIEP organizes lectures, seminars, conferences and roundtable discussions. In addition, CIEP members of staff lecture in a variety of courses and training programmes. CIEP's research, training and activities focus on two themes:

- European energy market developments and policy-making;
- Geopolitics of energy policy-making and energy markets

CIEP is endorsed by the Dutch Ministry of Economic Affairs, the Dutch Ministry of Foreign Affairs, the Dutch Ministry of Infrastructure and the Environment, BP Europe SE- BP Nederland, Coöperatieve Centrale Raiffeisen-Boerenleenbank B.A. ('Rabobank'), Delta N.V., GDF SUEZ Energie Nederland N.V., GDF SUEZ E&P Nederland B.V., Eneco, EBN B.V., Essent N.V., Esso Nederland B.V., GasTerra B.V., N.V. Nederlandse Gasunie, Heerema Marine Contractors Nederland B.V., ING Commercial Banking, Nederlandse Aardolie Maatschappij B.V., N.V. NUON Energy, TenneT TSO B.V., Oranje-Nassau Energie B.V., Havenbedrijf Rotterdam N.V., Shell Nederland B.V., TAQA Energy B.V.,Total E&P Nederland B.V., Koninklijke Vopak N.V. and Wintershall Nederland B.V.

CIEP Energy Papers are published on the CIEP website: www.clingendaelenergy.com/publications

TITLE
Solar PV in a Strategic World

AUTHOR
Pier Stapersma

NUMBER
2015 | 04

EDITOR
Deborah Sherwood

DESIGN
Studio Maartje de Sonnaville

PUBLISHED BY
Clingendael International Energy Programme (CIEP)

ADDRESS
Clingendael 7, 2597 VH The Hague, The Netherlands
P.O. Box 93080, 2509 AB The Hague, The Netherlands

TELEPHONE
+31 70 374 67 00

TELEFAX
+31 70 374 66 88

EMAIL
ciep@clingendaelenergy.com

WEBSITE
www.clingendaelenergy.com

SOLAR PV IN A STRATEGIC WORLD

RECENT DEVELOPMENTS IN THE SOLAR PV VALUE CHAIN

TABLE OF CONTENTS

EXECUTIVE SUMMARY

PV costs have declined substantially faster than anticipated by many and are today below the levels projected for 2030 at the time the European Commission presented its 2nd Strategic Energy Review in 2008. The main message of this report is that energy analysts need to better understand the manufacturing dynamics of the upstream PV industry. The capabilities of suppliers of PV manufacturing equipment to incorporate new PV technologies in production and assembly lines, combined with a worldwide appetite of governments to build domestic PV manufacturing capabilities, contributed to PV manufacturing growth, innovation, and cost declines.

While it is speculative to predict future growth rates for the solar PV manufacturing base, its present order of magnitude, approximating 50 GW/year, is already structurally changing markets. 25 years of manufacturing at such a level would lead to an installed PV capacity that is larger than projected by the IEA in its New Policies Scenario for 2040. As is demonstrated in chapter 4, further growth of the PV manufacturing base could lead to a globally installed PV capacity multiple times the amount projected by the IEA in its New Policies Scenario for 2040.

While energy analysts must be aware of this, they must also be aware of the limitations to the absorption capacity of electricity markets for PV. The generation profile of PV implies that significant amounts of solar electricity enter the market at the same time of the day. So even though the share of solar PV electricity in total annual energy consumption may still be limited, adding more solar PV capacity to the electricity system may be challenging without large-scale electricity storage and proper interaction with other energy infrastructures such as gas grids and heat networks.

Crucially, a limited absorption capacity of electricity markets for PV could result in an increased focus of businesses as well as governments on introducing energy conversion technologies that enable PV to play a role in other parts of the energy system; once such technologies gain a foothold, global PV manufacturing dynamics, as described in this report, can be expected to become as relevant for those parts of the energy system, as they are for electricity markets today.

The 2014 CIEP Report *Sunset or Sunrise? Electricity Business in Northwest Europe* explored the struggle of Northwest European utilities in today's power market environment. In that publication, it was argued that the challenge for utilities is to transform their business models while carrying legacy assets that serve the public interest by contributing to the security of electricity supplies, but for which, at present, the business case is very weak. Past years were characterised by write-downs and depreciations; balance sheets are weak and some utilities in the region are indebted.

Utilities in the region presently embrace offshore wind energy in the North Sea region, which is firmly financially supported through publicly funded feed-in tariffs, contracts-for-difference, or feed-in premiums. This raises the question as to how this technology's cost development path relates to the solar PV value chain explored in this report. The proof of the pudding will be in the eating. In the coming years, many tenders for new capacity in the region will reveal the cost of offshore wind energy. Crucially, if innovation and cost reductions in the offshore wind energy industry cannot keep pace with developments in the solar PV value chain, the focus of regional public policy makers on offshore wind may turn out to have shorter horizon. The question is whether utilities are currently preparing themselves sufficiently for such (distributed) electricity generation.

One could argue that this should not merely be a consideration for utilities, but for public policy makers as well. Is the regulatory framework for electricity markets ready for a significant amount of distributed generation? Market-based coordination of investments (which came with market liberalisation and unbundling) requires functioning markets and proper price signals. Time signals are important in encouraging investments in the right technologies, including technologies for backup electricity generation and storage; locational signals are also essential for ensuring the right balance between investments in transmission and distribution grids on the one hand, and investments in electricity generation on the other. If it proves impossible to create a market with price signals that truly reflect local supply and demand balances throughout the day, the coordinating role of grid operators may need strengthening through other means.

LIST OF ABBREVIATIONS

a-Si	Amorphous Silicon
BOS	Balance of System
CdTe	Cadmium Telluride
CI(G)S	Copper Indium (Gallium) (di)Selenide
CIEP	Clingendael International Energy Programme
c-Si	Crystalline Silicon
CSP	Concentrated Solar Power
ct	cent
DSO	Distribution System Operator
EPC	Engineering Procurement Construction
EPIA	European Photovoltaic Industry Association
EPSEC	European Photovoltaic Solar Energy Conference
EU	European Union
GoO	Guarantee of Origin
GW	Gigawatt
GWh	Gigawatt-hour
ICT	Information & Communications Technology
IEA	International Energy Agency
JRC	Joint Research Centre
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
LCOE	Levelised Cost of Electricity
MW	Megawatt
MWh	Megawatt-hour
O&M	Operations & Maintenance
PPA	Power Purchase Agreement
PV	Photovoltaic
Si	Silicon
SiO_2	Silicon Dioxide
SoG-Si	Solar Grade Silicon
TW	Terawatt
TWh	Terawatt-hour
UK	United Kingdom
US	United States
WACC	Weighted Average Cost of Capital

INTRODUCTION

Solar photovoltaics (PV) has become part of the global energy future. Over the past decade, solar PV has transformed from a novel technology for a range of niche applications into one adopted on a utility scale.

As will be described in this paper, solar PV costs have declined substantially faster in recent years than anticipated by many, and solar PV module manufacturing has reached a scale that is structurally changing electricity markets around the globe.

This paper is structured as follows. The first three chapters give insight into the solar PV value chain. Chapter 1 addresses the upstream part of the chain, i.e., poly-silicon production and solar PV module manufacturing. It elaborates on the role that industrial policies in Germany and China have played in the remarkable growth of these industrial activities.

Chapter 2 makes the step from PV module to PV electricity. It explains that a PV system entails more than the PV modules, elaborates on the levelised costs of electricity concept, and identifies the prime factors determining those costs.

Chapter 3 focuses on the downstream part of the chain, in which user value is created for solar PV modules. It does so by identifying factors affecting user value for solar PV. Finally, it explains how new downstream business models are emerging which aim to leverage the user value of solar PV in power markets, thus competing with traditional utility business models.

Chapter 4 explores the way forward. It does not make firm predictions about future manufacturing levels or future cost levels. Rather, it stresses a number of considerations which are relevant when assessing the future market potential and impact of solar PV technology. On the one hand, it argues that energy analysts should not overlook the significance of the PV manufacturing industry. On the other hand, it argues that they must also recognise potential limitations to the pace global electricity markets can absorb PV. The latter suggests that businesses and governments can be expected to increase their focus on energy conversion technologies that enable PV to play a role in other parts of the energy system.

Chapter 4 also argues that solar PV manufacturing appears to be regarded as a strategic industry by governments. In a strategic world, various countries and regions may continue to develop their own domestic solar PV value chains, irrespective of the availability of low-cost imports from countries such as China. This perspective could reveal that the pursuit of developing domestic PV industries might actually contribute to a continued expansion of PV manufacturing capacity across the globe.

It is important to stress that this paper focuses on solar photovoltaics (PV), and not on Concentrated Solar Power (CSP) or solar thermal, as the latter two have very different characteristics. By focusing on solar PV only, it is possible to express some of the fairly unique characteristics of this modular semiconductor based technology.

1 SOLAR PV UPSTREAM: MINING AND MANUFACTURING

Before shedding light on industry dynamics, it will be helpful to explain some of the fundamentals of today's most prominent solar PV technologies[1]. A vast range of solar PV technologies exists today[2]. However, at present, mass production of solar PV is dominated by just a few solar PV technologies, as is shown in Figure 1.

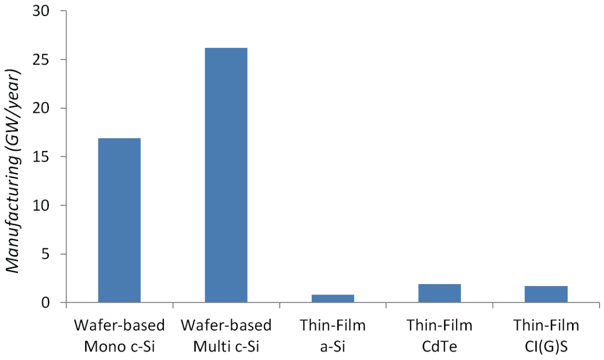


FIGURE 1. MANUFACTURING IN 2014, DOMINANT TECHNOLOGIES (FRAUNHOFER ISE, 2015)[3]

In 2014, silicon wafer-based technology dominated manufacturing, having a share of around 90 percent, while thin film technology dominated the remaining 10 percent[4]. Silicon is obviously the main component of silicon wafer-based technologies. While it is also used for some thin films, two alternative technologies play a more important role for thin film, namely CdTe (cadmium-telluride) and CI(G)S (copper indium gallium diselenide). Silicon thus plays an important role in the present day mass production of solar PV technology. While amorphous silicon (a-Si) is used for some thin films, crystalline silicon (c-Si) is used for wafer-based solar PV.

---

[1] Parts of the first section of this chapter, i.e. the technical section explaining the processes and process steps transforming quartz stone and sand into solar PV modules, are derived from Varadi (2014), "Sun Above the Horizon: Meteoric Rise of the Solar Industry", Singapore: Pan Stanford Publishing Pte. Ltd.

[2] The US National Renewable Energy Laboratory (NREL) keeps track of available solar PV technologies and publishes progress on efficiencies on a regular basis. See Figure 18 in the Appendix.

[3] Fraunhofer ISE (2015: 19-20), "Photovoltaics Report", version of 26 August 2015.

[4] IEA (2014: 10-11), "Technology Roadmap Solar Photovoltaic Energy", 2014 Edition.

In the medium term, the solar PV technology mix can shift, and in the long term, truly novel developments might displace present day solar technologies[5]. An exploration of the full potential of all solar technologies available now and potentially available in the future is beyond the scope of this paper. What is relevant here is that the present generation of silicon-based solar PV has reached the stage of mass production and that further innovation in this generation of solar PV, particularly in manufacturing processes (more automated, more efficient, reduced conversion losses) is not finished[6]. This in itself is highly relevant for the electricity supply system, irrespective of what emerging PV technologies may bring. The focus of the remainder of this section is therefore on silicon wafer-based technology, as this technology has dominated the recent emergence of solar PV and will continue to do so in the near future. A high-level product/process chart for wafer-based solar PV is shown in Figure 2.

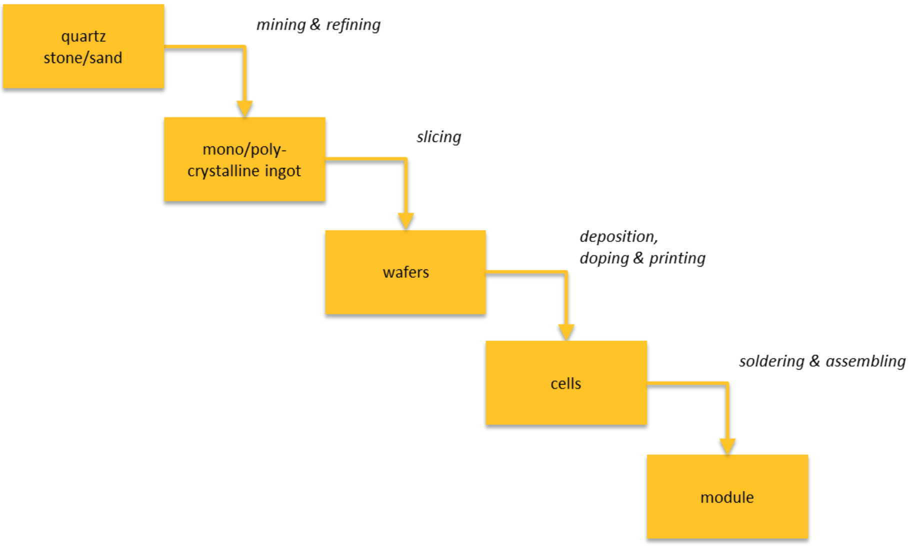


FIGURE 2. PRODUCT/PROCESS CHART FOR WAFER-BASED SOLAR PV TECHNOLOGY

---

[5] Consider IPCC (2014: 352-355), SRREN Chapter 3 "Direct Solar Energy", section 3.3.3. Or consider IRENA (2012: 4-8), "Solar Photovoltaics", Renewable Energy Technologies: Cost Analysis Series, Volume 1: Power Sector, Issue 4/5.

[6] Within this generation of PV technologies further reduction of conversion losses and closing the lab/fab gap are the most important factors; they may drive the main development of commercial modules for another 10-15 years, so that new generations may gradually take over starting from 2025-2030. Whereas PV tracking can be considered to be part of today's generation of PV technology, next generation PV technologies include multi-junction and concentration approaches. Source: personal communication with prof. dr. W.C. Sinke, Faculty of Science, Institute of Physics, University of Amsterdam (UVA).

POLY-SILICON PRODUCTION

Silicon is mined from quartz stone or quartz sand. In this respect, it is relevant to note that silicon is one of the most abundant elements in the earth's crust, second only to oxygen[7]. For this reason, structural problems with the availability of silicon are generally not considered very realistic[8]. This contributes to the attractiveness of silicon-based solar PV technologies. Yet it should be stressed that the quality of resource deposits varies. Some deposits are more economical than others; this conventional logic holds true for silicon resources as much as for others.

The long-term availability of the most important materials for non-silicon based thin-film technologies CdTe and CI(G)S is less certain; according to Fraunhofer ISE, contradictory statements have been made[9]. Moreover, materials other than silicon are also crucial for the production of solar PV modules, including silver. In 2010 the amount used by the solar industry was equal to 7 percent of total silver production for that year; however, innovation in the solar industry aims at reducing the amount of silver used by using it more efficiently and by using copper instead.

The first step from quartz to a solar PV module is to produce metallurgical grade silicon in electric furnaces. Metallurgical silicon is obtained by reducing quartz (SiO_2) to metallic quartz (Si). Most metallurgical silicon is subsequently used for alloying aluminium or iron and for the production of silicones. Only a small portion is further refined into poly-silicon. The Siemens chemical process is dominant in this respect[10]. The more novel "fluidised bed approach" has gained increased interest because of its potentially lower energy consumption and more continuous production[11].

Poly-silicon is further processed into either mono-crystalline rods or multi-crystalline ingots. Whereas a mono-crystalline rod consists of one single crystal, a multi-crystalline ingot consists of several crystals. The purest poly-silicon (the highest grade) is used in the semiconductor industry (computer hardware). The solar industry can accept a less pure poly-silicon called solar grade silicon (SoG-Si), although the quality used for PV today is often close or equal to semiconductor-grade silicon, since that allows for the highest efficiencies to be obtained while costs for it have

---

[7] Xalkalashe, B.S. and Tangstad, M. (2011: 87), "Silicon Processing: From Quartz to Crystalline Silicon Solar Cells", Paper presented at the Proceedings of the *Southern African Pyrometallurgy 2011 International Conference.* Edited by R.T. Jones & P. den Hoed, Southern African Institute of Mining and Metallurgy, Johannesburg, 6-9 March 2011

[8] Fraunhofer ISE (2014: 74), "Recent Facts about Photovoltaics in Germany".

[9] Fraunhofer ISE (2014: 74), "Recent Facts about Photovoltaics in Germany".

[10] Safarian, J., Tranell, G., Tangstad M. (2012: 89), Processes for upgrading metallurgical grade silicon to solar grade silicon. *Energy Procedia*, 20, 88-97.

