SOLAR IS DRIVING A GLOBAL SHIFT IN ELECTRICITY MARKETS

Rapid Cost Deflation and Broad Gains in Scale

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Executive Summary

Solar energy is taking an increasingly prominent role in driving the ongoing transformation of global electricity generation markets alongside gains in storage, wind, hydroelectricity and energy efficiency.

The speed of this transformation is hard to grasp, particularly in the crucial China and India markets, but the results of 2017 are a good indicator of the trend.

Bloomberg New Energy Finance (BNEF) reports that 98 gigawatts (GW) of solar was installed globally in 2017, a 31% increase from the prior year.[1] Meanwhile - and just as important - the levelized cost of solar dropped 15% year-on-year to US$86/MWh for capacity installed in 2017.

Leading the charge, China accounted for more than half the newly installed solar capacity, or some 53 GW, a figure that as recently as 2014 would have eclipsed the global total of solar installations.

While India's current installation numbers aren't as dramatic as China's, India is clearly embarking on a massive transformation of its electricity sector as well. The country's 2018 National Electricity Plan, released in March, affirms national intentions to increase renewable energy capacity to 275 GW by 2027, with solar representing two-thirds of this total. As renewables rise in India, thermal power capacity is forecast to decline to just 43% of the nation's total in 2027, down from 66% today.

China and India are hardly alone on this front, as scores of other countries embrace solar. Saudi Arabia, for one, announced in March 2018 a plan to build 200 GW of solar capacity by 2030, yet another marker in the transition under way across global energy markets. The uptake of solar is gathering momentum too in Europe and the Americas.

The International Renewable Energy Agency published a report in January 2018 that concluded the following:

> *"Falling renewable power costs signal a real paradigm shift in the competitiveness of different power generation options. Continuous technology innovation remains a constant in the renewable power generation market."*[2]

The solar-sector details in the pages that follow illustrate this shift. Global energy markets are changing, and fast. Last year saw a number of new solar milestones set:

- Record low utility solar tariffs, with deflation over the last two years hitting 50% in a number of markets ranging from Chile and Mexico to India and Saudi Arabia.
- A 1,547 MW project at Tengger, China, set a record for the being largest operational solar project globally.
- India's push for development of "Industrial Solar Parks" has driven construction on a number of the world's largest utility scale solar projects, including the nearly complete 2,225 MW Bhadla solar industrial park in Rajasthan, and with the State of Gujarat looking to beat that with an April 2018 announcement to build a 5,000 MW project.
- A new world record for the largest floating solar installation, 150 MW in China.
- A step-change in the commercially deployed cost of concentrated solar power (CSP).
- Commissioning of the world's largest rooftop solar unit, of 19 MW in Punjab, India.

[1] http://fs-unep-centre.org/sites/default/files/publications/gtr2018v2.pdf
[2] http://irena.org/publications/2018/Jan/Renewable-power-generation-costs-in-2017

- A record high number of corporate power purchase agreements (PPA) of which an increasing number are incorporating solar.

BNEF reports that total new global solar installations reached 98 GW in 2017, a growth of 31% year-on-year. China surprised all energy expectations by installing a record 53 GW in 2017, 55% of the global total.

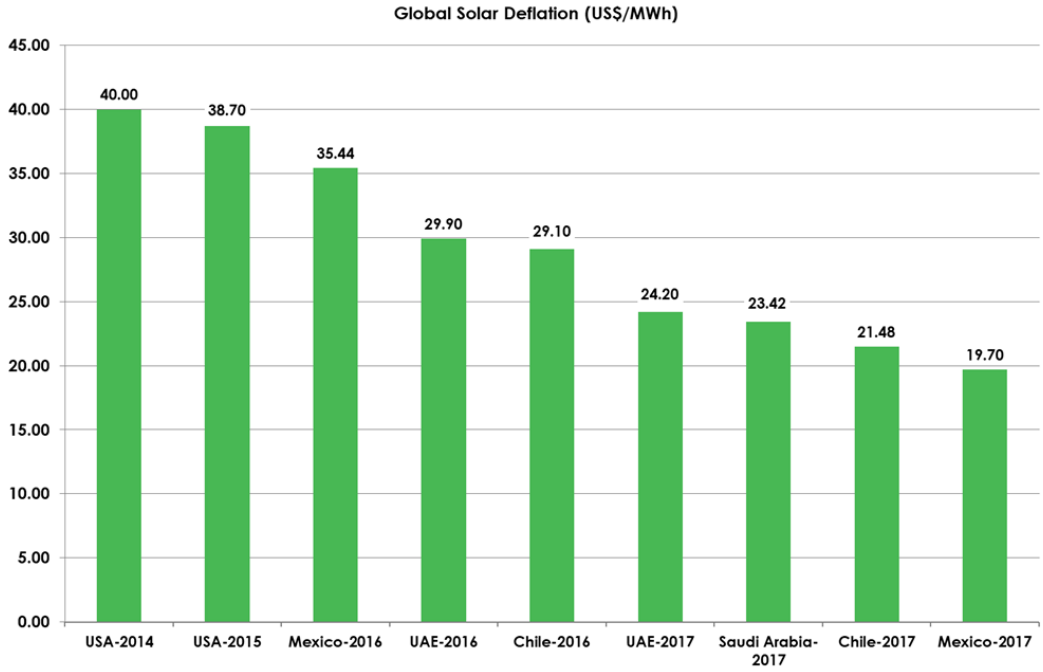
Cost deflation for PV solar and wind has been so extensive that it has created the risk that other renewable energy technologies, such as offshore wind and concentrated solar power (CSP), have already lost the race. However, gains in innovation and cost reductions are being increasingly being seen across a broad range of technologies.

As countries grapple with ever-higher shares of variable renewable energy generation, demand for system balancing will require a multitude of technology solutions including improved international grid connectivity, better demand response management, more pumped hydro storage, and appropriate system pricing signals to incentivise grid stability and peaking power supply. In this context, concentrating-solar technology and solar with storage have become increasingly valuable, cost-effective system tools.

What follows is an overview of solar expansion, illustrated through almost 100 examples of projects that are operational, under construction or in development.

Note: While this report describes many of the world's largest solar projects, it is not intended as a comprehensive review, in part because of limited access to verifiable information on Chinese companies, for instance. Nor does this report capture the full scope of the trend towards solar. It is meant, rather, as a snapshot in time of fast-moving technology and up-scaling, and illustrates the expanding geographic uptake of large scale solar investments. The authors invite email feedback that elaborates on special projects and that can help inform updates to this report.

Figure 1.1: Global Solar Price Deflation: New Record Lows Keep Being Set



Source: Press Articles, IEEFA estimates

1. World's Largest Operational Utility-Scale Solar Projects

A key rationale for this report is the rapid up-scaling of solar investment globally that is accelerating solar cost deflation beyond what any thought possible just two years ago.

India is one of the best examples of huge gains that have taken place in the last four years, and the importance of political leadership in framing long term energy policy. Following his election in 2014, Prime Minister Narendra Modi launched a renewable energy transformation of the country's electricity sector. By September of 2016, India had commissioned what was then the world's largest solar project, a 648 MW facility in Kamuthi, Tamil Nadu. China topped this record in 2017, opening the 1,000 MW Datang and the 1,547 MW Tengger solar projects.

By early 2019, India is expected to complete work on a 2,225 MW facility at Bhadla in Rajasthan (about a third of this plant is already operational), a project that will let India regain the title of having the world's largest solar installation.

More is on the way: In April 2018, Vijay Rupani, chief minister of Gujarat State, announced plans for a 5,000-MW solar park covering 11,000 hectares along the Gulf of Khambhat.[3]

Figure 1.1 below lists 14 of the largest solar projects globally that are commercially operational, with a focus on geographic diversity rather than highlighting just the largest projects overall, hence we have missed some Chinese and U.S. projects. Projects in India are featured in Section 1.2, while the other projects named here are described below.

Figure 1.2: Fourteen of the World's Largest Operating Utility-Scale Solar Projects

No	Project Name	Size (MW)	Country	Proponent
1	Tengger Desert Solar Park	1,547	China	China National Grid Zhongwei Power Supply Co.
2	Kurnool Ultra Mega Solar Park	1,000	India	Andhra Pradesh Solar Power Corporation Pvt Ltd
3	Datong Solar Power Top Runner Base	1,000	China	Multiple
4	Yanchi Ningxia Solar Park	1,000	China	Huawei Technologies Co
5	Longyangxia Dam Solar Park	850	China	State Power Investment Corporation (China)
6	Adani Kamuthi Solar Plant	648	India	Adani Green
7	Solar Star	579	USA	BHE Renewables
8	Topaz Solar Farm	550	USA	First Solar
9	Desert Sunlight Solar Farm	550	USA	NextEra Energy, GE Energy Financial & Sumitomo
10	Nova Olinda Solar Farm	292	Brazil	Enel Green Power
11	El Romero Solar Plant	246	Chile	Acciona Energy
12	De Aar Solar Farm	175	South Africa	Solar Capital
13	Solarpark Meuro	166	Germany	GP Joule
14	EA Solar Lampang	128	Thailand	Energy Absolute Public Company Ltd

Source: Company & Press reports, IEEFA estimates

[3] https://www.pv-tech.org/news/indias-gujarat-approves-5gw-solar-park

Tengger Desert Solar Park, 1,547 MW, China

This 1,547 MW solar project near Zhongwei City, Ningxia, is located on the southern edge of the Tengger Desert. It was developed by China National Grid Zhongwei Power Supply Company starting in 2012 as an industrial park involving a reported 45 grid-connected projects commissioned progressively over 2011-2017.[4] BNEF reports that owners and developers include Tianyun New Energy Technology Co. Ltd., Beijing Jingyuntong Technology Co. Ltd., Ningxia Qingyang New Energy Co. Ltd., Qinghai New Energy Co. Ltd. and Zhongwei Yinyang New Energy Co. Ltd.

Datong Solar Power Top Runner Base, 1,070 MW, China

The Datong Top Runner facility is in Datong City, in Shanxi province. Project developers and owners include Datong United Photovoltaics New Energy Co. Ltd., Datong Coal Mine Group Co. Ltd., Huadian Shanxi Energy Co. Ltd., JinkoSolar Holding Co. Ltd., China Guangdong Nuclear Solar Energy Co. Ltd., China Three Gorges New Energy Corp. and State Power Investment Corp Ltd. BNEF estimates total capacity operational in 2016 reached 1,070 MW, with a further 600 MW announced.

Yanchi, Ningxia Solar Park, 1,000 MW, China

This 1,000 MW solar park was the largest PV facility In the world when it was commissioned in September 2016, overtaking India's 648 MW solar project in Tamil Nadu.[5] The plant is owned by Huawei Technologies Co., China's largest mobile-phone manufacturer. Central management is via Huawei's Fusion Solar's "smart O&M cloud centre," which operates centrally to handle all plants for the group.

Longyangxia Dam Solar Park, 850 MW, China

The 850 MW Longyangxia facility is reported to cover 27 square km on the Tibetan plateau of China's Qinghai province.[6][7] Construction started in 2013 and the project is reported to have cost US$890m.[8] The project, developed by provincially owned Huanghe Hydropower Development, is integrated with the 1,280 MW hydroelectric power station on the Longyangxia Dam.[9]

Solar Star, 579 MW, U.S.

The 579 MW Solar Star project in the Antelope Valley was developed by SunPower on behalf of Berkshire Hathaway Inc.'s MidAmerican Energy Holdings.[10] Commissioned in June 2015, Solar Star took three years to build.[11] At that time, it was the largest operating solar project in the world. The project uses 1.7 million SunPower monocrystalline silicon modules on single-axis trackers spread over 3,200 acres[12] and is supported by a power purchase agreement (PPA) from Southern California Edison. Solar Star produced an

[4] http://www.escn.com.cn/news/show-310093.html (translated from Chinese)
[5] http://www.modernpowersystems.com/features/feature1-gw-pv-array-the-worlds-largest-comes-on-line-5664138/
[6] https://earthobservatory.nasa.gov/IOTD/view.php?id=89668
[7] https://www.theguardian.com/environment/2017/jan/19/china-builds-worlds-biggest-solar-farm-in-journey-to-become-green-superpower
[8] https://www.alternative-energies.net/longyangxia-dam-solar-park-in-china-is-now-the-biggest-solar-farm-in-the-world/
[9] https://web.archive.org/web/20160417014109/http://www.hydropower.org/blog/case-study-solar-pv–hydro-hybrid-system-at-longyangxia-china
[10] https://www.reuters.com/article/us-utilities-midamerican-solar/midamericans-giant-california-solar-star-power-plant-enters-service-idUSBREA090NV20140110?feedType=RSS&feedName=environmentNews
[11] https://www.greentechmedia.com/articles/read/solar-star-largest-pv-power-plant-in-the-world-now-operational#gs.9KvSxYw
[12] https://us.sunpower.com/sites/sunpower/files/media-library/fact-sheets/fs-solar-star-projects-factsheet.pdf

average 1,534 GWh of electricity annually in 2015 and 2016, giving it a strong 30.2% capacity utilization rate, reflective of the very high solar radiation in Southern California.

Topaz Solar Farm, 550 MW, U.S.

The US$2.5bn, 550 MW Topaz Solar Farm in San Luis Obispo County, California, developed by First Solar uses thin-film solar modules. Topaz was bought by MidAmerican Energy in 2011 and entered commercial service in November 2014. The project has a 25-year PPA with Pacific Gas & Electric, which the utility signed to help it comply with the state's 2020 renewable energy mandate of 33%. The project also benefitted from the U.S. government's 30% investment tax credit (ITC) subsidy.[13] Topaz produced an average 1,268 GWh of electricity annually from 2015 to 2017, resulting in a strong 26.3% capacity utilisation rate, well ahead of the expected 23%. The site covers 25 square km.

Desert Sunlight Solar Farm, 550 MW, U.S.

The 550 MW Desert Sunlight facility in California's Mojave Desert was built and managed by First Solar on behalf of project owners NextEra Energy, GE Energy Financial Services and the Sumitomo Group. Desert Sunlight was commissioned in February 2015. Like Topaz, the project tapped into the U.S. government's ITC subsidy. The facility, built on 3,600 acres of land managed by the U.S. Bureau of Land Management (BLM),[14] produced an average 1,318 GWh of electricity annually in 2015 and 2016, yielding a strong 27.4% capacity utilisation rate.[15]

Project construction took place in two phases, both of which were supported by PPAs. Phase I has a capacity of 300 MW, which was sold to Pacific Gas & Electric. Phase II has a capacity of 250 MW, which was sold to Southern California Edison.

America has other similarly sized projects including Sempra's 552 MW Copper Mountain solar project in Nevada, and Sempra's 400 MW Mesquite solar project in Arizona.[16]

Nova Olinda Solar Farm, 292 MW, Brazil

The 292 MW Nova Olinda facility, covering 690 ha in the state of Piauí, was commissioned in September 2017 at a cost of US$300m by Enel Green Power Brasil Participações,[17] a subsidiary of ENEL of Italy, one of the world's largest renewable energy infrastructure owners (see Section 7). The Brazilian Chamber of Commercialization of Electric Energy provided the enabling 20-year PPA for this project as part of the August 2015 Brazilian electricity auction.

Enel Green Power commissioned a second facility, the 254 MW Ituverava solar plant in the state of Bahia in 2017. Financing for this $400m facility was provided by Bank of China and Santander, supported by the China Export & Credit Insurance Corporation (Sinosure). To date, these projects are the largest in South America and together raise Enel's total operational renewable energy portfolio across Brazil to 2,276 MW.[18]

El Romero Solar Plant, 246 MW, Chile

The 246 MW El Romero facility in Chile's Atacama Desert is owned by Acciona Energy of Spain. This project was sponsored by the National Energy Commission of Chile with a 15-

[13] https://www.renewableenergyworld.com/articles/2011/12/billionaire-buffett-bets-on-solar-energy.html
[14] http://investor.firstsolar.com/index.php/news-releases/news-release-details/one-worlds-largest-solar-projects-starts-commercial-operation
[15] https://en.wikipedia.org/wiki/Desert_Sunlight_Solar_Farm
[16] http://www.semprarenewables.com/project/mesquite-solar-3/
[17] https://www.enelgreenpower.com/media/news/d/2017/02/nova-olinda-comes-to-life-first-solar-panel-is-installed
[18] https://www.pv-magazine.com/2017/09/19/enel-brings-online-546-mw-of-solar-projects-in-brazil/

year PPA. It took just 15 months to build and was commissioned in January 2017 at a cost of US$343m. HEC Global was the general contractor, JA Solar and Hareon supplied the solar modules and ABB the inverters. For a short time, it was the largest solar project in South America.[19] Its' expected capacity utilisation rate is 23%.[20]

De Aar Solar Farm, 175 MW, South Africa

The largest solar PV project to-date in Africa, the US$400m, 175 MW De Aar facility, was developed by Solar Capital.[21]

Solarpark Meuro, 166 MW, Germany

The 166 MW Solarpark Meuro in Brandenburg, Germany, was developed by GP Joule using panels from Canadian Solar of China and some thin film panels from First Solar. Operational since September 2011, this is one of the largest solar projects in Germany. The plant was built in just three months on a former lignite mine and covers 200 ha.[22]

EA Solar Lampang, 128 MW, Thailand

The 128 MW EA Solar project in Lampang, Thailand, was developed by the Thai renewable energy company Energy Absolute (EA Solar) and was commissioned in February 2015, making it possibly the largest solar project in operation in South East Asia.[23]

[19] https://www.youtube.com/watch?v=glvcc2jkRac
[20] http://www.acciona-energia.com/areas-of-activity/photovoltaic/major-projects/el-romero-solar-pv-plant/
[21] https://edition.cnn.com/2016/12/12/africa/de-aar-solar-south-africa/index.html
[22] http://phx.corporate-ir.net/phoenix.zhtml?c=196781&p=irol-newsArticle&ID=1613133
[23] https://www.pv-tech.org/news/engineering_contract_awarded_for_130mw_solar_plant_in_thailand

1.1 World's Largest Utility-Scale Solar Projects Under Construction

This section examines some of the largest utility-scale solar projects currently under construction (see Figure 1.3). Given the scale, speed and scope of solar deployments in China, India and the U.S., this list is not exhaustive, particularly for China. The speed of China's solar adoption efforts and the language barrier makes it difficult to keep track of every development, and we have erred here on the side of geographic diversity in our selection of projects to illustrate how solar-driven transformation is becoming a global phenomenon. One of China's largest solar firms is Huawei, which details it's FusionSolar cloud management system references managing several solar assets each of world scale including projects in Shanghai (1.4 GW), Jinan (900 MW), Zhangliagang (830 MW), Shenzhen (800 MW), Changshu (800 MW) and Beijing (600 MW) that suggest a separate China review is warranted to fully appreciate the scale of solar under development there.[24]

