DISTRIBUTED SOLAR AND STORAGE - ICEF ROADMAP 1.0

December 9, 2015

2015
Innovation for Cool Earth Forum

AUTHORS

This roadmap was commissioned by the Innovation for Cool Earth Forum and written by the following team:

David Sandalow
Center on Global Energy Policy, Columbia University
Chair, ICEF Innovation Roadmap Project

Colin McCormick
Senior Technical Adviser, ICEF Innovation Roadmap Project

BLOOMBERG NEW ENERGY FINANCE

Lead authors
Tom Rowlands-Rees
Ali Izadi-Najafabadi
Itamar Orlandi

Contributors
Nicole Aspinall
Monne Depraetere
Sara Giordano
Logan Goldie-Scot
I-Chun Hsiao
Shantanu Jaiswal
Samira Rudig-Sotomeyer
Ashish Sethia
Kieron Stopforth
Ben Vickers

Management
Michael Wilshire
Jon Moore

ENVIROMENTALLY SUSTAINABLE INDUSTRIES AND TECHNOLOGIES OFFICE, MINISTRY OF ECONOMY, TRADE AND INDUSTRY, JAPAN

This roadmap benefited from comments at the Innovation for Cool Earth Forum by leading experts including:

Afshin Afshari (Masdar Institute)
Amory B. Lovins (Rocky Mountain Institute)
Daniel G. Nocera (Harvard University)
Kazuhiko Ogimoto (University of Tokyo)
Itaru Yasui (University of Tokyo)

CONTENTS

SECTION 1. EXECUTIVE SUMMARY

Distributed solar and storage technologies could play a key role in reducing greenhouse gas emissions, strengthening grid resilience and improving energy access. A number of dynamics will shape the pace at which distributed solar and storage technologies are deployed and whether they can fulfill their potential. Key findings of this study include:

- **Multiple benefits of combining solar and storage**

  Solar and storage technologies each offer considerable benefits when deployed individually. Solar power provides zero-carbon energy throughout the day at no marginal cost. Storage provide backup power, frequency regulation and other grid services. Combining solar and storage brings additional benefits, notably the ability to increase the output of usable solar-generated electricity by extending power supply outside of daytime hours, as well as improved grid resilience. When deployed together in distributed community and rooftop applications, solar and storage can also result in a reduced strain on the distribution grid and a deferred or reduced need for infrastructure investment. On a macro level, storage and solar could help reduce emissions by enabling a higher penetration of solar without variability challenges. The combination could also be transformative in emerging markets as a fast-track to electrification.

- **Differing pathways for solar and storage in mature and emerging markets**
  - In mature markets the primary drivers for distributed solar and storage are reduced costs and a preference for reduced grid dependence. In the former case the incentive for a consumer or community to invest in the technologies is to reduce utility bills. As a result, solar is the lead technology, and the addition of storage is primarily intended to increase the number of solar-generated kWh that can be consumed, increasing financial benefit.
  - In emerging markets the primary driver is grid intermittency. Consumers are incentivised to buy a storage system to allow them to enjoy uninterrupted power – the addition of solar enhances this value proposition by supporting the storage system in providing power for a longer period of time.
  - This difference in hierarchy between the two technologies is already apparent. Germany, Japan and parts of the United States have all seen the rapid adoption of rooftop PV for economic reasons – in most cases without storage. In India, by contrast, there is already an established supply chain for lead-acid batteries to help end-users manage intermittency, without the addition of solar, as yet.

- **Regulation is both a barrier and enabler for rooftop solar and storage**

  Regulatory barriers that bias the market against solar and storage will need to be addressed if the market is to grow. These include connection charges, a lack of market structure for non-utilties to monetise generation and self-consumption taxes on distributed generation. Net-metering is a particularly interesting case, as it creates a strong incentive for the uptake of distributed solar technologies but reduces the financial benefit of storage.

- **The cost of storage is a more significant bottleneck than the cost of solar**

  Solar technology costs have fallen dramatically in the past two decades and will continue to do so. As this happens, labour and regulatory costs become an increasing fraction of the overall cost of installing residential PV. Cost reductions are less certain for storage, where the technology costs of the battery itself outweigh labour costs. The 15% cost reduction for every doubling of capacity estimated by Bloomberg New Energy Finance is based on the experience of just a few years, because EV batteries have been on the market for just a short period of time. For solar and storage to be a viable option in both mature and emerging markets, significant cost reductions are still necessary in storage technologies.

- **A global electric vehicle market could shape the future of solar and storage**

  Lithium-ion batteries are emerging as the leading storage technology to complement solar. For costs of lithium-ion batteries to fall, however, the industry needs to scale. A major driver for this would be the uptake of electric vehicles, which also (generally) use lithium-ion batteries. Electric vehicles represent a growing fraction of the global lithium-ion battery market, but it is not yet clear how rapidly this scaling will occur. The benefit of economies of scale will be reduced if trade barriers lead to a fragmented electric vehicle industry.
- **Solar and storage is not the only option**

  While energy storage can enhance the overall value of solar, there are other options for achieving increased use of solar-generated energy and ensuring grid stability. These include improved renewables forecasting, increased demand response and flexible loads, thermal storage, and emerging technologies such as power-to-gas. Most notably, cheap natural gas can provide low-cost, highly flexible generation that can complement solar, and reduce the attractiveness of energy storage. In emerging markets, increasing the reliability of grids, partly through the use of cheap coal, may also undermine the value proposition of distributed solar and storage.
- **Japan and Germany are poised to be early-movers on distributed solar and storage**

  Japan and Germany have both established momentum as early markets for solar and storage due to a combination of high electricity prices and supportive regulation. The development of these markets will result in innovation that will have a global benefit. Japan has a substantial battery manufacturing industry that will continue to develop with the domestic market. Germany is seeing the emergence of new solar and storage business models – such as consumers part-renting behind-the-meter storage to grid operators, as well as utility-owned community storage projects such as the StromBank to support rooftop solar. These countries both carry the burden of first-mover disadvantage and it may be that other countries ultimately benefit from lessons learnt in those markets.
- **The United States market is more fragmented, but could overtake in the long run**

  California and Hawaii are now seeing some of the hightest penetrations of solar in the world. The immediate challenge for solar and storage in the US, however, is the prospect of continued low natural gas prices and, as a result, cheap electricity. Nevertheless the country's advanced start-up scene is already developing sophisticated aggregation mechanisms for distributed solar and storage while companies such as Tesla are also leveraging the link between electric vehicles and storage with the recent launch of the PowerWall residential battery system.
- **China is prioritizing utility-scale solar, but distributed solar and storage could grow.**
- China is currently in the process of drafting its 13th Five-Year Plan and the most recent guidance documents suggest that although there is support for distributed solar, the emphasis for storage is on utility-scale applications that support reliability. If there is a future for rooftop and community solar and storage bundles in China, it will begin in the commercial and industrial sectors, where electricity prices are highest.
- **India is well placed to be a leader, but there are potential barriers**

  India already has a growing sector dedicated to the installation of lead-acid batteries to manage grid intermittency and is therefore well-placed to apply its domestic experience in foreign markets. However as the electricity sector grows and regulation develops it is crucial that the central and state governments implement policy frameworks that enable profitable and sustainable business models by both the state-owned entities and the private sector.

Quality standards and warranties would help support investments in distributed solar and storage technologies.

- **Industry and policy-makers need to start tackling future problems now**

  The immediate problems for solar and storage are the high cost of storage technology and regulatory barriers. However, other issues could affect the development of the market when it starts to achieve scale, especially if they are not anticipated today. These include reputational setbacks associated with low quality installations (recommendation: establish recognised standards and certification schemes), regulatory backlash in the face of poorly implemented grid integration (recommendation: provide continued investment in pilot projects and share best-practice learnings widely), a lack of a skilled workforce (recommendation: establish training programmes for installers and engineers) and threats such as cyberattacks (recommendation: establish consortium to facilitate collaboration on IT aspects of grid integration). Trade barriers and supply chain disruption could also hamper the industry, meaning that research focusing on reducing materials dependency and alternative chemistries will ensure that technology prices will continue to decline.

SECTION 2. INTRODUCTION AND SCOPE

Distributed solar generation is changing the power sector. This roadmap explores pathways for distributed solar and storage technologies in combination to do the same. Our premise is that maximizing deployment of solar power will serve important social goals. These include carbon mitigation, local air pollution reduction and job creation. Distributed solar and storage can offer special benefits, including resilience to grid outages and access to energy in places where grids do not reach.

Storage can also be an important tool for helping integrate solar power into electric grids. While other tools – including demand response, predictive analytics and flexible ramping resources – can also help with this integration, distributed solar and storage has the potential to offer significant benefits, especially if the cost of storage technologies can be reduced and regulatory hurdles overcome.

This roadmap explores pathways for the development of distributed solar and storage technologies in combination through the framework of a scenario planning exercise. The focus lies on solar and storage technologies for individual buildings and community microgrids (not solar and storage at utility scale). The study identifies drivers, risks, barriers and opportunities that will determine whether solar and storage can fulfill its potential between now and 2040.

Data sources for this report

References to figures and data points mentioned without a source in this report are attributable to Bloomberg New Energy Finance. Where the study relies on data, articles or studies by others, these are cited and referenced throughout the document.

SECTION 3. TECHNOLOGY BACKGROUND

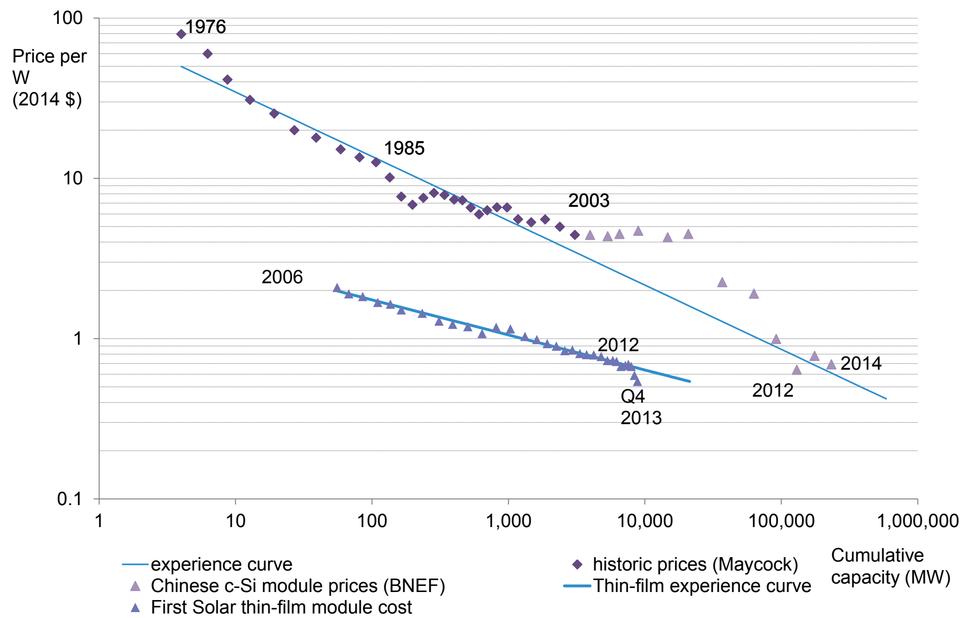
Over the past 15 years, PV capacity has surged more than 150-fold, driven by rapidly decreasing costs and performance improvements. A similar, albeit slower, transition is also underway with lithium-ion batteries. In order to meet growing demand for electric vehicles, leading storage manufacturers have invested heavily in the technology and ramped up production capacity. Although the levels of expected EV demand have yet to materialize, these actions have created an opportunity for energy storage in stationary applications.