[11] European Commission (2013: 41), "PV Status Report 2013", JRC Scientific and Policy Report.

come down[12]. For poly-silicon producers, 2006 was a remarkable year, because in that year demand for poly-silicon from the solar industry exceeded demand from the semiconductor industry for the first time in history[13].

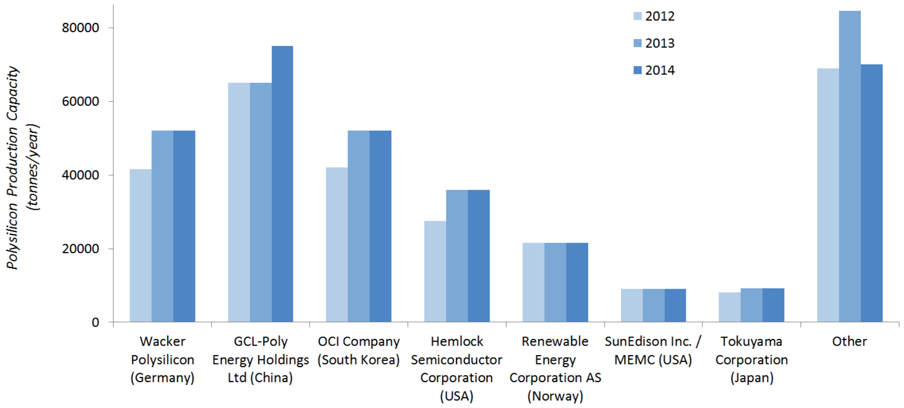


FIGURE 3. POLY-SILICON SUPPLY CAPACITIES (CITI RESEARCH, 2013)[14]

Although a range of poly-silicon producers is active in the market, there is a fair bit of concentration in the industry. Companies are headquartered in a range of countries, while production locations are more diverse. Figure 3 shows estimates for poly-silicon supply capacities for the years 2012, 2013, and 2014 for the major producers.

PV MODULE MANUFACTURING

A very different group of companies dominates the manufacturing of solar PV modules, although it should be stressed that some of the above-mentioned poly-silicon producers seek downstream integration[15]. At the same time, some manufacturers of PV modules also possess wafer and ingot production capabilities. Nevertheless, generally speaking, when considering the ‘upstream solar industry’ it is possible to distinguish between primarily poly-silicon producers on the one hand and primarily PV module manufacturers on the other.

---

[12] Personal communication with prof. dr. W.C. Sinke, Faculty of Science, Institute of Physics, University of Amsterdam (UVA).

[13] Varadi (2014: 358), “Sun Above the Horizon: Meteoric Rise of the Solar Industry”, Singapore: Pan Stanford Publishing Pte. Ltd.

[14] Estimates by Citi Research (2013: 38), “Launching On The Global Solar Sector”

[15] For instance, GCL-Poly Energy Holdings Ltd., OCI Company and SunEdison Inc. invested in downstream businesses. See European Commission (2013: 41-42), “PV Status Report 2013”, JRC Scientific and Policy Report.

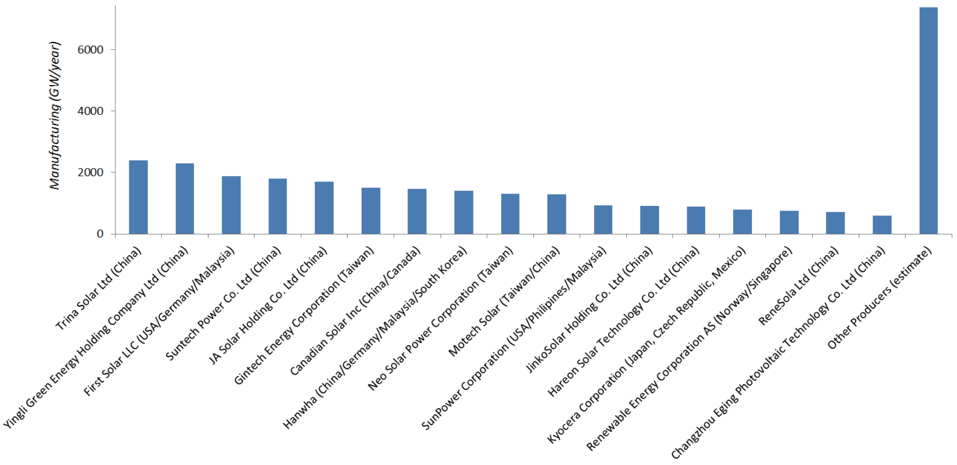


FIGURE 4. PV CELL/MODULE MANUFACTURERS IN 2012, COMPILED FROM JRC AND EPIA DATA[16]

The wide range of PV cell and module manufacturers in 2012 is shown in Figure 4. What is very clear from this figure is that this part of the solar value chain is not as concentrated as the poly-silicon segment. Consequently, not surprisingly, the manufacturing segment is very dynamic, with mergers, acquisitions, bankruptcies and new entrants to the market. As such, since 2012 the picture has evolved.

There are several steps in creating a PV module from poly-silicon. To begin, mono-crystalline or multi-crystalline poly-silicon ingots are sliced into wafers, usually by sawing. To be useful for the solar PV industry, a silicon-wafer must be either p-type or n-type[17]. Boron is generally used for p-doping, while phosphorus is used for n-doping. Poly-silicon ingots are pre-treated. In other words, module manufactures procure p-type or n-type poly-silicon ingots from which wafers are produced. A wafer must then be processed further. Etching the surface, for instance, is a common technique to increase light absorption, and the wafer is doped with either the n-type or p-type dopant in order to create the desired pn-junction. With its pn-junction, the wafer effectively becomes a semiconductor diode.

Several process steps follow, aimed at increasing the efficiency of the cell and completing it. Effectively, the solar cell is created from the wafer[18]. Treatments include adding deposit passivation layers, anti-reflective coating, and metal contacts. Solar cells are grouped, creating a PV module. Transparent glass is subsequently

---

[16] Production and sales figures quoted by European Commission (2013: 41), "PV Status Report 2013", JRC Scientific and Policy Report. Production by *'Other Producers'* is derived from 30 GW of new PV capacity installed in 2012 according to the same publication as well European Photovoltaic Industry Association (2014: 39), "Global Market Outlook for Photovoltaics 2014-2018".

[17] BINE Informationdienst (2011: 3), "Innovations in Photovoltaics", New concepts and production technologies for solar cells and modules, BINE-Themeninfo II/2011.

[18] IEA (2014: 10-11), "Technology Roadmap Solar Photovoltaic Energy", 2014 Edition.

added to the front, while a different weatherproof material is added to the back. Usually, this construction is put in a frame. These PV modules are the main product marketed by the great range of solar PV module manufactures shown in Figure 4.

MODULE COST DEVELOPMENTS

Projections for PV module cost developments are frequently the result of applying the learning curve concept. In the words of JRC, *'Learning curves express the hypothesis that the cost of a technology decreases with a constant fraction with every doubling of installed capacity or exercised activity'*[19].

The word *hypothesis* is important here, as one can debate whether this dynamic holds true for every technology. For solar PV, however, historic cost developments since the 1970s have been very much in line with this hypothesis. Specifically, for every doubling of installed capacity, the cost of a c-Si module (the dominant type) has gone down by 20 percent[20].

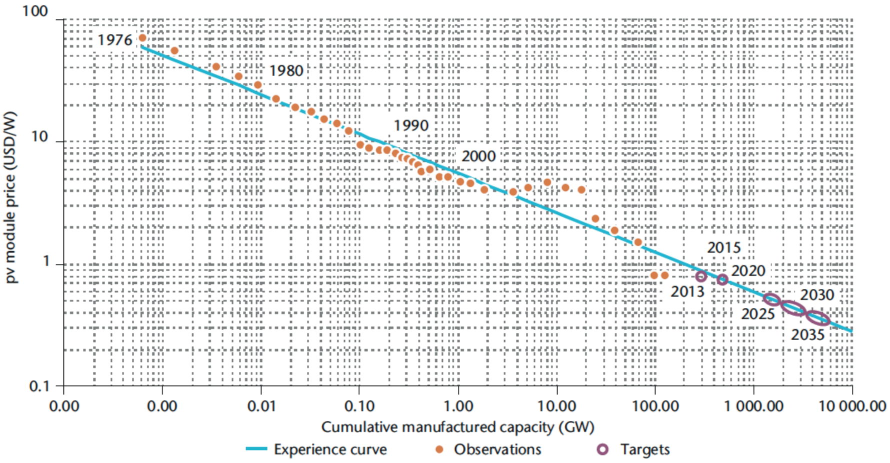


FIGURE 5. LEARNING (EXPERIENCE) CURVE FOR SOLAR PV MODULES (IEA, 2014)[21]

It is relevant to realise that technology *cost* and product *price* are different things. In the 2000s this became very clear when poly-silicon shortages occurred. Prices of poly-silicon rose from $25.5/kg in 2003 to $450/kg in 2008[22]. This can be observed in

---

[19] European Commission (2012: 8), "Technology Learning Curves for Energy Policy Support", JRC Scientific and Policy Report.

[20] IEA (2014: 23), "Technology Roadmap Solar Photovoltaic Energy", 2014 Edition.

[21] IEA (2014: 23), "Technology Roadmap Solar Photovoltaic Energy", 2014 Edition.

[22] IPCC (2014: 364), SRREN Chapter 3 "Direct Solar Energy", section 3.3.3. Or consider IRENA (2012: 4-8), "Solar Photovoltaics", Renewable Energy Technologies: Cost Analysis Series, Volume 1: Power Sector, Issue 4/5.

Figure 5 as module costs not declining for a period after 2000, suggesting that the learning hypothesis did not hold at the time. However, the emergence of these shortages was only a temporal phenomenon. Poly-silicon production capacity expansions (increasing supplies) resulted in price declines, from $30/kg in 2011 to $19/kg in April 2012[23]. Similar cyclical dynamics occurred in the PV manufacturing segment, i.e., a period of relatively high demand and low supply was followed by a period in which increases in supplies outpaced demand growth. In all, it cannot be concluded that the learning curve hypothesis for solar technology no longer holds. Rather, it seems that from time to time cyclical dynamics can be observed in the industry, and that module prices behave accordingly over time. In other words, fluctuations around the trend line have occurred and can be expected to continue to occur.

While for solar PV the learning curve concept suggests that costs decrease by 20 percent with the next doubling of installed capacity, it provides no clear view on whether this will occur over the course of two years, three years, or thirty years. It is thus relevant to bear in mind that the learning curve hypothesis provides no insights into the absolute pace of cost reduction. The absolute pace is the result of the adoption rate of the technology. The hypothesis suggests that prices continue to decrease in the long run, but for any actor involved in the electricity supply system it makes a huge difference as to whether a certain price level is reached in 2020 or 2040.

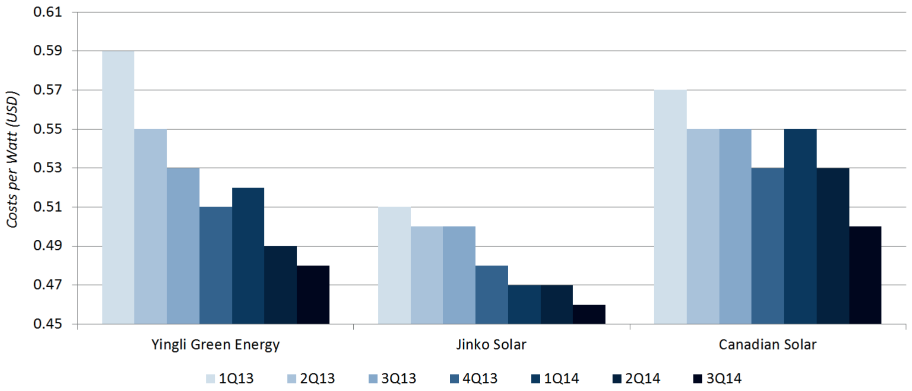


FIGURE 6. ESTIMATES OF MODULE MANUFACTURING COSTS (DEUTSCHE BANK, 2015) [24]

---

[23] Varadi (2014: 365), "Sun Above the Horizon: Meteoric Rise of the Solar Industry", Singapore: Pan Stanford Publishing Pte. Ltd.

[24] Deutsche Bank Markets Research (2015: 42), "2015 Outlook", Industry: Solar (8 January).

In any case, it is highly interesting to consider present cost levels. From Figure 5 it already becomes clear that cost levels fell to below $1/watt around 2010. At the time, the pace of decline in costs was not fully recognised. In 2012, for instance, the International Renewable Energy Agency (IRENA) reported prices of around $1.75/watt, while prices were expected to fall gradually in subsequent years to $0.85/watt in 2015[25]. However, already in 2013 research came out which indicated that module prices had fallen to $0.54/watt for Chinese and Taiwanese modules, to $0.65/watt for European modules, and to $0.68/watt for Japanese modules[26]. In 2014 the International Energy Agency (IEA) reported prices between $0.59-0.79/watt for Chinese modules and $0.91/watt for German modules in the first half year of 2014[27]. Figure 6 shows that in 2015 Deutsche Bank reported manufacturing costs below $0.50/watt for several manufacturers and indicated that best-in-class manufacturers could reach $0.40/watt by the end of 2015[28]. These recent figures are in line with statements by GTM Research, indicating that all-in module costs for Chinese modules will be around $0.45/watt in the final quarter of 2015, although such modules will be sold in the US for a price of around $0.64/watt as a result of profit margins, import duties, etc.[29].

What becomes very clear from the above is that the transition to mass production led to significant cost declines, larger and faster than expected by many. The next section explains that to a large extent this was the result of combined German and Chinese industrial and energy policies.

INDUSTRIAL POLICY IN GERMANY AND CHINA

Module costs fell below $1/watt around 2010, as shown in Figure 5. This is an interesting observation with respect to two 1997 studies presented at the 14th EPSEC in Barcelona[30]. Those studies concluded that large-scale manufacturing of PV modules would bring cost levels down to a range of $0.6-1.1/watt for both crystalline silicon and thin film technology. These findings provided impetus for the massive adoption of solar PV in Germany in the 2000s[31].

---

[25] IRENA (2012: 28), “Solar Photovoltaics”, Renewable Energy Technologies: Cost Analysis Series, Volume 1: Power Sector, Issue 4/5.

[26] EuPD Research (2013: 18). “Photovoltaik-Preismonitor Deutschland”, German PV ModulePriceMonitor 2013, Ergebnisse 1. Quartal. Commissioned by BSW-Solar.

[27] IEA (2014: 13), “Technology Roadmap Solar Photovoltaic Energy”, 2014 Edition.

[28] Deutsche Bank Markets Research (2015: 42), 2015 Outlook, Industry: Solar, 8 January 2015.

[29] GreenTechMedia (26 January 2015), “8 Solar Trends to Follow in 2015”, retrieved 24 February 2015 at www.greentechmedia.com/articles/read/The-Most-Important-Trends-in-Solar-in-8-Charts

[30] European Photovoltaic Solar Energy Conference (EPSEC). The two studies are mentioned in a publication by T. M. Bruton of BP Solar International. See Bruton, T. M. (1997), “Photovoltaic Research and Development - A Global View”, Proceedings of Solar ’97, Australian and New Zealand Solar Energy Society Paper 107

[31] For an extensive overview of the debate and processes of the time, consider Chapter 30 of Varadi (2014: 331), “Sun Above the Horizon: Meteoric Rise of the Solar Industry”, Singapore: Pan Stanford Publishing Pte. Ltd.

Financial support for renewables in Germany dates back at least several decades. Already in 1979 experiments started with tariffs to support renewables in Germany; in 1989 the *1000 Roofs Programme* was initiated, aimed at strengthening the industrial base with respect to solar, parallel to the 100 MW programme for wind[32]. In 1991, Germany introduced an electricity feed-in law to further stimulate renewables[33]. In 1998 a coalition of the Green Party and the Labour Party (SPD) took office, which led to the extension of the *1000 Roofs Programme* into the *100,000 Roofs Programme*, as well as to reform of the feed-in law, culminating in the *2000 Renewable Energy Sources Act* (or *Erneubare Energien Gesetz, EEG*). The 2000 Act increased the feed-in tariffs for solar PV[34]. This resulted in high annual installations of new solar PV capacity in Germany in subsequent years, as is shown in Figure 7, and consequently it led to significant demand for solar PV modules.

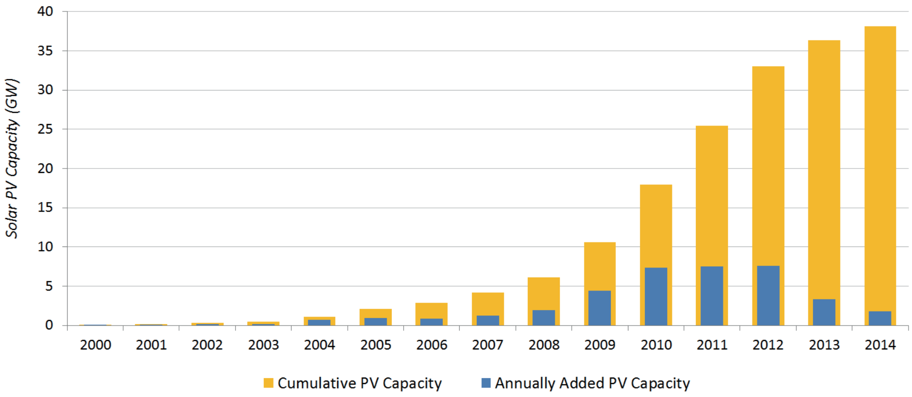


FIGURE 7. CUMULATIVE INSTALLED AND ANNUALLY ADDED PV CAPACITY GERMANY[35]

---

[32] Bosman, R. (2012: 9), "Germany's Energiewende", Redefining the Rules of the Energy Game, The Hague, Netherlands: Clingendael International Energy Programme (CIEP).