Figure 1.3: Fourteen of the Largest Under-Construction Utility Solar Projects

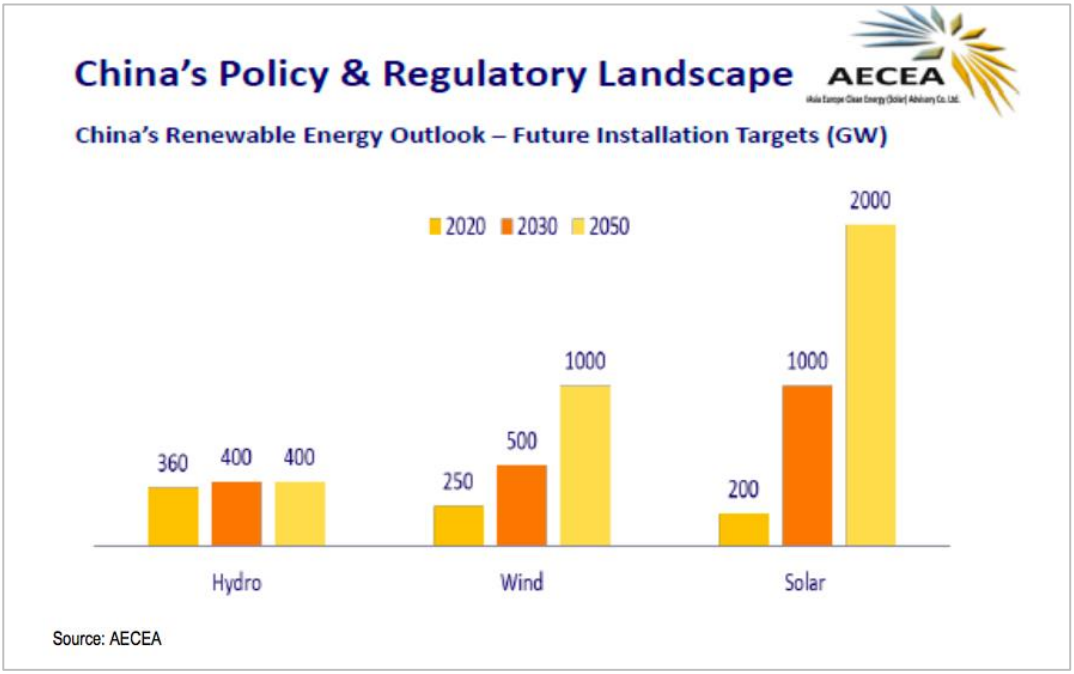
No	Project Name	Size (MW)	Country	Proponent
1	Bhadla Industrial Solar Park	2,225	India	Rajasthan Solar Park Development Company ltd, ESSEL, IL&FS, Adani RE Power Ltd
2	Pavagada Solar Park (Shakti Sthala)	2,000	India	Karnataka Solar Power Development Corporation
3	China Minsheng Investment Wuzhong Yanchi PV	2,000	China	China Minsheng Investment Group
4	Scatec Solar Benban V PV Plant	1,800	Egypt	Scatec Solar ASA
5	Ananthapuramu - I Solar Park	1,500	India	Andhra Pradesh Solar Power Corporation Pvt Ltd
6	Mohammed bin Rashid Al Maktoum Solar Park	1,013	UAE	DEWA, ACWA Power, TSK, Masdar consortium, EDF
7	Kadapa Ultra Mega Solar Park, Andhra Pradesh	1,000	India	Andhra Pradesh Solar Power Corporation Pvt Ltd
8	Quaid-e-Azam Solar Park	1,000	Pakistan	Xinjiang SunOasis, Zonergy
9	Rewa Solar Park	750	India	Rewa ultra Mega Solar Ltd
10	Enel Villanueva PV Plant	754	Mexico	Enel Green Power SpA
11	Cauchari Solar Project	300	Argentina	Jemse SE
12	Sakuto Solar Power Project	258	Japan	Pacifico Energy
13	Solara4 PV Plant	221	Portugal	WElink Energy
14	Bungala Solar Farm	220	Australia	Enel Green Power & Dutch Infrastructure Fund

Source: Company & Press reports, IEEFA estimates

In 2010, Germany and Italy dominated global solar installations, installing 7.5 GW and 4.5 GW, respectively, some 63% of the global total of 19 GW installed that year. Everything about solar has since become many-times bigger, with 2017 seeing China installing more than half of the global total of 98 GW. The 53 GW of solar installed by China in 2017 is a record best by any country. According to the director of the Asia Europe Clean Energy Advisory Company (AECEA) – Frank Haugwitz – China aims to install 200 GW of solar by 2020 and 1,000 GW by 2030 (2,000 GW by 2050 – refer Figure 1.4). Haugwitz's May 2018 discussion with Bank of America Merrill Lynch revealed these staggering Chinese government targets of 80 GW of solar installations between every year from 2020 to 2030.

[24] http://solar.huawei.com/na/utilityscale

Figure 1.4: China's Renewable Energy Outlook



Source: AECEA , Bank of America Merrill Lynch Research

Given the magnitude of solar projects under development in India, we detail the largest solar projects there separately (refer Section 1.2).

CMIG Wuzhong Yanchi PV Plant, 2,000 MW, China

In 2016, China's Minsheng Investment Group Co. Ltd. (CMIG) commissioned Phase 1, sized at 380 MW, of this PV facility at Zhongwei in the Ningxia Autonomous Region. Construction was undertaken by Jiangsu Electric Power Construction No3 Engineering Co. Over the planned five-year investment program, the total project size is reported at 2,000 MW over 4,600 hectares at a cost of US$2.3bn.[25] This project is reported to be part of CMIG's target to invest US$15bn in 20 GW of solar projects in China by 2020.[26] CMIG's website mentions completion of the 2 GW project, but provides no details.[27]

Scatec Solar Benban V PV Plant, 1,800 MW, Egypt

In March 2018, Egyptian Electricity Minister Mohamed Shaker reported that PPAs for the proposed Benban solar power complex in Egypt had been signed.[28] The first tranche of 400 MW, which reached financial close at the end of 2017, is being built by Scatec Solar of Norway. Equity partners include the Norwegian DFI Norfund and Africa50, the infrastructure fund for Africa.[29]

[25] https://www.bloomberg.com/news/articles/2016-09-20/out-of-china-s-dusty-northwest-corner-a-solar-behemoth-arises
[26] https://www.bloomberg.com/news/articles/2016-05-12/minsheng-new-energy-plans-15-billion-of-investments-in-5-years
[27] https://www.cm-inv.com/en/gffp/index.htm
[28] http://english.ahram.org.eg/NewsContent/3/12/292256/Business/Economy/Orascom-Construction,-Engie,-and-Toyota-Tsusho-to-.aspx
[29] http://www.scatecsolar.com/About/Press-and-media/Press-releases/Financial-innovation-enables-Scatec-Solar-to-launch-projects-worth-nearly-USD-one-billion

The overall Benban complex, which covers a 37 square km area allocated to Egypt's New and Renewable Energy Agency (NREA), has been sub-divided into plots allowing for plants of 20 MW to 50 MW each, with a total capacity for the site of up to 1.8 GW.[30]

The Asia Infrastructure Investment Bank has proposed loans of US$210m to support 11 new solar projects for this development.[31] This builds on a proposed US$335m debt package announced in November 2017 from a consortium of export credit agencies, including the U.N.'s Green Climate Fund, Norway's GIEK, EBRD, the Dutch development bank FMO, the Islamic Development Bank and the Islamic Corporation for the Development of the Private Sector.

Mohammed bin Rashid Al Maktoum Solar Park, 1,013 MW, UAE

This facility, in Dubai in the United Arab Emirates (UAE), is planned to have a total PV capacity of 1,013 MW plus an associated 700 MW of solar thermal (see Section 2).[32] Dubai Electricity and Water Authority (DEWA) commissioned the first phase of 13 MW in 2013; the second phase, totalling 200 MW, was commissioned in 2017. DEWA, along with its consortium partners EDF Energies Nouvelles SA of France and Masdar Abu Dhabi Future Energy Co., have scheduled a staged completion of the 800 MW third phase (200 MW in 2018, 300 MW in 2019 and the final 300 MW in 2020).[33] Phase one of 200 MW has just been commissioned,[34] taking the total commissioned capacity of the solar park to 413 MW. Just When work on this last phase began in 2016 the contracted power price was just $29.90/MWh, at the time a world record low for solar power.[35]

Quaid-e-Azam Solar Park, 1,000 MW, Pakistan

The Quaid-e-Azam facility in Bahawalpur in Pakistan's Punjab Desert has an ambitious 1,000 MW target. The project, part of China's Belt and Road Initiative, is being developed by China's Xinjiang SunOasis (100 MW) and Zonergy (900 MW). The first 100 MW was commissioned in September 2015 at a cost of US$131m,[36] and a total of 400 MW has been commissioned. The area is reported to have 13 hours of sunlight daily.[37] This project, along with several other enormously ambitious wind, hydro and coal power projects, is part of the strategic US$46bn China-Pakistan Economic Corridor.[38]

Enel Villanueva PV Plant, 754 MW, Mexico

Enel Green began building this PV facility in Viesca, Coahila, in March 2017 as part of a renewable energy investment program developed by the Energy Regulatory Commission (CRE) of Mexico. Commissioning of the US$650m project is due by September 2018; once operational it will be the largest solar project in the Americas.[39] As of March 2018, the project was 41% complete, but progressing rapidly.[40] [41]

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[30] http://www.ebrd.com/cs/Satellite?c=Content&cid=1395256092470&d=Mobile&pagename=EBRD%2FContent%2FContentLayout
[31] https://www.bloomberg.com/features/2018-asian-infrastructure-investment-bank-jin-liqun-interview/
[32] http://www.scmp.com/week-asia/business/article/2140281/uae-are-renewables-new-oil
[33] https://mercomindia.com/uae-phase-four-concentrated-solar/?lipi=urn%3Ali%3Apage%3Ad_flagship3_feed%3B2Ru42DnUTs+jHhUSl1fDbQ==
[34] https://gulfnews.com/news/uae/environment/solar-park-3rd-phase-starts-generating-clean-energy-1.2214900
[35] https://www.dewa.gov.ae/en/customer/innovation/renewable-energy/phases-of-energy-production
[36] http://www.pakistan-china.com/mn-news-detail.php?id=NDc0&pageid=news
[37] http://www.eco-business.com/news/china-helps-pakistan-build-worlds-largest-solar-farm/
[38] https://www.chinadialogue.net/article/show/single/en/7864-China-s-new-silk-road-What-s-in-it-for-Pakistan-
[39] https://www.enelgreenpower.com/media/press/d/2017/03/enel-begins-construction-of-the-americas-largest-solar-photovoltaic-plant
[40] https://www.enelgreenpower.com/media/news/d/2018/03/enel-green-power-mexico-inaugurates-villanueva-largest-solar-pv-plant-in-the-americas
[41] https://youtu.be/sQ7KnJxU66E

In October 2017, Enel sold an 80% stake in 1.7GW of Mexican renewable energy projects for US$1.35bn to two pension funds, Caisse de depot et placement du Quebec (CPDQ) and the CKD Infrastructure Mexico.[42] The projects were a mix of operational and under-construction projects, including the Villanueva PV facility.

Mexico's energy transition law, part of the country's 2014 energy reforms, stipulates that 25% of the nation's electricity must be generated from renewable sources by 2018; 30% by 2021; 35% by 2024; 45% by 2036; and 60% by 2050.

Cauchari Solar Project, 300 MW, Argentina

Construction of the Cauchari solar project in northern Argentina began in October 2017. The project comprises three 100 MW parks spread over 800 hectares. All told, the project will cost an estimated US$400m and will create 600 construction jobs. It is being actively supported by China, with the Export-Import Bank of China financing part of the project loans.[43] Jujuy Energia y Mineria Sociedad del Estado (JEMSE) is constructing the facility. Shanghai Electric Power Construction Co. Ltd. and Talesun Solar Co. Ltd. are the associate developers and own a 20% stake in the project, while JEMSE owns 80%.[44] The project is one of the two solar facilities, totalling 400 MW, that were selected in round one of the country's 1 GW RenovAr program. The plant will sell power under a 20-year PPA at US$60/MWh[45] to the wholesale electric market operator Compañía Administradora del Mercado Mayorista Eléctrico (CAMMESA).

Sakuto, 258 MW, Japan

The Sakuto project in Mimasaka, Okayama Prefecture, is being developed by Pacifico Energy K.K. with a target commissioning date of September 2019.[46] All electricity will be sold to Chugoku Electric Power, the regional utility. On completion, this project is likely to be the largest commissioned in Japan.[47] The plant is expected to generate 290 GWh of electricity annually, which translates to a capacity utilisation rate of just 12.8%. The facility is being built on a former golf course and will cover 400 ha. Japan was the second-largest nation globally in 2015-2016 in terms of total solar installs behind China, but it's very low solar radiation and resulting low utilisation rates, combined with the high cost of land and labour, has made the solar tariffs required prohibitively expensive for Japan absent significant subsidies.

Solara4 PV Plant, 221 MW, Portugal

Construction of the Solara4 in Vaqueiros, Algrave, began in October 2017. The proponent is the Irish renewables firm WElink Energy and the investment cost is US$242m. The project is Europe's largest unsubsidised solar plant to date. The engineering, procurement, and construction (EPC) contract sits with China Triumph International Engineering (CTIEC).[48]

Bungala Solar Farm, 220 MW, Australia

The Bungala facility, which is being built near Port Augusta, South Australia, is the largest solar project under construction in the country. The project was designed by Aurecon and is being built by Spain's Elecnor for project developers Reach Solar and PwC, who have

[42] https://www.pv-magazine.com/2017/10/09/enel-sells-80-of-1-gw-large-scale-solar-in-mexico/
[43] http://www.xinhuanet.com/english/2017-10/07/c_136663223.htm
[44] https://www.reportbuyer.com/product/5275141/jemse-cauchari-solar-power-plant-300-mw-jujuy-project-profile.html
[45] https://www.pv-magazine.com/2017/10/09/jemse-breaks-ground-on-300-mw-solar-park-in-argentina/
[46] https://www.pv-magazine.com/2017/04/28/pacifico-starts-building-258-mw-in-western-japan/
[47] https://www.businesswire.com/news/home/20170428005227/en/Pacifico-Energy-Commences-Construction-Japans-Largest-Solar & http://www.pacificoenergy.jp/en/project/
[48] http://solar.energy-business-review.com/news/welink-energy-begins-construction-of-221mw-solar-power-plant-in-portugal-271017-5958627

since sold the equity to a joint venture between Enel Green Energy and the Dutch Infrastructure Fund. The first phase, totalling 110 MW, was connected to the grid in April 2018, supported by an Origin Energy PPA. The second stage, also 110 MW, is due for completion in 2019. Total project costs are reported at A$315m. A third phase, to include another 80 MW of generation and a battery storage system, reportedly is under consideration. The project is spread over 800 ha of rural land owned by the Bungala Aboriginal Corporation.[49] It is being built near the last coal-fired power plant in South Australia, closed in 2016.[50]

In 2018 Australia has 5,056 MW of renewable projects under construction,[51] including Lighthouse Solar's 100 MW Claire solar project;[52] Edify Energy's 150 MW Daydream and ESCO's 148 MW Ross River solar projects, all in Queensland.

There is a growing multitude of Australian solar project proposals, including a 1.5 GW giant for South East Queensland,[53] Pacific Hydro's 500MW multi-stage Haughton solar proposal,[54] Equis Energy's 1,000 MW project at Wandoan in Queensland (plus their 127 MW Tailem Bend project in South Australia and a 150 MW Collinsville North solar farm in Queensland[55]), Photon Energy's 316 MW proposal in NSW, the Lyon Group's Riverland 330 MW project and Maoneng Australia's 250 MW venture in Sunraysia, NSW.[56]

200 GW of Solar in Saudi Arabia

Saudi Arabia's Crown Prince Mohammed Bin Salman signed a memorandum of understanding (MoU) in March 2018 with SoftBank Group founder Masayoshi calling for the construction of 200 GW of solar capacity, valued at US$200bn, in stages through 2030.[57] We include reference to this MoU even though financial close is yet to be reached because the project would be transformative, both for Saudi Arabia and the global solar industry. If developed to its full potential, this investment would singularly lift global solar installations by 20%, further driving a step-change in scale and investment that in turn would underpin investment in research and development (R&D), plus spur learning by doing and even greater economies of scale.

Saudi Arabia has the financial capacity to undertake this huge development, and its enormous desert area means land availability is not a constraint. The country also has some of the best solar radiation in the world, ensuring maximum solar productivity. If fully developed, the project would transform the Saudi economy over the next 13 years, giving it access to exceptionally low-cost wholesale electricity likely at just US$20-25/MWh. This would facilitate development of ancillary industries and vertical integration of the supply chain, with all the associated investment, employment and export opportunities.

A key feature of the project will be the construction of "the largest utility-scale battery" to supply "evening hour" power to consumers, albeit no details have been released on this.[58]

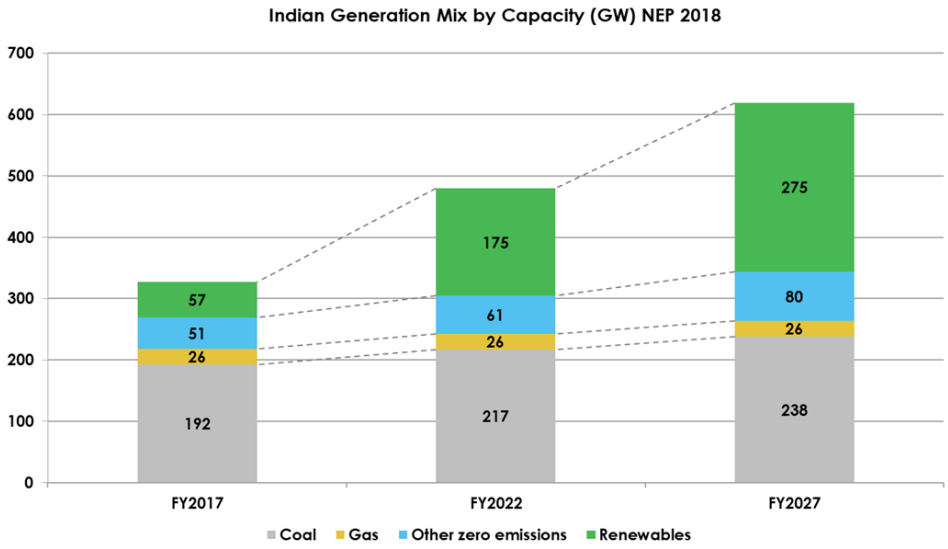
[49] https://www.power-technology.com/projects/bungala-solar-pv-plant-port-augusta/
[50] https://reneweconomy.com.au/australias-biggest-solar-farm-switches-port-augusta-52493/
[51] http://greenmarkets.com.au/news-events/renewable-energy-index-february-2018
[52] https://reneweconomy.com.au/queenslands-biggest-solar-farm-connects-grid-67965/
[53] https://reneweconomy.com.au/massive-1-5gw-solar-plant-proposed-for-south-east-queensland-16103/
[54] https://reneweconomy.com.au/powerlink-signs-500mw-solar-project-sees-30gw-pipeline-36402/
[55] http://reneweconomy.com.au/equis-plans-1000mw-solar-farm-in-heart-of-queenslands-gas-country-90246/
[56] https://www.smh.com.au/business/companies/australia-s-largest-solar-plant-to-build-in-2018-20171205-p4yxem.html
[57] https://www.bloomberg.com/news/articles/2018-03-28/saudi-arabia-softbank-ink-deal-on-200-billion-solar-project
[58] https://www.bloomberg.com/news/articles/2018-03-29/batteries-included-even-the-huge-saudi-solar-farm-will-use-them

1.2 India's Largest Utility-Scale Solar Projects Under Development

India has launched an aggressive program to accelerate deployment of renewable energy across the country, setting an ambitious target of 275 GW of renewable energy, representing 40% of India's total targeted installed generation capacity, by 2027 (see Figure 1.5 below). Solar will play the dominant role, with upward of 165 GW across utility-scale projects, rooftop installations, floating solar, hybrid wind-solar and concentrated solar power (CSP). The announcement in April 2018 of a 5 GW solar park in Gujarat highlights the size of the effort, which is motivated in large part by escalating pollution pressures and steep price declines in renewable energy tariffs, particularly solar, in the past several years. These price declines have topped 50% since the start of 2016, turning renewable energy into the lowest-cost source of new capacity, with pricing up to 20% below the average power tariff of existing, domestic thermal power plants.