3.1. DEVELOPMENTS IN SOLAR PHOTOVOLTAIC TECHNOLOGY

BACKGROUND

Crystalline silicon (cSi) PV system costs have fallen from $75/W in 1976 to a 2015 Chinese module price of $0.61/W in 2015 (Figure 1). This represents a learning rate of 26%, i.e. for every doubling of capacity, costs fell 26%.

Figure 1: Solar photovoltaic experience curve, 1976-2014

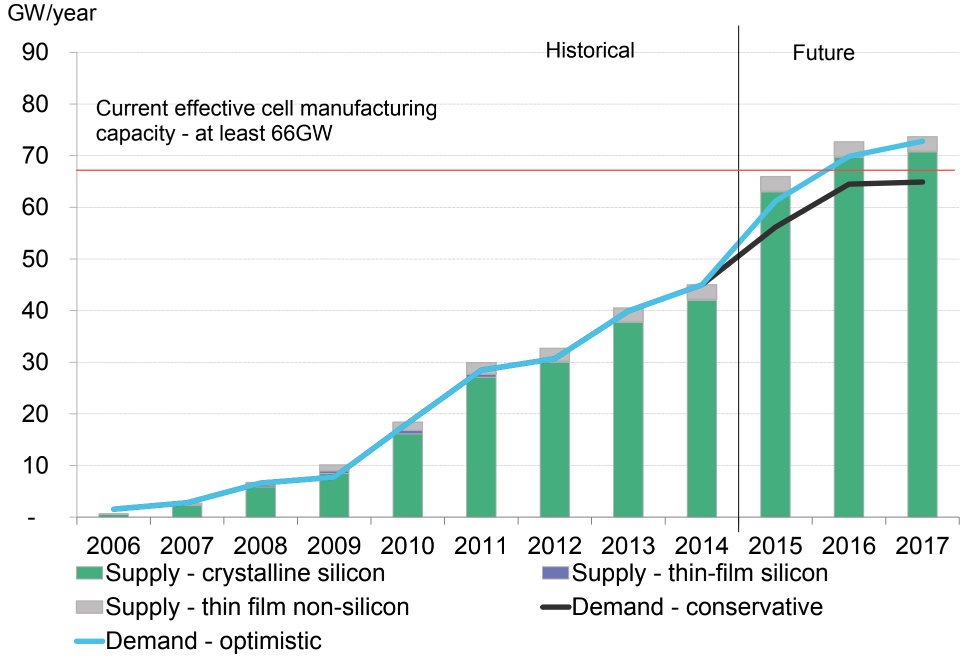


Source: Paul Maycock, First Solar, Bloomberg New Energy Finance. Note: Prices inflation indexed to US PPI.

The high learning rate was partially a result of significant oversupply in the industry, which forced module makers and their raw-material suppliers to adopt new technologies: in the ten years from 2000, supportive European subsidies triggered a disorderly expansion of PV manufacturing capacity. The boom collapsed in late 2008, and unraveled further in 2011. Despite industry consolidation, the whole PV value chain remained in oversupply. The excess for 2015 is expected to be at least 20% and oversupply in the PV industry is expected to continue at least until 2017 (Figure 2).

Despite industry consolidation, the whole PV value chain is in oversupply and is expected to remain so until 2017

Figure 2: Demand and supply for PV modules, 2006-17

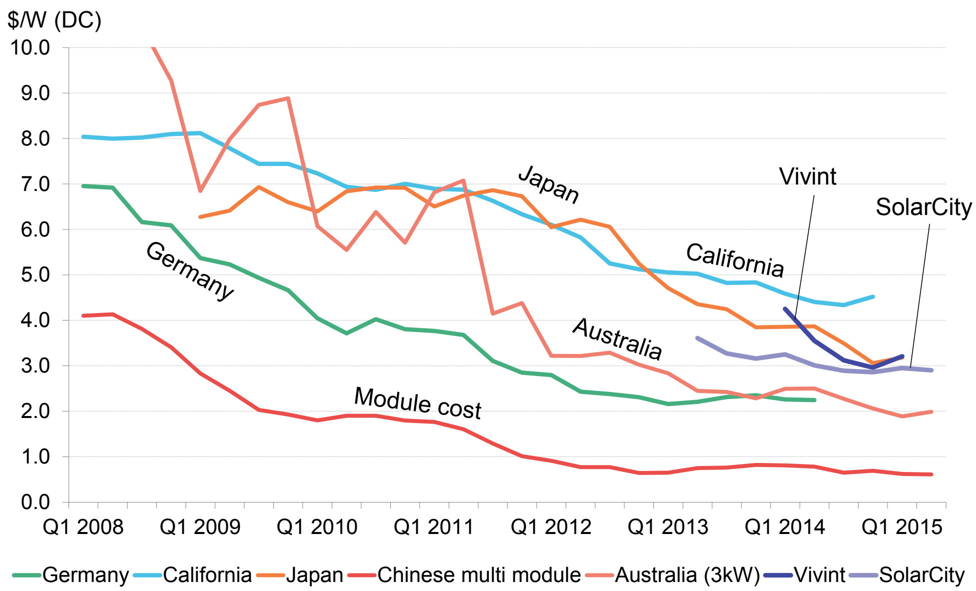


Source: Bloomberg New Energy Finance

FUTURE OUTLOOK

Further cost reductions will come from technological and manufacturing improvements rather than from squeezing margins. Manufacturers are setting up new production lines and upgrading their existing facilities with improved technologies.

Figure 3: Public benchmarks of residential PV system capex



Source: Source: Bloomberg New Energy Finance, Solarchoice, METI, BSW-Solar, California Solar Initiative, Vivint and SolarCity filings

As technology costs fall, labour costs are an increasing fraction of the overall costs of installing a residential PV system

From a fundamental perspective, the technologies Bloomberg New Energy Finance has explored could account for a reduction of at least 36% in module costs within 10 years, while the company expects average efficiency will rise by 20%. PV system costs are anticipated to fall a further 50% by 2040 -- within that, module costs will account for a 30% drop.

As technology costs fall, labour costs are an increasing fraction of the overall costs of installing a residential PV system. These costs vary considerably by country and reflect local expertise and competition. Germany and Australia currently have the lowest costs reflecting their relatively mature markets (Figure 3).

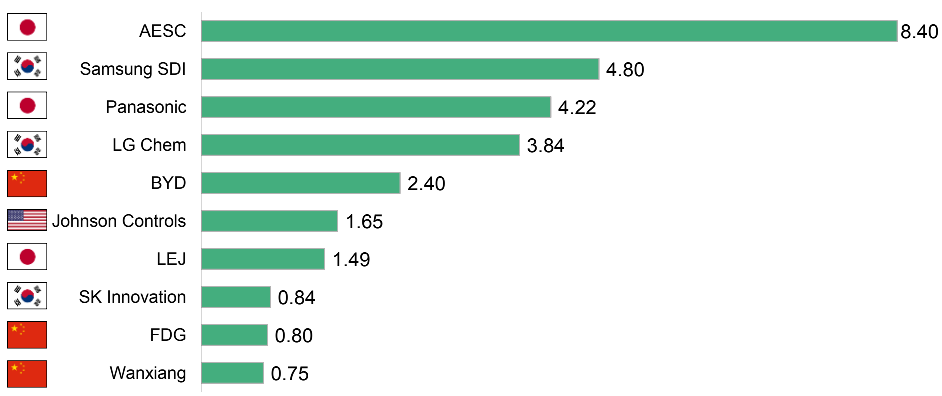
3.2. DEVELOPMENTS IN LITHIUM-ION BATTERY TECHNOLOGY

BACKGROUND

Lithium-ion batteries have become ubiquitous in our daily lives through portable electronic devices and are now increasingly important in both larger stationary applications and electrified transport: in 2014, the technology accounted for 75% of electric vehicle battery demand, and 92% of announced grid-connected stationary energy storage projects.

The industry is dominated by a smaller number of large manufacturers: these top 10 companies own 78% of manufacturing capacity dedicated to passenger EVs (Figure 4). Manufacturing is focused on the Asia Pacific region and to a lesser extent the US: Japan and South Korea have the largest capacities due to major players like Panasonic, AESC, Samsung SDI and LG Chem.

Figure 4: 10 largest li-ion battery manufacturers globally, 2015 (GWh)

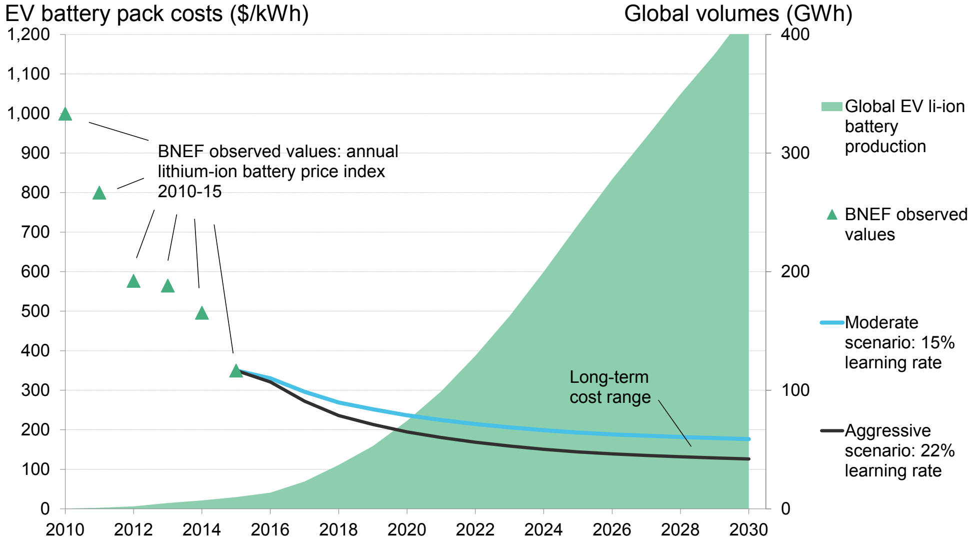


Source: Bloomberg New Energy Finance

Sales of electric vehicles grew 34% in 2014 and cumulative lithium-ion EV production is expected to exceed 400GWh by 2030 (Figure 5). As a result, although consumer devices make up the largest share of lithium-ion batteries in 2015, electric vehicles will overtake them to become the largest application for the technology in the early 2020s.