[33] Rutten, D. (2014: 39), "The Energiewende and Germany's Industrial Policy", The Hague, Netherlands: Clingendael International Energy Programme (CIEP).

[34] The Breakthrough Institute (2009: 24), "Case Studies in American Innovation, A New Look at Government Involvement in Technological Development."

[35] Figure compiled from data from Bundesministerium für Wirschaft und Energie and from Fraunhofer ISE. See Bundesministerium für Wirtschaft und Energie (2014: 12), "Erneubare Energien in Zahlen, Nationale und internationale Entwicklung im Jahr 2013". And see Fraunhofer ISE (2015: 5), "Stromerzeugung aus Solar- und Windenergie im Jahr 2014".

What can be observed in Germany's approach to solar PV is a push-and-pull strategy, i.e., a combination of stimulating the supply side as well as the demand side of new technology[36]. As suggested by the 2014 CIEP publication *The Energiewende and Germany's Industrial Policies*, Germany's energy policy is best understood by also considering its industrial policy aspect. Interestingly, however, a push-and-pull strategy can also be recognised in Chinese energy and industrial policies[37]. As explained in the 2012 CIEP publication *China and the Future of New Energy Technologies*, Chinese industrial policies aim toward building strategic emerging industries; energy technologies, including solar, have a prominent role in that respect[38].

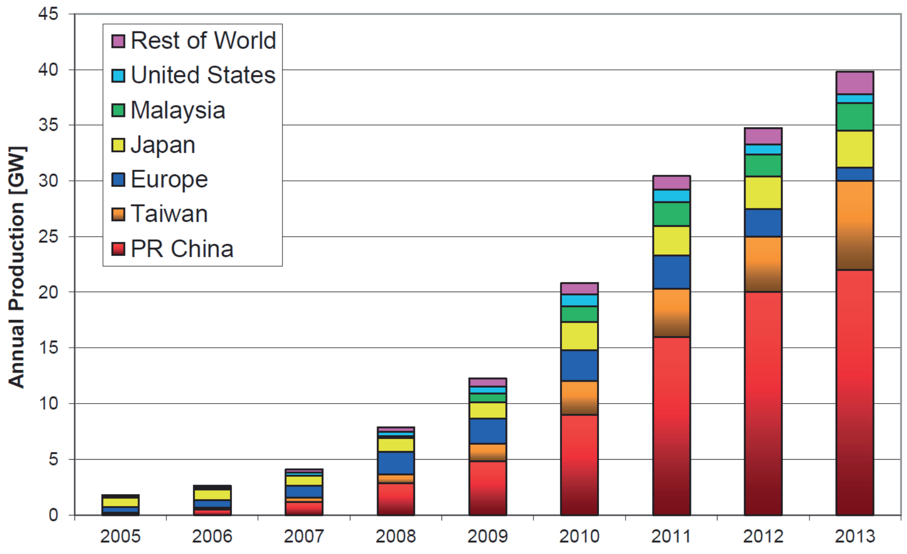


FIGURE 8. PV MODULE MANUFACTURING (JRC, 2014)[39]

German pull and Chinese push found each other in the past decade. While demand for PV modules in Germany surged, the manufacturing of PV modules in Europe remained relatively constant over much of the 2005-2013 period, after some initial growth. At the same time, module manufacturing in China grew enormously, as can be observed in Figure 8.

---

[36] Push-and-pull refers to technology push policies that foster research and development complemented by market pull policies. See European Commission (2012: 5), "Technology Learning Curves for Energy Policy Support", JRC Scientific and Policy Report.

[37] Zhang, S., Andrews-Speed, P., Zhao, X., & He, Y. (2013)."Interactions between renewable energy policy and renewable energy industrial policy: Acritical analysis of China's policy approach to renewable energies". *Energy Policy 62*, 342-353.

[38] Buijs, B. (2012), "China and the Future of New Energy Technologies, Trends in Global Competition and Innovation", The Hague, Netherlands: Clingendael International Energy Programme (CIEP).

[39] European Commission (2013: 7), "PV Status Report 2014", JRC Scientific and Policy Report.

The build-up of the Chinese solar PV industry led to intense debates. Specifically, the question arose as to whether the low-cost of PV modules made in China were the result of unfair state support. In 2012, the United States Department of Commerce began imposing tariffs on PV modules imported from China, as American manufacturers were being pushed out of business[40]. Similar dynamics occurred in Europe. That same year, the European Commission launched an anti-dumping investigation on solar panel imports from China[41]. However, in December 2014 a World Trade Organization trade body concluded that US duties on Chinese imports violated trade rules, reversing an earlier finding[42].

The conjunction of German pull and Chinese push policies was not widely anticipated. German feed-in tariffs indicated an expectation of a gradual decline in solar PV manufacturing costs. In the early 2000s, PV prices declined very little as a result of the aforementioned cyclical characteristics of the upstream solar business. However, when the tide turned around 2008, solar PV module prices decreased dramatically, while German feed-in tariffs did not adjust accordingly, i.e. not rapidly enough. Since a solar service industry had emerged in Germany, this window of opportunity for solar investment resulted in a surge in PV capacity additions in the years following 2008, as seen in Figure 7.

For German electricity consumers, this came at a cost. In 2014, the PV share of the surcharge that finances the feed-in tariff stood at around 9.4 billion euros[43]. This amount should not be expected to become lower in coming years, as PV projects now in operation will continue to be eligible for the feed-in tariff for 20 years after their start date. At the same time, the surge in solar PV capacity contributed to strengthening the industrial base of Germany. That is to say, even though the market share of Chinese manufacturers exceeded 50 percent in 2012, as seen in Figure 8, the global market share of all German PV suppliers (components, machinery, plant manufacturers) stood at 46 percent in 2011, and the industry realised an export quota of around 87 percent[44]. Indeed, most PV modules are produced in China, but to a large extent Chinese manufacturers have been utilising imported technology[45].

---

[40] New York Times (16 December 2014), "U.S. Imposes Steep Tariffs on Chinese Solar Panels".

[41] European Commission Press Release (6 September 2012), "EU Initiates Anti-dumping Investigation on Solar Panel Imports from China".

[42] Bloomberg (18 December 2014), "WTO Body Says U.S. Duties on Chinese Solar Panels Break Rules".

[43] BDEW Bundesverband der Energie- und Wasserwirtschaft e.V. (2015: 44), "Erneuerbare Energien und das EEG: Zahlen, Fakten, Grafiken (2015)", Energie-Info.

[44] Fraunhofer ISE (2014: 31), "Recent Facts about Photovoltaics in Germany".

[45] Zhang, S., Andrews-Speed, P., Zhao, X., & He, Y. (2013: 347)."Interactions between renewable energy policy and renewable energy industrial policy: Acritical analysis of China's policy approach to renewable energies". *Energy Policy 62,* 342-353.

2 FROM PV MODULE TO PV ELECTRICITY

A SOLAR PV SYSTEM: MORE THAN A MODULE

There is not much value in a PV module if it is not integrated into a system. A PV system is composed of the PV module and Balance-of-System (BoS) components, which can include an inverter, storage, charge controller, system structure, and the energy network[46].

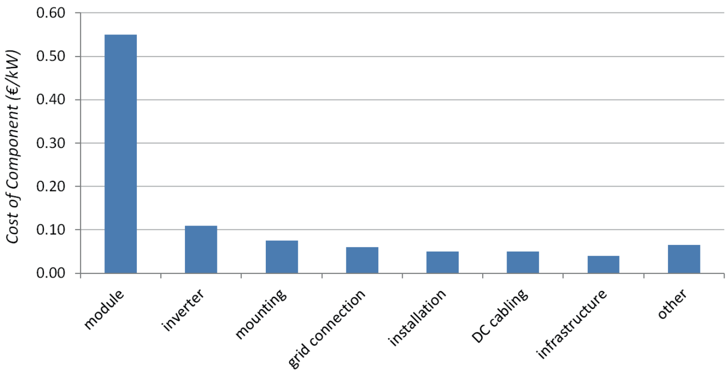


FIGURE 9. A 1 MW PV-SYSTEM IN GERMANY IN 2015 (FRAUNHOFER, 2015)[47]

Until several years ago, when PV modules were still very costly, the costs of BoS components did not matter as much as they do today. Even though module costs are still the single most expensive cost component of a relatively large-scale PV system, as is shown in Figure 9, the costs of other components are becoming more relevant with falling module prices. According to a recent study by Fraunhofer ISE, module costs constitute 55 percent of total installation costs for a 1 MW PV system in Germany at present[47]. The other 45 percent is thus non-module cost. For smaller-scale residential systems, non-module costs make up even a substantially larger share[48].

[46] IPCC (2014: 376), SRREN Chapter 3 "Direct Solar Energy", section 3.3.3; IRENA (2012: 4-8), "Solar Photovoltaics", Renewable Energy Technologies: Cost Analysis Series, Volume 1: Power Sector, Issue 4/5.

[47] Fraunhofer ISE (2015: 40), "Current and Future Cost of Photovoltaics: Long-term Scenarios for Market Development, System Prices, and LCOE of Utility-Scale PV Systems".

[48] According to the Joint Research Centre of the European Commission, in 2013 the non-module costs for an even larger system of 10 MW were about 55% while for a residential system they make up approximately 70%. See European Commission (2013: 27-31), "PV Status Report 2013", JRC Scientific and Policy Report.

While it is clear that further reductions in PV module costs continue to have an important downward effect on prices for PV systems, most notably in the case of larger-scale systems, costs of other components have thus gained in relevance. As a result, the inverter market has become more competitive, placing manufacturers under pressure[49].

It is useful to note that some cost components are country and location specific. While a global market exists for modules and inverters, locational factors strongly affect other costs, resulting in significant price differences for installed PV systems across the globe. For example, in 2013 a 10-100 kW PV system was priced at $4.1/watt in the US, whereas this was $1.9/watt in Germany[50]. The maturity of its PV industry, combined with relatively lean procedures, contributed to efficient PV project development in Germany, relative to the United States.

LEVELISED COSTS OF PV ELECTRICITY

Once a PV system is installed, it generates megawatt-hours (MWh) or kilowatt-hours (kWh) of electricity. The cost of this electricity is generally expressed in terms of euros per MWh or cents per kWh. In the electricity sector, these costs are referred to as the *levelised costs of electricity (LCOE)*.

Several years ago, LCOE from solar PV were estimated to be much higher than the costs of alternative renewables. In 2008, at the time of the 2nd Strategic Energy Review, the European Commission estimated PV costs in the range of €ct 52-88/kWh for 2007, falling to €ct 27-46/kWh in 2020 and further to €ct 17-30/kWh in 2030[51]. At the same time, it identified a cost range of €ct 8-9.5/kWh for biomass, €ct 7.5-11/kWh for onshore wind and €ct 8.5-14/kWh for offshore wind for 2007. With a view to module prices around that time, this can hardly be considered a surprise. As a consequence, solar PV was not widely recognised as an affordable option that could make a contribution toward achieving the 2020 targets for renewables.

---

[49] Renewable Energy Policy Network for the 21st Century (2014: 50), “Renewables 2014: Global Status Report”.

[50] Berkeley Lab (2014: 19), “Tracking the Sun VII: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2013”.

[51] European Commission (2008: 4-5), “Commission Staff Working Document accompanying the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Second Strategic Energy Review”; and COM (2008), “EU Energy Security and Solidarity Action Plan: Energy Sources, Production Costs and Performance of Technologies for Power Generation, Heating and Transport”, retrieved 5 March 2015 at https://ec.europa.eu/jrc/sites/default/files/strategic_energy_review_wd_cost_performance.pdf

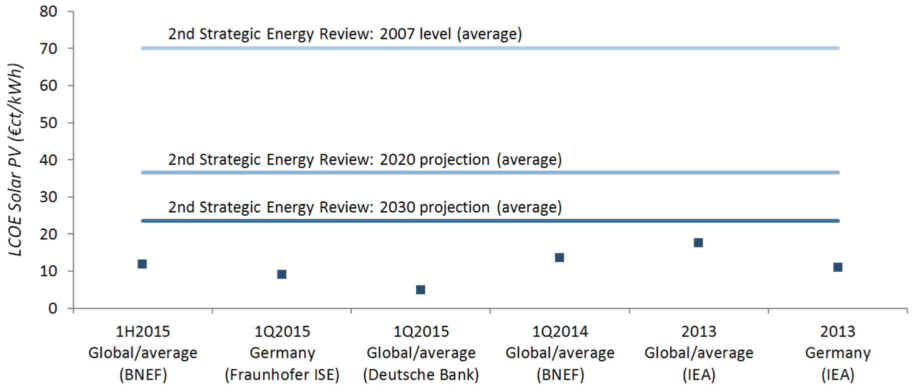


FIGURE 10. RECENT STUDIES QUOTING LEVELISED COSTS OF ELECTRICITY FOR SOLAR PV[52]

Today's cost realities, shown in Figure 10, are very different. The IEA reported LCOE for PV between €ct 7.8-14.2/kWh for utility-scale PV in Germany in 2013[53]. Bloomberg New Energy Finance (BNEF) found a global average around €ct 14/kWh for the first quarter of 2014 and lower cost levels in a range of cases; for the first half of 2015, BNEF identified a global average of approximately €ct 12/kWh[54]. Fraunhofer ISE concluded that cost levels for utility-scale systems reached €ct 9 / kWh in Germany in 2014[55]. Early in 2015 Deutsche Bank identified cost levels between €ct 4-7/kWh for utility-scale projects[56].

The picture is very mixed with regard to the *exact* present cost levels, because of regional differences and case-specific factors. But what stands out is that present cost levels are substantially below 2007 levels and, impressively, even below levels previously anticipated for 2020 and 2030.

FACTORS DETERMINING LEVELISED COSTS OF PV

How should these PV electricity cost levels be understood? For gas-fired or coal-fired plants, fuel costs and potentially carbon costs are highly relevant factors determining the levelised costs of electricity. In contrast, for a PV system the costs of the actual PV system stand out, while operation and maintenance (O&M) during its lifetime play an additional but less significant role[57].

---

[52] Compiled from different sources, see main text and footnotes no. 51, 53, 54, 55, 56.

[53] IEA (2014: 15), "Technology Roadmap Solar Photovoltaic Energy", 2014 Edition.

[54] FS-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, & Bloomberg New Energy Finance (2015: 19, 37), "Global Trends in Renewable Energy Investment 2015".

[55] Fraunhofer ISE (2015: 1), "Current and Future Cost of Photovoltaics: Long-term Scenarios for Market Development, System Prices, and LCOE of Utility-Scale PV Systems".

[56] Deutsche Bank Markets Research (2015: 12), "Crossing the Chasm", Industry: Solar (27 February).

[57] European Commission (2013: 27-31), "PV Status Report 2013", JRC Scientific and Policy Report.

Crucially, much of the cost of the PV system are incurred before any electricity has been generated, i.e., largely it entails an up-front investment, while future revenues must provide sufficient return.

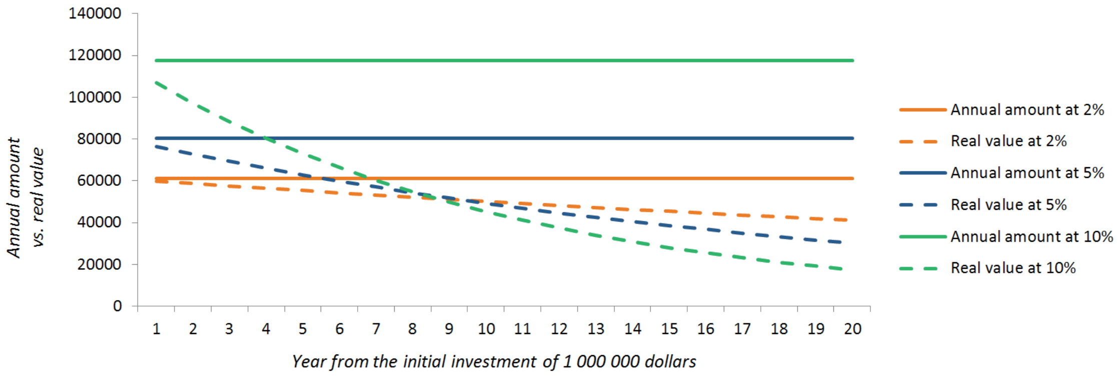


FIGURE 11. INVESTMENT IN PV: FUTURE REVENUE STREAMS AND THE EFFECT OF DISCOUNTING

It makes a difference as to whether a discount factor of 2%, 5%, or 10% is applied to such future revenues when calculating levelised costs. The weighted average cost of capital (WACC) for the investment is relevant at this point. The Net Present Value (NPV) of three alternative revenue streams, shown in Figure 11, represents one million dollars. This one million dollars could represent the initial investment in a PV system. The annual revenues required for the PV business case to work subsequently depends highly on the discount factor applied to this revenue stream, since the real value of future revenues is affected by this factor. Put differently, imagine that a one million dollar loan is required for the investment; the 'annual amount' shown in Figure 11 can then be interpreted as the periodic instalment for this loan. It then follows that the annual instalment would be around $120,000 at a rate of 10%, while it would be just $60,000 at a rate of 2%.