In terms of exploring various models of new technology application in India, solar-wind-battery hybrid systems have now entered the Indian electricity sector. In April 2018, Hero Future Energies co-located a 50 MW wind farm with a 29 MW solar project[59] to best leverage the 50 MW grid connection investment and start the process of addressing how the grid will increasingly accommodate higher variable renewable energy generation. This model also employs better land use and takes advantage of existing regulatory approvals. Following this, in the same month, Andhra Pradesh government announced a tender for 2 GW of solar and wind to be co-installed with existing operational 2 GW of solar and wind projects in the Ananthapur district of the state.[60] This emergence of a hybrid model in India stems from the Ministry of New and Renewable Energy's (MNRE) draft wind-solar-battery hybrid policy which targets 10 GW by 2022.[61]

Figure 1.5: India's National Electricity Plan to 2027



Source: Indian National Electricity Plan 2018, CEA, IEEFA estimates

[59] https://www.pv-tech.org/editors-blog/hero-launches-indias-first-solar-wind-hybrid-project
[60] https://energy.economictimes.indiatimes.com/news/renewable/seci-invites-bids-for-2000-mw-hybrid-solar-and-wind-projects/63943302
[61] https://economictimes.indiatimes.com/news/economy/policy/government-announces-national-wind-solar-hybrid-policy/articleshow/64163756.cms

India has pioneered the concept of the ultra mega power plant (UMPP) in a single solar Industrial park, and India's Ministry of New and Renewable Energy (MNRE) initially set a target for 40 industrial solar parks with a combined capacity of 20 GW, but in 2017 doubled this target to 40 GW by 2022.

The UMPP concept involves a state government or local distribution company facilitating a single central grid connection and taking on the procurement and time-delay risks relating to land acquisition. This approach has been instrumental in driving economies of scale and procuring global capital flows into India over the last two years, with an immediate boon in the form of a halving of solar tariffs to a record low of Rs2.44/kWh (US$39/MWh) achieved in mid-2017.

Over 2016/17, India commissioned two of the four largest solar projects in the world, one each in Tamil Nadu and Andhra Pradesh, two of the best solar radiation sites in the country. What will be the largest operational solar project in the world, at 2,225 MW, is due for commissioning in 2019 at Bhadla in the desert of Rajasthan, with a 2,000-MW facility at Pavagada in Karnataka due online at the same time. A renewable energy grid transformation in India is under way, driving deflation, improved energy security, reduced reliance on fossil fuel imports and providing some relief from pollution pressures as well.

Figure 1.6 below outlines 12 of the largest industrial solar parks in India to date. We have listed them by size, grouped by those already operational, then those partly operational and grid connected, then those understood to be under construction. Finally, we detail several plants that have been announced but are not yet under construction.

Figure 1.6: Twelve of the Largest Indian Utility Solar Projects in Development

No	Project Name	Size (MW)	Status	State
1	Kurnool Ultra Mega Solar Park	1,000	Operational	Andhra Pradesh
2	Adani Kamuthi Solar Plant	648	Operational	Tamil Nadu
3	Bhadla Industrial Solar Park	2,225	Partially Operational	Rajasthan
4	Pavagada Solar Park	2,000	Partially Operational	Karnataka
5	Ananthapuramu - I Solar Park	1,500	Partially Operational	Andhra Pradesh
6	Kadapa Solar Park	1,000	Under construction	Andhra Pradesh
7	Rewa Solar Park	750	Under construction	Madhya Pradesh
8	Dholera Solar Park (Gulf of Khambhat)	5,000	Announced	Gujarat
9	Fatehgargh Solar Park	1,500	Announced	Rajasthan
10	Agar-Shajapur-Rajgarh Solar Park	1,050	Announced	Madhya Pradesh
11	Ramanathapuram Solar Park	500	Announced	Tamil Nadu
12	Ananthapuramu - II Solar Park	500	Announced	Andhra Pradesh

Source: Company & Press reports, IEEFA estimates

Kurnool Ultra Mega Solar Park, 1,000 MW, Andhra Pradesh

The 1,000 MW Kurnool solar facility is India's largest operational solar project. The project, located in Andhra Pradesh's Kurnool district. epitomises the UMPP model, which relies on attracting international capital from firms such as Greenko, backed by sovereign wealth funds of Abu Dhabi and Singapore, SoftBank of Japan in partnership with Foxconn of

Taiwan and BHEL (trading as SBG Cleantech), as well as Indian investors such as Adani Green Power and Azure Power.[62]

Andhra Pradesh Solar Power Corporation (APSPCL) led the development effort, first by acquiring nine square miles of land for the project and then working to secure funding of Rs500,000 ($7,700) per MW to improve roads, drinking water and training facilities in surrounding villages. Local skilled and semi-skilled workers also were given preference for job opportunities in the solar park.[63]

Under the UMPP scheme, the national government provided a subsidy of Rs200,000 (US$3,000) per MW to APSPCL to develop the solar park.

The first 500 MW was awarded to Sun Edison at Rs4.63/kWh in January 2016, and 350 MW was awarded to SBG Cleantech at Rs4.63/kWh, 100 MW to Azure Power of India at Rs5.12/kWh and 50 MW to Adani Green at Rs5.13/kWh. Just a year later, solar tariffs were up to 50% lower,[64] highlighting the price deflation sweeping through the Indian market.

Adani Kamuthi Solar Plant, 648 MW, Tamil Nadu

Adani Green Power's Kamuthi facility in Ramanathapuram district was the world's largest solar plant when it was commissioned in September 2016. The plant was planned and built in two years with an investment of US$679m and covers 2,500 acres.[65]

It was built without securing the necessary water licences for module maintenance and washing, forcing developers to look for other solutions. They solved this issue by incorporating a new self-charging, remotely operated, waterless robotic cleaning system developed by Israel's Ecoppia and manufactured in India, a cost-effective and efficient technique that optimises the cleaning process, guaranteeing long-term high performance.[66] [67]

Bhadla Industrial Solar Park, 2,225 MW, Rajasthan

The Bhadla facility in Rajasthan will have a total capacity of 2,225 MW when completed in 2019. The first 680 MW was commissioned in August 2017. The facility is being developed by Adani Renewable Energy Parks Rajasthan Ltd., a joint venture of the government of Rajasthan and Adani Green Power.

Various developers are involved in the park, including ACME, SBG Rising Sun, Rattan India, Fortum of Sweden, Azure Power, Avaada Power and ENGIE of France. In March 2018 SBG Cleantech confirmed it was on-track to commission 600 MW of new solar at Bhadla this coming year as part of its US$20bn commitment to Indian solar development.[68] The full 2,225 MW is due for completion by April 2019.[69] The Bhadla plant also features the Ecoppia module cleaning system.[70]

[62] https://www.thehindubusinessline.com/news/national/ap-makes-rapid-strides-1-gw-ultra-mega-solar-park-nearing-completion-in-kurnool/article9670458.ece
[63] https://www.nrdc.org/experts/anjali-jaiswal/worlds-largest-solar-park-kurnool-india
[64] http://apspcl.ap.gov.in/content/kurnoolultramegasolarparks
[65] http://indianexpress.com/article/india/india-news-india/solar-power-plant-kamuthi-tamil-nadu-world-largest-4403895/
[66] https://www.greentechmedia.com/articles/read/india-holds-the-crown-for-worlds-largest-solar-pv-project-for-now#gs.BjGIO6Y
[67] http://www.ecoppia.com/technology/
[68] http://www.powertoday.in/News/Govt-needs-to-provide-certainty-on-regulatory-front/111271
[69] https://energy.economictimes.indiatimes.com/news/renewable/rajasthan-aims-3780-mw-solar-capacity-by-april-next-year/63812414
[70] https://www.pv-magazine-india.com/2018/03/14/engie-commisions-140-mw-plant-bhadla-signs-250-mw-solar-ppa/

Pavagada Solar Park (Shakti Sthala), 2,000 MW, Karnataka

The Pavagada solar park in Karnataka is the second largest industrial solar park globally currently under construction. This facility illustrates how quickly renewable energy infrastructure can be planned, financed and built when a suitable energy policy framework is in place.[71] As of January 2018, 600 MW was already operational (priced back in 2016 at Rs4.79/kWh, or US$73/MWh). March 2018 saw a further 550 MW successfully tendered by the state government-owned Karnataka Renewable Energy Development Limited (KREDL) at prices of Rs2.91-2.93/kWh (US$45/MWh)—39% lower than the first tender two years earlier.[72] This section should be operational no later than 2019. Leading Indian domestic renewable energy developers to win this round were Renew Power (300 MW), Avaada Energy (150 MW) and Azure Energy (100 MW). An additional 650 MW tender for Pavagada has been deferred due to regulatory uncertainties relating to the threat of a 70% solar module import duty combined with the 25% rise in the price of Chinese modules in India since the middle of 2017.[73]

Ananthapuramu - I Solar Park, 1,500 MW, Andhra Pradesh

Ananthapuramu – I Solar Park is the largest under construction in Andhra Pradesh; it is spread across two villages in the district of Ananthapuramu and Kadapa. The 1,500 MW project will be the largest PV facility to be built from domestically manufactured solar cells and modules, aligning with Indian government's 'Make in India' program. NTPC Ltd, India's state owned utility, is planning to develop 1,000 MW of the 1,500 MW total. The first phase of 250 MW was commissioned by NTPC in 2015 with a PPA with the Andhra Pradesh state-owned electricity distribution company at Rs5.96/kWh (US$91/MWh).[74] In May 2018 NTPC completed a tender for the remaining 750 MW at Rs2.71-2.72/kWh, just 45% of the tariff pricing of just three years ago.[75]

Ananthapuramu – II, totalling 500 MW, will be built near four villages of the same district.

Kadapa Solar Park, 1,000 MW, Andhra Pradesh

The 5,928 acre, 1,000 MW Kadapa facility is being developed by the Andhra Pradesh Solar Power Corporation (a joint venture of the government of Andhra Pradesh and the government of India). The Solar Energy Corporation of India (SECI) awarded the bulk of the facility's capacity, 750 MW in April 2017 at what was then a competitive price of Rs3.15/kWh result.[76] But with the continuing, sharp price deflation that characterised 2017 that saw solar tariffs drop to a record low of Rs2.44/kWh, the distribution companies involved refused to honour the proposed contracts. While clearly an issue for the solar sector, this price deflation is a much graver threat for the country's already financially troubled thermal power generators, raising serious concerns about massive stranded asset risks in the sector. The remaining 250 MW was won by ENGIE of France's SolaireDirect under a bundling strategy (tying at-the-time more expensive solar with lower-cost coal-fired power that can be supplied when solar electricity is not being generated).[77]

[71] https://mercomindia.com/karnataka-top-solar-state-india/
[72] https://mercomindia.com/lowest-tariff-kredl-pavagada-solar-auction/
[73] https://mercomindia.com/solar-manufacturers-expansion-plan-import-tariff/
[74] http://apspcl.ap.gov.in/content/npkuntasite
[75] https://energy.economictimes.indiatimes.com/news/renewable/strong-response-drop-in-tariffs-at-ntpc-solar-auction/64109174
[76] http://apspcl.ap.gov.in/content/kadapa-ultra-mega-solar-park-1000-mw-1
[77] https://economictimes.indiatimes.com/industry/energy/ntpc-searches-for-buyer-for-kadapa-solar-parks-power/articleshow/61193076.cms

Rewa Solar Park, 750 MW, Madhya Pradesh

This 750 MW facility in Madhya Pradesh is being developed by Rewa Ultra Mega Solar Ltd., a joint venture between SECI and the Madhya Pradesh distribution company (MPUVNL). Three developers—Mahindra Renewables, ACME Solar and Solenergi Power Ltd.—have each won the right to develop a 250-MW solar project at the competitive tariff of Rs2.97/kWh (US$44/MWh),[78] with commissioning scheduled for December 2018. An interesting feature of this solar park is that 24% of its generated electricity will be sold to the Delhi Metro, providing 90% of its daytime electricity requirements;[79] the balance will be purchased by MPUVNL.

Gulf of Khambhat Solar, 5,000 MW, Gujarat

Vijay Rupani, chief minister of Gujarat, announced plans in April 2018 for a 5,000 MW solar park covering 11,000 ha along the Gulf of Khambhat at an estimated cost of US$4bn. The development would create 20,000 jobs during construction.[80]

Fatehgarh Solar Park, 1,500 MW, Rajasthan

The Adani Renewable Energy Park Rajasthan Ltd (AREPRL) in the Jaisalmer district of Rajasthan is a proposed joint venture between Adani Green Power Ltd. and the Rajasthan Renewable Energy Corporation Ltd.[81]

A transmission agreement covering 1,000 MW has been signed between AREPRL and PGCIL.[82] Beyond the agreement, however, there is little evidence of progress or tendering activity within the park.

Agar-Shajapur-Rajgarh Solar, 1,050 MW, Madhya Pradesh

In Madhya Pradesh, the 1,050-MW Agar-Shajapur-Rajgarh facility has been proposed by Rewa Ultra Mega Solar Ltd. This follow the 750 MW Rewa project noted above, with a third, the 700 MW Neemuch-Mandsaur solar park to follow. Madhya Pradesh plans to bring 2.5 GW of industrial solar online by 2020.[83]

Ramanathapuram Solar Plant, 500 MW, Tamil Nadu

The state's distribution company (TANGEDCO) won the right in December 2017 to convert a 1,500 acre site in Kadaladi originally procured for the development of a now stranded import-coal-fired power plant. TANGEDCO is now proposing to use the site for a 500-MW industrial solar park, taking advantage of the area's high solar radiation. Completion is due in 2019.[84] Given that there are upward of 50 GW of stranded, partly-built thermal power plants across India, and an additional 48 GW of end-of-life thermal power plants slated for closure by 2027, land rezoning for solar reuse is a major opportunity in the country.

[78] https://mercomindia.com/new-record-low-solar-tariff-rs-3-30kwh-logged-rewa-solar-park-auction-madhya-pradesh-india/
[79] https://timesofindia.indiatimes.com/city/bhopal/madhya-pradesh-to-produce-cheapest-solar-power-in-india-at-rs-2-97-per-unit/articleshow/57086986.cms
[80] https://www.pv-tech.org/news/indias-gujarat-approves-5gw-solar-park
[81] https://www.areprl.com
[82] https://www.areprl.com/features/#projGlance
[83] https://timesofindia.indiatimes.com/city/bhopal/mp-push-towards-solar-energy-addition-of-2000-mw-in-next-3-years/articleshow/62301110.cms
[84] https://energy.economictimes.indiatimes.com/news/renewable/tamil-nadu-power-utility-to-set-up-solar-park-in-ramanathpuram/62127999

2. World's Largest Concentrated Solar Power Projects

Steady expansion has occurred across the concentrated solar power (CSP) sector over the past decade, that it has happened slower than the deployment of PV or wind power. Given the relative simplicity of manufacturing and constructing solar PV and wind, plus their enormous ongoing cost deflation, some analysts argue that CSP with storage at a capital cost of US$6-12m/MW (more than six times that of solar PV) has lost the renewable energy race already. However, a CSP tariff analysis by the International Renewable Energy Agency (IRENA) in its 2018 report highlights that recent tendering activity shows such a conclusion is premature. CSP generation costs on projects for delivery over 2020-2022 of US$80-110/MWh are 50-70% below the 2014-2016 results of US$240-280/MWh. After a decade of research, development and deployment (RD&D), SolarReserve looks ready to deliver a step-change down in costs that could prove CSP is a competitive option for delivering the most valuable form of electricity, on-demand renewable energy.

China is also getting into the CSP sector. China's National Energy Administration (NEA) includes in its 13th five-year (2016-2020) solar development plan a target for 5 GW of CSP by 2020. As happened with PV, China's involvement could provide the global impetus in terms of critical mass in deployments and learning by doing to drive even faster deflation.[85]

Figure 2.1: Fifteen of the Largest CSP Projects Globally Under Development

No	Project Name	Size (MW)	Storage (MWh)	Status	Country	Proponent
1	Mojave Solar Project	250	0	Operational	USA	Abengoa
2	Solana Plant	250	1500	Operational	USA	Abengoa
3	Genesis Solar	250	0	Operational	USA	NextEra Energy Group
4	Solaben Solar Thermal Plant	200	0	Operational	Spain	Abengoa & ITOCHU
5	Andasol Solar Power Station	150	1,010	Operational	Spain	ACS Group, Marquesado Solar SL
6	Crescent Dunes	110	1,100	Operational	USA	Solar Reserve
7	PDO Amal Solar Thermal Plant	1,021	0	Partially Operational	Oman	Petrolium Development Oman LLC
8	Noor-Ouarzazate Solar Power Plant	500	2,805	Partially Operational	Morocco	Moroccan Agency for Solar Energy (MASEN)
9	Mohammed bin Rashid Al Maktoum Solar Park	700	0	Under Construction	UAE	ACWA Power & Shanghai Electric Co.
10	Aurora Solar Energy project	150	1,100	Under Construction	Australia	Solar Reserve
11	SunCan Dunhuang Phase I & II	110	1,210	Under Construction	China	Beijing Shouhang IHW, SunCan
12	Sandstone STEG Plant	2,000	20,000	Announced	USA	Solar Reserve
13	Dongfang Energy CSP Project	2,000	0	Announced	China	SPIC Shijiazhuang Dongfang Energy
14	Copiapó Solar Thermal Project	260	3,380	Announced	Chile	Solar Reserve
15	Redstone Solar Thermal Power Project	100	1,200	Announced	South Africa	Solar Reserve

Source: Company & Press reports, IEEFA estimates

[85] http://helioscsp.com/china-targets-5gw-of-concentrated-solar-power-for-2020/

Figure 2.2: CSP is Becoming Cost Competitive for Peaking Electricity

Project	Location	Developer	Capacity (MW)	Status	Power Price US$/kWh	Date Priced
Crescent Dunes	Neveda US	Solar Reserve	110	Operational	13.5	2009
Noor III	Morocco	ACWA Power/Sener	150	Under Construction	15.0	2014
Redstone	South Africa	SolarReserve/ACWA Power	100	Preferred Bidder	12.4	2015
MBR Solar Park Phase 4	Dubai	ACWA Power/Shanghai Electric	100	Construction Beginning 2017	7.3	2017
Aurora	South Australia	SolarReserve	150	Construction Beginning 2018	6.0	2017
Copiapo	Copiapo, Chile	SolarReserve	260	Pending Bid	5.0	2017

Source: SolarReserve, NRE, Paul Horn Inside Climate News, IEEFA estimates

Mojave Solar Project, 250 MW, U.S.

This 250 MW facility in California's Mojave Desert was completed in December 2014. The developer, Abengoa of Spain, was the primary investor in the US$1.6bn project[86] supported by a US$1.2bn loan guarantee from the U.S. Department of Energy (DOE).[87] Pacific Gas & Electric (PG&E), a California utility, signed a 25-year PPA for the power.[88] The National Renewable Energy Laboratory (NREL) estimates that the plant, which covers two square miles, will produce 600 GWh annually, giving it a capacity factor around 27%.

Solana, 250 MW, U.S.

Located in Arizona, Spain's Abengoa Solar built the 250 MW Solana parabolic-trough CSP. This is the first U.S. plant to incorporate a six-hour molten salt thermal energy storage capacity, supplying peak electricity to Arizona Public Service under a 30-year PPA at US$140/MWh. The plant was commissioned in October 2013 at a cost of US$2bn, of which US$1.45bn was supported by a DOE loan guarantee. Solana covers 780 ha.[89] The plant has been producing 725 GWh of electricity, about 80% of its expected electricity generation (a 31% capacity factor relative to the expected 38%).[90] [91]

Genesis Solar, 250 MW, U.S.

The Genesis thermal project is a 250 MW CSP parabolic trough facility west of Blythe in California owned by NextEra Energy Partners.[92] Genesis uses solar collector mirrors to concentrate sunlight to heat synthetic oil that, in turn, heat water to create steam, which is then used to generate electricity. The facility, on land managed by the U.S. Bureau of Land Management, took just over three years to construct; it was commissioned in March 2014. The project has a 25-year PPA with PG&E.[93]

Solaben Solar Thermal Plant, 200 MW, Spain

Solaben CSP (also known as the Extremadura Solar Complex) is in the city of Logrosan, Extremadura; it was built by Abengoa Solar of Spain and Itochu of Japan. Commissioned

[86] https://www.pv-magazine.com/2014/12/02/abengoa-puts-a-250-mw-solar-csp-plant-online-in-california_100017351/#axzz3KsDKEti6
[87] https://web.archive.org/web/20120127091257/https://lpo.energy.gov/?projects=abengoa-solar-inc-mojave-solar
[88] https://www.utilitydive.com/news/abengoa-puts-250-mw-csp-array-online-in-california/339957/
[89] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=23
[90] https://www.eia.gov/electricity/data/browser/#/plant/56812
[91] http://www.phoenixnewtimes.com/news/arizonas-solana-solar-plant-transformer-fires-more-air-pollution-9640548
[92] https://www.nexteraenergyresources.com/pdf_redesign/Genesis_factsheet.pdf
[93] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=54

in September 2013, Solaben has four 50 MW units using parabolic troughs with single-axis trackers. Each of the four units covers 280 acres.[94] The 25-year PPA is for €0.27/kWh.[95]

Andasol Solar Power Station, 150 MW, Spain

The Andasol station near Guadix in Andalusia has a total parabolic trough solar capacity of 150 MW and 7 hours or 1,010 MWh of molten salt storage across three units. Andasol I & II, each with 50 MW capacity, were commissioned in 2008 and 2009 respectively. Developed by ACS/Cobra Group, the units have a 25-year PPA with Endesa at a pricey €270 MWh. Andasol III, also 50 MW, cost €315m and was commissioned in January 2010. It was developed by Ferrostaal AG.[96]

Crescent Dunes, 110 MW, U.S.