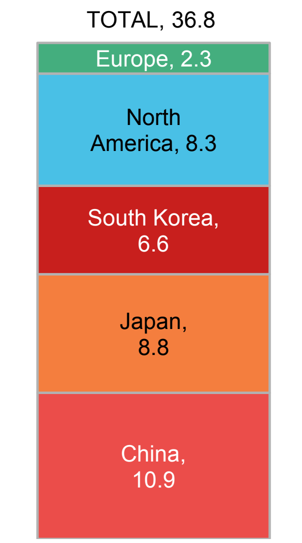
Prices for EV lithium-ion battery packs have fallen from roughly $1,000/kWh in 2010 to around $350/kWh in 2015 (Figure 5). This represents a 15% learning rate and has been driven by continual improvements in battery chemistry, materials processing, manufacturing and greater economies of scale. Historically, consumer lithium-ion batteries have exhibited a 22% reduction in cost for each doubling of manufacturing capacity but they are more commoditized and have lower performance than those needed for energy applications. Manufacturers also overestimated EV demand and, faced with significant overcapacity, have been forced to squeeze margins or lose market share: as of 2015, there is 37 GWh of global EV lithium-ion battery manufacturing capacity online while 2015 demand is estimated at just 9.7 GWh (Figure 5).

Figure 5: EV Lithium-ion battery cost outlook, 2011-2030



Source: Bloomberg New Energy Finance. Note: Values from 2010-2014 are based on BNEF's annual battery price index. Cumulative production is based on total EVs sold and their respective battery pack size.

Figure 6: Global li-ion battery manufacturing capacity by country and region, 2015 (GWh)



Source: Bloomberg New Energy Finance

FUTURE OUTLOOK

Assuming no technology breakthroughs, the bulk of further cost reductions will come from incremental technological and manufacturing improvements, although it is possible margins could be further squeezed. Any reduction in raw materials costs would also have a major impact because they are the most significant contributor to the battery pack cost.

There are also several key disruptive technologies that could be implemented commercially in the next ten years that would not only drastically reduce the cost of lithium-ion batteries but would also enhance their performance. They involve improvements to the manufacturing processes, changes to the composition of the binders and solvents used, and altering the structure and chemistry of the electrodes:

There are several key disruptive technologies that could be implemented commercially in the next 10 years

- The use of semi-solid battery technology, as has been commercialised by Massachusetts' 24M, greatly simplifies the manufacturing and architecture of the cell.
- The use of aqueous solvents and binders has not only been touted as a cost saving measure, but also beneficial to the environmental impact of the batteries and end-of-life options.
- A great deal of research focuses on the potential of using silicon as the active anode material in lithium-ion batteries. The material has an enormous capacity to store lithium ions and hence could increase the energy density of the cell by as much as 40%.

Further industry consolidation is likely as the large players announce further capacity additions and price reductions in order to gain, or even hold, market share.

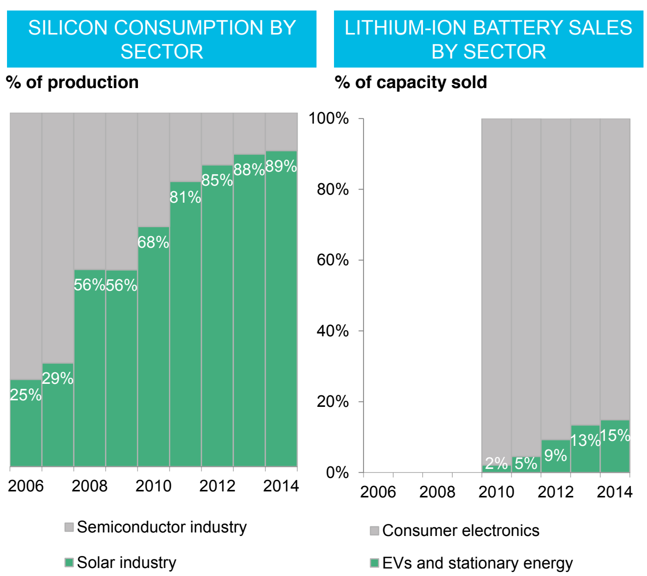
3.3. COMPARING STATE OF THE LITHIUM-ION BATTERY AND SOLAR PHOTOVOLTAIC INDUSTRIES

Cost reductions: there have been significant cost reductions in both the PV and lithium-ion battery sectors. This has been driven in part by excess capacity but also by technological and manufacturing improvements. At 26%, the learning rate for cost reductions in PV is currently higher than the 15% rate for lithium-ion EV battery packs. This could change though – whilst the first lithium-ion battery pack was invented in the 1970s, the lithium-ion EV market really only kicked off with the launch of the Nissan Leaf and the Chevy Volt in 2010/2011. Since the learning rate is based on a smaller data sample, it could change significantly as the market continues to develop. In addition to any incremental improvements to lithium-ion technology, the commercialisation of any one of the various disruptive technologies listed above would have a major impact.

The learning rate for EV scale lithium-ion batteries is based on a smaller data sample so it could change significantly as the market continues to develop

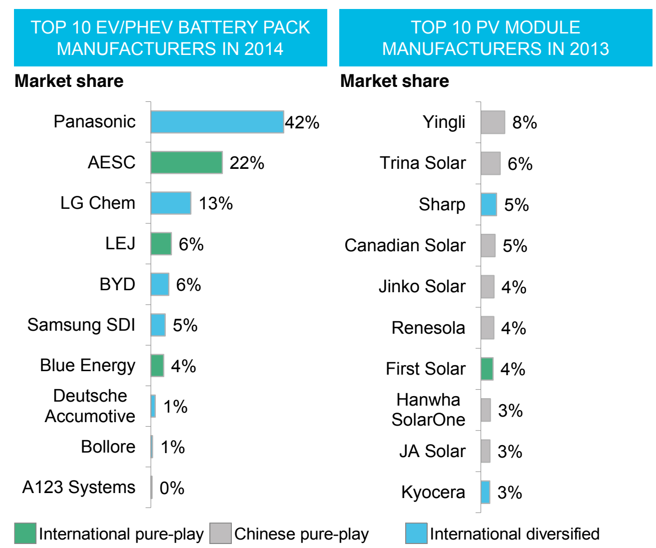
Technology convergence: roughly 90% of PV demand in 2015 was crystalline silicon (cSi) and the remainder is largely thin-film, notably cadmium telluride (CdTe) developed by First Solar. This convergence around cSi happened when alternative technology companies such as Solyndra and Abound Solar went bankrupt and the industry consolidated. This convergence has not yet been replicated in the lithium-ion industry, where there are five main chemistries being developed for automotive lithium-ion batteries: nickel cobalt aluminium (NCA), lithium manganese oxide (LMO), nickel manganese cobalt (NMC), lithium iron phosphate (LFP) and lithium titanate (LTO). No single chemistry is superior across all metrics: LMO might be the most cost effective but has a short lifetime whereas LTO is expensive but offers much better safety and a longer lifetime. Convergence within specific applications is likely, although not to the same extent as for PV since there are a greater number of different uses for lithium-ion batteries and each necessitates different characteristics.

Figure 7: PV and lithium-ion supply chains



Source: Bloomberg New Energy Finance. Note: Electric vehicles includes hybrid, plug-in-hybrid and fully electrified.

Figure 8: EV/PHEV battery pack and PV module market share



Source: Bloomberg New Energy Finance. Note: Market share for battery packs is calculated as share of supplied output in MWh.

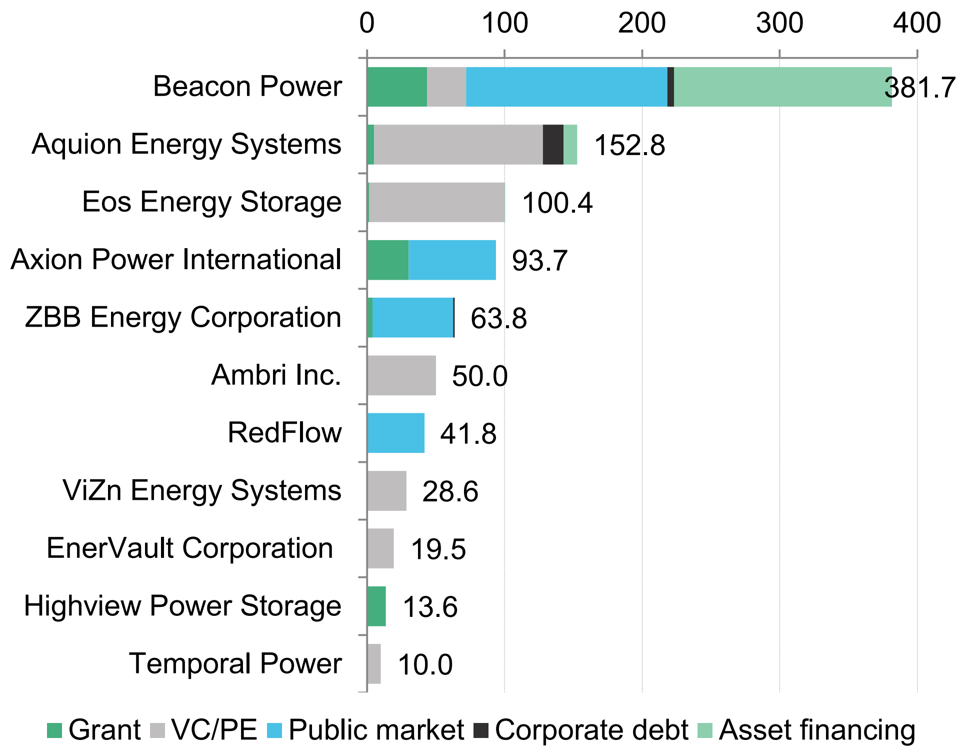
Consumer electronics and solar vs EVs and stationary energy storage: A decade ago the bulk of pure silicon was consumed by the electronics industry (Figure 7). Now, solar consumes almost 90% of high purity silicon and drives production expansion. EVs and end-user energy storage may have a similar relationship with consumer electronic lithium-ion batteries. However, PV piggy-backed off the semi-conductor industry, which demanded pure silicon. By contrast, quality requirements on consumer electronics Li-ion batteries are lower than those for end-user storage and EVs so the same pattern may not result.

Competition: A key to the rapid cost declines in PV is the strong competition amongst manufacturers. Newer Chinese pure-plays have now outcompeted the diversified electronics manufacturers, which have exited the industry (Figure 8). Battery manufacturing is dominated by a few diversified energy, electronics and machinery conglomerates. New entrants may be required to boost competition and drive down the costs of Li-ion production.

3.4. ALTERNATIVE STORAGE TECHNOLOGIES

Although lithium-ion is currently the preferred technology for both EVs and shorter-duration stationary energy storage, numerous potential alternatives to lithium-ion exist. Indeed, since 2008 hundreds of millions of dollars have been invested in other energy storage technologies (Figure 9). The largest investors have been US venture capital firms, as well as the investment arms of larger conglomerates such as GE and Total. The investment is split over a wide range of technologies including flywheels (Beacon Power), zinc-air (Eos), liquid metal (Ambri) and flow batteries (ZBB, RedFlow).

Figure 9: Disclosed financing in alternative energy storage technologies, 2008-H1 2015 ($m)



Source: Bloomberg New Energy Finance

Advantages of redox flow batteries (RFBs) include the ability to size energy and power components independently, economies of scale, and low self-discharge. Sodium-based batteries have garnered interest due to the high abundanc and low cost of sodium. But sodium ions are nearly twice as large as lithium ions, which means that repeated insertion / removal in the chemical structure decreases battery stability. None of these alternatives currently appear well suited for residential energy storage and Bloomberg New Energy Finance expects lithium-ion to remain dominant in this space.