Discount factors thus matter. When costs of required capital are low, a correspondingly low discount factor can be applied for a levelised cost calculation. The effect is significant. Other factors being equal, the above example shows that the costs of PV electricity *halve* if a 2% discount factor rather than a 10% discount factor is applied, setting aside O&M costs. As can be observed in Figure 12, the IEA concludes that over half of the LCOE of PV is made of financial expenditures when the weighted average costs of capital (WACC) exceeds 9%.

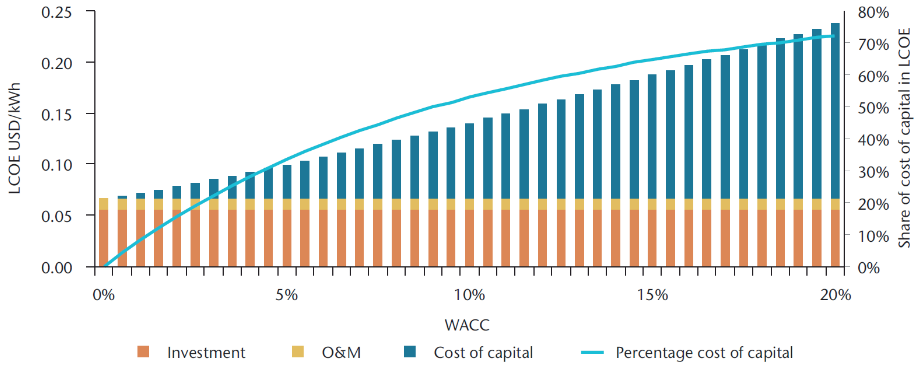


FIGURE 12. THE SHARE OF THE COSTS OF CAPITAL IN THE LCOE OF PV SYSTEMS (IEA, 2014)[58]

Another factor strongly affecting the levelised cost of electricity from a solar PV system is the amount of electricity generated by the system. A PV system installed in a sunny southern region generates considerably more electricity than the same PV system installed in a cloudy northern region. In technical terms, the capacity factor or load factor differs significantly from one place to another. As is shown in Table 1, the Italian PV base is substantially more efficient than the German PV base, generating an impressive 39 percent more electricity per kW. Logically, cost per unit of electricity produced decreases accordingly if the system produces more units. It is important to keep in mind here, however, that this effect can be outweighed by other factors, such as the cost of capital[59].

	Installed Capacity (GW)	**Generated Power (TWh)**	**Implied Capacity Factor (%)**	**Energy yield (kWh/kW)**
Germany[60]	38.1	32.8	9.7%	860
Italy[61]	18.6	22.3	13.9%	1199

TABLE 1. PV INSTALLED CAPACITY AND GENERATED ELECTRICITY IN 2014

In sum, electricity costs for solar PV are very much determined by three key factors: (1) the costs of the PV system, which follow from the factors described in the previous section and previous chapter; (2) the cost of capital; and (3) the amount of electricity generated by the PV system.

[58] This example by the International Energy Agency is based on output of 1360 kWh/kW/year, investment costs of 1500/Watt, annual operations and maintenance (O&M) of 1% of the investment, project lifetime of 20 years, and residual value of 0. When the weighted average costs of capital (WACC) exceeds 9%, over half of the LCOE of PV is made up of financial expenditures. See IEA (2014: 25), "Technology Roadmap Solar Photovoltaic Energy", 2014 Edition".

[59] Thanks to the low cost of capital for certain projects in Germany, the cost of electricity from these projects is actually lower than the cost of electricity from certain projects in, for instance Spain, where (sudden change in) the regulatory environment has negatively affected risk perception of potential investors, making cheap finance less readily available.

[60] Fraunhofer ISE (2015: 6-7), "Stromerzeugung aus Solar- und Windenergie im Jahr 2014".

[61] For the installed PV Capacity in Italy, see Terna (2015: 31), "Impianti di Generazione"; for the amount of solar PV electricity generated, see Terna (2015: 12), "Dati Generali".

3 SOLAR PV DOWNSTREAM: MONETISING USER VALUE

The downstream solar PV industry aims to monetise the user value of solar PV. User value of a PV module emerges once it is integrated in a system. User value is not merely a characteristic of the PV module itself. Rather, it emerges from the costs of alternatives.

User value for PV has existed for decades[62]. It started with space applications, where it was soon a lower cost alternative to other energy solutions. By adding solar cells to a satellite, a battery pack could be recharged, which is cheaper than bringing larger batteries into space or periodically replacing batteries manually. User value for PV modules also emerged at remote terrestrial locations such as buoys at sea or distant communication towers. Rather than sending workers to such places by ship or helicopter to replace batteries, a solar cell could recharge batteries.

EMERGING USER VALUE OF DISTRIBUTED PV

User value for solar PV is not merely a characteristic of the PV system itself. Rather, it emerges from the costs of alternatives. In that respect, advocates of solar PV have long focused on *grid parity* or *socket parity.* Grid parity or socket parity is achieved once the cost of PV electricity falls below the cost of electricity from the grid. At this point, user value emerges and electricity users are likely increasingly tempted to install a PV system. Albeit a useful concept, the idea of grid parity should not suggest that there is one single cost level below which solar PV is competitive. In reality, there is a sliding scale.

In past decades PV electricity was a very uneconomical alternative to grid electricity for most grid-connected consumers. Only under very specific conditions was a PV system an interesting value proposition for home owners or small businesses. However, as PV module costs declined (as well as the costs of other system components), it became ‘politically affordable’ to socialise the costs of PV electricity, as seen in the introduction of the feed-in tariff for solar PV in Germany. The feed-in tariff in effect ensured significant PV user value for German PV systems, by ensuring generous payments for the electricity supplied by such PV systems to the grid. One can argue that solar PV costs had reached *policy parity*.

[62] For an extensive overview of applications in past decades, consider Varadi (2014), “Sun Above the Horizon: Meteoric Rise of the Solar Industry”, Singapore: Pan Stanford Publishing Pte. Ltd.

In other countries such as the Netherlands, a German-style support system for solar PV did not exist. As PV costs declined, a PV system nevertheless became an attractive proposition for some consumers. Largely, this was the result of *net metering*. Net metering implies that electricity produced with a PV system over the course of a year can be subtracted from the electricity consumed in that year. Irrespective of hour-to-hour consumption and production, the PV owner can thus be sure that the price for the electricity s/he sells to the grid is equal to the price of electricity s/he consumers from the grid. The PV owner avoids paying taxes over *all* electricity consumed from the grid, which is a key factor affecting the business case for her/his solar PV system. In reality, most PV system owners still consume significant amounts of electricity from the grid but do not pay the full amount of taxes on such consumption when net metering is the standard.

Without net metering, a PV system owner may still manage to avoid paying taxes and levies over electricity from the grid, to the extent that s/he truly reduces consumption from the grid on a minute-to-minute basis throughout the year[63]. In this case, the economics of solar PV deteriorate, but with declining PV system costs this can potentially be compensated – consider Table 2 for an example based on a PV system available in the Dutch market in early 2015.

PV System[64]	1.5 kW priced at €2383.-
Annual generation	1350 kWh per year
Self-consumption (minute-to-minute)	600 kWh per year
Retail electricity price incl. taxes/levies	€0.22/kWh
Avoided costs for electricity from the grid	600 x 0.22 = €132 per year
Remainder is fed into the grid	750 kWh per year
Market price at electricity wholesale markets	€0.04/kWh
Revenues from sales at wholesale price	750 x 0.04 = €30 per year
Annual savings and revenues	132 + 30 = €162 per year
Payback time for system	2383 / 162 = 15 years

TABLE 2. BASIC ECONOMICS OF A PV SYSTEM IN DUTCH MARKET WITHOUT NET METERING

---

[63] The exact extent to which this is possible depends on the regulatory environment.

[64] A 1.5 kW PV system available in the Dutch market, including inverter, fully installed, generating 1350 kWh per year in normal conditions. Product available 5 March 2015 at http://www.zonnepanelen.nl

When net metering is no option while *grid parity without net metering* is achieved, the PV system in effect becomes an electricity savings measure, reducing consumption of electricity from the grid. Sales to the grid have become a relatively minor factor in the economics of the PV system, and over time electricity storage and the utilisation of energy conversion technologies could further increase self-consumption and reduce consumption of grid electricity[65].

What has not been mentioned so far is that the electricity grid comes at a cost and that this cost is generally paid by its users. When total costs of a PV system plus electricity storage and/or back-up (e.g. by means of a diesel generator, gas turbine or fuel cell) are lower than the cost of grid electricity including the grid costs, more radical dynamics can occur. A process called *grid defection* is initiated if actors choose to go off-grid in order to avoid paying electricity grid costs[66]. Crucially, at this point grid costs must be borne by fewer actors and costs per actor may go up, providing impetus for further *grid defection.* This continuous process is what is often referred to as *the utility death spiral*. Interestingly, when no extensive grid is yet in place, these economic realities may prevent a grid from emerging. Indeed, landlines for telecommunications services have never become widespread in Africa, while mobile telecommunications have shown spectacular growth in the past decade.

VALUE DRIVERS FOR UTILITY-SCALE SOLAR PV

For PV generation projects, a broad range of project sizes can be imagined. Distributed solar PV in the residential sector can be placed at one end of the spectrum, utility-scale projects can be found at the other end, while larger-scale (rooftop) projects in, for instance, commercial or industrial settings can be found between those extremes. With this in mind, it becomes even more clear that grid parity is just one small part of the story. Especially for projects at the utility-scale, the story is quite different.

---

[65] Consider a battery pack of 2 kWh. Assume that the PV system owner manages to charge the battery pack 200 days per year. This would enable the system owner to consume self-generated electricity 200 evenings a year, totalling 200 x 2 = 400 kWh. This would imply that the PV system owner could sell less electricity to the grid, but at the same time it would enable her/him to reduce consumption from the grid by another 400 kWh. By doing so, s/he would gain €0.18/kWh, as s/he would avoid paying €0.22/kWh for grid electricity while no longer selling it at the wholesale market for €0.04/kWh. This would constitute a gain of 400 x 0.18 = €72/year. If the battery pack has a technical lifetime of 10 years, the 2 kWh pack should cost less than 10 x 72 = 720 euro, that is, 360 euro per kWh. The IEA estimates costs of a Li-ion battery to be in the range of USD 500-2300/kWh and sees room for cost reductions. See IEA (2014: 254, 258), "Energy Technology Perspectives 2014", chapter 7 "Electricity Storage: Costs, Value and Competitiveness".

[66] For an analysis of the economics of potential grid defection in the US, consider Rocky Mountain Institute (2014), "The Economics of Grid Defection: When and where distributed solar generation plus storage competes with traditional utility service" .

Utility-scale solar projects generate electricity for wholesale markets and face competition from alternative technologies. For example, at the time of the 2nd Strategic Energy Review by the European Commission, PV had severe competition from other renewables that all needed government support, such as onshore and offshore wind energy as well as biomass combustion. As explained in previous sections, the picture has changed dramatically since 2007. One could argue that *renewable new-build parity* has been reached. For PV business this is relevant, as public policy makers may reconsider financial support for renewables, favouring solar PV over, for instance, offshore wind energy.

Conventional electricity projects are generally not subsidised. Nevertheless, plants are expensive to build. Coal-fired power plants cost more than gas-fired power plants, and nuclear plants even substantially more. The traditional utility approach to project development basically implies that a project developer is likely to proceed with realizing a new power generation plant if s/he expects wholesale market prices to be higher than the LCOE from her/his intended plant. In a liberalised market environment, this is no different for unsubsidised utility-scale solar PV projects than for conventional plants, as investors 'just see business cases' and do not carry responsibility for guaranteeing security of supply. When LCOE for utility-scale solar PV fall below the costs of conventional plants, one could argue that *conventional new-build parity* is reached.

Crucially, electricity generation from utility-scale solar PV is non-dispatchable. In other words, it may not be available when it is needed. As a result, back-up capacity for utility-scale solar PV is essential and PV is therefore likely to be confronted with other power plants that are in the system for purposes of electricity supply security. In these circumstances, utility-scale PV must be competitive with the variable costs of electricity generation from those sources, largely fuel costs and potentially carbon costs. When this cost level is reached, one could say that PV has reached *fuel & carbon parity*. Here, too, PV becomes in effect an energy-saving technology, reducing the fuel consumption of power plants at the system level. Effectively, this is the point at which PV is attractive for monopolist utilities seeking to save on fuel and carbon costs by adding solar PV for their generation portfolio; moreover, at this point PV is likely to be competitive in electricity wholesale markets, since in many liberalised markets wholesale prices are largely determined by the variable costs of generation plants.

UTILITY-SCALE PROJECT DEVELOPMENT

In most markets, utility solar PV has not reached the level of *conventional new build parity* or *fuel and carbon parity*. In other words, it is more economical to build a conventional power plant for producing power than to invest in a utility-scale solar project; in fact, this can be observed in LCOE studies which show that LCOE of conventional technologies are still lower than LCOE of solar PV[67]. By definition, the milestone of *fuel and carbon parity* is even further away. Most utilities would not introduce PV in their portfolios as a fuel and carbon cost-saving measure or develop a utility-scale PV generating project based purely on sales at wholesale electricity market prices.

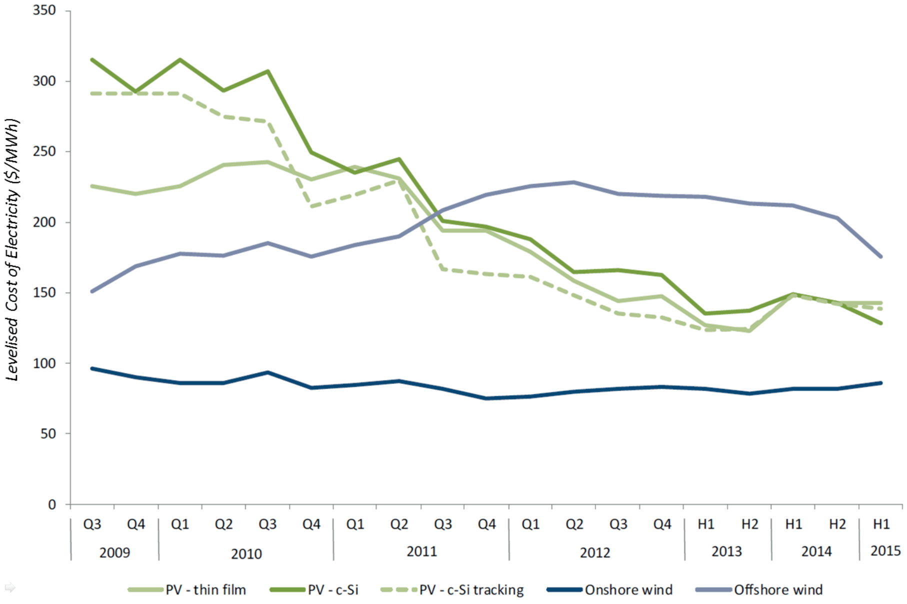


FIGURE 13. GLOBAL AVERAGE LEVELISED COST OF ELECTRICITY FOR WIND AND PV[68]

---

[67] See Figure 20 in the Appendix, figure from FS-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, & Bloomberg New Energy Finance (2014: 37), "Global Trends in Renewable Energy Investment 2014".

[68] FS-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, & Bloomberg New Energy Finance (2015: 19), "Global Trends in Renewable Energy Investment 2015". The authors report: *"Offshore wind had been travelling in the wrong direction on levelised costs, seeing these increase from $151 to $203 per MWh over 2009-14, as project developers moved out into deeper waters and had to deal with bottlenecks in the supply of vessels and cables. But the latest snapshot, for H1 2015, shows offshore wind levelised costs falling back again in dollar terms, helped by low debt costs and exchange rate effects."* One interesting case deserves some attention, however. Vattenfall recently won the Horns Rev 3 tender in Denmark, accepting a record-low level of subsidy, potentially showing that the costs of offshore wind energy projects have finally come down significantly. At the same time, it cannot be ruled out case specific circumstances led to this particular outcome and that costs of other projects in the North Sea region will be higher again.

However, it can be argued that *renewable new build parity* has been reached. Different from the time of the 2nd Strategic Energy Review in 2008, today large-scale solar PV has become a competitor to other renewable energy options such as wind energy, as can also be observed in Figure 13. The global business community has responded accordingly. Tax incentives, renewable portfolio standards, feed-in tariffs and feed-in premiums have enabled a wide range of actors to develop large-scale PV projects worldwide.