The Crescent Dunes facility has 110 MW of capacity and 10 hours or 1,100 MWh of total molten salt thermal energy storage. This facility, which uses dry cooling to minimize water consumption, was commissioned in late 2015. It was built by SolarReserve in Tonopah, Nevada, and has a planned life of 40 years.[97] Crescent Dunes has a 25-year PPA with the NV Energy utility at US$135/MWh. The project employs 40 permanent staff for operations and maintenance, covers 725 ha, and took just over four years to construct.[98]

PDO Amal Solar Thermal Plant, 1,100 MW, Oman

The 1,100 MW PDO Amalis being developed by Petroleum Development Oman LLC (PDO).[99] The project is already partially operational, with 100 MW providing steam for enhanced oil recovery at Oman's Amal oil field. Construction commenced in 2015 and is being managed by GlassPoint.[100]

Mohammed bin Rashid Al Maktoum Solar Park, 700 MW, UAE

This 700 MW facility, at Seih Al-Dahal in Dubai, is being sponsored by Dubai Electricity & Water Authority (DEWA). Project development is being jointly undertaken by Saudi Arabia's ACWA Power and China's Shanghai Electric Co. The consortium's bid for the project was US$73/MWh. Commissioning of the first phase of the facility is due at the end of 2020;[101] ground-breaking took place in March 2018.[102] The project will feature a 600 MW parabolic basin complex and a 100 MW solar tower.

As detailed in Section 1.1 above, this 700 MW CSP is Phase IV of the overall project, which has a planned capacity total of 1,713 MW.

Noor-Ouarzazate Solar Power Plant, 580 MW, Morocco

Morocco wants to be the Saudi Arabia of solar energy, and its flagship Noor project is a first of its kind, $9bn energy plant at Ouarzazate.[103] Totalling a planned 580 MW of solar capacity, it has four stages:

1. Noor I, at 146 MW net capacity and 480 MWh of molten salt storage, was commissioned at the start of 2016, supported by a 25-year PPA costing US$189/MWh. It

[94] https://www.protenders.com/companies/itochu/projects/solaben-solar-power-station
[95] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=233
[96] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=117
[97] http://www.solarreserve.com/en/global-projects/csp/crescent-dunes
[98] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=60
[99] https://www.glasspoint.com/miraah/
[100] https://www.glasspoint.com///wp-content/uploads/GPS_MiraahFactSheet_v2.0_201802.pdf
[101] https://www.dewa.gov.ae/en/customer/innovation/renewable-energy/phases-of-energy-production
[102] https://mercomindia.com/uae-phase-four-concentrated-solar/?lipi=urn%3Ali%3Apage%3Ad_flagship3_feed%3B2Ru42DnUTs%2BjHhUSl1fDbQ%3D%3D
[103] https://www.pbs.org/newshour/show/morocco-turns-the-sahara-desert-into-a-solar-energy-oasis

had a capital cost of €1,042m and covers 450 ha. This stage is owned and was developed by ACWA Power; the EPC contractors were Acciona, Sener and TSK.[104]

2. Noor II at 185 MW net capacity and 6.5 hours of storage was commissioned in January 2018 at a cost of US$3.9bn. Noor II has a PPA of US$140/MWh; the developer is ACWA and the EPC contractor was Sener.[105]
3. Noor III is planned as a 134 MW CSP unit with 7.5 hours of storage. The PPA is priced at US$150/MWh.
4. Noor IV is a planned 80 MW solar PV project.[106]

Aurora Solar Energy, 135 MW, Australia

SolarReserve U.S., aims to commission a facility with 135 MW of net deliverable generation (150 MW gross) and with 8 hours of molten salt storage totalling 1,100 MWh. The capacity factor is estimated at 42%, delivering 500 GWh annually over a planned 40-year life.[107] The project involves a 227-meter solar tower 30 km north of Port Augusta in South Australia. It is scheduled to enter commercial service at the end of 2020, and will cost US$600m (A$750m). The plant, termed a high-temperature solar thermoelectric generator (STEG),[108] is in one of the best solar resource locations in Australia.

The project is contracted to provide dispatchable solar plus grid services at a very competitive peak power price reported at just over US$60/MWh (A$75-78/MWh) over the 20-year contract life, well below the prevailing wholesale price average over the past few years. The estimated A$9.50/MWh average for the renewable energy certificates plus a a maximum agreed price of A$78/MWh suggests a total electricity price of A$85-88/MWh (US$70/MWh). This exceptionally competitive pricing is also conditional upon a loan totalling A$110m at 3% interest from the Australian Renewable Energy Agency (ARENA).[109]

Announced in 2015 and permitted in January 2018, construction on this project may be slowed by the recent election in South Australia, where the Labor Party and Premier Jay Weatherill were turned out of office. Weatherill's government had been a strong supporter of the Aurora project.

SunCan Dunhuang Phase I & II, 110 MW, China

After a decade of prioritising solar PV, China is now looking at peaking-electricity demands and grid stability, and as a result is moving forward with 20 CSP solar projects totalling 1.35 GW of capacity. One of the largest is the SunCan Dunhuang Phase I & II in the city of Dunhuang in Gansu Province. Beijing Shouhang IHW and SunCan commissioned a pilot in December 2016, a 10 MW unit with 15 hours of storage at a cost of Rmb420m.[110] In November 2016, SunCan commenced construction of Phase II, a 100 MW unit with 11 hours of molten salt storage. The targeted commissioning date is August 2018.[111] [112]

[104] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=270
[105] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=4292
[106] https://en.wikipedia.org/wiki/Ouarzazate_Solar_Power_Station#cite_note-noor2nrel-3
[107] http://www.solarreserve.com/en/global-projects/csp/aurora
[108] https://www.energy.gov/sites/prod/files/2014/01/f7/csp_review_meeting_042313_ginley.pdf
[109] http://reneweconomy.com.au/aurora-what-you-should-know-about-port-augustas-solar-power-tower-86715/
[110] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=6315
[111] https://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=4303
[112] http://helioscsp.com/suncan-dunhuang-100-mw-concentrated-solar-power-tower-project-to-operate-by-aug-2018/

Sandstone STEG Plant, 2,000 MW, U.S.

The Sandstone STEG Plant in Nevada is being developed by SolarReserve. Announced in October 2016, the US$5bn proposal would use at least 100,000 mirrors and 10 towers across 6,500 ha with a target for commissioning by 2024.[113] With a proposed capacity of 2,000 MW, storage is put at 10 hours, or 20,000 MWh.[114] No PPA has been signed, nor has a site been selected, suggesting that this remains a speculative project.

Dongfang Energy CSP Project, 2,000 MW, China

A January 2018 Shenzhen stock exchange announcement noted that China's SPIC Shijiazhuang Dongfang Energy plans to build a CSP plant in Inner Mongolia with a capacity of 2 GW at a cost of US$7.3bn. The project would be the largest of its kind in the world.[115] The first phase would be a 200 MW unit costing an estimated US$728m as part of China's target for 5 GW of CSP by 2020.

Copiapó Solar Thermal Project, 260 MW, Chile

The proposed US$2bn Copiapó project, located northeast of the city of Copiapó in Chile's Atacama region, will provide 260 MW of capacity with 13 hours of storage totalling 3,400 MWh of continuous 24-hour solar power. Copiapó received all of its permits in 2015 and is shovel ready.[116] In March 2017, SolarReserve unsuccessfully bid this unsubsidized project into Chile's renewable energy auction at just US$63/MWh, less than half the price of SolarReserve's US$135/MWh tariff on Crescent Dunes commissioned in 2015.[117]

Redstone Solar Thermal Power Project, 100 MW, South Africa

In April 2018, SolarReserve and International Company for Power and Water (ACWA Power) signed a US$120/MWh, 20-year PPA with Eskom, South Africa's public utility, for the 100 MW/1,200 MWh Redstone project. This integrated molten salt energy storage project is a key part of the South African Department of Energy's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), being able to deliver electricity for up to 17 hours per day. The project will have 26% Black Economic Empowerment shareholding, and has committed to a 2.5% community trust.[118] The Redstone project will be located near Postmasburg in the Northern Cape Province, adjacent to the 75 MW Lesedi and 96 MW Jasper PV solar power projects, developed by SolarReserve.

[113] http://www.solarreserve.com/en/global-projects/csp/sandstone
[114] https://www.pv-tech.org/news/solarreserve-plans-2gw-csp-plant-in-nevada
[115] https://af.reuters.com/article/africaTech/idAFL4N1PK34T
[116] http://www.solarreserve.com/en/global-projects/csp/copiapo
[117] https://cleantechnica.com/2017/03/13/solarreserve-bids-24-hour-solar-6-3-cents-chile/
[118] https://reneweconomy.com.au/solarreserve-and-acwa-sign-power-purchase-agreement-for-100-megawatt-solar-thermal-project-with-energy-storage-in-south-africa-19278/

3. Floating Solar Projects

Floating solar infrastructure has emerged as a new field of utility-scale solar development. After several years of small scale, distributed pilot projects, 2017 saw the announcement of several large scale projects across China and Indonesia. To-date in 2018, South Korea and India have also joined the race, seeing the merits in optimal land-use. The global scope is very significant, particularly for solar-pumped hydro storage hybrid applications.

Construction costs are materially higher for floating solar, but the technology comes with four mitigating benefits:

1. **Improved Performance**: The waterborne nature of these projects keeps the solar system cooler, therefore limiting panels' vulnerability to the "temperature coefficient" that results in performance degradation as ambient temperatures increase.
2. **Better Land Utilisation**: The use of significant amounts of previously unutilised surface area at dams and wastewater treatment facilities improve asset utilisation and can reduce loss of prime agricultural lands, and/or leverage areas close to high density urban demand. Several of these facilities have been built on mine-reclamation sites.
3. **Better Utilisation of Grid Infrastructure**: The hybrid pairing of solar with hydro leverages the grid connection infrastructure that already has been built for the seasonal use of hydroelectricity, and the rapid start capacity of hydro means this hybrid can improve combined facility utilisation of this grid connection and reduce variability relative to stand-alone solar.
4. **Peak Power Supply**: If hybrid hydro facilities are appropriately configured, a pumped hydro storage facility can better deliver into peak evening electricity demand periods, providing a significant value uplift relative to midday solar generation.

Figure 3.1: Thirteen of the World's Largest Floating Solar Projects

No	Project Name	Size (MW)	Status	Country	Proponent
1	Huainan Panji Pingweizhen Floating PV Plant I	40.0	Operational	China	Sungrow Power & JA Solar
2	Kyocera Yamakura Dam Floating PV Plant	13.7	Operational	Japan	Kyocera TCL solar LLC
3	Queen Elizabeth II Reservoir Floating PV Plant	6.3	Operational	England	Lightsource Renewable Energy Ltd
4	Banasura Sagar reservoir, Wayanad	0.5	Operational	India	Kerala State Electricity Board Limited
5	Floating Solar Plant by Three Gorges Corp.	150.0	Partially Operational	China	China Three Gorges New Energy Corp.
6	Sungrow Floating Solar PV Plant	150.0	Under construction	China	SunGrow & Ciel & Terre (France)
7	CECEP's Anhui Province floating solar	70.0	Under construction	China	CECEP Solar (China), Ciel & Terre (France)
8	Yen Bai province	500.0	Announced	Vietnam	Govt. of Vietnam and Solkiss
9	JSW Floating Solar Plant	250.0	Announced	India	JSW Energy
10	Masdar Floating Solar Project in Indonesia	200.0	Announced	Indonesia	Masdar Abu Dhabi Future Energy
11	Hwaseong Lake Floating Solar Plant	100.0	Announced	South Korea	Korea Hydro & Nuclear Power, Korea Rural Community Corporation
12	Rihand Dam Floating Solar Project	150.0	Announced	India	Tender announced March 2018
13	Hangzhou Fengling Solar-Fish Farm	200.0	Operational	China	Hengtong Optic-Electric

Source: Company & Press reports, IEEFA estimates

Huainan Panji Pingweizhen Floating PV Plant I, 40 MW, China

The largest operating floating solar project to date is the 40 MW Huainan Panji facility, completed by Sungrow Power Supply Co. Ltd. in May 2017 in the Huainan mining area of Anhui Province in eastern China. The plant was built on a lake formed by a collapsed coal mine. Anhui expects to build 3.2 GW of floating solar power on abandoned coal mines and reported already is building a second project in the province, this one at 150 MW – refer next page.[119] Sungrow Power provided the inverters and JA Solar Holdings Co. the modules; the electricity goes to the State Grid Corporation of China (SGCC) utility.

Kyocera's Yamakura Dam Floating PV Plant, 13.7 MW, Japan

In March 2018, Kyocera TCL Solar commissioned its 13.7 MW Yamakura Dam Floating PV Plant in Ichihara, Chiba Prefecture; the largest such project to date in Japan. Tokyo-based Kyocera TCL Solar is a joint venture between Kyocera Corporation and financial services company Tokyo Century Corporation, which provided the financing. The electricity generated is sold to Tokyo Electric Power Company (TEPCO) as part of the country's effort to replace electricity generation lost in the wake of the Fukushima nuclear power plant disaster. Floating solar is an especially good solution in Japan in the face of cost and difficulties posed by land-acquisition issues. Japan has a number of inland waterways and reservoirs built for agricultural and flood-control purposes that could be used for the development of solar power plants. This installation covers 18 ha and has an expected capacity factor of 13.5% due to Japan's relatively low solar radiation.

Harold Meurisse, international business developer at floating solar developer Ciel et Terre of France states that "in some countries, we are already more competitive than ground-mounted systems … (particularly) where land is expensive and rare."[120] Ciel et Terre is reported to have a target to build 100 MW of floating solar across Japan by 2020.

Banasura Floating Solar Power Plant, 0.5 MW, India

The smallest project featured in this report, the 500 kW system at the Banasura Sagar reservoir in Wayanad was completed in 2017 at a total cost of US$1.5m. The project was built so the Kerala State Electricity Board could test the technology as a potential addition to the state's extensive hydroelectricity infrastructure.

Showing the scope for exponential growth in solar technologies, SECI issued a 10 GW contract exclusively for floating PV in December 2017.[121] It is conceivable that no such plans would be in the cards were it not for the humbly sized but strategically significant project, which is in the southern state of Kerala.[122]

In February 2018, JSW Group of India announced that it would build a 4 MW floating solar pilot with a view to setting up future projects totalling 250 MW.[123]

In April 2018, Maharashtra State Electricity Distribution Company Limited issued a request for expressions of interest for up to 1 GW of floating solar for development on the Ujjani Dam reservoir in the Solapur district of Maharashtra.[124]

[119] https://www.pv-tech.org/news/sungrow-building-another-record-150mw-floating-solar-project-in-china
[120] https://www.thenational.ae/business/energy/japan-s-biggest-floating-solar-plant-sparks-into-life-1.718330
[121] https://www.pv-tech.org/news/indias-seci-invites-expression-of-interest-for-10gw-of-floating-solar
[122] https://www.pv-tech.org/features/monsoon-rising-an-anchor-for-indias-floating-pv-dreams
[123] https://www.pv-tech.org/news/jsw-plans-250mw-floating-solar-across-india-mahagenco-eyeing-250mw
[124] https://mercomindia.com/msedcl-expression-interest-1-gw-floating-solar/

China Three Gorges Floating Solar Power Plant, 150 MW, China

The largest partly operational floating solar project to-date is the 150 MW system being built in Huainan, in the coal province of Anhui. This facility, which is being developed by China Three Gorges New Energy, is similar to the operational Huainan Panji plant noted above. The reported cost is Rmb1bn (US$150m); it is scheduled for completion in May 2018.[125]

Sungrow Floating Solar Power Plant, 150 MW, China

Using lessons learned from its previous 40 MW facility, Sungrow is now building a 150 MW project in the same region. Ciel & Terre of France is involved in the EPC work.[126]

CECEP's Anhui Province Floating Solar Project, 70 MW, China

France's Ciel & Terre in June 2017 was reported to have commenced building a 70 MW floating solar project in Anhui Province for China's CECEP. China's National Energy Administration (NEA) issued a tender for 1 GW of floating solar for Anhui province. This capacity is to be built across 12 inland reservoir sites, with nine companies being awarded capacity, including CECEP, GCL, China Three Gorges and Sungrow.[127]

Yen Bai Province Project, 500 MW, Vietnam

In March 2017, the Vietnam government announced that Yen Bai province was teaming up with South Korean renewable energy developer Solkiss to develop a 500 MW floating solar project at Thac Ba Lake. Solkiss plans to request Korean government financial assistance for the proposed US$1.1bn project.[128] Given the extremely high development costs, IEEFA assigns it a low probability of proceeding anytime soon at the current scale. Still, the project highlights the scale of opportunity that is fast emerging in this solar niche.

Masdar Floating Solar Project, 200 MW, Indonesia

Masdar Abu Dhabi Future Energy Co. announced plans in November 2017 to build the US$300m, 200 MW Masdar Floating Solar project across 225 ha of the Cirata Reservoir, site of a 1,000 MW hydro facility in the West Java province of Indonesia.[129] Indonesian local partner PT Pembangkitan Jawa Bali (PJB) is reported to be taking a 51% stake, with Masdar controlling the balance. Commissioning is reported to occur progressively by 2020. No electricity tariff has been finalized with Perusahaan Listrik Negara (PLN, the state-owned utility), making financial close and then construction entirely subject to a binding agreement. The project is supportive of the Indonesian government's 23% renewables target.[130]

Hwaseong Lake Floating Solar Plant, 100 MW, South Korea

In February 2018, state-run Korea Hydro & Nuclear Power signed an MoU with solar developer Hwaseong Solar Energy to construct a 100 MW, US$200m floating solar farm on the western coast of South Korea.[131]

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[125] https://www.pv-tech.org/news/worlds-largest-floating-solar-plant-comes-partially-online-in-china
[126] https://www.pv-tech.org/news/ciel-terre-starts-building-70mw-floating-pv-project-with-longi-mono-modules
[127] https://www.pv-tech.org/news/ciel-terre-starts-building-70mw-floating-pv-project-with-longi-mono-modules
[128] https://www.pv-magazine.com/2017/03/27/vietnam-province-taps-korean-government-for-assistance-on-500-mw-solar-project/
[129] https://www.pv-tech.org/news/masdar-and-indonesian-power-giant-to-build-worlds-largest-floating-solar-pl
[130] https://www.rambuenergy.com/2017/12/indonesia-to-have-its-first-and-largest-floating-solar-power-by-2019/
[131] https://www.pv-magazine.com/2018/02/12/south-korean-state-energy-firm-plans-100-mw-floating-pv-project/

This project is part of South Korean President Moon Jae-in's renewable energy initiative to increase renewables' electricity-generation market share to 20% by 2030 from 7% currently.