SECTION 4. SUMMARY OF NATIONAL R&D PROGRAMS ON SOLAR PV AND STORAGE

4.1. OVERVIEW

Many national governments are conducting publicly funded R&D programs to advance solar PV and energy storage technology. These programs are often accompanied by policies to create demand and accelerate the deployment of these technologies. Individual national R&D programs loosely coordinate their efforts through a number of bilateral and multilateral policy regimes and collaborative programs (notably the IEA Photovoltaic Power Systems Program and the IEA Energy Conservation through Energy Storage Program) but generally retain their own processes for developing strategic areas of focus, technical targets and timelines, and specific projects and budgets to support them.

This section summarizes the key features of several of the most prominent national R&D programs on solar PV and energy storage, as they pertain to this roadmap. For that purpose, the discussion includes only photovoltaics (not CSP/solar thermal), and only distributed and community-scale systems (not utility scale). It also addresses relatively early-stage R&D, not commercialization or deployment efforts (with the exception of technical research into reliability and grid integration). This summary is not exhaustive, and is intended primarily to give the reader a general sense of the highlights of national-level R&D efforts on these topics.

By virtue of their scale and reach, the national programs of the US, Japan, Germany, and Korea have been chosen for analysis[1]. These various programs are structured somewhat differently, with multiple ministries/agencies participating in each case. These are described in turn below.

4.2. UNITED STATES

The primary US R&D program for solar PV is the SunShot Program, administered by the US Department of Energy (DOE). Launched in 2011, it has set the following strategic targets, to be achieved by 2020[2]:

Topic	Target (2020)
Utility-scale PV system cost	USD 1.00/WDC
Commercial-scale PV system cost	USD 1.25/WDC
Residential-scale PV system cost	USD 1.50/WDC
LCOE of [utility-scale] PV system	USD 0.06/kWh

Source: US DOE

To accomplish this, SunShot has three areas of focus:

1. Reducing technology costs
2. Reducing grid integration costs
3. Accelerating deployment.

The overall structure of the program combines competitive, cost-shared grants to universities and companies with research at government laboratories. The current awarded grants fall into seven

1 For more details on R&D funding levels and other national programs, see "Trends in Photovoltaic Applications 2015", IEA-PVPS (2015) and the IEA RD&D statistical database.
2 "Strategic Plan, 2014-2018", US Department of Energy (2014); SunShot website (accessed November 2, 2015).

themed programs[3]. While various public laboratories participate in these research programs, the primary institution is the National Center for Photovoltaics at the National Renewable Energy Laboratory (NREL). Recent topics of targeted R&D projects include:

1. PV module degradation (including metallization corrosion, solder joint failure, backsheet degradation, and weathering[4])
2. PV cell efficiency (including ultra-thin-film c-Si, light trapping with photonic crystals, reducing the CZTS open-circuit voltage deficit, and MBE-grown CdTe[5])
3. New concepts in PV (including stabilizing perovskite materials, alternatives to lead, dye-sensitized cells, multi-junction organic PV, integrated Si/III-V cells, and roll-to-roll printing of III-V cells[6])

The SunShot program supports a variety of projects related to community solar and storage through the Solar Market Pathways program, with topics including developing virtual net metering, integrating distributed solar and storage into emergency planning, and reducing regulatory costs associated with solar installations. Most recently, the SunShot program is supporting new research in integrating energy storage and solar PV so that the combined system can work with smart buildings, smart appliances, and utility communication and control systems[7].

DOE's Advanced Research Projects Agency – Energy (ARPA-E) also conducts research related to solar PV and energy storage, with programs designed to pursue high-risk projects with large potential impacts. Recent programs include MOSAIC (Micro-scale Optimized Solar Cell Arrays with Integrated Concentration), which aims to develop micro-scale concentrated photovoltaic (CPV) systems with costs and profiles similar to flat-plate PV technology; and FOCUS (Full-spectrum Optimized Conversion and Utilization of Sunlight), which aims to develop hybrid solar PV/thermal technologies that use the entire spectrum of available sunlight.

The primary US R&D program for energy storage technology is the Energy Storage Program administered by DOE, although numerous other offices also oversee related programs[8]. Solar- and storage-related research is also carried out by the National Science Foundation (NSF) through the Energy for Sustainability Program, and the Department of Defense (DoD) through the Environmental Security Technology Certificate Program (ESTCP).

4.3. JAPAN

The primary Japanese framework for solar PV R&D is described in the "NEDO PV Challenges" document, a strategy for supporting the mass introduction of solar PV to Japan[9]. As part of this framework, the New Energy and Industrial Technology Development Organization (NEDO) has established the following high-level technology cost and performance targets, to be accomplished by several future dates[10]:

3 US DOE SunShot website (accessed November 4, 2015).
4 This work is under the PREDICTS 2 program.
5 This work is under the F-PACE 2 program.
6 This work is under the Next Generation Photovoltaics 3 program.
7 This work is under the Sustainable and Holistic Integration of Energy Storage and Solar PV (SHINES) program.
8 For a detailed list, see "2014 Storage Plan Assessment Recommendations for the U.S. Department of Energy", Electricity Advisory Committee (September 2014).
9 "NEDO PV Challenges", New Energy and Industrial Technology Development Organization (2014). Japanese language only.
10 From "Overview of Photovoltaic R&D in Japan and International Activities of NEDO", Presentation by Hiroyuki Yamada at 42nd IEEE Photovoltaic Specialists Conference (June 2015). Slides received from NEDO.

Topic	Target	Date
LCOE of commercial-scale PV	JPY 14/kWh	2020
Module efficiency, lifetime	22%, 25 years	2020
LCOE of utility-scale PV	JPY 7/kWh	2030
Module efficiency, lifetime	25%, 30 years	2030

Source: NEDO

To support the 2030 system-level targets, NEDO has also developed technology-specific sub-targets for c-silicon (100 JPY/W, 25% efficiency), III-V (125 JPY/W, > 30% efficiency), and perovskites (< 100 JPY/W, with 20% efficiency). NEDO's program has four areas of focus:

1. Reducing the levelized cost of electricity (LCOE) from solar PV
2. Enhancing system reliability
3. Enlarging the range of applications of PV
4. Establishing a recycling system.

Key recent results of the research program include

- Crystalline silicon cells with 25.6% efficiency[11]
- Triple-junction III-V concentrator cells with 44.4% efficiency[12]
- Triple-junction thin-film silicon cells with 13.6% efficiency[13].

NEDO conducts a range of domestic and collaborative international projects to demonstrate the integration of distributed solar PV systems and energy storage, including stabilizing distribution networks with batteries (in Spain)[14], providing customer autonomy during cold-weather grid outages (in Canada)[15], and enabling community level self-generation and consumption with PV and storage (in Germany)[16].

In addition to the NEDO program, the National Institute of Advanced Industrial Science and Technology (AIST) conducts extensive solar PV research at its Research Center for Photovoltaics, including advanced processing, module reliability research, and calibration and standards. In 2014, AIST established the Fukushima Renewable Energy Institute (FREA), whose program of research includes a focus on thin-film silicon PV technology and advanced III-V concepts[17], as well as tandem nano-wire silicon PV[18]. AIST conducts energy-storage-related research at its Research Institute of Electrochemical Energy, opened in April 2015.

The Japan Science and Technology Agency (JST) also conducts basic research related to solar PV and energy storage under three programs: ERATO (Exploratory Research for Advanced Technology), CREST (Core Research for Evolutional Science and Technology), and PRESTO (Precursory Research for Embryonic Science and Technology).

11 "Back contact HIT solar cell from Panasonic pushes efficiency record to 25.6%", PV-Tech, April 10, 2014.
12 "Concentrator solar cell with world's highest conversion efficiency of 44.4%", Phys.org, June 14, 2013.
13 "Solar cell sets world record with a stabilized efficiency of 13.6%", Phys.org, June 4, 2015.
14 "Demonstration Project Using a Battery Energy Storage System to Stabilize Distribution Networks Begins in Spain", NEDO News Release, September 30, 2015.
15 "NEDO Signs MOU for Demonstration for Hybrid Solar Inverter & Battery System with Monitoring and Control in Oshawa, Ontario, Canada", NEDO News Release, July 21, 2015.
16 "Local Energy Production and Consumption Model Smart Community Demonstration Project Launches in Speyer, Germany", NEDO News Release, July 24, 2015.
17 FREA website (accessed November 5, 2015).
18 Research Director Makoto Konagai statement, FUTURE-PV Innovation website (accessed November 5, 2015); "Can Japan Recapture Its Solar Power?", *MIT Technology Review*, December 18, 2014.

4.4. GERMANY

The primary framework for solar PV and energy storage R&D in Germany is the 6th Energy Research Program, launched in 2011[19]. This program combines project funding focused on cost-shared, collaborative research among universities, research centers, and industry with direct institutional funding. Key research centers for energy include those of the Helmholtz Association of German Research Centers and the Fraunhofer Energy Alliance.

From 2010 until 2014, the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Economics and Technology (BMWi) administered a comprehensive solar R&D program known as the Photovoltaics Innovation Alliance. This program, funded at 100 million euros, had the strategic aim of strengthening the photovoltaic industry through collaborative projects[20]. In May 2013, BMWi and BMBF launched the "Research and Development for Photovoltaics" initiative, focusing on PV production technology and systems engineering.

Recent important results from these programs include:

- PERC silicon standard-format solar modules of 306W
- P-type mono-crystalline silicon PERC cells with 21.7% efficiency[21]
- Hybrid silicon-perovskite tandem solar cells with 18% efficiency[22]
- Multi-junction concentrating PV cells with 46% efficiency[23]
- Thin-film silicon cells on flexible substrates[24]
- Cadmium-free CIGS thin-film cells with 21% efficiency[25].

In 2007, BMBF launched the Innovation Alliance Lithium-Ion Battery LIB 2015 program, an industrial consortium effort aimed at improving lithium-ion battery technology that has resulted in numerous battery technology roadmaps. In April 2011, BMWi and BMBF launched the Energy Storage Funding Initiative, funded at 200 million euros, with R&D focus areas including:

1. High-voltage batteries for PV systems[26]
2. Zinc-air batteries[27]
3. System-integration analysis for distributed PV and storage systems[28]
4. Demonstrations such as the Smart Region Pellworm project emphasizing integrated PV-storage systems on an island.

---

19 "Research for an environmentally sound, reliable and affordable energy supply: 6th Energy Research Programme of the Federal Government", BMWi (November 2011).
20 "Federal Report on Energy Research 2015", BMWi (April 2015).
21 "German R&D project reports record PERC solar module performance", PV-Tech, January 15, 2014; "New solar cell sets efficiency record", BMWi newsletter, September 21, 2015.
22 "Monolithic perovskite/silicon tandem solar cell achieves record efficiency", Helmholtz Zentrum Berlin, October 28, 2105.
23 "New world record for solar cell efficiency at 46%", Fraunhofer ISE press release, December 1, 2014.
24 "Project: SiSoFlex", Next-Energy website, accessed November 10, 2015.
25 "ZSW boosts efficiency of cadmium-free thin-film solar cells to world record level", ZSW press release, February 4, 2015.
26 "High-voltage battery improves its own electricity usage", Forschung-energiespeicher website (accessed November 12, 2015).
27 "Higher current density for zinc-air batteries", Forschung-energiespeicher website (accessed November 12, 2015).
28 "Battery storage can relieve the electric grid", Forschung-energiespeicher website (accessed November 12, 2015).