To name just a few of the larger projects completed in the past few years, in Germany the 70 MW Solarpark Meuro was initiated by Berlin-based unlimited energy GmbH. The initiative, at an old lignite mining location, was sold to GP Joule GmbH, an engineering, procurement and construction (EPC) and project development company[69]. Supported by the German feed-in tariff system, GP Joule GmbH developed the project utilising PV modules provided by Canadian Solar[70]. In California, the 550 MW Topazz Solar Farm was developed by US-based First Solar, utilising its own thin-film technology and financially supported through California's Renewable Portfolio Standards (RPS) scheme. In January 2012, when it was up and running, it was sold to Berkshire Hathaway Energy (BHE) Renewables[71].

In the province of Madhya Pradesh in India, a 151 MW solar PV plant was commissioned by Welspun Energy in 2014[72]. Welspun Energy is part of the larger Indian industrial conglomerate Welspun. Welspun is involved in a range of industries, but in 2013 it stated that it would source PV modules from Italy, Germany, and Japan, not providing more details[73]. In the Qinghai province of China, Huanghe Hydropower invested in a 200 MW PV project which was commissioned in December 2011[74]. Huanghe Hydropower is involved in the development and construction of power plants, silicon and solar equipment, and aluminium products, and is a

---

[69] Canadian Solar news release (2 September 2011), "Canadian Solar supplies 70 MW of Solar Modules for Germany's Largest Project; built by Leading EPC Company GP Joule".

[70] Renewable Energy Installer (8 January 2013), "Canadian Solar project scoops POWER-GEN award. Retrieved 7 October 2015 at http://www.renewableenergyinstaller.co.uk/2013/01/canadian-solar-project-scoops-power-gen-award.

[71] BHE Solar website. Retrieved 16 September 2015 at http://www.bherenewables.com/topaz_solar.aspx.

[72] Welspun Energy Press Release (26 February 2014), "Gujarat CM Narendra Modi unveils one of world's largest 151 (DC) MW solar project in MP". Retrieved 16 September 2015 at http://www.welspunenergy.com/welspunenergy/Images/26Feb2014_NeemuchInauguration.pdf. And Welspun Energy corporate website. Retrieved 16 September 2015 at http://www.welspunenergy.com/welspunenergy/Businesses_WREL.html.

[73] PV-Tech.org (5 March 2013), "Welspun Energy completes financing for India's 'largest' solar project". Retrieved 8 October 2015 at http://www.pv-tech.org/news/welspun_energy_completes_financing_for_indias_largest_solar_project.

[74] Powertechnology.com (29 August 2013), "The world's biggest solar power plants". Retrieved 8 October 2015 at http://www.power-technology.com/features/feature-largest-solar-power-plants-in-the-world.

subsidiary of China Power Investment Corporation[75]. Yingli, however, supplied the PV modules[76]. In Chile, a 100 MW project was built, developed and interconnected by Amanecer Solar[77]. Amanecer Solar is a subsidiary of SunEdison and, unsurprisingly, it utilised SunEdison modules. The Amanecer Solar CAP project was financially supported through a 20-year contracts-for-difference agreement with the CAP Group, the largest steel producer of Chile.

The general approach to utility-scale projects is that one party identifies an opportunity and initiates the first steps of an extensive process (similar to prospecting in traditional resource and mining industries); it may market the potential, and the initiative may be acquired by a project developer. The project developer focuses on arranging financing and identifying and awarding a contract to an engineering, procurement, and construction (EPC) company to manage the construction of the plant. The EPC company is likely to select a preferred solar PV technology and supplier of PV modules. What can be observed today is that project development, EPC activities, and PV module supply can be intertwined; one party can be active in one or more of these activities, as can be observed in the project examples mentioned above.

The list of utility-scale solar projects is long and continues to grow. As argued, this suggests that *renewable new build parity* for utility-scale PV has been reached. In a range of countries and regions, other renewable energy technologies such as wind energy face increasing competition from solar PV technology at the utility scale. This is a relevant observation, as those renewables compete not only in the market, but also for (limited) public financial support (or government subsidies).

FINANCIAL ARRANGEMENTS FOR UTILITY-SCALE PV AND THE YIELDCO

The financial arrangements can be complicated. There are a number of relevant aspects to be kept in mind. Perhaps most notably, the market risks with respect to electricity sales must be managed. A long-term (15-25 years) *power-purchase-agreement (PPA)* is vital here. In non-liberalised markets, a state-owned monopolist

---

[75] Bloomberg Business, Company Overview of Huanghe Hydropower Development Co., Ltd. Retrieved 8 October 2015 at http://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=145859100.

[76] Yingli Solar Press Release (7 August 2014), "Yingli Green Energy Surpasses 10 GWs of Global Solar Module Deliveries". Retrieved 1 October 2015 at http://www.yinglisolar.com/assets/uploads/press_releases/downloads/10%20GWs%20of%20Global%20Solar%20Module%20Deliveries%20.pdf. And PV-Magazine.com (1 July 2011), " Yingli and Huanghe Hydropower enter 110 MW supply agreement". Retrieved 8 October at http://www.pv-magazine.com/news/details/beitrag/yingli-and-huanghe-hydropower-enter-110-mw-supply-agreement_100003524/#axzz3gd8V1GKb.

[77] Powertechnology.com, "Amanecer Solar CAP Power Plant, Copiapo, Chile". Retrieved 8 October 2015 at http://www.power-technology.com/projects/amanecer-solar-cap-power-plant-copiapo.

utility can sign the PPA, committing itself to buying electricity from the PV plant for a given period; it could do so for a price that brings the PV project forward and, depending on the regulatory environment, might adopt a *cost pass-through* strategy, in which the electricity consumers pay. To some extent, a *feed-in tariff* such as the German scheme resembles this, although it is usually framed differently, as the German market (and other European markets) have been liberalised.

If a utility has a regulatory or legal obligation to ensure a certain generation portfolio mix (different technologies), i.e., a *portfolio standard*, it needs to adopt a strategy to source electricity according to this standard, which may include solar PV. As a result, it is incentivised to select a competitive PV project and engage in a PPA, potentially agreeing to an electricity price that brings the PV project forward. This model is delicate, since a utility must be able to recover those prices, which is not a given; this is more straightforward in a regulated monopoly environment than in a competitive liberalised market environment.

A utility in a liberalised market environment (without portfolio standards) is unlikely to engage in a PPA at a price level that can presently bring the PV project forward (since neither *conventional new build parity* nor *fuel and carbon price parity* is the norm globally). As a result, an additional revenue is required to bring a PV project forward; one approach is a *subsidy scheme* such as a *feed-in premium*.

Theoretically, any party that is creditworthy (e.g. thanks to a strong balance sheet or due to regulated returns) could sign such a PPA. In that respect, the present Northwest European market environment is delicate, since incumbent utility balance sheets have seriously weakened in recent years, potentially affecting their capability to perform this (systemic) role.

The PPA (in cases thus supplemented by long-term guaranteed subsidies) is effectively a hedge for the market risks of a utility-scale solar project. This is important because a lower risk profile can ensure access to low-cost capital. A PPA is therefore not a neutral concept; the creditworthiness of the parties involved matters. A PPA by a solid party, such as a state-owned monopolist with stable regulated income, can thus be highly attractive[78]. As explained, the cost of capital strongly determines the cost of electricity from the PV project.

[78] A PPA signed by Dubai State utility DEWA enabled one of the lowest cost solar projects to proceed late 2014. A consortium led by Saudi-Arabia based ACWA Power and Spanish engineering firm TSK won a contract to build a large-scale solar PV plant Dubai. ACWA Power is to receive 5.84 dollar ct/kWh under a 25-year power purchase agreement (PPA) DEWA, possibly reflecting the costs of the electricity from the solar plant. See Gulf Business, “ACWA Power, TSK Win Contract To Build Power Plant In Dubai’s Solar Park”, 15 January 2015.

Once a PV project is developed and the system is up and running, the most risky phase is over (project development risks including licensing, etc., are gone and technological risks are significantly reduced). When the plant is generating electricity and there is a solid PPA, potentially supplemented by revenues from a public support scheme, the financial future of the plant is fairly straightforward. Project developers may therefore create a new legal entity for the plant or for a number of such plants, i.e., the *YieldCo*, and put it up for sale.

A YieldCo with a low-risk profile is attractive to investors who seek secure, long-term investments with stable returns. Given such a low-risk profile, the investor is willing to accept a relatively low return on investment. In effect this means that a source of relatively low-cost capital results in low-cost electricity from the project (as stated, capital costs strongly affect the cost of PV electricity). At the same time, once the YieldCo has been sold, the project developer has the financial means to develop a new project. This approach can be recognised in the California example, where the PV plant was developed by First Solar and then sold to Warren Buffet's BHE Renewables.

Interestingly, such an approach to energy project financing is not exclusive to renewable electricity projects, but can also be recognized in unconventional gas and oil developments in the United States. Not merely technological innovation, but also financial innovation has thus contributed to driving down the costs of electricity from utility-scale solar PV generation plants.

DISTRIBUTED PV: INTEGRATION, AGGREGATION, EMPOWERMENT

As explained earlier in this chapter, value drivers for distributed applications are different, and businesses focusing on distributed solar have developed accordingly. In some markets *policy parity* has implied that schemes were available for households (and potentially small businesses) to adopt small-scale (rooftop) systems. While such schemes may not have been available elsewhere, *grid parity with net metering* was reached in some markets, and small-scale systems began to be adopted; the state of affairs in 2013 is shown in Figure 14.

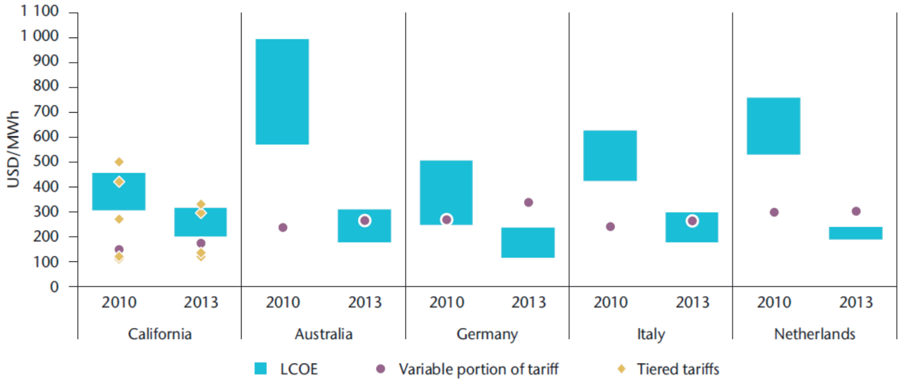


FIGURE 14. GRID PARITY WAS REACHED IN SEVERAL COUNTRIES (IEA, 2014)[79]

A downstream solar service industry emerged, focussing first and foremost on installation and *integration*. PV systems were being integrated into consumer product offerings. In many instances, consumers had funds (usually bank savings) to install a system and in their rationality applied a discount factor for the solar investment in the range of the interest rates of their bank savings account.

Since cost of capital is highly determining for solar PV electricity costs, an investor needing a 10% rate of return on its capital cannot compete with a household applying a 2% factor. As demonstrated in Figure 12, the LCOE of solar PV electricity are substantially lower when a 2% rather than a 10% discount rate is applied. As a consequence, many market parties (including incumbent utilities) were more tempted to sell a PV product, install it, and service it, rather than to invest in it themselves. Unsurprisingly, a range of businesses now sell PV products; in some markets this goes not only for new entrants, but also for incumbent utilities such as the integrated gas and electricity company Origin Energy in Australia and Engie through the Electrabel brand in the Netherlands[80].

Integrators also started offering solar PV systems through *leasing* to overcome the investment hurdle. With leasing, the PV product is offered through a loan, to be paid back through periodic instalments. For instance, California-based SolarCity, one of the major downstream solar businesses active in the US, has done this[81]. Another

---

[79] Figure from IEA (2014: 15), "Technology Roadmap Solar Photovoltaic Energy", 2014 Edition. Household electricity tariffs exclude fixed charges. LCOE are calculated using average residential system costs (including value added tax and sales tax in where applicable, and investment tax credit in California); ranges mostly reflect differences in financing costs. The tiered tariffs in California are those of Pacific Gas and Electric. Tiers 3 to 4 to 5 are tariffs paid on monthly consumption when it exceeds given percentages of a set baseline. All costs and prices are in 2012 USD.

[80] See the solar product page of Origin Energy. Retrieved 8 October 2015 at https://www.originenergy.com.au/for-home/solar.html. See the solar product page of Electrabel GDF Suez. Retrieved 8 October 2015 at https://www.electrabel.nl/zon.

[81] See the SolarLease product page at the website of SolarCity. Retrieved 8 October 2015 at http://www.solarcity.com/residential/affordable-solar-lease.

major California-based firm, Sungevity, offers similar products in the US[82]. Costs of capital are higher, so, strictly speaking, solar PV electricity costs are higher in a leasing product than when bank savings are used.

Another innovation, usually related to smaller-scale projects, is *crowdfunding*. For instance, in the UK, several solar projects have sought finance through the crowdfunding portal Trillion Fund[83]. Again, an important reason for doing so is that attracting low-cost capital improves the competiveness of PV electricity. Here again, market and regulatory risk (as well as other risks) may have been transferred to one or many parties involved, and it is questionable whether all involved understand the risks. However, it is the risk *perception* of potential capital providers that matters most, and some project developers in the distributed PV business have learned this in recent years.

With distributed generation spreading, business ideas other than selling PV systems or leasing arrangement have started to receive attention, too. The idea of *aggregation* involves buying and (re)selling electricity production from distributed producers and consumers. One could argue that many of the green electricity supply contracts offered in the Netherlands today reflect aggregation. Through the existing European certificate system of Guarantees-of-Origin (GoO), retailers buy electricity and GoOs at exchanges from a range of producers, bundle it in product offerings, and sell it to electricity consumers. At this point, however, it is relevant to keep in mind that this is very much a virtual arrangement, since GoOs have a 12-month-validity. In effect, ‘wind energy’ or ‘solar energy’ produced in March can thus be ‘stocked’ administratively and sold in September, potentially at a time when no wind energy or solar energy is being produced in reality. In distribution grids, the information infrastructure is not always present to facilitate real-time electricity trading. The reality in distribution grids is that DSOs manage the physical electricity flows to ensure security of electricity supply.

A step beyond aggregation is what could be labelled *empowerment*. The crucial difference between aggregation and empowerment is that the business offering empowerment has no direct interest in the product or product flows (electricity and electricity flows) but merely owns, operates, or controls an (ICT) platform facilitating exchanges of the product and corresponding financial transactions. This is an approach that is increasingly recognised as *platform economics* and can be observed

---

[82] See the page about Buying and Financing Solar at the website of Sungevity. Retrieved 8 October 2015 at http://www.sungevity.com/financing-options.

[83] At the start of October 2015, six solar projects were seeking finance through the Trillion Fund portal. See http://www.trillionfund.com. Retrieved 8 October 2015.

in business models in various sectors[84]. For instance, Uber offers a platform that brings together producers and consumers of transport services; Airbnb manages supply and demand for rooms and apartments; Postmates On-Demand Delivery does so for postal services; TaskRabbit for chores and tasks; etc[85].

The new Dutch entrant *Vandebron* proclaims that it enables consumers to buy renewable electricity 'directly' from the source[86]. As such, it appears to seek empowerment, although it could be argued that the business models reflects an enhanced version of aggregation, due to the present Dutch regulatory framework for the retail market[87]. Another Dutch new entrant, *ZonOver*, also explores empowerment of PV system owners by aiming to facilitate the real-time exchange of electricity between home-owners[88]. Also the extent to which *ZonOver* will be successful in truly empowering producers and consumers of (distributed) electricity will depend very much on the information infrastructure in distribution grids and likely even more on the regulatory framework for the retail market.

In all, it can be argued that much innovation can be observed in business activities surrounding distributed solar PV, likely more so in liberalised markets than in regulated monopolies. The extent to which present-day business model innovations will be successful is uncertain. One relevant lesson for these new business can be learned from the dynamics preceding the dot-com bubble that eventually burst in 2002. That is, business model innovations may prove to be innovations in the right direction, but they can come too early. Indeed, while shopping online for groceries at *WebVan* or buying dog food at *pets.com* was far-fetched around the year 2000, online shopping has become the new norm[89].

---

[84] For a further exploration of this theme, consider a post by Matthew Crosby to the RMI Outlet blog of 2 September 2015, "An Airbnb or Uber for the Electricity Grid? How DERs prepare the power sector to evolve into a sharing economy platform". Retrieved 8 October 2015 at http://blog.rmi.org/blog_2014_09_02_an_airbnb_or_uber_for_the_electricity_grid.

[85] See https://www.uber.com for Uber; https://airbnb.com for Airbnb; https://postmates.com for Postmates On-Demand Delivery; and https://www.taskrabbit.com for TaskRabbit.