In July 2017, Korea Rural Community Corp. revealed plans to build up to 280 MW of floating solar capacity at three sites by 2019. Two of the projects, 100 MW each, will be located on lakes in Chungcheongnam province. The third, at 80 MW, is planned for a 96 ha site in Jeollanam province; it will be developed by Hanwha Q Cells jointly with Korea Hydro & Nuclear Power in collaboration with Korean floating solar specialist Solkiss.[132]

In November 2017m a consortium led by Hanwha General Chemical was selected by Korea Rural Community Corp. as the preferred bidder on construction of a 100-MW floating solar plant in Dangjin, South Chungcheong Province.[133]

In early 2016, state-run Korea Water Resources Corp (K-water) signed an agreement with LG Electronics to build 1 GW of floating solar by 2022 on ponds and reservoirs throughout South Korea.[134] In February 2017, K-water announced it would partner with Korea Electric Power Corp. (KEPCO) for a 40-MW floating solar power plant at the Hapcheon Dam.[135]

Rihand Dam Floating Solar Project, 150 MW, India

In March 2018, SECI tendered 100 MW of floating solar PV projects to be developed at the Rihand Dam/Govind Ballabh Pant Sagar Reservoir, in the Sonbhadra district of Uttar Pradesh.[136] In April 2018, SECI upgraded the tender from 100 MW to 150 MW.[137]

Hangzhou Fengling Solar-Fish Farm, 200 MW, China

This is not a floating solar project per se, but its concept and associated advantages are similar. The Hangzhou Fengling Solar-Fish Farm is a 200 MW project mounted on piles above the surface of the Changhe and Zhouxiang reservoirs in Cixi, in Zhejiang province. Completed in January 2017 at a cost of Rmb1.8bn (US$262m), the project spans 300 ha. This was reported as a "new model" for solar-aquaculture projects, with PV modules spaced far apart to allow enough sunlight to reach the water's surface, which is critical for the growth of fish.[138]

In January 2018, a 100 MW solar fish farm project in Shandong province was reported to have been completed by China's Hengtong Optic-Electric at a cost of US$120m.

A third 120 MW project, in Jiangxi province was completed in May 2016.[139]

[132] https://www.pv-tech.org/news/hanwha-q-cells-developing-80mw-rotating-floating-solar-project-in-korea
[133] http://www.koreaherald.com/view.php?ud=20171102000734
[134] https://www.pv-magazine.com/2017/07/10/korean-firm-to-build-280-mw-of-floating-pv-capacity/
[135] http://www.businesskorea.co.kr/news/articleView.html?idxno=17358
[136] https://mercomindia.com/seci-100mw-floating-solar-tender/
[137] https://www.pv-tech.org/news/seci-increases-uttar-pradesh-floating-solar-tender-to-150mw
[138] https://www.pv-magazine.com/2017/01/23/hangzhou-fengling-finishes-200-mw-solar-aquaculture-project/
[139] https://www.pv-magazine.com/2018/01/30/china-hengtong-launches-100-mw-solar-pv-plant-on-top-of-fish-farm/

4. Rooftop Solar Projects

BNEF estimates that worldwide installations of solar projects less than 1 MW in size grew by 15% to US$49.4bn in 2017. Given the ongoing decline in total installation costs, global residential plus commercial & industrial (C&I) by volume totalled 28 GW, up 27% year on year versus 22 GW in 2016. BNEF puts cumulative global installations at 173 GW. With module prices expected to fall an additional 15% in 2018, deflation remains a central theme that means more markets globally are seeing rooftop solar pricing move below grid parity.[140]

A similar deflationary pattern is emerging in stationary storage devices, which leads IEEFA to project that the adoption of distributed solar with storage will accelerate in a manner similar to other disruptive technologies such as mobile phones, the internet, and computers (see Section 5).

Figure 4.1: Thirteen of the World's Largest Rooftop Solar Projects

No	Project Name	Size (MW)	Status	Country	Proponent
1	Dera Baba Jaimal Singh Solar Rooftop plant	19.0	Operational	India	L&T Constructions & Tata Power
2	Tsuneishi Zhoushan Shipyard solar station, China	19.0	Operational	China	Asia Clean Capital & Tsuneishi Group
3	Apple Park Solar Rooftop	17.0	Operational	USA	SunPower
4	Westmont Solar Energy Project	16.4	Operational	USA	PermaCity Solar
5	General Motors Zaragoza	11.8	Operational	Spain	Veolia Environment, Clairvoyant Energy
6	Whirpool Corporation Rooftop Solar	10.0	Operational	USA	Southern California Edison
7	Amazon Carteret Warehouse Solar Rooftop	7.5	Operational	USA	Sol Systems
8	Danone China Food & Beverage, China	5.2	Operational	China	Asia Clean Capital & Danone China
9	Sydney Markets Rooftop Solar	3.0	Partially Operational	Australia	Autonomous Energy
10	Weinan Hancheng Longmen Rooftop Plant	180.0	Under construction	China	Hancheng Yipin Sunshine New Energy Technology Co Ltd
11	Azure Indian Railways Rooftop PV Project	66.0	Announced	India	Azure Power
12	Microsoft Singapore (Data Centres)	60.0	Announced	Singapore	Sunseap
13	Zimbabwe Microgrid Rooftop Solar Project	20.0	Announced	Zimbabwe	Oxygen Energy

Source: Company & Press reports, IEEFA estimates

Dera Baba Jaimal Singh Solar Rooftop Project, 19 MW, India

The 19 MW Dera Baba solar rooftop project in Amritsar, Punjab was installed on the 82-acre campus of the R.S.S.B. Educational and Environmental Society.[141] Tata Power Solar commissioned 11.5 MW in December 2015 across eight campus venues[142] and L&T

[140] http://fs-unep-centre.org/sites/default/files/publications/gtr2018v2.pdf
[141] http://www.business-standard.com/article/economy-policy/world-s-largest-rooftop-solar-power-plant-inaugurated-in-punjab-116051701113_1.html
[142] https://www.indiatoday.in/india/story/tata-power-solar-commissions-worlds-largest-solar-rooftop-in-amritsar-276607-2015-12-10

Construction installed a 7.5 MW system in April 2014.[143] A 25-year PPA for the output was signed between Dera and the Punjab State Power Corporation Limited.

SBG Cleantech highlighted in March 2018 the significant growth prospects for Indian C&I rooftop solar due to a tiered pricing structure that requires C&I customers to pay Rs7-8/kWh (US$115/MWh), double the retail tariffs available for residential customers.[144]

Tsuneishi Zhoushan Shipyard Solar Station, 19 MW, China

This shipyard rooftop solar facility is in the city of Zhoushan, China; the 19 MW unit was connected to the grid in August 2017. Built by Asia Clean Capital Limited (ACC), the project is currently the world's largest building-integrated PV (BIPV) power station, including more than 72,000 solar modules. ACC owns and maintains the solar system, selling the electricity generated to Tsuneishi Group at an agreed-on price to deliver savings and price certainty.[145]

ACC in February 2018 completed the installation of a 5.2 MW rooftop and carport solar system for Danone at its factory in Xi'an, China. Danone has committed to supporting four such factory projects across China.[146]

ACC also announced a joint venture in February 2018 with EDF Energies Nouvelles to leverage ACC's China rooftop expertise and to accelerate deployments.[147]

Apple's Cupertino Headquarters, 17 MW, U.S.

Apple's new US$5bn Cupertino Campus 2 headquarters in California and two associated 10,000 car carparks, host a 17 MW rooftop solar system, the largest in terms of generation capacity in the U.S..[148] Installed by SunPower, the system began operations in May 2017; it is supplemented by a microgrid, 4 MW Bloom Energy fuel cell generation system and a naturally ventilating building requiring no heating or air-conditioner cooling for nine months of the year.[149]

Westmont Solar Energy Project, 16.4 MW, U.S.

The Westmont project in Los Angeles includes 50,000 solar panels over 20 ha that can generate 16.4 MW of electricity. The project was developed by PermaCity Solar and benefits from a feed-in tariff run by the Los Angeles Department of Water and Power (LADWP). At completion in early 2017, developers said it was the world's largest rooftop solar project; the Punjab project is bigger, but covers multiple buildings on one campus.[150]

General Motors Zaragoza Rooftop Plant, 12 MW, Spain

The 12 MW rooftop solar facility on General Motor's factory in Zaragoza was developed and commissioned in 2008 by Veolia Environment and Clairvoyant Energy. It cost €50m and uses 85,000 solar panels made from a flexible, thin-film laminate branded as Uni-Solar by Energy Conversion Devices (EDC) as a BIPV system.[151]

[143] https://www.ecowatch.com/worlds-largest-solar-rooftop-system-goes-online-will-power-8-000-homes-1891142279.html
[144] http://www.powertoday.in/News/Govt-needs-to-provide-certainty-on-regulatory-front/111271
[145] http://www.asiacleancapital.com/acc-tsuneishi-grid-connection/
[146] https://www.pv-tech.org/news/acc-develops-rooftop-carport-hybrid-pv-project-for-danone-in-china
[147] https://www.pv-tech.org/news/edf-asia-clean-capital-announce-joint-venture-for-rooftop-solar-in-china
[148] https://blog.pickmysolar.com/apples-new-campus-country-largest-solar-commercial-project
[149] https://www.renewableenergyworld.com/ugc/articles/2017/02/28/new-apple-headquarters-sets-records-in-solar-and-green-building.html
[150] https://www.pv-tech.org/news/los-angeles-completes-16.4mw-rooftop-project
[151] http://www.uni-solar.com/wp-content/uploads/pdf/Corporate_Overview_Brochure.pdf

Whirlpool Distribution Centre, 10 MW, U.S.

This 10 MW rooftop system in Perris, California, was completed in 2012 at a DEXUS Property Group 40 acre distribution centre leased by Whirlpool Corp. Southern California Edison leased the rooftop for 20 years and as of 2014 had 84 MW of rooftop solar across 23 rooftops. This is understood to be the second-largest operating rooftop solar project in the U.S.[152] [153]

Amazon Carteret Warehouse Solar, 8 MW, U.S.

Sol System commissioned a 7.5 MW rooftop solar system at Amazon's Carteret Warehouse in New Jersey in August 2017. It includes 22,000 Hanwha Q-Cell solar modules and is owned by IGS. In May 2017, Amazon announced that it would install up to 41 MW of solar on 15 fulfilment centres by the end of the year.[154]

Sydney Markets Rooftop Solar, 3 MW, Australia

This Sydney rooftop project is a collection of units, of which the last 2.2 MW were commissioned in March 2018 by Autonomous Energy at a cost of A$8.9m (US$7m). Previous phases included a 640 kW solar car park and a 270 kW existing rooftop system.[155] Estimates put the expansion capacity at up to an additional 4 MW. This is currently the largest rooftop array in Australia

February 2018 the South Australian Produce Market in Adelaide announced plans to install a A$10.5m hybrid system including 2.5 MW of rooftop solar, a 4.2 MWh Tesla battery storage unit and a 2.5 MW onsite back-up diesel generator.[156]

Tesla Gigafactory, 70 MW, U.S.

Tesla[157] has started construction on a 70 MW rooftop solar array at its US$5bn lithium ion battery Gigafactory in Reno, Nevada. When complete, this will be by far the world's largest rooftop system.[158]

Tesla Rooftop Virtual Plant, 125 MW, Australia

In February 2018, the South Australian state government announced a landmark "virtual power plant" (VPP) linking household rooftop solar and Tesla Powerwall battery storage systems. With three proposed stages, the project will begin with a trial including 1,100 Housing Trust properties, which will have 5 kW solar and 13.5 kWh storage systems installed at no cost, funded by the state government's Renewable Technologies Fund. An initial A$2m grant is to be followed with a A$30m government loan. Phase 2 is proposed to involve 24,000 Housing Trust houses, with 25,000 houses in Phase 3, bringing the size of the A$800m project to more than 50,000 houses generating 250 MW of rooftop solar. Estimates show that tenants and homeowners would see a 30% reduction in electricity costs. The 650 MWh of combined battery storage would also improve grid stability and provide demand management opportunities.[159]

The Tesla project will build on AGL Energy's 5 MW South Australian pilot VPP supported financially by ARENA using a SolarEdge inverter linked with an LG Chem Resu battery, or a

[152] https://www1.eere.energy.gov/solar/pdfs/highpenforum2013_1_12.sce.pdf
[153] http://www.cityofperris.org/news/2011_stories/09-19-11_solarpanels.html
[154] https://pv-magazine-usa.com/2017/08/31/amazon-puts-online-new-jerseys-largest-rooftop-solar-installation/
[155] https://reneweconomy.com.au/sydney-markets-takes-rooftop-solar-massive-3mw-maybe-come-15096/
[156] https://onestepoffthegrid.com.au/states-biggest-solar-battery-storage-microgid-power-sa-produce-markets/
[157] https://electrek.co/2017/01/10/tesla-gigafactory-1-model-3-battery-pack-rooftop-solar/
[158] http://www.notey.com/@electrek_unofficial/external/20041197/tesla-finally-starts-installing-its-massive-'world's-largest-solar-rooftop-array'-at-gigafactory-1.html
[159] https://reneweconomy.com.au/tesla-to-build-250mw-virtual-power-plant-in-south-australia-44339/

Tesla Powerwall 2 battery with an integrated inverter with the aim of covering 1,000 houses by the end of 2018.[160]

Azure Indian Railways Rooftop PV Project, 66 MW, India

The Azure project is neither a single rooftop nor a single campus or shipyard of associated rooftops, but we have included it here because it focuses on the rooftops of one company, Indian Railways, the largest railway network operator in Asia. The project, launched in March 2017 and then expanded by a third in September 2017 to involve 66 MW of rooftop solar, ultimately could include all 8,000 stations in 17 states and union territories where the company does business. Azure Roof Power will provide power for 25 years at a tariff range of US$60-70/MWh based on location.[161] Indian Railways has committed to a 5 GW solar target across its national portfolio, incorporating both rooftop and utility-scale projects, including leveraging existing land holdings alongside the railway routes. Indian Railways uses 2% of all electricity consumed in India and is aiming to reduce its electricity procurement costs by 50-70%.[162]

Microsoft Data Centres Rooftop Plant, 60 MW, Singapore

In March 2018, Microsoft Singapore Data Centres contracted with Sunseap of Singapore to set up a rooftop solar portfolio of 60 MW under a 20-year PPA. While this is a single project, the contract involves hundreds of rooftops across Singapore. Microsoft is now on track to exceed its goal of powering 50% of its global data centre load with renewable energy by the end of 2018.[163]

Microgrid Rooftop Solar Project, 20 MW, Zimbabwe

The US$28m, 20 MW Zimbabwe Microgrid Rooftop Solar Project is being developed by Oxygen Energy and involves buildings owned by Old Mutual Property Group Zimbabwe. The project's goal is to end near-daily blackouts and replace 12 million litres of imported diesel annually. In May 2017, the African Development Bank (AfDB)-managed Sustainable Energy Fund for Africa (SEFA) made a US$1m grant to Zimbabwean investment company Oxygen Energy for the preparation of a business plan for this project.[164] The project has received support from the Ministry of Energy & Power Development and is looking to work with Jabil Inc. USA and Soventix GMBH Germany for EPC services.[165]

[160] https://www.agl.com.au/about-agl/media-centre/asx-and-media-releases/2018/march/agl-upgrades-vpp-with-latest-technology-from-tesla-solaredge-and-lg-chem
[161] https://www.pv-tech.org/news/azure-roof-power-to-develop-20mw-rooftop-pv-portfolio-for-indian-railways
[162] https://mercomindia.com/railways-to-tender-5gw-solar/
[163] https://www.pv-tech.org/news/microsofts-singapore-data-centres-to-be-powered-by-60mw-sunseap-rooftop-sol
[164] https://www.pv-magazine.com/2017/05/08/african-development-bank-supports-20-mw-off-grid-solar-project-in-zimbabwe/
[165] https://www.forbes.com/sites/mfonobongnsehe/2017/12/21/meet-the-32-year-old-entrepreneur-who-is-building-zimbabwes-largest-solar-company/#45af389563f7

5. Solar PV With Storage

This section looks at some of the largest projects incorporating solar and battery storage.

The world's largest lithium-ion battery facility to date is the Tesla-Neoen Hornsdale Power Reserve facility of 100 MW/129 MWh in South Australia, commissioned in December 2017.[166] However, this facility has no associated solar, and neither does the 150-MW lithium-ion facility proposed in South Korea by Hyundai Electric & Energy Systems Co., scheduled for commissioning in the first half of 2018.[167]

But the development of battery storage with renewables is becoming increasingly standard as variable renewable energy takes an ever greater share of electricity generation.[168]

A 2018 report by a research firm IHS Markit found that the total pipeline of announced energy storage projects globally has reached 10.4 GW at the end of Q1 2018 from 7.5 GW at the end of 2017. Of this, 40% of this total capacity pipeline is to be co-located with solar projects as a key step to helping address the intermittency of solar power, and maximise its' value in the electricity generation sector.

Similar to the advantages achieved by combining floating solar with pumped hydro storage, renewable energy projects can be enhanced by pairing them with batteries. Among the benefits of such projects is the resulting ability to time-shift solar supply into more valuable peak demand periods, increase behind-the-meter self-consumption (also known as self-supply, a strategy that allows for on-site storage of solar generation) reduce curtailment losses, reduce transmission congestion and enhance grid stability.

In stark contrast to the rest of Australia's energy policy chaos, Energy Minister Josh Frydenberg clearly endorses solar with storage as a value-enhancing proposition, stating:[169]

> *"They will not only allow currently unused renewable energy to be stored instead of wasted, but also inject electricity into the grid at times of peak demand in an area known for transmission congestion. Together, they will help lower power prices and stabilise the grid."*

Figure 5.1 below lists 15 of the largest solar-with-storage infrastructure investment projects globally either in operation or under development.

[166] http://reneweconomy.com.au/tesla-big-battery-goes-full-discharge-100mw-first-time-37826/
[167] https://www.bloomberg.com/news/articles/2017-11-30/musk-s-battery-boast-will-be-short-lived-as-rivals-go-bigger
[168] https://www.energy-storage.news/news/ihs-markit-40-of-energy-storage-pipeline-is-co-located-with-solar-pv#.WtltLU0v78E.twitter
[169] http://www.joshfrydenberg.com.au/guest/mediaReleasesDetails.aspx?id=541

Figure 5.1: Sixteen of the World's Largest Solar-With-Storage Projects

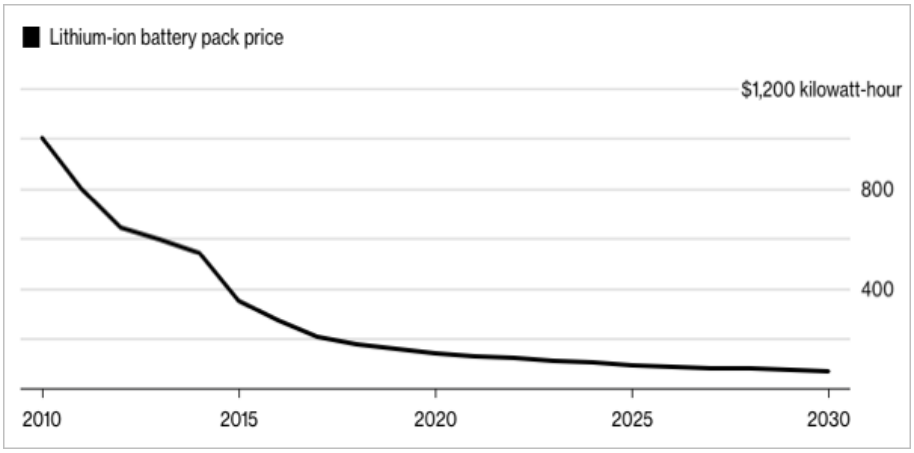
No	Project Name	Solar Size (MW)	Battery Size (MW)	Storage (MWh)	Status	Country	Proponent
1	KIUC's Tesla solar with storage project	13.0	13.0	52.0	Operational	Hawaii	KIUC & Tesla
2	FPL Citurs Solar Energy Centre with Storage	74.0	4.0	16.0	Operational	USA	Florida Power & Light Co
3	Clayhill Solar and Storage Project	10.0	6.0	-	Operational	England	Anesco
4	Lakeland Solar and Storage Project, Cooktown, Qld	10.8	1.4	5.3	Operational	Australia	Conergy
5	Akuo Olmo 1 Corsica Solar Storage Project	9.0	-	9.0	Operational	France	Akuo Energy
6	Genex Power Kidston stage 1 & 2, Australia	320.0	250.0	2,000.0	Partly Operational	Australia	Genex Power
7	AES Kauai Solar Energy Storage Project	28.0	20.0	100.0	Under Construction	USA	AES Distributed Energy
8	KIUC's AES Corp solar with storage project	28.0	20.0	100.0	Under Construction	Hawaii	KIUC & AES Corp
9	Simec Zen Energy South Australia	200.0	120.0	-	Announced	Australia	Simec Zen Energy GFG Alliance
10	NextEra Energy (FLP) Tuscon Solar plus Storage Project	100.0	30.0	120.0	Announced	USA	NextEra Energy
11	Carnegie Western Australia Solar Plant with Storage	100.0	-	20.0	Announced	Australia	Carnegie Energy
12	First Solar Arizona Solar plus Storage Project	65.0	50.0	-	Announced	USA	First Solar
13	Tesla's Battery Storage Gannawarra Solar Farm	60.0	25.0	50.0	Announced	Australia	Tesla
14	Tilt Renewables Snowtown South Australia	44.0	21.0	26.0	Announced	Australia	Tilt Renewables
15	NLC Andaman & Nicobar Islands Solar Plus Storage	20.0	-	16.0	Announced	India	To be Announced
16	KIUC & US Navy's AES Corp solar with storage project	19.3	19.3	70.0	Announced	Hawaii	KIUC, US Navy & AES Corp

Source: Company & Press reports, IEEFA estimates

An example of the potential of linking variable renewables and storage is evident in the partnership between Bay State Wind (a joint U.S. venture of Ørsted of Denmark and New England-based Eversource) and NEC Energy Solutions to incorporate 55 MW/110 MWh of storage in the 800 MW offshore wind farm under development off Martha's Vineyard, a project announced in March 2018.[170] This strategy suggests a key way forward in balancing demand and supply, providing grid stability and frequency control, and maximising value by enabling delivery during peak electricity demand periods.