4.5. SOUTH KOREA

The primary framework for solar PV and energy R&D in South Korea is the 2nd Energy Master Plan, launched in 2014[29], and the subsequent 4th Basic Plan for Technology Development, Application, and Deployment of New and Renewable Energy[30]. This plan includes high-level technology targets, including

1. Lowering the cost of energy storage systems by half by 2020
2. Commercializing solar and storage systems beyond silicon and lithium-ion batteries.

The leading ministries involved in R&D programs to achieve these targets are the Ministry of Trade, Industry, and Energy (MOTIE), its subordinate office the Korea Institute of Energy Technology Evaluation and Planning (KETEP), and the Ministry of Science, ICT, and Future Planning (MSIP). The Korea Smart Grid Institute (KSGI) conducts related projects, including maintaining the Korean Smart Grid Roadmap[31].

Recent important results from these programs include:

- A stable perovskite solar cell with efficiency of 20.1%[32]
- Improved perovskite fabrication techniques[33]
- Ultra-thin, flexible organic solar cells based on nanowires[34]
- Improved solar cell recycling techniques that do not involve hydrofluoric acid or other toxic chemicals[35].

There are several smart grid test beds that focus on integrating distributed renewable generation with energy storage, including Jeju Island and the Gochang power testing center[36], and collaborative work with the US state of Hawaii[37]. To extend this work, KETEP has just launched a collaborative research initiative with the UK Engineering and Physical Sciences Research Council (EPSRC) to address distributed energy generation and storage on large island grids[38].

---

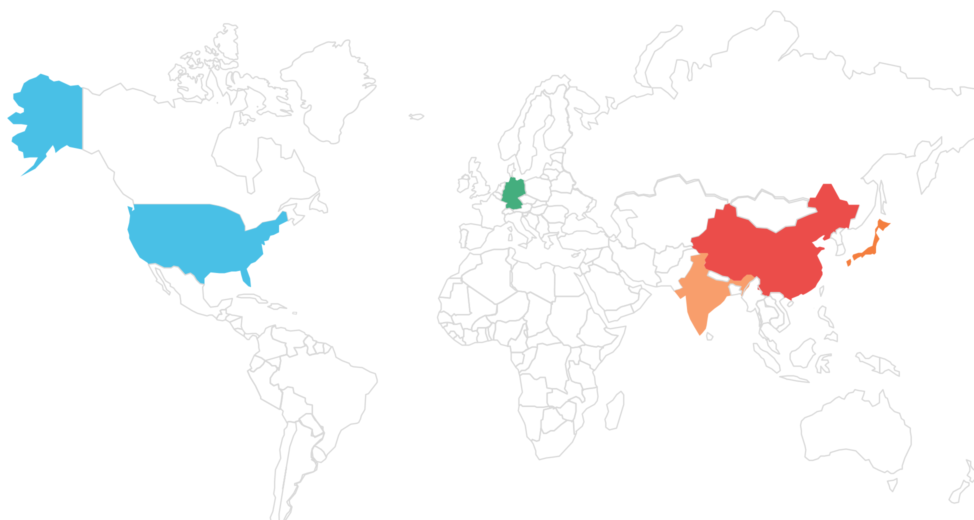
29 "Korea Energy Master Plan: Outlook & Policies to 2035", Ministry of Trade, Industry & Energy, January 2014.
30 Promotion of New and Renewable Energy, MOTIE website (accessed November 21, 2015).
31 Korean Smart Grid Institute website (accessed November 23, 2015).
32 "Perovskite Solar Cell Bests Bugbears, Reaches Record Efficiency", IEEE Spectrum, January 7, 2015.
33 "Researchers develop method of fabricating perovskite solar cells that is more efficient, costs less", Phys.org, May 22, 2015.
34 "Tech developed for flexible solar cells 1/20 as thick as a human hair", Business Korea, October 6, 2015.
35 "A bright future for silicon solar cell recycling", Chemistry World, November 18, 2015.
36 "Recent Trends in Renewable Energy Resources for Generation in the Republic of Korea", *Resources* **2015**, 4, 751-764.
37 "Teaming up (again): Hawaii, Korea to test residential batteries", Smart Grid News, August 13, 2015.
38 See "EPSRC-KETEP Call for Collaborative Research Between the UK and Korea in Smart Grids", EPSRC website (accessed November 19, 2015).

SECTION 5. ROADMAP COUNTRIES BACKGROUND

According to BNEF's New Energy Outlook, global electricity demand is expected to grow 60% by 2040, driven mainly by emerging nations' economic growth and increases in electrification rates. By contrast mature economies' power demand is flat and in some cases decreasing, with weak and even negative population growth and shifts towards less energy-intensive economic activity expected. While solar generation capacity is expected to increase significantly between now and 2040 in the base case, fossil fuels such as coal and natural gas are still expected to make up a significant proportion of generation capacity.

5.1. OVERVIEW

Figure 10: Roadmap countries



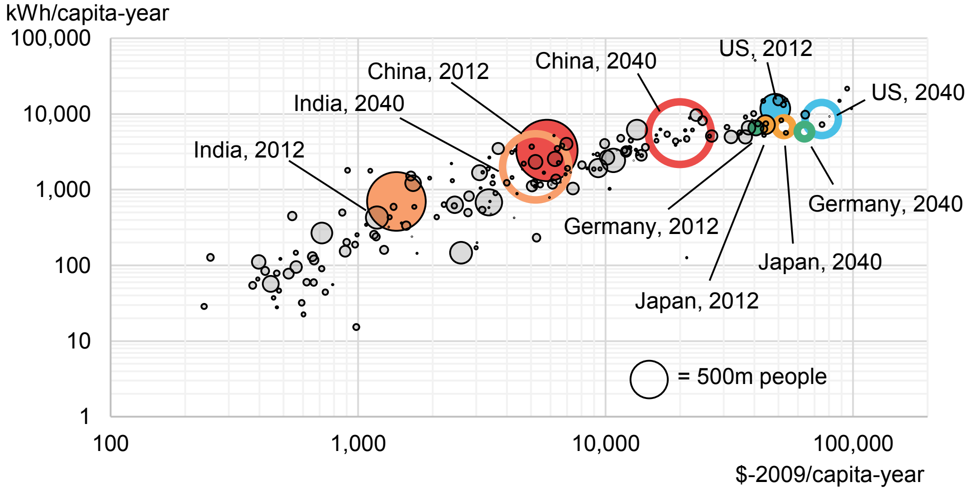
While the analysis on this report is intented to be applicable to any country, Bloomberg New Energy Finance has applied the roadmap framework specifically to Japan, Germany, the US, China and India. These countries were selected both because of their individual importance to the global outlook and because collectively they capture many of the challenges and opportunities that will define the future of distributed solar and storage.

5.2. ECONOMIC TRENDS

By 2040 China is expected to have a per capita GDP similar to today's South Korea

As the trend in Figure 11 demonstrates, there is a strong correlation between economic maturity (with GDP per capita as a proxy) and per-capita electricity consumption. Therefore substantial increases in power demand should correlate with increased income. It is worth keeping in mind when considering the state of these markets in 2040 the degree to which they are expected to have grown economically. According to OECD forecasts, China will have a per capita GDP similar to today's Czech Republic, Portugal, or South Korea by 2040. India's expected growth will give it a per capita GDP equal to today's China, Thailand, Ecuador or Peru. Thus, in addition to an increased demand for power in China and India, these countries will have undergone significant socioeconomic change by 2040.

Figure 11: Electricity consumption per capita vs GDP per capita 2012 data and 2040 forecasts for selected countries



Source: World Bank, EIA, OECD, Bloomberg New Energy Finance

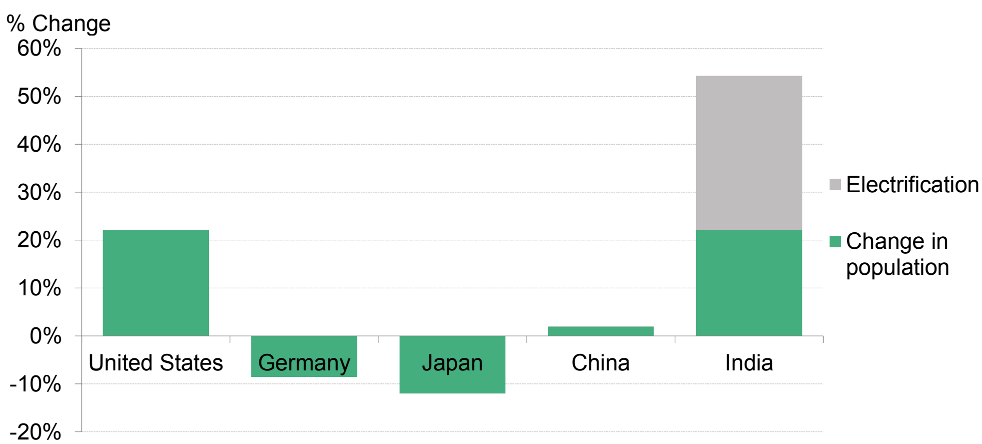
For the US, Germany and Japan, all of which have a high per capita GDP and for whom more modust growth is forecast, the relationship will be inverted – the electricity consumption associated with a particular level of GDP is expected to decrease slightly, due to the higher efficiency of newer technologies and an increased share of services and digital economies.

5.3. POPULATION TRENDS

While changes in per capita electricity consumption are significant, changes in population have an even more direct impact on the outlook for the electricity sector. The World Bank predicts that between now and 2040 the population in Germany and Japan is likely to shrink, which in turn will impact electricity demand and the economy at large. This will create challenges for utilities that will see the size of their market and customer base decreasing. By contrast, India is expecting to see its grid-connected population increase by 50% through a combination of population growth and electrification – which creates a different challenge of meeting rapidly growing demand.