[86] Q&A section at the website of Vandebron. Retrieved 8 October 2015 at http://vandebron.nl/faq.

[87] As argued, GoOs play an important role in Dutch regulations for the retail market. For their 'green' products, retailers are obliged to surrender GoOs for every kWh sold to their clients. In cases, clients can choose preferred suppliers. The challenge is that retailers are also required to balance their portfolios each moment of the day. Clients may require electricity at a moment in time when the preferred supplier is not producing due to the variable nature of the solar or wind resource. Now, GoOs have a 12-month-validity and can thus be stockpiled. As a consequence, GoS enable a retailer to deliver electricity from its portfolio or from the market, combine it with a GoO from the preferred supplier that was created administratively earlier in time, and claim that electricity from the preferred source was supplied. Naturally, this product is very much a virtual product, since in the real world the preferred supplier was not producing at the particular moment. Facilitating true real-time electricity exchanges between suppliers and consumers continues to be a challenge.

[88] Website of ZonOver. Retrieved 8 October 2015 at http://www.zonover.nl.

[89] Consider reading Wall Street Journal (12 January 2015), "Rebuilding History's Biggest Dot-Com Bust"; and consider reading Wired.com (12 August 2014), "Turns Out the Dot-Com Bust's Worst Flops Were Actually Fantastic Ideas".

4 THE WAY FORWARD: SOLAR PV IN A STRATEGIC WORLD

The preceding chapters sketched recent developments in the solar PV value chain. The chapters adopted an historic perspective; this chapter looks forward. It does not make firm predictions about the future cost of PV electricity, nor about the amount of solar that can be expected to be installed worldwide. Rather, it discusses a number of considerations that should be kept in mind when thinking about the future development of solar PV, the solar PV industry, and the impact on markets. Crucially, in a strategic world, new PV manufacturing capacity can be expected to continue to be added to the global PV manufacturing base – not exclusively driven by global supply and demand balances, but also by government policies promoting domestic PV manufacturing.

PRESENT MANUFACTURING CAPACITY IN PERSPECTIVE

As indicated in the first chapter, global PV manufacturing capacity has reached a level that is significant for power markets. Every year tens of gigawatts of modules are manufactured and subsequently find markets across the globe. The IEA reported a manufacturing capacity of around 35 GW/year in 2013. While the most conservative estimate of the European Photovoltaic Industry Association shows little growth in coming years, reaching 39 GW/year in 2018, its optimistic scenario points to a potential doubling of the global market, up to 69 GW/year[90]. In its medium scenario it reaches 50 GW/year around 2017. This order of magnitude is in line with reports by several banks and Fraunhofer ISE[91].

It is important to keep in mind what these capacities mean. Essentially, every manufactured module is likely to find a market and be part of an electricity system somewhere around the world for the next 20 to 30 years. Numbers add up, and cumulative capacity matters in this respect. If every year 50 GW of modules are produced, after one year these 50 GW will have a lasting impact on electricity systems around the globe. The next year, this will be 100 GW, the year after 150 GW, etc.

---

[90] European Photovoltaic Industry Association (2014: 39), "Global Market Outlook For Photovoltaics 2014-2018"

[91] Deutsche Bank Markets Research (2015: 32), "Crossing the Chasm", Industry: Solar (27 February); Morgan Stanley (2014: 4), "Solar Power & Energy Storage: Policy Factors vs. Improving Economics"; Morgan Stanley Blue Paper; Citi Research (2013: 18), "Launching On The Global Solar Sector"; Fraunhofer ISE (2015: 19-20), "Photovoltaics Report", version of 26 August 2015.

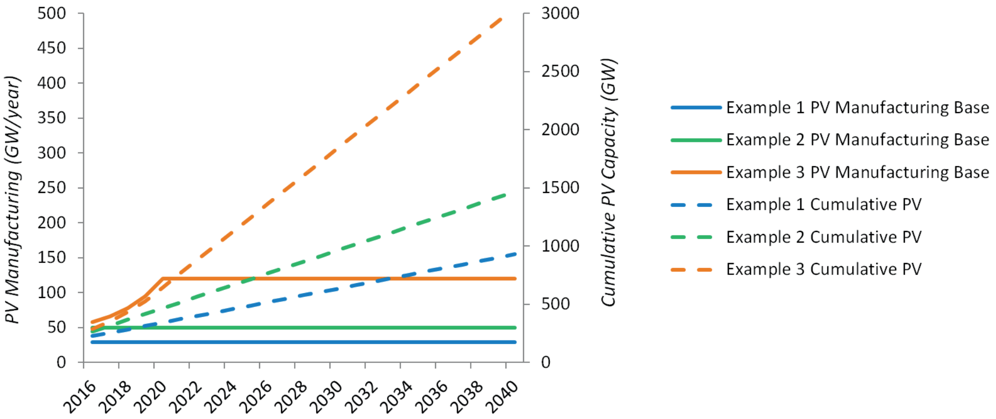


FIGURE 15. RELATIONSHIP BETWEEN PV MANUFACTURING AND CUMULATIVE INSTALLED PV[92]

In its World Energy Outlook 2014, the IEA is more conservative, as it expects global installed solar PV to reach 930 GW by 2040, up from 98 GW in 2012[93]. This is reflected in Example 1 in Figure 15. A PV manufacturing base of about 30 GW/year would then suffice, not accounting for potential decommissioning of existing PV capacity.

Given the present size of the solar PV manufacturing base, such a projection seems conservative. When assuming no substantial growth of the manufacturing base beyond 50 GW, 25 years of PV manufacturing at a level of 50 GW/year would add 1250 GW, leading to cumulative PV manufacturing approaching 1500 GW in 2040. This is reflected in Example 2 in Figure 15.

The reality of the past years has not been stagnant PV manufacturing, but rather significant growth. Fraunhofer ISE reported a growth rate of 50 percent each year over the 2000-2013 timeframe[94]. Estimates for the 2013-2015 timeframe are substantially lower at 20 percent, and expectations for the period 2015-2020 are at 17 percent per year. Even so, this slowing of growth would still imply a PV manufacturing base of around 120 GW/year by 2020. In Figure 15 this is represented by Example 3, leading to more than 3000 GW of cumulative installed PV capacity by 2040. From this example the effect of growth of the PV manufacturing base

---

[92] The figure shows cumulative installed capacity. Installed PV capacity may potentially be decommissioned after 20 or 30 years, which implies that the installed PV capacity in power systems may in fact be somewhat lower.

[93] IEA (2014: 608). "World Energy Outlook 2014".

[94] Fraunhofer ISE (2015: 19), "Current and Future Cost of Photovoltaics: Long-term Scenarios for Market Development, System Prices, and LCOE of Utility-Scale PV Systems".

becomes clear; an example showing growth after 2020 is not included, but the effect of further growth is not difficult to imagine.

To place these figures in perspective, global demand for electricity worldwide is projected by the IEA in its New Policies Scenario to be 34,887 TWh in 2040[95]. Theoretically, this demand could be satisfied by approximately 4,000 GW of generation capacity producing baseload[96]. In reality this demand is generally higher during daytime hours, requiring more capacity to produce electricity at those moments and less during the night-time[97]. Moreover, due to its relatively low load factor, PV capacity can only reach its maximum output for a limited number of hours. Nevertheless, what this calculation illustrates is that the scale of global PV manufacturing has become substantial in relation to the scale of the global electricity supply system.

THE ABSORPTION CAPACITY OF POWER MARKETS

While energy analysts must recognise the significance of the scale of PV manufacturing, they must also be aware of limitations to the adoption of PV in electricity markets. Even while costs of PV modules may come down further, the user value of PV modules can be affected by the amount of PV already installed in a power system. Even with fairly low amounts of solar PV electricity being generated over the course of a year, the absorption capacity of power markets for more PV can become a consideration.

As so often is the case, Germany is interesting in this regard. In 2013, generation from PV was 31.0 TWh, while total German *electricity* consumption was 529.2 TWh[98]. Total final *energy* consumption was 2527 TWh[99]. The share of PV in Germany *electricity* mix was thus 5.9 percent, while the share of PV in Germany's total final *energy* mix was about 1.2%.

Now imagine five times as much PV electricity in Germany's energy market. Theoretically, that could lead to a share of 6 percent of PV electricity in the final *energy* mix, while it could constitute some 30 percent of PV electricity in the final

---

[95] IEA (2014: 206). "World Energy Outlook 2014".

[96] 4000 GW of generation capacity producing 8760 hours in one year (that is, all hours in a year, thus baseload) would result in 4000 * 8760= 35 040 000 GWh = 35 040 TWh of electricity.

[97] In technical terms, 'system load' fluctuates from minute to minute.

[98] Data from Bundesministerium für Wirtschaft und Energie (BMWi). Retrieved 15 September 2015 at http://www.bmwi.de/DE/Themen/Energie/Strommarkt-der-Zukunft/zahlen-fakten.html.

[99] 2527 TWh equals 217.3 mteo. Eurostat data. Retrieved 15 September 2015 at http://ec.europa.eu/eurostat/statistics-explained/index.php/Consumption_of_energy.

electricity mix. However, PV electricity is generated only at certain hours of the day. Moreover, generation from PV across continents is highly correlated; when it's daytime in Italy, it's also daytime in France and Spain. This implies that the electricity system can be saturated with solar energy at some moment in time, while there is hardly any solar electricity available at other times.

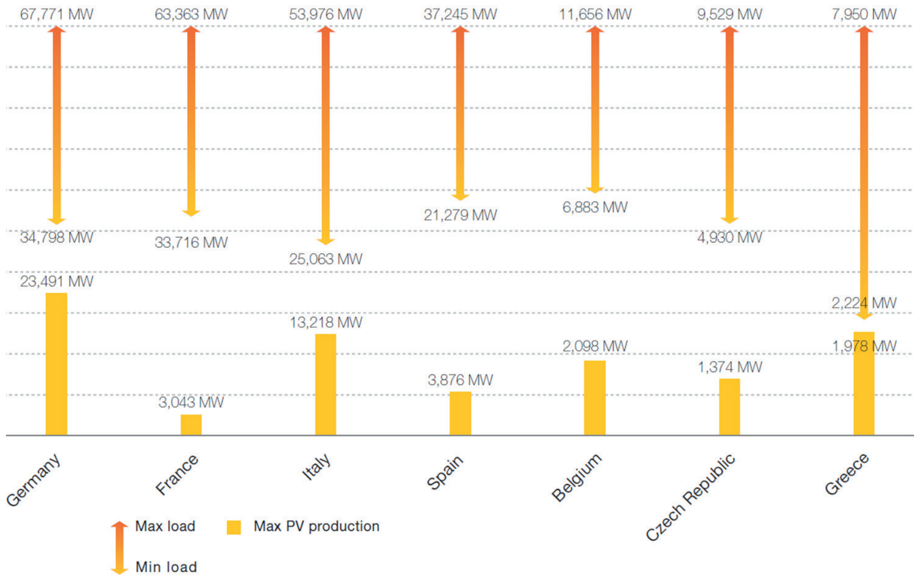


FIGURE 16. MAXIMUM PV PRODUCTION AND COUNTRY LOAD PROFILE IN 2013 (EPIA, 2014)[100]

Coming back to the German case, multiplying the amount of PV electricity by five could turn out to be a challenge. The maximum output of the installed PV capacity in Germany in 2013 was 23.5 GW[101]. Five times as much PV capacity would imply a maximum output of 117.5 GW. At the same time, Figure 16 shows that German demand ('system load') generally fluctuates between 34.8 GW and 67.7 GW. Multiplying the amount of PV would therefore lead to substantial surpluses of electricity from time to time. At the same time, the share of PV in Germany's final energy mix would still be a mere 6 percent. This illustrates the challenge that lies ahead; the drive for electrifying other parts of the energy economy and increasing electricity demand ('system load') can be understood in this context.

---

100 European Photovoltaic Industry Association (2014: 53), "Global Market Outlook for Photovoltaics 2014-2018".

101 Even though the installed PV capacity was 36.3 GW, maximum output was 23.5 GW.

While the typical generation profile of PV can be a technological challenge for grid operators, it can potentially be even more of an economic challenge to PV businesses. Even while PV module costs may decline further, the user value of PV modules may be restricted by a limited absorption capacity of electricity markets for PV. Power prices are likely negatively affected during hours at which large amounts of PV electricity enter the market, weakening the business case for market-based PV capacity additions.

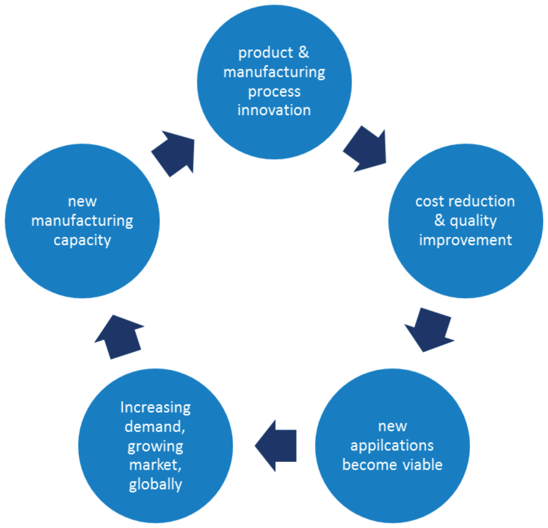


FIGURE 17. MARKET GROWTH AND PRODUCT & MANUFACTURING PROCESS INNOVATION

According to the learning curve hypothesis, cost reductions for PV result from every doubling of cumulative installed PV capacity. This is often referred to as the Swanson Effect. Parallels are frequently drawn with the computer semiconductor industry, which has shown dramatic growth for decades. Computer chips have improved and become cheaper, making new applications in new fields viable, opening up new markets, and creating opportunities for continued growth. Only the future can tell for how long the solar industry can maintain the cycle depicted in Figure 17. If PV applications are mainly to be found in electricity supply systems, the industry may be confronted with a limited absorption capacity of power markets for PV. The question to be answered therefore is: how do the solar PV learning curve, future growth of PV capacity, cost reductions, and electricity market developments relate to each other? Will PV user value be structurally higher than PV costs? Or will the point be reached relatively soon at which user value in relevant markets worldwide will fall below PV manufacturing costs, inhibiting further growth of PV?

The analysis in this section suggests is that it is crucial to understand the relationships between PV capacity, the electricity system, and the wider energy system. Electricity storage can increase the absorption capacity of electricity markets for PV. Recent product announcements including Tesla's home battery (the Tesla Powerwall) can be welcomed in this respect[102]. However, it is important to keep in mind that most of PV capacity in today's major markets is not residential solar, but larger-scale systems; the business case for incorporating batteries in large systems is significantly more challenging than for applications in the residential market[103].

For PV to play a significant role in the wider energy system, innovation in energy conversion technologies and proper interaction between electricity infrastructure and other energy infrastructures such as heat networks and gas grids may therefore prove to be essential. In a 2011 study, Fraunhofer IWES identified substantial storage potential in existing gas infrastructures[104]. In the same vein, more recently, ADEME identified storage in gas infrastructure as one of the elements contributing to achieving a renewable electricity system in France by 2050[105]. The limited absorption capacity of electricity markets for solar PV could in fact contribute to an increased focus of businesses and governments on introducing conversion technologies that result in solar PV manufacturing impacting other parts of the energy system.

SOLAR PV MANUFACTURING AND GOVERNMENT

Although it is crucial for upstream as well as downstream PV businesses to understand limitations to the absorption of PV in power markets, it is important to recognise dynamics in the upstream PV industry, as briefly mentioned in the first section of this chapter. It should be understood that it is not only global supply and demand that determines the amount of PV modules flowing into global markets, it is also government. The future of the upstream industry is not determined solely by manufacturing cost levels in a global competitive pricing environment, but also by industrial policies, the creation of and support for industrial sectors, and the protection of domestic industries. This has been the situation in recent years and can be expected to be the case in coming years, and the protection of domestic industries (consider Box 1 and 2 for two remarkable examples in India and the US).

[102] See the PowerWall product page at the website of Tesla. Retrieved 8 October 2015 at http://www.teslamotors.com/powerwall.

[103] In Germany and Italy, around 1/5th of the installed PV capacity is residential solar; most PV capacity is part of larger-scale systems. PV capacity in Germany and Italy represented approximately 2/3rd of the installed capacity in the European Union in 2013 See Figure 19 in the Appendix for overview of European markets.

[104] Fraunhofer IWES (2011), "Energiewirtschaftliche und Ökologische Bewertung eines Windgas Angebotes", commissioned by Greenpeace Energy e.G.

[105] Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) (2015), "Vers un mix électrique 100% renouvelable en 2050".

The state of the global PV manufacturing industry in the past several years can be characterised as an industry with overcapacities. This in turn must be viewed in light of industrial overcapacities that existed in a range of sectors in China, very well described in the Financial Times Article *China Zombie Factories Kept Open to Give Illusion of Prosperity*[106]. Overcapacities tend to result in a low price environment, and the Wall Street Journal reported this accordingly in the article *China Exports Come With Low Prices*[107]. While overcapacities could thus be observed in a range of sectors, they were quite obvious in the Chinese solar industry. In 2013, Zhang et al. described overcapacities in PV module manufacturing as well as in wind turbine manufacturing[108]. A senior Chinese energy official argued that PV manufacturers in China were like a patient on life support[109]. Unsurprisingly, in 2012 the Wall Street Journal reported high debt among Chinese solar companies in China, and in 2014 it reported consolidation and a shake-out in the sector[110].