An important driver of this trend is the massive deflation evident in battery costs, with total lithium-ion battery pack prices falling by more than 20% in 2017 and a similar rate of decline expected for 2018. BNEF's price forecast to 2030 is illustrated in Figure 5.2 below.

Figure 5.2: BNEF Forecasts Lithium Ion Battery Price Deflation Still to Come



Note: Prices starting in 2018 are forecasts.
Source: Bloomberg New Energy Finance

[170] https://www.greentechmedia.com/articles/read/is-offshore-wind-a-better-deal-with-batteries#gs.s6Kc2I4

Germany's Behind-the-Meter Storage Market: 385 MW in 2018

The German behind-the-meter storage market is the most developed globally. GTM estimates German residential battery installs will reach 385 MW in 2018, driven by volume growth of 38% year on year.[171]

Saudi Arabia's 200 GW Solar Plan

A key characteristic of the Saudi Arabi's aggressive solar development plans (refer Section 1.1) is the proposal for "the largest utility-scale battery" to provide evening power.[172] The project will be funded from Softbank's US$100bn Vision Fund, which counts the Saudi Sovereign Wealth Fund as its largest investor. If successful, it would enable Saudi Arabia to replace oil-fired power generation, which in turn frees up oil for export. Given the size of the project, it could also create zero-emissions electricity export opportunities, but that would depend on the construction of transmission infrastructure and / or the successful commercialisation of hydrogen or ammonia storage capacity.[173]

Australian 9 GW Wind-Solar-Storage-Interconnect Hybrid

In November 2017 CWP Renewables announced plans to develop a hybrid clean energy export hub in the north-west of Western Australia that is paradigm-shifting for the Asian region if they can be implemented. CWP has announced a grand plan to ultimately build 6 GW of wind and 3 GW of solar to produce 33 TWh annually.[174] One-third of production is targeted for sale to the remote, micro-grid mining industry and processing sector, with two-thirds of generation aimed for export to Indonesia via a proposed 2,500 km subsea cable and exported to markets like Japan after being stored in ammonia and/or hydrogen. CWP's Asian Renewable Energy Hub has identified 7,000 square kilometres of government controlled land in the East Pilbara region. CWP is working with and has the support the traditional owners, the Nyangumarta people. Financial close is targeted for 2021 and financial support from the North Australia Infrastructure Fund is being sought.[175]

While this A$20bn proposal is beyond ambitious and full of political, regulatory, engineering and financial challenges, ultimately like the 200 GW Saudi Arabian MoU, it illustrates the absolute scale of technology driven transformation evident, and illustrates the enormous opportunities and changes that in our view will inevitably challenge and even progressively destroy incumbent industries and conventional thinking.

Australian Residential Solar-With-Storage

Australia installed a record 1.1 GW of residential rooftop solar in 2017, with this trend accelerating; cumulative installs reached 7 GW in May 2018, the highest penetration per capita globally. The ongoing double-digit annual deflation of solar costs has seen Australian installed costs decline 80% from US$6.40/w in 2010 to US$1.40/w in 2017. Distributed behind-the-meter residential battery storage is a major new growth market, with installations doubling each year in the last three years. Major storage competitors vying for this market include Tesla, BYD and Sonnen.[176]

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171 https://www.greentechmedia.com/articles/read/german-energy-storage-sector-employs-half-number-people-as-lignite#gs.=6Jg9A0

172 https://www.bloomberg.com/news/articles/2018-03-29/batteries-included-even-the-huge-saudi-solar-farm-will-use-them

173 http://reneweconomy.com.au/thats-not-solar-farm-solar-farm-51282/

174 http://asianrehub.com/wp-content/uploads/2018/04/AREH-Media-Release-1-May-2018-web.pdf

175 https://reneweconomy.com.au/pilbara-renewables-hub-adds-3gw-wind-and-solar-to-20bn-plan-86697/

176 http://www.afr.com/business/energy/solar-energy/warren-buffetts-chinese-battery-giant-byd-to-take-on-tesla-in-australia-20180321-h0xszp#ixzz5AWv7xX59

Hawaii's KIUC Solar-With-Storage-Projects, U.S.

The Kauai Island Utility Cooperative (KIUC) has pursued solar-plus-storage projects aggressively over the past several years to comply with the Hawaii state target of having renewables supply all the islands' electricity by 2045. The first project came online in March 2017; it includes 13 MW of solar and a 13 MW/52 MWh Tesla Powerpack battery storage facility. The 20-year PPA for the facility, signed in 2015, is at US$139/MWh — less than the US$150/MWh average cost of oil-fired generation in 2016.[177]

Construction on the cooperative's second project began in February 2018. This facility, being built by AES Distributed Energy, includes a 28 MW solar array and a 20 MW/100 MWh battery system.[178] The PPA was signed in January 2017 at US$110/MWh, a 20% drop in the price in just two years and 35% below the prevailing cost of oil-fired power generation.[179]

Finally, the cooperative agreed to a third project in December 2017, also to be developed by AES Distributed Energy. This project, 19.3 MW of solar with 70 MWh of battery storage, will be built at the Pacific Missile Range Facility – Barking Sands (PMRF) in cooperation with the U.S. Department of the Navy.[180] The 25-year PPA is for US$109/MWh.

FPL Citrus Solar Energy Centre with Storage, U.S.

A NextEra Energy utility subsidiary, Florida Power & Light (FPL), in 2016 developed the Citrus Solar Energy Center in Florida's DeSoto County with 74.5 MWh of solar and in February 2018 announced it had added 4 MW/16 MWh of storage. As of February 2018, NextEra Energy operates 130 MW of batteries with more than 100 MWh of storage capacity.[181]

Clayhill Solar and Storage Project, England

September 2017 saw the commissioning in England of a 10 MW solar plus 6 MW battery storage project near Flitwick, built by Anesco without any government subsidy support.[182] The project uses BYD solar modules and Huawei string inverters. Three earlier Anesco solar farms located in Northampton, Chesterfield and Stratford-upon-Avon were each 5 MW in size and supported by a 1.1 MWh battery. Anesco is expecting to install 380 MW of new storage capacity in the UK by 2020.[183]

Lakeland Solar and Storage Project, Australia

The Lakeland Solar and Storage Project in Cooktown in far north Queensland is a 10.8 MW solar facility combined with 1.4 MW / 5.3 MWh of battery storage. Australia's first large scale hybrid system, the project was sponsored by BHP Billiton and developed by Germany's Conergy, assisted by funding from Germany's Nord LB. The remote Lakeland end-of-grid project was announced in 2016 and commissioned in February 2018 at a total project cost of A$42m (US$32m), aimed at providing electricity for BHP's copper project.

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[177] https://www.utilitydive.com/news/teslas-dispatchable-solarstorage-project-in-hawaii-brought-online/437858/
[178] http://aesdistributedenergy.com/wp-content/uploads/2018/02/AES_KIUC-Groundbreaking-Announcement_02-22-2018.pdf
[179] https://www.utilitydive.com/news/hawaii-co-op-signs-deal-for-solarstorage-project-at-11kwh/433744/
[180] http://aesdistributedenergy.com/wp-content/uploads/2017/12/AES-Distrubuted-Energy-selected-by-KIUC-and-PMRF-for-Solar-PV-Plus-Storage-Project.pdf
[181] http://newsroom.nexteraenergy.com/2018-02-09-FPL-unveils-first-solar-plus-storage-system-in-the-U-S-that-can-increase-solar-power-plant-output
[182] https://www.pv-magazine.com/2017/09/26/anesco-formally-opens-uks-first-subsidy-free-solar-farm-complete-with-storage/
[183] https://www.pv-magazine.com/2018/05/14/anesco-to-deploy-380-mw-of-storage-by-2020/?utm_source=dlvr.it&utm_medium=twitter

This project was supported by a A$17m ARENA grant and is underpinned by a PPA with Origin Energy; it clearly demonstrates the commercial-scale scope for solar plus storage deployment in remote communities and off-grid mining sites. Conergy intends to add another 20MW of solar in a stage 2 development, which is set for completion in 2019.[184]

This area of Queensland is also the site for the proposed A$160m (US$135m), 60MW Kennedy Energy Park, a hybrid model involving 42 MW of wind, 15 MW solar and 2 MW of lithium-ion battery storage. Located 300 km inland, it is being developed by a joint venture between ASX-listed Windlabs and Eurus Energy.

Akuo Bardzour Solar Storage Project, France

This project on France's Reunion island includes a 9 MW solar project and a 9 MWh lithium-ion battery system and has been operational since 2014.[185] Akuo Energy has four island projects with 29 MW of solar capacity coupled with 29 MWh of batteries in operation.

Genex Power's Kidston Solar Power, Australia

Genex Power has built a A$115m 50 MW AC solar PV project in far north Queensland that has been progressively commissioned since December 2017. Its capacity factor during the first four months of operation was over 33%, a world-beating mark made possible by brilliant solar radiation coupled with single-axis trackers, First Solar Series 4 modules, trackers by NEXTracker and SMA inverters. The project is underwritten by a 20-year PPA with the Queensland government.[186]

Genex is now developing phase II at the site, a A$420m (US$300m) project that will add 270 MW of solar and an associated 250 MW of pumped hydro with 8 hours of storage.

In April 2018, Genex disclosed it is considering a pumped hydro-solar-wind phase III involving adding 150 MW of wind in a strategy aimed at best-utilisation of grid infrastructure by running close to 24x7 (building a new 275kV transmission line connection is a prerequisite to financial close on phase II).[187]

One key feature of this project is that it is built on the tailings dams and unrehabilitated overburden wastelands left at the site of Australia's largest gold mine operation. The grid infrastructure built decades ago to supply mine electricity is being repurposed to take electricity for delivery into the grid in peak demand periods.[188]

AES SCE Energy Storage Project, U.S.

AES has been contracted to build a 100 MW/400 MWh battery storage installation in California under a 20 year PPA with Southern California Edison. It is designed to replace aging and increasingly expensive gas generators in that state. John Zahurancik, president of AES Energy Storage, expects to see the market for grid-scale battery storage reach 28GW by 2022 (from 3 GW in 2016), and estimates costs have fallen 90% since AES first entered the market a decade ago, concluding that:[189]

> *"Battery storage is becoming a solution because of its flexibility, the ease of permitting, and its scaleability, and because it can be deployed very rapidly."*

[184] http://reneweconomy.com.au/australias-first-large-scale-solar-storage-plant-connected-to-grid-69396/
[185] http://www.akuoenergy.com/en/bardzour
[186] http://reneweconomy.com.au/kidston-solar-farm-lays-case-going-merchant-84317/
[187] http://www.afr.com/news/politics/genex-adds-wind-project-to-its-kidston-renewables-hub-in-north-queensland-20180405-h0ycvp
[188] http://www.genexpower.com.au/250mw-kidston-pumped-storage-hydro-project.html
[189] http://reneweconomy.com.au/aes-siemens-combine-to-tackle-tesla-dominate-battery-storage-market-38413/

SIMEC Zen Energy's Whyalla Steelworks Solar Project, Australia

Sanjeev Gupta's SIMEC Zen Energy in March 2018 proposed adding a 200 MW solar PV array, a 120 MW storage battery, and a cogeneration unit to reuse waste heat at the Whyalla Steelworks in South Australia, which Gupta recently acquired.[190] [191] Assisted by a A$10m state government grant, this is an upgraded target relative to an October 2017 plan to install a 100 MW/100 MWh battery storage unit to reduce energy costs at the steel mill by 40%. In September 2017, Gupta acquired a 50.1% stake in South Australia's Zen Energy storage business.[192]

Gupta also has proposed building a 120 MW/600 MWh pumped hydro storage facility at a disused iron ore mine pit in the Middleback Ranges that used to serve the steelworks,[193] but with the recent change in state government, that plan may be put on hold.

NextEra Energy Tucson Solar Plus Storage Project, U.S.

Announced in May 2017, NextEra Energy's Tucson project is a 100 MW solar project linked with a 30 MW/120 MWh battery storage system. The PPA signed by Arizona utility Tuscan Electric Power is priced at a new U.S. record low of below US$30/MWh for the solar and below US$45/MWh including the storage capacity.[194] [195] Commissioning is due in 2019.

Carnegie Solar Plant with Storage, Australia

Carnegie Clean Energy announced plans in February 2018 to build a 100 MW solar plant with 20 MWh of storage at a site in Western Australia next to the Mungari Strategic Industrial Area near Kalgoorlie, an isolated, end-of-grid location requiring increased generation capacity to support mining activity in the area.[196]

In March 2018, Carnegie Clean Energy announced a second project, this one including 10 MW solar and 10 MWh of battery storage, for Western Australia.[197]

In April 2018, ABB of Switzerland announced it was installing a 30 MWh battery storage system at a remote off-grid site supplying electricity for iron ore mining in the Pilbara in Western Australia. The current gas power plant is backed up by expensive imported diesel generators, and this microgrid development paves the way for a follow-on solar development, highlighting the rate of change in the very traditional mind-set of the Australian mining sector.[198]

While unrelated to Carnegie, this builds on the 2016 commissioning of the A$40m off-grid pilot project at the DeGrussa copper-gold mine in Western Australia owned by Sandfire Resources. This project, including 10.6 MW of solar and a 6 MW/1.8 MWh battery storage

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[190] https://www.bloomberg.com/news/articles/2018-03-16/metal-tycoon-to-leapfrog-elon-musk-with-world-s-biggest-battery
[191] http://www.afr.com/business/energy/sanjeev-gupta-to-beat-teslas-elon-musk-with-bigger-battery-in-south-australia-20180315-h0xjgb?btis
[192] http://www.afr.com/business/energy/british-billionaire-sanjeev-gupta-buys-majority-stake-in-zen-energy-20170919-gykvgf
[193] http://reneweconomy.com.au/whyalla-steel-city-goes-green-with-1gw-of-solar-and-storage-92904/
[194] https://www.greentechmedia.com/articles/read/todays-top-solar-developers-have-become-storage-developers-too#gs.7gOVKMI
[195] https://www.tep.com/news/tep-to-power-21000-homes-with-new-solar-array-for-historically-low-price/
[196] https://reneweconomy.com.au/carnegie-proposes-100mw-solar-20mwh-battery-near-kalgoorlie-49643/
[197] https://reneweconomy.com.au/carnegie-eyes-another-10mw-solar-battery-project-w-15491/
[198] https://www.pv-magazine-australia.com/2018/04/18/abb-supplies-30-mwh-battery-microgrid-to-the-pilbara/

unit, was designed to reduce the use of expensive imported diesel power by 5 million litres annually, with funding assistance by ARENA.[199]

First Solar's Solar Plus Storage Project, U.S.

In February 2018, First Solar was awarded a contract to build and operate a 65 MW solar project supported by three utility-scale batteries totalling 50 MW from Arizona Public Service, the state's largest utility.[200] APS has signed a 15-year PPA to buy electricity from the project. The 50 MW battery storage facility will provide a clean energy solution for peak demand during hot summer days. APS has plans to add more than 500 MW of solar with storage.

Tesla Battery Storage at the Gannawarra Solar Farm, Australia

Tesla has been contracted to supply a 25 MW/50 MWh battery storage facility adjacent to the existing 60 MW Gannawarra Solar Farm in Kerang, Victoria.[201] [202] The project is owned by Edify Energy and Wirsol Energy; it will be operated by EnergyAustralia under a long-term PPA. Completion is due before the end of 2018. This is the third major Tesla battery project in Australia. Tesla's absolutely transformative Hornsdale Power Reserve in South Australia began commercial operations in December 2017 and has been enormously profitable since,[203] and it is now working with Neoen of France to build a 20 MW/34 MWh project next to the 194 MW Bulgana wind farm at Horsham, Victoria.[204]

A second battery with 30 MW/30 MWh of capacity is to be built nearby at Ballarat by Fluence (a joint venture between Siemens and AES Energy Storage [205]) on behalf of the local grid operator AusNet, albeit with no associated solar development. These two projects are being supported by A$50m of funding from ARENA and the Victorian state government to address significant grid congestion problems in the area.