India is expecting to see its grid-connected population increase by 50% through a combination of rapid population growth and electrification

Figure 12: Projected change in grid-connected population between 2015 and 2040



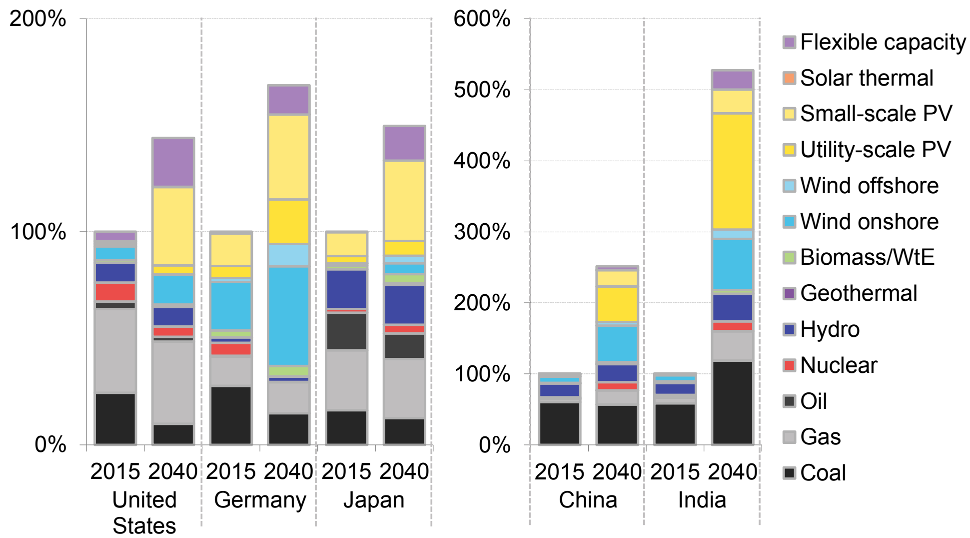
Source: World Bank, Bloomberg New Energy Finance

5.4. ENERGY SECTOR TRENDS

BNEF forecasts – based on an economic analysis with no explicit policy support for renewables – predict that by 2040 small-scale PV will be a significant proportion of capacity in the US, Germany and Japan. Solar will also be a significant proportion of capacity in the higher growth markets of China and India, but the bulk is expected to be installed at utility scale.

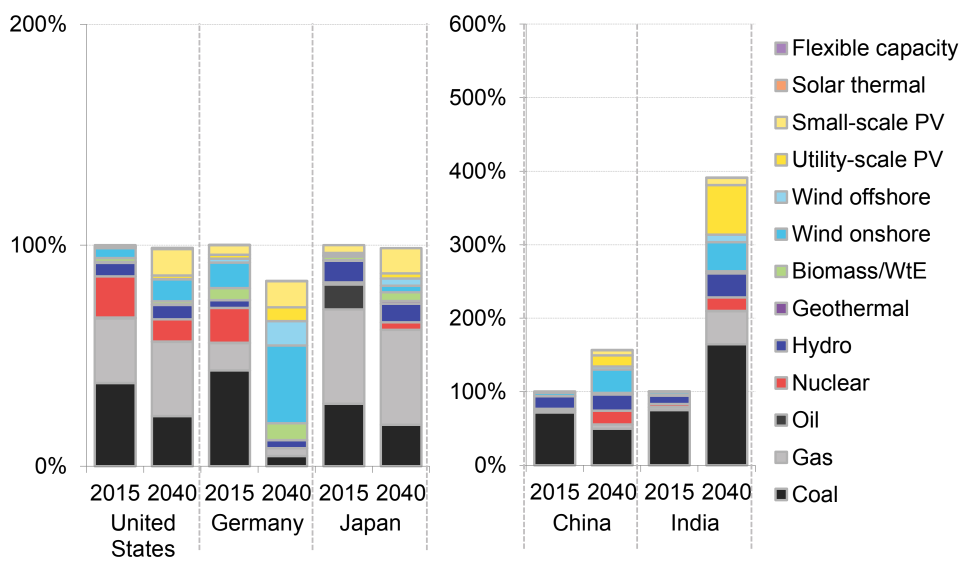
Despite the growth in solar generation capacity across all markets, the amount of energy generated (kWh) is expected to be relatively low, with fossil fuels still being relied on heavily. This further emphasizes the need for flexible capacity (such as batteries) and flexible load (such as demand-response-capable devices) to enable greater uptake of solar-generated electricity.

Figure 13: Electricity capacity mix in 2015 and 2040, normalised to 2015



Source: Bloomberg New Energy Finance New Energy Outlook 2015

Figure 14: Electricity generation mix in 2015 and 2040, normalised to 2015



Source: Bloomberg New Energy Finance New Energy Outlook 2015

SECTION 6. SOURCES OF UNCERTAINTY

The role that distributed solar and storage will play in the future of energy depends on a broad range of factors. New technologies are not rolled out into a vacuum and factors such as economics and regulation have an obvious impact on their uptake. However there are also a large number of softer characteristics, such as consumer habits and wide social trends, that also affect the eventual outcome for the technology. The outlook is therefore influenced by events and trends that seem unrelated and are beyond the control of the industry. This section outlines some of these known uncertainties.

Filtering along the lines of both level of uncertainty and likely impact helps focus on the highest-impact sources of uncertainty. The most important uncertainties for the roadmap are those that are both highly uncertain and have a high impact on the future for distributed solar and storage. The results of Bloomberg New Energy Finance's first analyst workshop, which focused on identifying and categorising uncertainties along these lines, are summarised in Figures 15 and 16. Mature and emering markets were considered separately.

Figure 15: Source of uncertainty in mature markets

	Low impact	Medium impact	High impact
High uncertainty		• Electric vehicles	• Electricity price • Storage costs • Competing solution cost • Regulation
Medium uncertainty	• Future lifestyle trends	• Solar costs • Natural gas availability • Wealth • Utility finances	• Business model innovation
Low uncertainty		• Population growth • Urbanization	• Political instability • Grid reliability

Figure 16: Sources of uncertainty in emerging markets

	Low impact	Medium impact	High impact
High uncertainty		• Electricity price • Future lifestyle trends • Wealth • Population growth • Electric vehic.	• Storage costs • Competing solution cost • Regulation • Grid reliability
Medium uncertainty	• Natural gas availability	• Solar costs	• Utility finances • Urbanization • Business model innovation • Political instability
Low uncertainty			

Least important → Most important

The uncertaintiies that are likely to have the strongest impact on the roll-out of distributed solar and storage solutions in both mature and emerging markets are regulation, electricity prices and the cost of storage and of competing technologies. The cost of PV modules is likely to have only a limited impact, as installation and customer acquisition already make up a larger share of the system cost, and because future price reductions are well understood. Grid reliability is the main differentiator between mature and emerging economies. Blackouts will be among the most important drivers of distributed solar and storage in Africa and much of Asia if grid operators are unable to increase the reliability of supply. More detail is provided in the pages that follow.

PRICE OF ELECTRICITY

	Mature markets	Emerging markets
Impact	High	Medium
Un-certainty	High	High

Electricity prices depend on fuel availability, demand and tax – meaning that future electricity prices are highly uncertain.

The main incentive for customers in mature markets to install solar and storage is to save money on utility bills and reduce exposure to future supply costs. Electricity price therefore has a high impact on the appeal of such systems.

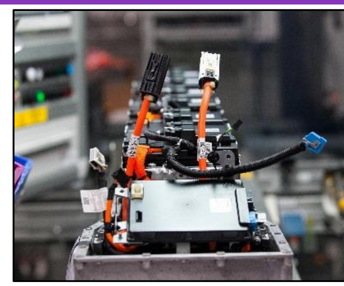
In emerging markets, where grids may be less reliable, the impact of electricity prices is lower because customers are more likely to be motivated to invest in solar and storage as an independent source of backup power.

STORAGE COSTS

	Mature markets	Emerging markets
Impact	High	High
Un-certainty	High	High

Storage technology costs currently represent a significant fraction of the cost of a distributed solar and storage system and as such have a high impact on uptake in all markets.

BNEF estimates that lithium-ion EV battery costs drop by 15% for every doubling of capacity built to date – but this pattern is far from established and capacity growth is highly dependent on demand for electric vehicles. As such the future cost of stationary storage systems is closely related to developments in the car industry, which are highly uncertain.



COST OF SOLAR TECHNOLOGY

	Mature markets	Emerging markets
Impact	Medium	Medium
Un-certainty	Medium	Medium

Unlike storage, the future cost of photovoltaic solar technology is well understood with long-standing trends and parallels with other semiconductor industries.

PV modules are of course a major component of solar systems. However the cost of PV modules and inverters already amounts to less than half the cost of a residential solar system. The remainder is made up of customer acquisition, installation equipment, labour and other overheads. This means that technology cost improvements will have a medium impact.

NATURAL GAS AVAILABILITY

	Mature markets	Emerging markets
Impact	Medium	Low
Un-certainty	Medium	Medium

Natural gas prices are an important input for power generation for both utlity-scale and distributed applications. However, gas prices only represent a fraction of end-user power prices, which is the most relevant metric when deciding on whether to install distributed solar and storage. The impact of gas prices is likely to be even lower in emerging markets, which tend to rely more on coal and have less developed gas infrastructure.

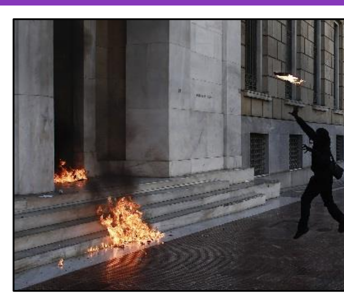
While natural gas is considered costly in many parts of the world, the fracking revolution in the US shows how quickly this can change.

POLITICAL INSTABILITY

	Mature markets	Emerging markets
Impact	High	High
Un-certainty	Low	Medium

Distributed solar and storage competes with the power grid, which is often among the most basic services orchestrated by governments. Political upheaval or even poor governance often reduces grid reliability, either because they result in a failure to maintain the network or underinvestment in the infrastructure.

This will make the grid less competitive and incentivise consumers to switch to more reliable, self-managed solutions like diesel generators or increasingly solar and storage systems. However it also discourages private investment, meaning that the effect of political instability is hard to predict.



UTILITY FINANCES

	Mature markets	Emerging markets
Impact	Medium	High
Un-certainty	Medium	Medium

Without sustainable profits utilities struggle to finance investments into the grid and power generation. In many emerging economies such as South Africa or India, publicly owned utilities offer artificially low prices, and their quality of service suffers.

If a utility has weaker finances than its customers or new entrants then they are poorly placed to take advantage of new technologies when they become economically viable. In such cases, independently-owned solar and storage options at the grid edge will precede centralised utility-owned ones.

COST OF COMPETING SOLUTIONS

	Mature markets	Emerging markets
Impact	High	High
Un-certainty	High	High

Residential and community-scale solar and storage competes with a variety of options for the service of generating, storing and delivering power. These include grid power generation and grid-level storage applications as well as emerging or future technologies such as fuel cells, automated demand response, wind or geothermal.

Breakthroughs in any of these areas could potentially alter the future economic attractiveness of distributed solar and storage technology.

REGULATION

	Mature markets	Emerging markets
Impact	High	High
Un-certainty	High	High

Regulation can be both a barrier and enabler for distributed solar and storage. Grid connection codes, ownership rules, electricity tariff frameworks, quality and safety requirements, standardisation, operating rules and subsidies are just some examples of regulatory factors that can block, enable or distort the economics (positively and negatively) for solar and storage.

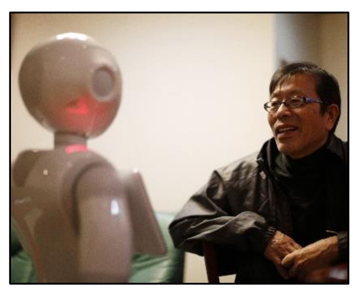
Because regulation is subject to influence from a variety of stakeholders, including small interest groups, it is both very impactful and uncertain.