The strategic importance of the PV industry was not only recognised by China. India adopted a target of having 100 GW of PV installed by 2022[111]. The CEO of India-based Tata Power Solar stated that a local content requirement was unofficially part of the government's commitment; one quarter of the installed capacity is supposedly to be sourced from Indian manufacturers[112]. A recent announcement by China-based Trina Solar can be understood in this light. Trina Solar revealed its intention to realise the largest PV manufacturing facility ever – a 2 GW/yr facility is planned to be constructed in India[113]. By doing so, Trina Solar can both supply modules to the domestic Indian market and export modules to the US and EU without being confronted by import duties on Chinese modules.

BOX 1. PV MANUFACTURING IN INDIA AND THE TRINA SOLAR 2 GW/YR INITIATIVE

---

[106] Financial Times (28 December 2014), "China Zombie Factories Kept Open to Give Illusion of Prosperity".

[107] Wall Street Journal (13 January 2015), "China Exports Come With Low Prices".

[108] Zhang, S., Andrews-Speed, P., Zhao, X., & He, Y. (2013: 347-348)."Interactions between renewable energy policy and renewable energy industrial policy: Acritical analysis of China's policy approach to renewable energies". *Energy Policy 62*, 342-353.

[109] Financial Times (18 October 2012), "China's solar industry 'on life support'"

[110] Wall Street Journal (30 November 2014), "Debt Cloud Hangs Over Chinese Solar Industry"; Wall Street Journal (30 November 2014), "Debt-Mired GCL-Poly Energy to Sell Solar Factories".

[111] Financial Times (6 November 2014), "India Targets Renewables in $250bn Power Plan".

[112] PV Magazine (4 February 2015), "Quarter of India's 100 GW PV Target to be Locally Sourced, Official Claims".

[113] Forbes (22 June 2015), "Why Trina Solar Is Building Manufacturing Capacity in India".

If global supply and demand balances had been the only determining elements for the future of the PV industry, those years would have been particularly challenging. In its 2013 report *Launching on the Global Solar Sector*, Citi Bank reported on overcapacities and identified a range of manufacturers at risk, as their *cash costs* of production were above PV module prices of the moment[114]. Cash costs of PV manufacturing (as in mining industries) include most notably the costs of operations (including poly-silicon feedstock), but not depreciations and amortisations (resulting from past investments). Indeed, if PV prices fall below the cash cost of production, it makes sense to shut down production.

While such a price environment is challenging for existing manufacturers, it is even more difficult for new entrants seeking market share. Building a new manufacturing facility only makes sense if not just *cash costs* are recovered, but also the investment in the new plant (CAPEX). Only significant innovation and cost reductions for new technologies would make an investment attractive.

This is the point where government comes in. As pointed out, as demand in its export markets fell, China began to implement policies to absorb a significant amount of PV modules itself, greatly in line with the push-and-pull strategy mentioned in the first chapter[115]. Global PV upstream businesses clearly struggled in this price environment[116]. Both the United States and the European Union introduced import tariffs in order to shield their markets from Chinese overcapacities and low-priced exports, as was explained in the first chapter. Although duties on Chinese imports were recently lowered in the US, import tariffs are still in place[117].

The flip side of the same coin was a move by France in 2013 in which it adopted a feed-in tariff that included a bonus for PV modules produced in the European Union (i.e., it included a local content requirement). Interestingly, around that time French electric utility EDF revealed plans to construct a PV manufacturing plant after acquiring French-based solar company Photowatt[118].

---

[114] Citi Research (2013: 15, 19), “Launching On The Global Solar Sector: The Sun Will Shine But Look Further Downstream”.

[115] For an interesting insight in the manner in which China started to absorb part of its domestically produced PV capacity, consider the report by Dutch public broadcaster NOS (30 December 2014), “Zonnepanelen Tegen Armoede in China”.

[116] Financial Times (9 January 2013), “China solar industry aims to shine out”.

[117] Bloomberg (6 January 2015), “U.S. Solar Tariff Review Hints at Halved Chinese Cells Rate”; Bloomberg (5 June 2015), “Three China Solar-Panel Groups Lose EU-Tariff Exemptions”; Bloomberg (9 July 2015), “US Revises Tariffs and Duties on Chinese Solar Imports”.

[118] PV Magazine (4 February 2013), “France Publishes PV FIT Bonus Details”.

While it could be tempting to think that the US adopts a laissez-fair market approach, the aforementioned import duties on Chinese imports suggest the contrary. It may have provided impetus to a remarkable announcement in June 2014 by SolarCity[119]. SolarCity stated it planned to acquire high-efficiency solar manufacturer Silevo, in order to take hold of its technology, and to subsequently develop a 1 GW/year manufacturing plant in Buffalo in New York State[120]. The initiative seems to be framed in terms of creating manufacturing jobs in a deprived region; CNBC reports that New York State is granting a subsidy and seeks ownership of the plant, while SolarCity commits itself to investing heavily in the region[121]. So even though the 1 GW/year facility is a market-based initiative by a significant downstream solar PV business, governments clearly play their part in this potentially significant increase in global PV manufacturing capacity.[122]

BOX 2. PV MANUFACTURING IN THE US AND THE SOLARCITY 1 GW/YR INITIATIVE

By the second half of 2015 about a tenth of Chinese PV production had been relocated to other countries, with the aim of circumventing import duties in the EU and US[123]. To a large extent, relocations happened in Asia[124]. Yet Dutch-based Solland Solar, subsidiary of Italian PV company Pufin Power, announced in July 2015 that it would manufacture modules for China-based Trina Solar, destined for the US market. By producing in the EU, Trina Solar can circumvent US import duties levied on Chinese modules[125]. However, Solland Solar filed for bankruptcy one month later[126]. Trina Solar is yet exploring other ways to serve the US market, as was mentioned in Box 1.

While some production is truly relocated, a fierce battle continues over alleged re-exports of Chinese modules from other Asian countries into the European Union[127]. For many countries and regions, domestic manufacturing of PV modules

---

[119] Wall Street Journall (18 September 2014), “The Musk Family Plan for Transforming the World's Energy”.

[120] Greentech Media (16 January 2016), “First Solar Now Officially in the Silicon PV Production Business”.

[121] CNBC (11 June 2015), “Elon Musk's Biggest Challenge Yet: Recharging Buffalo, NY”.

[122] More generally, one could argue there’s an environment supporting the PV manufacturing in the United States. See Massachusetts Institute of Technology (2013: 12), “A Duel in the Sun: The Solar Photovoltaics Technology Conflict between China and the United States”.

[123] PV Magazine (15 July 2015), “Tenth of Chinese Solar Production Capacity Located Overseas by End of 2015”.

[124] In this respect, it is interesting to see the remarkable growth of PV manufacturing activity in Taiwan in recent years, as can be observed in Figure 8 in the first chapter of this publication.

[125] Energeia (15 July 2015), “Anti-dumpingbeleid Pakt Goed Uit voor Solland Solar”.

[126] PV-Tech.org (26 August 2015), “Trina Solar’s purchase of cells from Solland Solar in doubt with supplier bankruptcy”.

[127] EurActiv.com (1 June 2015), “EU reopens China solar dumping probe”.

matters. Debates have been going on in Europe for years, and a battle is currently being fought between the US and China[128].

THE SUPPLIERS OF PV MANUFACTURING EQUIPMENT

The (economic) lifetime of a PV manufacturing plant can be as short as 5 years, whereas it takes only about 1.5 years to set up a new manufacturing plant. With a wide range of PV innovations in the pipeline to be implemented in mass production, this provides seemingly fertile ground for further PV module quality improvements and cost reductions[129]. The capabilities of suppliers of solar PV manufacturing equipment are relevant to consider here.

Box 3 provides some insight into the role of such companies, which are based in a range of countries, including Switzerland, Germany, the United States, and China. These businesses sell manufacturing machines and turnkey PV manufacturing lines to PV manufacturers and can be expected to be most successful if they offer manufacturing equipment for competitive prices. In other words, they must enable the buyers of the equipment to manufacture PV modules at a competitive cost level.

Either strategic reasons or employment considerations likely played a role in a wide range of announcements of new PV manufacturing capacity around the world, often serving domestic markets. In Brazil, S4 Solar do Brazil started the construction of a 100 MW/year assembly line in 2014; manufacturing equipment is supplied by Swiss group Meyer Burger, but also by China-based Confirmware and Jinchen Machinery Co[130]. Also in Brazil, in 2015, developer Desert Solar Systems and Renovasol engaged in a partnership with solar equipment manufacturer Thoma; Germany-based Thoma is to supply a turnkey manufacturing plant[131].

In Argentina, energy provider Energeia Provincial Sociedad del Estado engaged in a partnership with German-based Schmid Group; in early 2015 Schmid Group began delivering systems for the production of ingots, wafers, solar cells and modules[132].

---

[128] Massachusetts Institute of Technology (2013), "A Duel in the Sun: The Solar Photovoltaics Technology Conflict between China and the United States".

[129] The US National Renewable Energy Laboratory (NREL) keeps track of available solar PV technologies and publishes progress on efficiencies on a regular basis. See Figure 18 in the Appendix.

[130] PV Magazine (21 August 2014), "S4 Solar to build 100 MW module assembly plant in Brazil".

[131] PV Magazine (19 January 2015), "Thoma plans Brazilian production line

[132] Solar Novus Today (22 January 2015), "Photovoltaic Manufacturing Plant Progresses in Argentina".

In 2014, South-African thin-film manufacturer PTiP engaged in a partnership with German-based Singulus, which is envisioned to culminate in a 100 MW/year manufacturing plant for CIGS thin-film modules in South Africa[133]. In Russia, Russian PV company Hevel initiated a 100 MW/year project delivering thin-film modules in 2014; Hevel, subsidiary of Russian energy companies Rusnavo and Renova, envisions 500 MW/year of manufacturing capacity by 2020[134]. Also in 2014, China-based power equipment manufacturer Amur Sirius announced plans to set up PV manufacturing facilities in Samara, Volgograd and Stavropol, totalling some 100 MW/year of manufacturing capacity by 2016[135].

Solar PV has also been clearly embraced by the rulers of Saudi Arabia; the Kingdom envisions having 41 GW of installed PV electricity capacity by 2032[136]. At the same time, the country seeks to diversify its economic base, including industrial development of new sectors, and the potential of domestic PV manufacturing was identified as an option[137]. Unsurprisingly, in 2015 the Al-Afandi Group started the development of a 110 MW/year PV manufacturing facility, partnering with US-based PV Tech Group and Avid Engineers, as well as Saudi-based DAR Engineers[138].

BOX 3. PV MANUFACTURING INITIATIVES AROUND THE WORLD AND EQUIPMENT SUPPLIERS

PV advocates have been arguing in favour of building up a new PV manufacturing base in Europe and. For instance, the *European Gigawatt Fab* initiative sketched the possibilities of revitalising the European photovoltaic industry. Perhaps most illustrative is the statement that *'Europe needs big players in the Photovoltaic Industry'*[139]. Also the European Commission has been exploring this theme[140].

---

[133] PV Magazine (3 February 2014), "Hopes for a CIGS boom in South Africa".

[134] PV Magazine (2 March 2015), "Russia: Hevel launches first full-cycle PV module factory".

[135] PV Magazine (30 June 2014), "Chinese group looking for partners to develop solar projects in Russia".

[136] In 2015, however, it was announced that the plans were delayed. See: Bloomberg (20 January 2015), "Saudi Arabia Delays $109 Billion Solar Plant by 8 Years"; PV Magazine (28 October 2014), "Solar power key for Saudi future, says energy chief".

[137] King Abdullah University of Science and Technology (2009: 45), "Saudi Arabia Solar Energy: Manufacturing and Technology Assessment".

[138] Electric Light & Power (31 March 2015), "Design firm plans 110 MW solar power project in Saudi Arabia"; CleanTechnica (9 April 2015), "Work Set To Begin On Saudi Arabia's First Solar PV Module Manufacturing Facility".

[139] European Gigawatt Fab (27 January 2015), "Need and opportunities for a strong European Photovoltaic Industry - The xGWp Approach". Presentation by xGWp to the Round Table of the European Forum for Science and Industry, Brussels, 27 January 2015. Retrieved 8 October 2015 at https://ec.europa.eu/jrc/sites/default/files/20150127-efsi-roundtable-pv-industry-support-weber.pdf. It is relevant to ad that, in cases in China, lenders have allowed for longer payback times up to 10 years; in the European environment, however, this not the norm.

[140] Source: personal communication with prof. dr. W.C. Sinke, Faculty of Science, Institute of Physics, University of Amsterdam (UVA).

Box 3 demonstrates that the knowledge base is present in Europe; a range of European companies and groups supply manufacturing equipment and turnkey production lines to interested parties across the globe.

The Massachusetts Institute of Technology concluded that China's advantage was primarily the result of scale and supply-chain development and not so much of country-specific advantages[141]. The IEA argues that labour costs are a relatively minor factor in PV manufacturing; other factors such as energy costs and the availability of low cost capital matter more[142]. It remains to be seen, though, whether Europe or EU member states will adopt a strategic approach to the PV industry, but this would indeed fit a pattern that can be observed around the world.

What follows from the developments sketched in the previous section is that new manufacturing capacity can be expected to continue to be added to the global PV manufacturing base – not exclusively driven by global supply and demand balances, but also by government policies promoting domestic PV manufacturing. The capabilities of solar PV manufacturing equipment suppliers to deliver are a relevant factor here. Logically, this can be a challenge for incumbent PV manufacturers, as they may be structurally confronted with a well-supplied global solar PV market.

CONSOLIDATION AND VERTICAL INTEGRATION?

As was shown in the first chapter, the PV manufacturing industry is not very concentrated; a wide range of manufacturers is active. Some of them may not be competitive at present, due to the significant module price declines in recent years. The number of Chinese manufacturers is relatively high, and some of them are struggling. This could provide impetus for consolidation in the PV manufacturing industry.

Meanwhile, poly-silicon supplies seem to go through commodity boom-and-bust-cycles. A period of high prices for poly-silicon was followed by a low-price environment, which may have hindered new poly-silicon capacity additions, which may in turn lead to a new high-price environment. A range of poly-silicon suppliers went bankrupt in recent years, leaving only a limited number of major suppliers in the market[143]. The poly-silicon market is fairly concentrated.

---

[141] Goodrich, A. C., Powell, D. M., James, T. L., Woodhouse, M., & Buonassisi, T. (2013). "Assessing the drivers of regional trends in solar photovoltaic manufacturing". *Energy & Environmental Science,* 6, 2811-2821; and personal communication with prof. dr. W.C. Sinke, Faculty of Science, Institute of Physics, University of Amsterdam (UVA).

[142] IEA (2014: 11), "Technology Roadmap Solar Photovoltaic Energy", 2014 Edition.

[143] Deutsche Bank Markets Research (2015: 29), "Crossing the Chasm", Industry: Solar (27 February).

A PV manufacturer that has a window of some 5 years to earn back the investment in a new manufacturing facility risks being confronted with a high-price environment for its poly-silicon feedstock, while incumbent manufacturers may have locked-in lower prices. In other cases, new entrants may benefit from low-cost feedstock while incumbents are locked in high-priced contracts[144]. An appropriate hedging strategy for poly-silicon supply risks may prove to be essential for PV manufacturers. Also, some PV manufacturers may pursue upstream integration into poly-silicon production, so to ensure access to the strategic feedstock of poly-silicon.

Similar strategic challenges may emerge for the downstream PV industry, i.e., businesses that offer PV products to consumers and businesses that are involved in PV electricity generation projects. For the downstream PV industry, PV modules are strategic goods. A downstream business is more likely to outperform its competitors when it has access to low-cost PV modules. Hence, here as well some companies may pursue upstream integration. The move by SolarCity, described in Box 2, can be viewed in this light; SolarCity intends to utilise the output of the 1 GW solar PV manufacturing plant in Buffalo for its own project portfolio, mostly in the US.

While the global PV downstream industry is very fragmented at present and differs significantly from one country to another, some champions may eventually emerge. A number of fairly large players are active in the US; some of them are exploring the potential in overseas markets. SolarCity, for instance, offers micro-grid solutions worldwide[145], and US-based Sungevity is active in the European market through partnerships with utility E.On in the United Kingdom, Germany, and the Netherlands[146].

A particular challenge to downstream PV businesses is subsidy-induced boom-and-bust cycles. A few years of generous public support schemes for PV could oversize a national PV industry, while a cut-down in subsidies later can subsequently pose a

---

[144] Fraunhofer ISE (2013: 26), “Levelised Cost of Electricity - Renewable Energy Technologies”.

[145] SolarCity Press Release (16 May 2015), “SolarCity Launches Microgrid Service, Available Worldwide”. Retrieved 12 August 2015.