ARENA CEO Ivor Frischknecht said:[206]

> *"Battery storage will play a crucial role in the future energy mix, alongside other forms of storage and in conjunction with variable renewables and demand management."*

Tesla commissioned a 18 MW battery storage system in Belgium in May 2018, to be subsequently linked in with two proposed solar projects (one of which is floating solar), showing how rapidly this grid stabilisation service technology is being integrated and scaled up globally.[207]

Tilt Renewables Snowtown Solar with Storage Project, Australia

In February 2018, Tilt Renewables announced a A$90m (US$70m) project in Snowtown, South Australia, that will include 44 MW of solar and a 21 MW/26 MWh battery system. It will be near an associated 370 MW wind farm development. Tilt Renewables has also

[199] https://arena.gov.au/projects/degrussa-solar-project/
[200] https://www.aps.com/en/ourcompany/news/latestnews/Pages/aps-first-solar-partner-on-arizonas-largest-battery-storage-project.aspx
[201] http://reneweconomy.com.au/tesla-fluence-to-build-two-big-batteries-in-victoria-88655/
[202] https://reneweconomy.com.au/victorias-biggest-solar-farm-connected-to-grid-now-for-new-tesla-battery-80621/
[203] https://reneweconomy.com.au/the-stunning-numbers-behind-success-of-tesla-big-battery-63917/
[204] http://reneweconomy.com.au/neoen-starts-work-on-next-tesla-big-battery-project-in-victoria-28218/
[205] http://reneweconomy.com.au/aes-siemens-combine-to-tackle-tesla-dominate-battery-storage-market-38413/
[206] https://arena.gov.au/news/arena-provide-25-million-jointly-fund-victorias-first-large-scale-grid-connected-batteries/
[207] https://www.pv-magazine.com/2018/05/14/from-black-to-green-in-flanders/?utm_source=dlvr.it&utm_medium=twitter

announced plans for a 300 MW/1,350 MWh pumped hydro energy storage project to be constructed in the disused Highbury quarry near Adelaide.[208]

NLC Andaman & Nicobar Islands Solar Plus Storage, India

In April 2018, Indian solar EPC firm Mahindra Susten again offered the lowest bid for a solar and energy storage project, this time in the Andaman and Nicobar Islands, bidding a price of Rs1.33bn (US$20m). The project, tendered by NLC India, the state-run mining and power firm, will include 20 MW of solar and 8 MWh of storage.[209] The pricing is half that bid last year, reflecting a far lower battery storage component (8 MWh vs 28 MWh previously). The viability and suitability of solar and storage on the Andaman Islands is clear, since the local government currently has to import diesel from 1,200 km away and burn it in inefficient generators to generate electricity. In March 2018, India Energy Minister R.K. Singh called for battery manufacturers to consider establishing operations in India, stressing that future solar and wind tenders will likely include battery storage.[210] Praveer Sinha, the newly appointed Managing Director of Tata Power, India's largest renewable energy infrastructure owner, in May 2018 highlighted the critical role battery storage will play in enabling India's aggressive solar deployment plans.[211]

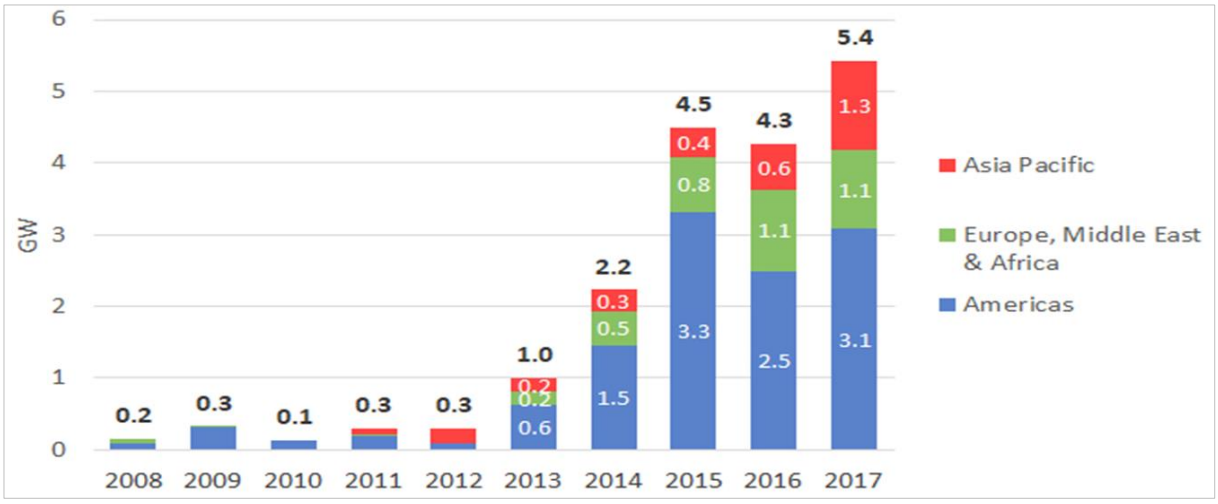
[208] http://reneweconomy.com.au/south-australia-unveils-another-big-battery-this-time-with-solar-16727/
[209] https://www.pv-tech.org/news/mahindra-wins-again-in-andaman-solar-storage-retender
[210] https://www.pv-tech.org/news/indian-power-minister-appeals-to-battery-manufacturers-with-solar-wind-stor#.WrixwQuFeLk.twitter
[211] https://energy.economictimes.indiatimes.com/energy-speak/the-future-of-renewable-energy-in-india/3016

6. Corporate PPAs

Corporations signed long-term agreements for a record 5.4 GW of clean energy capacity globally in 2017, up from 4.3 GW in 2016 (estimates from BNEF, detailed in Figure 6.1). That is enough to displace 10 coal-fired power plants[212] and provides US$5-10 bn of high credit-rating backing for new renewable energy projects.

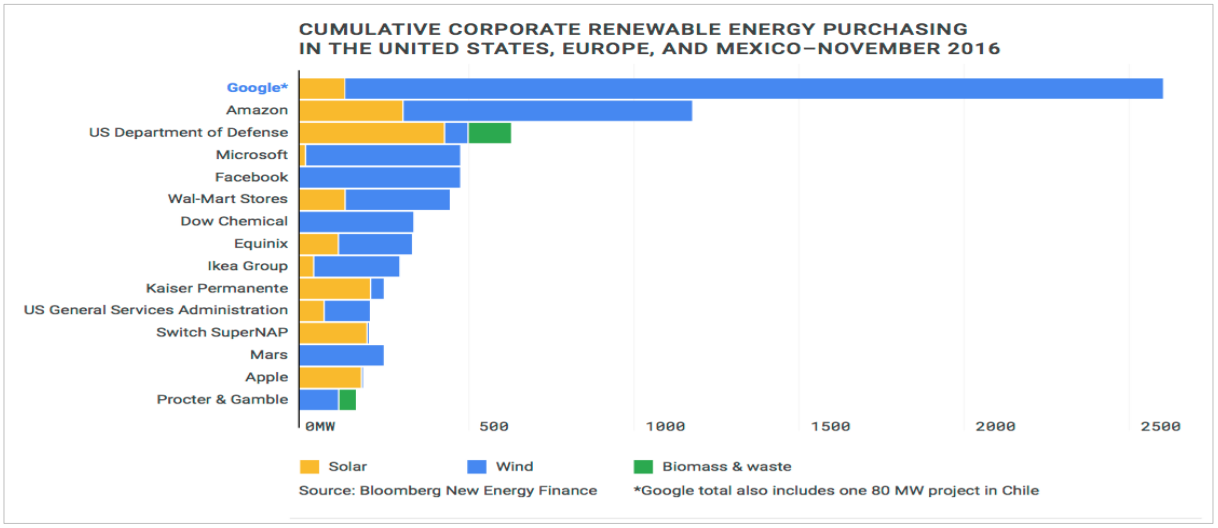
In addition, as major corporations sign on to such deals, they continue to look to "green" their entire supply chains, many of which sit in emerging markets. This activity helps expand access to capital in markets, which is often a key constraint.

Figure 6.1: Global Renewable Energy PPAs Signed by Corporates FY2008-FY2017



Source: BNEF Corporate PPA Deal Tracker, January 2018

Figure 6.2: Renewable Energy Sourced by Corporates by November 2016



Source: BNEF, Google December 2016 Sustainability Report[213]

[212] https://www.bloomberg.com/news/articles/2018-04-04/google-bought-enough-clean-power-for-whole-company-and-then-some

[213] https://environment.google/projects/announcement-100/

Figure 6.2 above shows the largest corporate procurements of renewable energy globally as of November 2016, while also detailing the split between wind and solar generation. Internet companies with their enormous data centre energy requirements top the list along with the U.S. Department of Defence.

Figure 6.3 details a number of the largest solar PPA contracts announced globally. We include a cross-section, illustrating the expanding interest of corporations in these deals.

Figure 6.3: Global Solar Energy PPAs Signed by Corporates

No	Project Name	Size (MW)	Country	Developer
1	Microsoft Virginia Data Centre	315.0	USA	sPower
2	Apple Nevada Data Centre	200.0	USA	NV Energy
3	Airport Authority of India	200.0	India	To be Tendered
4	Sun Metal	125.0	Australia	Sun Metal
5	Shell UK	69.8	UK	British Solar Renewables
6	Microsoft Singapore	60.0	Singapore	Sunseap
7	University of New South Wales	124 GWh	Australia	Maoneng & Origin Energy
8	Carlton & United Breweries	74 GWh	Australia	BayWa r.e.

Source: Company & Press reports, IEEFA estimates

Alphabet Inc's Google

Google estimates that it used 7 terawatt-hours (TWh) of electricity to run its global operations in 2017 (up from 5.7 TWh in 2015), and it is now set to source 100% of that demand from clean energy once new projects committed to in 2017 come online.

Google signed agreements for 3 GW of renewable projects over 2017, making it by far the largest corporate buyer of renewable energy certificates and sponsor of zero-emissions corporate PPAs.[214] One example is the 10-year PPA it signed with Eneco of Netherlands for the 30 MW Sunport solar project at Delfzijil (reported as the largest in the Netherlands). This project will supply Google's recently opened Eemshaven data centre, serving the company's desire for proximity and additionality.[215] Other solar facilities associated with Google PPAs are a 61 MW plant in the U.S. (with Duke Energy in North Carolina) and the 80 MW El Romero facility in Chile's Atacama Desert (signed with Acciona Energia).

Google operates 15 data centres. Estimates show that its U.S. facilities account for 3% of the nation's annual electricity consumption.[216] Google is reported to have invested more than US$3.5bn in renewable energy globally in its move to 100% clean energy.[217]

The company has a clear strategy to green its image and is committed to being carbon neutral, but the deals also make good business sense. Google reports cost reductions of between 60-80% since it moved to direct purchasing of renewables.[218] while having a focus on energy productivity has driven Google's data centres to use 50% less electricity than the industry average (on Google's own reported estimate).[219]

[214] https://www.vox.com/energy-and-environment/2017/12/6/16734228/google-renewable-energy-wind-solar-2017
[215] http://www.datacenterdynamics.com/content-tracks/power-cooling/google-signs-10-year-ppa-with-netherlands-largest-solar-farm/98606.fullarticle
[216] https://www.energy.gov/videos/energy-101-energy-efficient-data-centers
[217] https://storage.googleapis.com/gweb-environment.appspot.com/pdf/google-2017-environmental-report.pdf
[218] https://electrek.co/2017/11/30/google-is-officially-100-sun-and-wind-powered-3-0-gigawatts-worth/
[219] https://static.googleusercontent.com/media/www.google.com/en//green/pdf/achieving-100-renewable-energy-purchasing-goal.pdf

Amazon

Amazon Web Services (AWS) planned to add 180 MW of solar in Virginia by the end of 2017 as part of the company's move toward powering its AWS Cloud with 100% renewable energy.[220] Amazon's preference for renewables can be seen also in its signing of a PPA In October 2017 for 228 MW of wind in Texas—its largest PPA to date.[221] The company says it now has 18 wind and solar projects across the U.S., with 35 more projects in the pipeline.

Microsoft

Microsoft received regulatory approval in July 2017 to buy power directly to cover 25% of the electricity used at its corporate headquarters in Redmond, Wash., instead of relying on Puget Sound Energy, its local utility. The deal, which included a transmission fee, will enable Microsoft to buy green power. In March 2018, Microsoft announced a deal with AES Power to buy 315 MW from solar projects in Virginia to supply its data centres and offices there. This deal could be the largest single solar corporate PPA to date.[222]

Microsoft announced its first clean energy deal in Asia in March 2018, a 60 MW rooftop solar portfolio investment to be implemented by Sunseap and backed by a 20-year Microsoft PPA (see Section 4). Microsoft aims to exceed its goal of powering 50% of its global data centre load with renewable energy in 2018. Once operational, the new Singapore solar project will bring Microsoft's total global direct procurement in renewable energy projects to 860 MW.[223]

Apple

Apple now has retail stores, offices and data centres in 43 countries running on clean energy, with a total investment to date of US$2.5bn in both energy efficiency and 25 renewable energy plants worldwide, with another 15 more now being built.

Apple is urging its suppliers to follow its lead. Apple said in April 2018 that nine additional manufacturing partners had agreed to power all their Apple production facilities with clean power.[224] Including its suppliers, Apple currently owns, operates or buys 1.1 GW of clean energy capacity (46% solar, 48% wind, 5% biomass). The company also has 1.9 GW of clean energy projects in development. In April 2018 Apple announced it had reached its commitment to use 100% renewable power as part of the RE100 campaign.

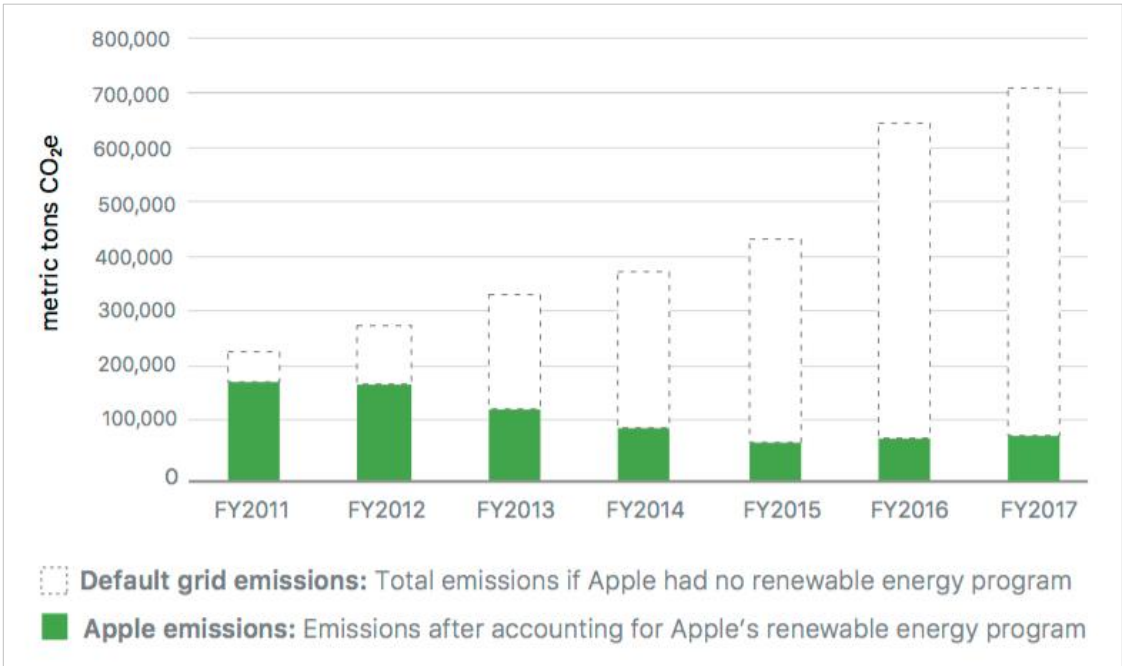
Apple has funded much of its renewable energy work through green bonds. Its first green bond offering in 2016 raised US$1.5bn; a second in June 2017 raised another US$1 billion.[225]

Apple's renewable investment efforts began in 2011 when it self-funded its first solar project, a 20 MW facility in North Carolina.

Apple's new corporate headquarters includes the largest U.S. rooftop solar project, at 17 MW (see Section 4). Despite rapid growth in energy demand, Apple estimates it has halved its direct emissions since 2011 (see Figure 6.4 below).

[220] https://www.pv-tech.org/news/amazon-adds-180mw-to-renewable-portfolio-in-five-solar-projects-across-virg
[221] https://www.windpowermonthly.com/article/1447901/amazon-texas-project-goes-online
[222] https://apnews.com/90fda017ad7e46a8b4bbea6226e03230/Microsoft-announces-major-solar-buy-in-Virginia
[223] https://reneweconomy.com.au/microsoft-sunseap-sign-agreement-largest-ever-solar-project-singapore-65142/
[224] https://www.bloomberg.com/news/articles/2018-04-09/apple-s-entire-business-is-now-being-powered-with-clean-energy
[225] https://www.reuters.com/article/us-apple-climate-greenbond/apple-issues-1-billion-green-bond-after-trumps-paris-climate-exit-idUSKBN1941ZE

Figure 6.4: Apple's Emissions – Scope 1 & 2, FY2011-FY2017



Source: Apple Environmental Sustainability Report 2018[226]

Airport Authority of India

Civil Aviation Minister Ashok Gajapathi Raju has announced that the Airport Authority of India will undertake solar projects totalling 200 MW across all its sites in India, with a target completion date of 2022/23. Projects totalling 90 MW are already operational. The three projects detailed below illustrate how this investment program will be configured:

1. Cochin International Airport (CIAL) installed 13 MW of solar across 45 acres, on both rooftops and unused land. The work was completed in 2015 by Bosch of Germany.[227] On completion, CIAL announced plans to double this to 26.5 MW.[228]
2. Kolkata international Airport in West Bengal commissioned a US$14m, 15 MW solar system in December 2017. Sterling & Wilson served as lead EPC using modules supplied by Waaree Energies, one of the largest solar manufacturers in India.[229]
3. Ahmedabad Airport in January 2018 announced plans for a 700-kW rooftop solar system at a price of US$754/kW, making the system immediately cost effective.[230]

Sun Metals

The Korean Zinc miner is on the verge of commissioning a 125 MW solar plant to support the electricity needs of its Townsville, Queensland refinery in May 2018.[231] This is likely to be Australia's largest single site renewable energy consumer, at the same time, the plant will be connected to the national grid and will sell excess electricity to the national market. Sun Metals needs 900,000 MWh of electricity to produce 225,000 tonnes of zinc each year.

[226] https://www.apple.com/environment/pdf/Apple_Environmental_Responsibility_Report_2018.pdf
[227] http://cial.aero/Pressroom/newsdetails.aspx?news_id=358&news_status=A
[228] http://www.thehindu.com/news/cities/Kochi/cial-to-double-solar-energy-capacity/article7926145.ece
[229] https://mercomindia.com/grid-connected-commissioned-kolkata-international-airport/
[230] https://mercomindia.com/rooftop-solar-ahmedabad-airport/
[231] https://reneweconomy.com.au/australias-biggest-solar-farm-about-to-begin-commissioning-89615/

Shell UK

Shell UK announced a five-year PPA in January 2018 with British Solar Renewables, manager of the 69.8 MW Bradenstoke solar project (owned by Siem Europe SARL). Shell had previously announced plans to invest US$1-2bn annually through 2020 in renewable energy as part of a new corporate strategy.[232]

Shell followed this development in January 2018 by announcing the US$200m acquisition of a 44% stake in Silicon Ranch, a solar developer based in the state of Tennessee with a solar portfolio of 880 MW.[233]

University of NSW, Australia

The University of NSW (UNSW) signed a 15-year PPA in December 2017 to buy 124 GWh of electricity annually from the Sunraysia Solar plant being built in Bairanald, NSW. The A$275m, 250 MW project is expected to come online by the end of 2018. Maoneng Australia is the project developer and Origin Energy is the energy utility. UNSW Vice Chancellor Ian Jacobs said the agreement was part of the university's goal to become energy carbon neutral by 2020. This Australian first is appropriately being undertaken by UNSW, which has a long history as a world leader in solar technology development under the leadership of Professor Martin Green and the late Professor Stuart Wenham.[234]

Carlton & United Breweries, Australia

Carlton & United Breweries Australia (owned by the multinational AB InBev) has contracted to acquire 74 GWh of electricity annually through a 12-year PPA with solar developer BayWa r.e. The electricity will come from a new 112 MW solar project in Mildura, Victoria. This is part of the brewer's broader plan to move to 100% renewable energy.[235]

[232] https://www.pv-magazine.com/2018/01/18/uk-shell-signs-5-year-ppa-with-bsr-for-69-8-mw-solar-project-comment/
[233] https://www.pv-magazine.com/2018/01/16/shell-to-acquire-44-stake-in-solar-developer-silicon-ranch/
[234] https://newsroom.unsw.edu.au/news/general/unsw-signs-world-first-solar-energy-agreement
[235] http://www.afr.com/news/vb-maker-gets-greener-as-cub-plunges-into-solar-energy-20180319-h0xpe5#ixzz5Ar7xq2Mc

7. Top Renewable Energy Utilities

Half of largest renewable energy investors globally are Chinese energy firms, consistent with China as the driving force in low emissions energy sectors of the future. BNEF estimates domestic China investment in 2017 represented 40% of the global clean energy total. Additionally, IEEFA calculates that China is taking an ever-larger role in global clean energy mergers and acquisition activity, with major transactions alone accounting for over US44bn of Chinese outbound investment in 2017, up 35% year on year.[236]

Beyond China's clear global leadership, European utilities are the other major group dominating investment in renewable energy. Enel of Italy, Iberdrola of Spain, EDP of Portugal, EDF and ENGIE of France and have been progressively building out renewable energy infrastructure investments over the last decade, consistent with Europe's global leadership on the issue of the need for urgent, concerted global action to address energy policy as a core cause of man-made climate change.