FUTURE LIFESTYLE TRENDS

	Mature markets	Emerging markets
Impact	Low	Medium
Un-certainty	Medium	High

Future lifestyle trends can impact the value proposition of distributed solar and storage in ways that are difficult to predict. Increased tele-working, for instance, would shift residential consumption into the hours when solar panels produce power, reducing the need for storage. By contrast a shift towards eating out or outsourcing other home activities such as laundry would reduce residential power use, and thus the attractiveness of home solar and storage solutions.

In emerging markets, where behavioural patterns are changing more rapidly with economic growth, such changes are even more uncertain and will have a higher impact.

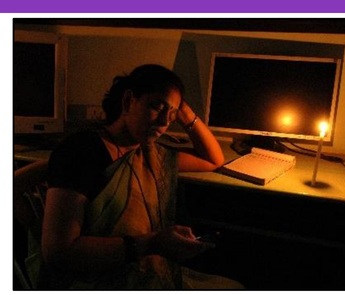


GRID RELIABILITY

	Mature markets	Emerging markets
Impact	High	High
Un-certainty	Low	High

Unstable grids are a daily reality for populations across much of Africa and Asia. Many consumers in such situations already rely on grid alternatives such as diesel generators, making them highly likely to switch to solar and storage once the economics are preferable and they are widely available.

In many emerging markets it is unclear whether the grid will improve or deteriorate under the pressure of increasing demand. The risk of deteriorating grid reliability is far lower in mature markets that already have a grid and face flat demand growth.



ELECTRIC VEHICLES

	Mature markets	Emerging markets
Impact	Medium	Medium
Un-certainty	High	High

Electric vehicles are interlinked with distributed solar and storage applications in more than one way.

Most importantly, the transport sector is likely to serve as a major demand centre for lithium-ion batteries, and faster uptake of EVs will accelerate industry development, resulting in cheaper stationary systems.

EVs could also create a new source of demand, posing technical challenges for utilities while increasing revenue. If vehicle-to-grid applications are realised, battery-powered cars may also reduce the need for distributed stationary storage.

WEALTH

	Mature markets	Emerging markets
Impact	Medium	Medium
Un-certainty	Medium	High

A consumer's wealth usually determines not only how much power they consume, but also their ability to finance long-term investments such as solar and storage. Wealthier consumers are also more likely to be able to afford additional services such as a reliable back-up to the grid. They are also more likely to pay a premium for solar and storage products marketed as a lifestyle choice such as Tesla's Powerwall.

Wealth is a function of both growth and the degree of inequality within an economy – it is therefore difficult to predict, particularly in high-growth emerging markets.

POPULATION GROWTH

	Mature markets	Emerging markets
Impact	Medium	Medium
Un-certainty	Low	High

Population growth has an indirect impact on the opportunity for distributed solar and storage in a number of ways. It is an underlying driver of GDP growth, wealth and electricity demand. It also impacts demographics and lifestyle patterns, which in turn can affect energy demand and political agendas, all of which influence the future of solar and storage.

This is most pronounced in emerging economies, where – generally speaking – population growth is expected but its exact extent is difficult to predict. In mature economies the rate of population growth tends to be lower and less uncertain.

BUSINESS MODEL INNOVATION

	Mature markets	Emerging markets
Impact	High	High
Un-certainty	Medium	Medium

There are a variety of ways that business-model innovation can impact the outlook for solar and storage in rooftop and community applications. This could include software and operations that reduce customer acquisition costs, financing bundles to reduce the initial outlay for consumers, community-ownership models and aggregation platforms for tapping into additional grid-service revenue streams. However, by their very nature, these innovations are difficult to predict.

.

URBANIZATION

	Mature markets	Emerging markets
Impact	Medium	High
Un-certainty	Low	Medium

Urbanisation is an ongoing trend, particularly in emerging economies, and it could impact the outlook for solar and storage in various ways.

An influx of people from rural areas unserved by the grid will further strain the urban power network, reducing its reliability and increasing demand for backup solutions.

The rise of dense cities with high-rise buildings instead of larger single houses substantially limits rooftop space that can be used for residential solar applications.

SECTION 7. SCENARIO DEVELOPMENT

Scenario planning is a tool for structured analysis of uncertainties, such as those discussed in the previous sections. It can provide insights on how to overcome barriers and help shape strategies for achieving goals. This section develops a scenario framework for assessing the future of distributed solar and storage in both mature and emerging markets.

7.1. PROCESS

The first step in scenario planning is to identify uncertainties relevant to the exercise (in this case understanding the future of distributed solar and storage). We then sort these uncertainties both in terms of their degree of uncertainty and their potential impact – as was done in Section 6.

Figure 17: Scenario planning process overview

The next stage is to bundle these uncertainties along common themes. Many uncertainties are relevant for the same or similar reasons: for example the cost of storage systems and the price of electricity are (largely) uncorrelated but both impact the economics of owning a solar and storage system. Drawing on the previous analysis, we form two broad themes around the most important uncertainties (ie. those with highest uncertainty and impact) that also capture as many of the lower ranking uncertainties as possible. These themes, which are different for mature and emerging-market cases, form the basis of two axes which define four scenarios. The final stage of the scenario development phase is to create a self-consistent description for each scenario within the bounds of the scenario definition. The steps described above were conducted over the course of four Bloomberg New Energy Finance analyst workshops.

7.2. MATURE MARKETS

SCENARIO AXES

Theme 1 : Economic attractiveness of distributed solar and storage

In mature markets, distributed solar and storage systems are potentially an economically attractive alternative to consuming electricity from the grid. The most important factors that influence this proposition are the price of grid electricity and the cost of solar and storage. The cost of alternative options is also clearly relevant. The amount and distribution of wealth also has a role to play since wealthier individuals and businesses may have more spare capital to invest in upgrades to their homes and buildings. Future lifestyle trends could also have an impact (positive or negative) on the amount of electricity consumed in the home, which influences the economic proposition in the residential sector.

Theme 2 : Defensiveness or supportiveness of regulation

Regulation can be a barrier or an enabler to the deployment of distributed solar and storage, for many reasons. The most direct impacts are through regulatory requirements on permitting and grid connection, installer training, and system operation (such as during blackouts). Indirectly, regulation strongly influences the types of business models that can be used to bring solar and storage systems to the market. The regulatory environment also helps determine the state of utility finances and grid reliability. Policies that lead to a high penetration of electric vehicles could create new challenges that require either protecting utilities or reforming markets, both through regulatory change.

Figure 18: Development of mature markets scenario axes

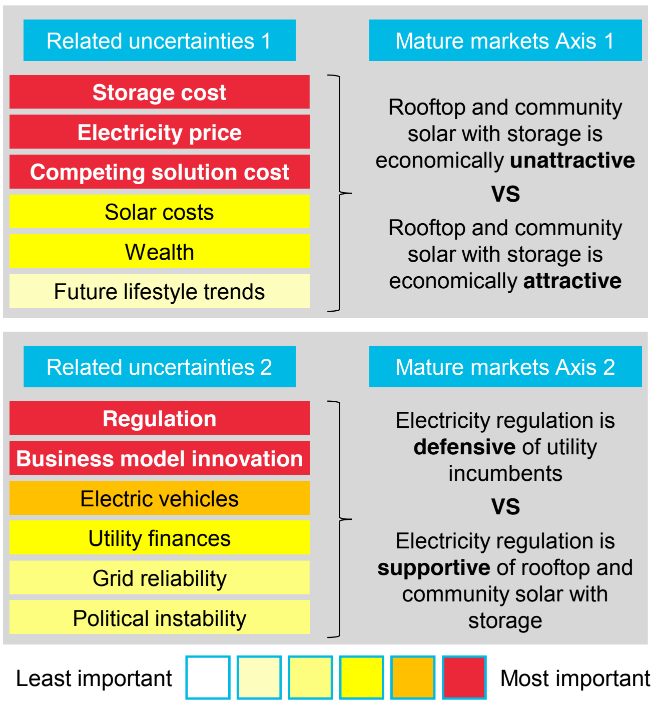
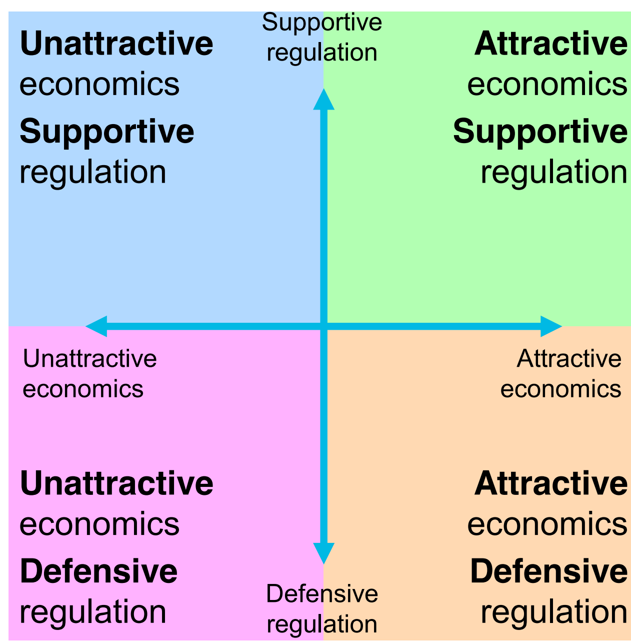
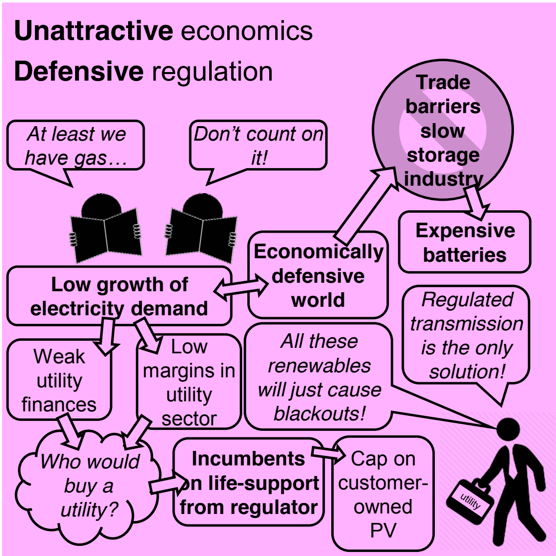


Figure 19: Mature markets scenario overview



SCENARIO DESCRIPTIONS

The axes shown in Figure 18 define four scenarios for mature markets. While not all market characteristics are captured here, the majority of mature solar and storage markets can be mapped into one of these four scenarios. To further clarify the situation that these scenarios represent, the following vignettes highlight the essential nature of each one.