[146] E.ON UK Press Release (29 July 2015), “E.ON and Sungevity join forces to offer residential solar panel systems with 20 year ‘SunSure’ guarantee”; Greentech Media (12 May 2015), “Sungevity Partners With E.ON in Germany to Scale Residential Solar”; Sungevity Nederland Press Release (4 June 2014), “Sungevity en E.ON starten samenwerking in Europa voor uitbreiding zonne-energie”.

threat to it. Germany may be illustrative[147]. Downstream PV businesses worldwide need to be capable of managing regulatory change in individual markets, suggesting that global solar downstream champions may eventually emerge which are capable of managing risks in individual markets through geographic diversification.

---

[147] Also see Figure 7 for the sharp decline in PV capacity additions in Germany in recent years. After several years of large capacity additions, offering great opportunities for downstream PV players, German demand for new PV plants declined significantly, posing a challenge to a range of businesses active in the market. German PV wholesale Energiebau, for instance, was filed for insolvency in 2015; in a new report, the company's founder Schäfer mentioned the difficult market environment. See PV Magazine (7 January 2015), "Germany: Innotech Solar buys Energiebau"; and see PV Magazine (7 January 2015).

CONCLUSION

The 2014 CIEP Report *Sunset or Sunrise? Electricity Business in Northwest Europe* explored the struggle of Northwest European utilities in today's power market environment[148]. In that publication, it was argued that the challenge for utilities is to transform their business models while carrying legacy assets that serve the public interest by contributing to the security of electricity supplies, but for which, at present, the business case is very weak. Past years were characterised by write-downs and depreciations; balance sheets are weak and some utilities in the region are indebted.

Utilities in the region presently embrace offshore wind energy in the North Sea region, which is firmly financially supported through publicly funded feed-in tariffs, contracts-for-difference, or feed-in premiums. This raises the question as to how this technology's cost development path relates to the solar PV value chain explored in this report. The proof of the pudding will be in the eating. In the coming years, many tenders for new capacity in the region will reveal the cost of offshore wind energy. Crucially, if innovation and cost reductions in the offshore wind energy industry cannot keep pace with developments in the solar PV value chain, the focus of regional public policy makers on offshore wind may turn out to have shorter horizon. The question is whether utilities are currently preparing themselves sufficiently for such (distributed) electricity generation.

One could argue that this should not merely be a consideration for utilities, but for public policy makers as well. Is the regulatory framework for electricity markets ready for a significant amount of distributed generation? Market-based coordination of investments (which came with market liberalisation and unbundling) requires functioning markets and proper price signals. Time signals are important in encouraging investments in the right technologies, including technologies for backup electricity generation and storage; locational signals are also essential for ensuring the right balance between investments in transmission and distribution grids on the one hand, and investments in electricity generation on the other. If it proves impossible to create a market with price signals that truly reflect local supply and demand balances throughout the day, the coordinating role of grid operators may need strengthening through other means.

---

[148] Stapersma, P. (2014), "Sunset or Sunrise? Electricity Business in Northwest Europe", The Hague, Netherlands: Clingendael International Energy Programme (CIEP).

PV costs have declined substantially faster than anticipated by many and are today below the levels projected for 2030 at the time the European Commission presented its 2nd Strategic Energy Review in 2008[149]. The main message of this report is that energy analysts need to better understand the manufacturing dynamics of the upstream PV industry. The capabilities of suppliers of PV manufacturing equipment to incorporate new PV technologies in production and assembly lines, combined with a worldwide appetite of governments to build domestic PV manufacturing capabilities, contributed to PV manufacturing growth, innovation, and cost declines.

While it is speculative to predict future growth rates for the solar PV manufacturing base, its present order of magnitude, approximating 50 GW/year, is already structurally changing markets. 25 years of manufacturing at such a level would lead to an installed PV capacity that is larger than projected by the IEA in its New Policies Scenario for 2040. As was demonstrated in the previous chapter, further growth of the PV manufacturing base could lead to a globally installed PV capacity multiple times the amount projected by the IEA in its New Policies Scenario for 2040.

While energy analysts must be aware of this, they must also be aware of the limitations to the absorption capacity of electricity markets for PV. The generation profile of PV implies that significant amounts of solar electricity enter the market at the same time of the day. So even though the share of solar PV electricity in total annual energy consumption may still be limited, adding more solar PV capacity to the electricity system may be challenging without large-scale electricity storage and proper interaction with other energy infrastructures such as gas grids and heat networks.

Crucially, a limited absorption capacity of electricity markets for PV could result in an increased focus of businesses as well as governments on introducing energy conversion technologies that enable PV to play a role in other parts of the energy system; once such technologies gain a foothold, global PV manufacturing dynamics, as described in this report, can be expected to become as relevant for those parts of the energy system, as they are for electricity markets today.

---

[149] European Commission (2008: 4-5), "Commission Staff Working Document accompanying the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Second Strategic Energy Review"; and COM (2008), "EU Energy Security and Solidarity Action Plan: Energy Sources, Production Costs and Performance of Technologies for Power Generation, Heating and Transport", retrieved 5 March 2015 at https://ec.europa.eu/jrc/sites/default/files/strategic_energy_review_wd_cost_performance.pdf

APPENDIX – ADDITIONAL FIGURES

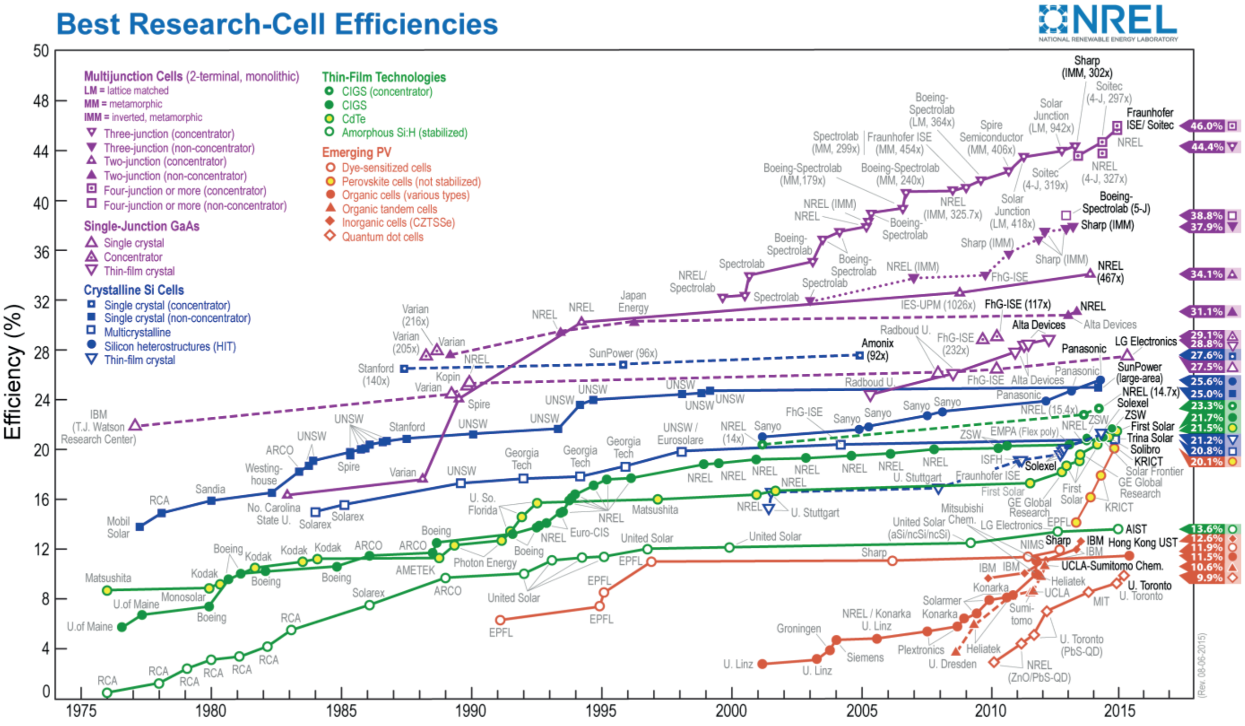


FIGURE 18. BEST RESEARCH-CELL EFFICIENCIES (NREL, 2015)[150]

---

[150] Figure available at the website of the National Renewable Energy Laboratory(NREL). Retrieved 7 October 2015 at http://www.nrel.gov/ncpv

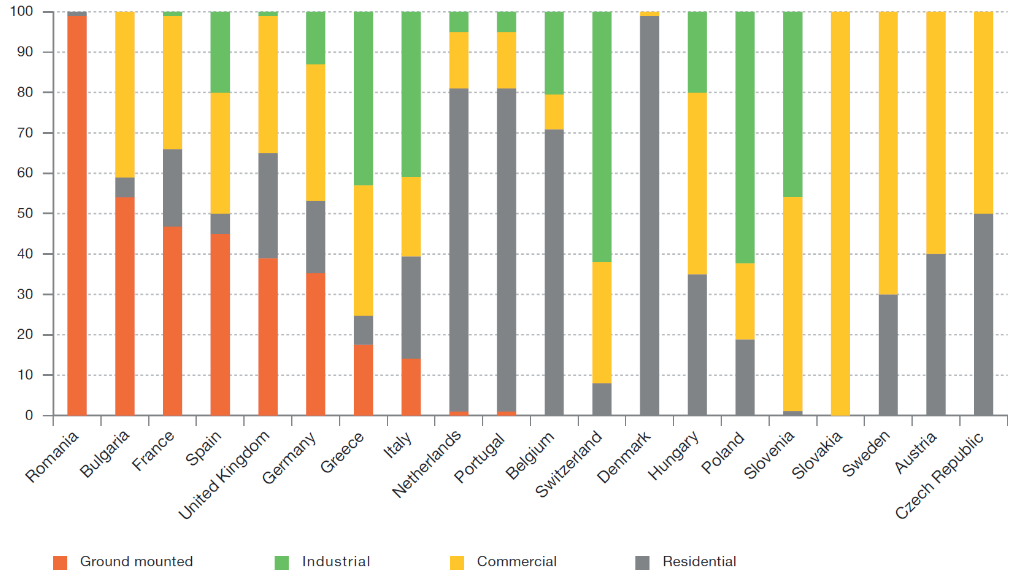


FIGURE 19. EUROPEAN PV MARKET SEGMENTATION BY COUNTRY IN 2013 (EPIA, 2014)[151]

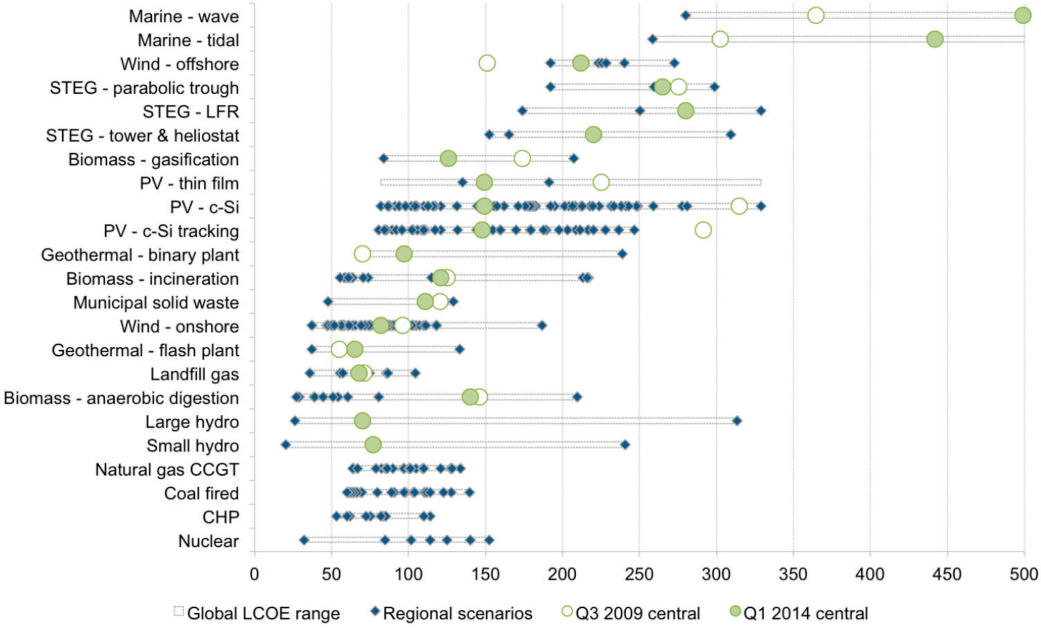
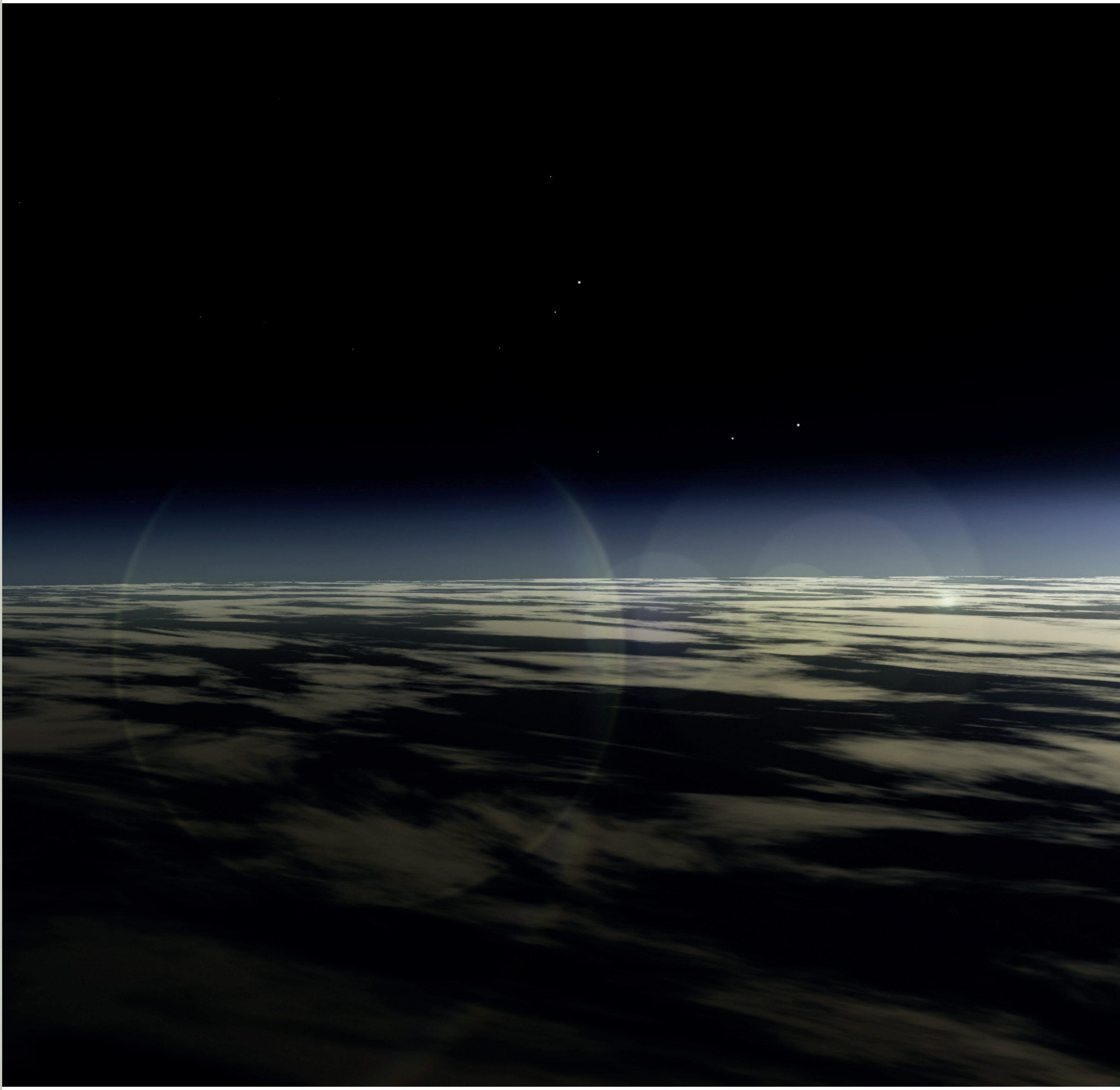


FIGURE 20. LEVELISED COST FOR GENERATION TECHNOLOGIES ($/MWH) (BNEF, 2014)[152]

---

151 European Photovoltaic Industry Association (2014: 28), "Global Market Outlook For Photovoltaics 2014-2018"

152 FS-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, & Bloomberg New Energy Finance (2014: 37), "Global Trends in Renewable Energy Investment 2014".



CLINGENDAEL INTERNATIONAL ENERGY PROGRAMME | CIEP

VISITING ADDRESS
Clingendael 12
2597 VH The Hague
The Netherlands

POSTAL ADDRESS
P.O. Box 93080
2509 AB The Hague
The Netherlands

TEL +31 (0)70-374 67 00
www.clingendaelenergy.com
ciep@clingendaelenergy.com