NextEra Energy U.S. is now the largest and most successful utility in North America, having consistently delivered superior shareholder returns for the last 15 years via a strategy of redeploying profits from its legacy thermal and nuclear power fleet into consistently building some 2 GW annually of renewables, with an even more ambitious target to deploy up to 4 GW annually through to 2022. With renewable energy now the low cost source of electricity in America, NextEra's foresight has been proven repeatedly. IEEFA's October 2017 report "Winners and Losers Among Big Utilities as Renewables Disrupt Markets" provides more detail on this topic.[237]

Figure 7.1 details twelve of the largest renewable energy firms globally, selected for scale and geographic diversity as well as our view of global renewable energy industry leaders.

Figure 7.1: Global Renewable Energy Leaders

Rank	Utility Name	Country	Total capacity installed by the end of FY2017 (MW)	Capacity installed in 2017 (MW)
1	China Energy Investment Corp	China	65.0	2.6
2	State Power Investment Corp Ltd	China	44.3	3.6
3	Enel SpA	Italy	40.9	2.1
4	Electricitie De France (EDF)	France	33.8	1.3
5	Iberdrola SA	Spain	29.2	1.4
6	ENGIE	France	26.8	2.2
7	China Datang Corp	China	20.3	3.3
8	Brookfield Asset Management	Canada	16.4	0.1
9	NextEra Energy Inc	U.S.	14.1	2.7
10	China General Nuclear Power Corp	China	13.3	1.3
11	Energias de Portugal (EDP)	Portugal	11.0	0.6
12	Ørsted	Denmark	8.9	1.5

Source: Company and press reports, IEEFA estimates

[236] http://ieefa.org/ieefa-report-china-continues-position-global-clean-energy-dominance-2017/
[237] http://ieefa.org/ieefa-report-winners-losers-global-electricity-market-renewables-disrupt-markets-across-asia-europe-u-s-africa/

The outlier for now on this list of global majors is Brookfield Asset Management (BAM), one of the largest infrastructure investors globally. Canadian rather than Chinese, and an asset management firm rather than a power utility.

IEEFA expects the global pension funds management sector to play a significantly larger and more positive role in funding the US$2 trillion annual capital investment made in the global energy sector. With the April 2018 vote by the Conservative Party of Norway agreeing for the US$1 trillion Norwegian Sovereign Wealth Fund to consider diversifying into unlisted renewable energy infrastructure.[238] IEEFA's Tom Sanzillo has written extensively on this topic,[239] as has Gerard Wynn.[240]

Macquarie Group in March 2018 highlighted renewable energy infrastructure is one of its four global mega-themes.[241] Blackrock's Jim Barry, global head of Infrastructure in May 2017 stated clearly: "Coal is dead."[242] Likewise the October 2017 move by an asset management consortium led by Global Infrastructure Partners (GIP) to pay US$5bn for Singapore based Equis Energy (an Asian renewable infrastructure investor), one of the largest M&A deals globally to-date in the renewables sector.[243] No surprise to see Macquarie, Blackrock and GIP emerging alongside BAM as four of the largest global renewable energy infrastructure investors outside of China.

China Energy Investment Corp (CEIC), China

China's top coal miner Shenhua Group acquired China Guodian Group in August 2017 to form world's largest power utility named as CEIC that is worth US$278bn. The merged entity boasts 65 GW of renewable energy with 33 GW of wind energy, out of which 27 GW of wind that came to its portfolio from China Guodian Group.[244] Shenhua Group was China's largest coal miner and produced 13% of China's total coal in 2017. CEIC is vertically integrated from mining coal through to producing electricity from thermal as well as renewable energy generation capacity. The group operates railroads, ports, seaborne shipments and produces chemicals from coal.

CEIC installed 2.63 GW of renewable capacity in 2017 according to BNEF. The acquisition of Guodian Group will reduce the combined entity's dependence on coal-fired power generation. CEIC ranks number 1 in renewable energy capacity globally.

State Power Investment Corp (SPIC), China

SPIC ranks #2 in our global renewable leaders list with total installed capacity of 44.3 GW renewable energy. SPIC was established in June 2015 through the merger of China Power Investment Corporation and State Nuclear Power Technology Corporation. 43% of the installed capacity of the nuclear giant comes from zero emissions energy sources including its 4.8 GW nuclear portfolio. SPIC installed an impressive net 3.6 GW of renewable energy in 2017. SPIC is committed to implementing the Chinese Government's policy of restructuring nuclear SOEs (state owned enterprises) to also take a lead in the clean energy transition of China's power sector.[245]

[238] https://www.reuters.com/article/us-norway-swf/norway-fund-should-be-able-to-invest-in-unlisted-renewables-ruling-party-idUSKBN1HE0N7
[239] http://ieefa.org/ieefa-norway-case-sovereign-wealth-fund-invest-global-renewable-energy-infrastructure/
[240] http://ieefa.org/uk-pension-funds-can-reap-growing-renewables-infrastructure-opportunity/
[241] http://www.afr.com/business/banking-and-finance/macquaries-world-part-4-patience-pays-as-asia-transforms-20180226-h0woop
[242] http://www.afr.com/business/mining/coal/blackrock-says-coal-is-dead-as-it-eyes-renewable-power-splurge-20170524-gwbuu6
[243] https://www.bloomberg.com/news/articles/2017-10-25/global-infrastructure-acquires-equis-energy-in-5-billion-deal
[244] https://www.reuters.com/article/us-china-power-shenhua-guodian-factbox-idUSKCN1B918I
[245] http://eng.spic.com.cn/2016SiteEn/aboutSPIC/CompanyOverview/

SPIC has a presence in 36 countries with 1.2 GW of overseas projects and 10 GW currently under construction. SPIC aspires to reach installed capacity of 170 GW of total installed capacity with 50% of it from clean energy technology totalling asset value of US$150bn.

Enel, Italy

The Italian power giant Enel had new renewable energy installs of 2.4 GW in 2017, taking the total installed renewable energy capacity to 40.9 GW by year end.[246] The utility ranked #3 in IEEFA's global renewable energy leaders is truly a transition leader, and the utility had net decrease in thermal power capacity this fiscal year. Enel aims to channel its 80% incremental capex in mature economies in networks and renewable energy.[247] It has a massive 15 GW pipelined renewable capacity to be commissioned by FY2020.[248]

Électricité De France (EDF), France

French state-owned utility EDF is ranked #4 globally at the end of 2017. March 2018 saw EDF commit to invest €8bn (US$9.9bn) between 2018 and 2035 to become the European market leader in electricity storage.[249] This builds on EDF's commitment in December 2017 to invest €25bn to build 30 GW of solar capacity by 2035.[250] The French utility installed 1.3 GW new capacity in 2017 taking its total renewable portfolio at 33.8 GW.

EDF has been a dominant force in making renewable energy economically competitive with thermal power. EDF bid as low as US$17/MWh for a 300 MW solar project in Saudi Arabia. The contract was eventually awarded to the second lowest bidder due to certain technical intricacies involved in technology proposed by EDF.[251]

ENGIE, France

ENGIE is the second largest French electric utility and has installed renewable capacity of 26.8 GW as on end of 2017, including pumped hydro storage.[252] The utility acknowledges the need for energy sector transition towards more and more cleaner energy. ENGIE installed 2.2 GW of renewable energy in the year 2017 and continues to invest in prospects of energy efficiency, decentralised energy generation, microgrids and storage.

Iberdrola, Spain

The public multinational utility Iberdrola of Spain has a 29.2 GW renewable energy portfolio as of March 2018 up by 1.4 GW since March 2017.[253] The utility in its' "2018-22 outlook" aims to invest in a smart grid project to make Spain 99% connected with smart meters. Iberdrola's pipeline of projects includes the 350 MW Wikinger offshore wind project operational before 2022 and offshore wind projects in UK and Brazil.[254] Iberdrola recently became the first company to close a green financing deal in Latin America with the launch of a US$400m five year bond in Mexico as it aims to build 11GW of renewables in Mexico by 2022.[255]

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[246] https://www.enelgreenpower.com/about-us
[247] https://www.enel.com/investors/strategy/2017-executive-summary
[248] Enel Annual presentation FY2017
[249] https://energy.economictimes.indiatimes.com/news/power/french-utility-edf-to-invest-8-billion-euros-in-power-storage-by-2035/63491626
[250] https://www.reuters.com/article/us-edf-solar/edf-announces-big-push-into-solar-sees-cost-at-25-billion-euros-idUSKBN1E525Q
[251] https://www.pv-magazine.com/2018/01/05/saudi-arabia-announces-shortlist-for-300-mw-tender-excludes-lowest-bid/
[252] https://www.engie.com/en/group/
[253] https://www.iberdrola.com/about-us/figures/operating-data#2
[254] https://www.iberdrola.com/wcorp/gc/prod/en_US/conocenos/docs/Outlook_18_22_Q118.pdf
[255] https://www.iberdrola.com/press-room/news/detail/iberdrola-closes-mexico-first-green-financing-deal-company-latin-america

China Datang Corp, China

China Datang Corp consists of two main subsidiaries - Datang International Power Generation Company, that owns 8.9 GW of hydro power assets and China Datang Renewable Corp which owns 8.8 GW of wind and solar assets as of 2017 end. This Chinese SOE installed a total of 3.3 GW of renewables capacity in 2017. China Datang Corp is committed to implement China's 15-year general plan to meet its incremental energy demands through zero emissions energy sources. In December 2017, the installed capacity of the Company's wind farm in Saihanba reached 1.5 GW, making it the world's largest independent wind farm in service located at a single site.[256]

Brookfield Asset Management, Canada

Brookfield Renewable Partners, a subsidiary of the Canadian company Brookfield Asset Management, owns 16.3 GW of renewable assets as of end 2017. Brookfield installed just 75 MW of new capacity, while progressing an additional 248 MW of construction and advanced stage projects that are expected to enter commercial operations over the next four years.[257] This reflects a financial services bias to avoid construction risk where possible. In contrast, Brookfield acquired 5 GW of new renewable assets in 2017. Hydro-electricity represents 82% of Brookfield's renewable capacity.

NextEra Energy, USA

NextEra, one of the largest and most successful power utilities in North America, is a leader in renewable energy industry with a portfolio of 14.1 GW at the end of 2017. NextEra in 2017 implemented a record 1.6 GW of wind re-powering;[258] a great example of how this industry to progressively take advantage of technology improvements to reconfigure and upscale end-of-life wind power projects.

Figure 7.2: Five Year Relative Performance: Nextera Energy vs Southern Co.

Source: Yahoo Finance

[256] http://www.cdt-re.com/Article/UploadFiles/201804/2018042615261414.pdf
[257] https://bep.brookfield.com/~/media/Files/B/Brookfield-BEP-IR/Annual%20Reports/2017-annual-report.pdf
[258] https://reneweconomy.com.au/nextera-worlds-leading-renewables-installer-powers-90661/

Figure 7.2 above details the relative share price performance of NextEra Energy (up 97%, blue) vs Southern Co. (down 6%, red) over the last five years. At the start of this period Southern Co. was the top utility in America, while NextEra was #3 behind Duke Energy. Southern Company has invested heavily in the Kemper clean coal (carbon capture and storage) and Vogtle nuclear debacles while NextEra has focussed on building renewables as fast as was commercially practical. To IEEFA, the relative returns to shareholders is a telling and clear validation of the economic merits of avoiding stranded assets and investing in industries of the future.

China General Nuclear Power Corp (CGN), China

CGN New Energy Holdings Co Ltd is CGN's global platform that develops and operates power generation projects using non-nuclear clean and renewable energy. CGN has a total installed renewable capacity of 13.3 GW as of December 2018. The nuclear giant is one of the top wind power developers globally with total wind capacity of 9.1 GW.[259]

EDP (Energias de Portugal), Portugal

EDP ranks among Europe's major renewable electricity operators, as well as being one of Portugal's largest business groups. EDP's renewable portfolio stands at 11 GW as on FY2017 end.[260] EDP is following a financial policy of using operating cashflow plus asset recycling (selling down the equity holding in fully commissioned projects once construction risks have been removed) to pursue a self-funded organic growth strategy. EDP's 2016-2020 strategy aims to undertake US$5.5bn investment in new renewable projects.

As a consequence of financial distress following the global financial crisis of 2008, China Three Gorges progressively acquired a 23% shareholding in EDP (with another Chinese firm CNIC acquiring another 5% shareholding) and jointly funded a significant portion of EDP Renewables development pipeline. This culminated in China Three Gorges making a full takeover bid for EDP in May 2018, putting a enterprise value of €25bn of EDP (including debt).[261] To IEEFA this highlights the ongoing strategic profile of China's "going global" strategy to build up its global clean energy industry leadership.

Ørsted, Denmark

The Danish utility targets 96% of electricity generation from clean energy sources by 2023.[262] Formerly known as DONG Energy, Ørsted holds a total of 8.9 GW of offshore wind projects in Europe. In May 2017, the utility made a landmark bid for the He Dreiht offshore wind farm in Denmark at a zero strike price, which means the company will offer electricity entirely subsidy free, providing merchant electricity at wholesale power price prevalent at the time of trade.[263] In another landmark transaction, in April 2018 Ørsted was awarded a 900 MW offshore wind farm contract in Taiwan. This will be Taiwan's largest offshore wind farm built in Changhua County and aims to be connected to the grid by 2021.[264]

[259] http://en.cgnpc.com.cn/encgn/c100056/newenergy.shtml
[260] https://www.edpr.com/en/key-data/operating-data
[261] https://www.reuters.com/article/us-edp-m-a-china/china-three-gorges-launches-10-8-billion-bid-for-portuguese-power-firm-edp-idUSKBN1IC2NC
[262] https://orsted.com/en/Sustainability/Our-priorities/Transformation-in-figures
[263] http://www.nera.com/content/dam/nera/publications/2017/PUB_Offshore_EMI_A4_0417.pdf
[264] https://orsted.com/en/Company-Announcement-List/2018/04/1732224

8. Top Solar Module Manufacturers

This report focuses on the growing presence of gigawatt-scale solar in all its forms around the globe over the last few years.

Chinese projects feature relatively infrequently in the IEEFA list of top projects globally, mainly because it is difficult to track the multitude of solar projects in the country. But there is no doubt that China is focused on dominating the low-emissions industries of the future, both in terms of domestic deployment and increasingly in terms of international mergers and acquisitions, with the goal of becoming a world leader in terms of capital investments, employment, exports and technology development.[265]

One snapshot that highlights China's absolute dominance is the list here of the largest module suppliers (by shipment volume) for calendar year 2017; nine are Chinese-controlled firms, with only South Korea's Hanwha Q-CELLS offering any non-Chinese competition.[266]

The top 10 module suppliers shipped 57 GW in 2017, just under 60% of global supply. This includes production from China as well as company-run subsidiaries across Malaysia, Thailand and Vietnam, with new Chinese-owned manufacturing proposals for India and the U.S. under consideration in 2018. Firms that have dropped out of the Top 10 in recent years include First Solar, Renesola, Sharp, and SunPower.

While the Japanese entered last decade along with the Germans as world leading suppliers for solar cells and modules, the very long dated strategic intent of the Chinese solar firms drives an ongoing pursuit of rapidly growing global market share driven by a combination of ever-lower costs, ever-better technology and mind-blowing economies of scale. February 2018 saw Longi Solar announcing a plan to triple solar mono wafer capacity to 45 GW annually by 2020.[267] While America and India both contemplate import tariff barriers to Chinese solar modules due to this uncompetitive (or super-competitive, long dated) behaviour, to IEEFA this shows a dangerously short sighted approach in light of the enormous whole of society benefits of ever-lower solar electricity generation costs. Renewable energy deflation is transforming world energy markets.

Figure 8.1: The Top Ten Solar Module Manufacturers Globally in 2017

2017 Rank	Company	Manufacturing Base
1	Jinko Solar	China
2	Trina Solar	China
3	Canadian Solar	China
4	JA Solar	China
5	Hanwha Q Cells	South Korea
6	GCL-SI	China
7	Longi	China
8	Risen Energy	China
9	Shunfeng	China
10	Yingli	China

Source: PV Tech & Solar Media Ltd

[265] http://ieefa.org/ieefa-report-china-continues-position-global-clean-energy-dominance-2017/
[266] https://www.pv-tech.org/editors-blog/top-10-module-suppliers-in-2017
[267] https://www.pv-magazine.com/2018/02/09/longi-to-triple-wafer-capacity-to-45-gw-by-2020/

Conclusion

The sheer size and number of solar power-based generation projects in operation and under construction around the world is a clear indication that solar as a technology has come of age. This report has examined key facets of the global expansion of solar technology, with the widening of focus from traditional ground-mounted PVs to more recent innovations including floating solar plants, concentrating solar thermal and hybrids of wind-solar-batteries.

This spectrum of innovation will keep expanding with technologies such as bi-facial solar installed with trackers being proposed for a number of projects globally. Solar with storage and solar-wind hybrid generation could well be amongst the final pieces of the jigsaw that make this energy source available across the daily demand curve whilst becoming ever cheaper. In addition, we are witnessing innovation in financing, project management and policy making, further facilitating the scaling-up of the clean energy transition.

India, following in the footsteps of China with its National Solar Park Policy, has been successfully building ultra-mega sized solar parks. Investors in advanced economies have until recently been apprehensive of the bureaucratic and implementation challenges that are common to developing economies. However, solar parks have been a highly significant new model to rapidly attract foreign capital in Indian infrastructure projects.

On the corporate front, global tech giants such as Google, Amazon, Microsoft and Apple have either installed their own renewable generation capacity or signed corporate PPAs to satisfy their electricity requirements through clean energy sources. This is not only driven by a commitment to reduce carbon emissions, but also represents a sound economic and reputational risk decision.

In the Middle East, oil-rich economies like Saudi Arabia, Oman and UAE have seized on the technology transition. Under-construction ultra-mega solar parks and concentrated solar thermal projects have seen interest and investment from global utilities from China and Europe as well as the Middle East itself. The latest US$200bn solar deal between Saudi Arabia and Japanese tech-giant SoftBank is a key example of this clean energy globalisation. Meanwhile, in Latin America, Mexico and Chile set a record for lowest solar bids in 2017, close to US$20/MWh and attracting investments from global utility leaders such as Enel of Italy.

The accelerated rate of solar deployment all around the world is due to technology improvements, availability of cheaper financing and sensible policy support from governments. While there has been an extraordinary build-up of momentum behind solar, it is crucial to address the current challenges faced by the global solar industry. Protectionist threats to this sector in countries like India and the U.S. could seriously hamper the economic viability of solar energy and shrink its growing competitive advantage over thermal power.

Solving this problem as soon as possible is key to allowing the continuation of the global energy technology transition, locking in further, deflationary solar capacity and reducing costs for consumers whilst improving access to electricity.

Appendix: Videoclips of Solar

Following are the links to videoclips of some of the projects featured in this report.

1. Bhadla Industrial Solar Park, India
2. Kurnool Ultra Mega Solar Park, India
3. Banasura Sagar Reservoir Floating Solar Plant, India
4. Mohammed bin Rashid Al Maktoum Solar Park, Dubai
5. Miraah Solar Thermal Plant, Oman
6. Huainan Panji Pingweizhen Floating PV Plant I, China
7. Apple park Solar Rooftop, USA
8. Queen Elizabeth II Reservoir Floating PV Plant, England
9. Noor-Ouarzazate Solar Power Plant, Morocco
10. El Romero Solar Plant, Chile

Institute for Energy Economics and Financial Analysis

The Institute for Energy Economics and Financial Analysis (IEEFA) conducts research and analyses on financial and economic issues related to energy and the environment. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy and to reduce dependence on coal and other non-renewable energy resources. More can be found at www.ieefa.org.

About the Authors

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Tim Buckley, IEEFA's director of energy finance research, Australasia, has 25 years of financial market experience covering the Australian, Asian and global equity markets from both a buy and sell side perspective. Tim was a top-rated Equity Research Analyst and has covered most sectors of the Australian economy. Tim was a Managing Director, Head of Equity Research at Citigroup for many years, as well as co-Managing Director of Arkx Investment Management P/L, a global listed clean energy investment company that was jointly owned by management and Westpac Banking Group.

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Important Information