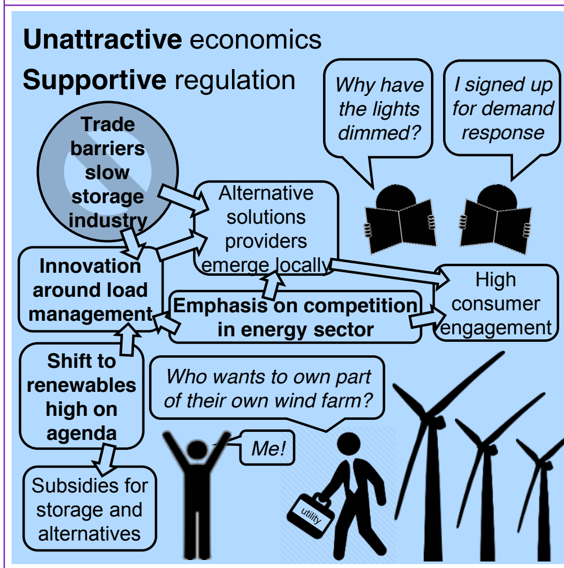


Description

The mature markets scenario of unattractive economics for distributed solar and storage on the one hand, and regulation that is defensive of the utility status quo on the other, is consistent with a weak economy that stifles innovation both globally and locally.

In this scenario slow growth or even recession leads to governments taking a defensive position on the economy. This leads to increased trade barriers which, if a global trend, limits the scope of the storage and solar industries to scale and reduce technology costs. Concerns over utility bills may also see the introduction of subsidies on electricity, worsening the economics of non-utility options further.

The weak economy also leads to risk-averse decisions at a policy level, which would favour incumbent utilities. They successfully argue that protecting utility jobs is a priority and that they represent the only tried-and-tested option for delivering cheap and reliable electricity to support economic growth. Renewables are cast as an expensive future technology and distributed systems are seen as a luxury for the well-off, which should be taxed rather than subsidised.

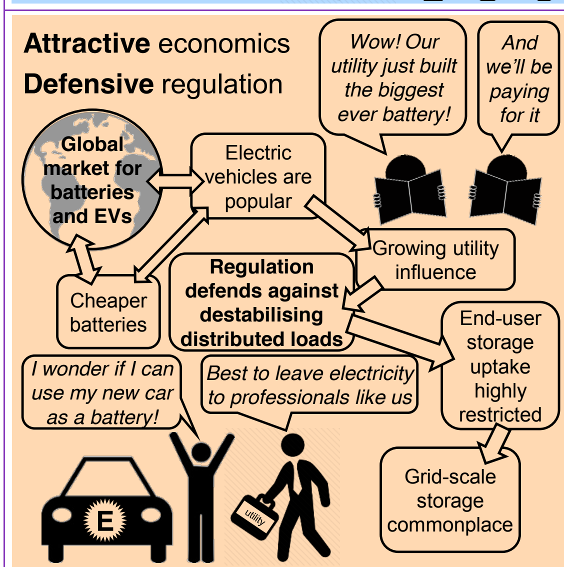


Description

The mature markets scenario where regulation is supportive for distributed solar and storage, but the economics remain unattractive, is consistent with a political and public drive to increase the adoption of new technologies and business models in energy, driven by concerns over climate change or a shortage of key fuels. Whichever way, reform is a priority.

Despite the high price of electricity and possible subsidies, solar and storage remains unattractive economically due to insufficient progress on technology costs. This may be due to pre-existing trade barriers, poor financing options for distributed solar and storage or because alternatives such as demand response or energy efficiency measures have emerged and become more attractive financially.

In this scenario consumers are highly engaged – both because of the high price of electricity and the array of new options they are faced with. Accordingly, bill-reduction propositions can include the purchasing of micro-stakes in renewable generation assets and opting in to automated demand response or time-of-use pricing to receive favourable rates.

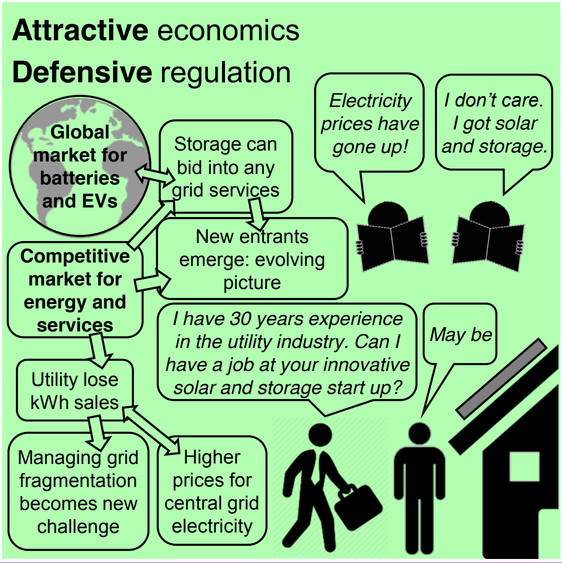


Description

The mature markets scenario where distributed solar and storage is attractive economically but regulation remains defensive of incumbent utilities is consistent with both a high uptake of electric vehicles and the prioritisation of grid reliablity over consumer choice.

Economic growth sees an increase in global trade and the lowering of barriers – there is now a growing market that can afford electric vehicles which are cheaper than ever given the growing scale of the battery industry. The increase in e-mobility creates a new challenge for grid operators as well as further deepening social and economic dependence on always-available electricity. With this in mind, policy-makers are more willing than ever to listen to the utility perspective, and the outcome is defensive regulation. This means restrictions on distributed solar and storage – cast as potentially destabilising – while grid-scale utility-owned solar and storage projects are regularly approved and rate-based.

International grid equipment providers develop or acquire expertise in management of large-scale storage in order to serve their base of utility clients. With no visible alternatives, the public are largely disengaged.



Description

The mature markets scenario where distributed solar and storage is attractive economically and supported by regulation is consistent with economic growth, technology cost declines and high energy prices.

Utility arguments for defensive regulation in the face of increasing challenges from new entrants offering community solar and storage and consumer-owned systems are disregarded. Regulators and policy-makers see no need for reduced competition when proven alternatives exist. As incumbents lose market share their role of providing low-cost electricity becomes increasingly challenging – higher prices and reduced grid reliability result, reinforcing the cycle further by making distributed systems more attractive.

Regulatory changes are introduced to remove barriers to the uptake of solar and storage at the grid edge and to ensure that such systems can also serve grid applications such as frequency regulation, opening up new revenue streams to system owners. The continually-evolving picture of managed grid fragmentation continues – regulatory changes are introduced, new entrants and business models emerge and regulation is further refined as the cycle starts again.

7.3. EMERGING MARKETS

SCENARIO AXES

Figure 20: Development of emerging markets scenario axes

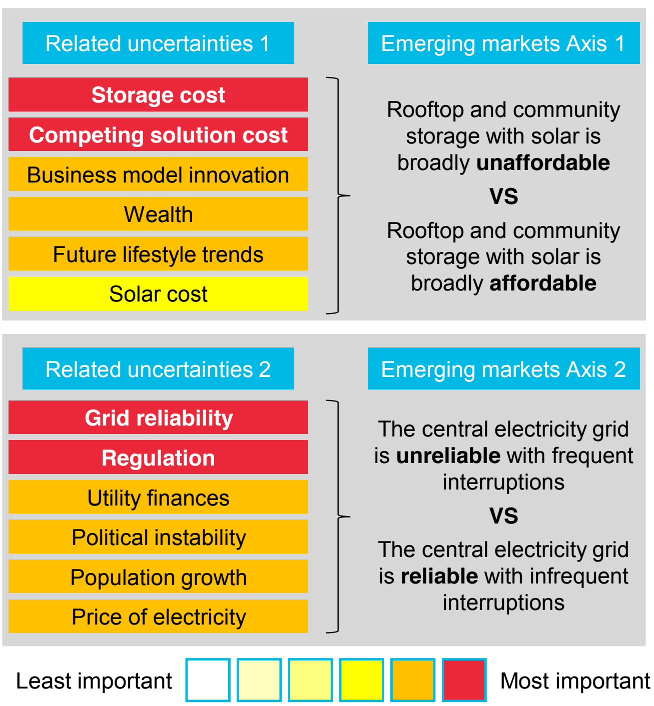
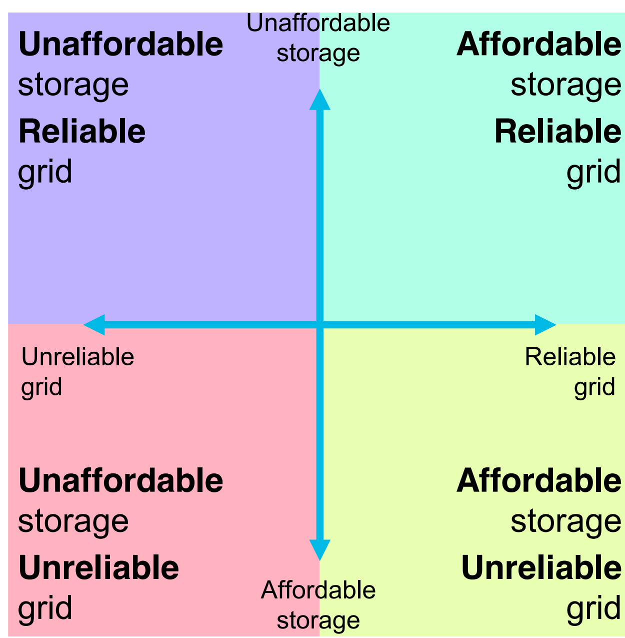


Figure 21: Emerging markets scenario overview



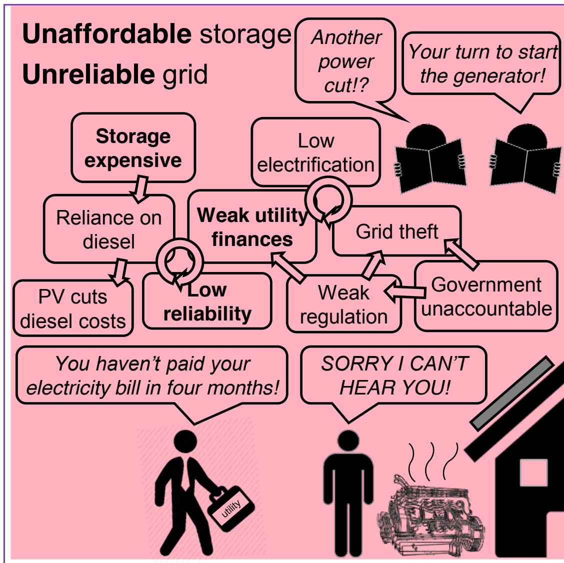
Theme 1 : Affordability of storage with solar

In many regards this axis is equivalent to the *economic attractiveness* axis in the mature markets exercise, although it is slightly more nuanced. Financial solutions can help make a system more affordable without changing the technology economics. This is particularly important in emerging economies, where households on average have smaller disposable incomes and may be more cash constrained. It is therefore not just important that distributed solar and storage can compete with alternative power generation technologies, but also that they are within reach of the household budget.

Theme 2 : Grid reliability

Given the use of storage with solar to maintain power during grid interruptions is a major driver, reliability should be an axis of uncertainty for emerging markets. Some of the other unknowns discussed also influence grid reliability – regulation influences the utilities' profit margin, which in turn affects their ability to finance infrastructure upgrades to improve reliability. Political instability can reduce investment appetite which can also make infrastructure financing difficult. Population growth has a very direct influence on power demand, which also creates an additional challenge for utilities to keep the lights on.

SCENARIO DESCRIPTIONS

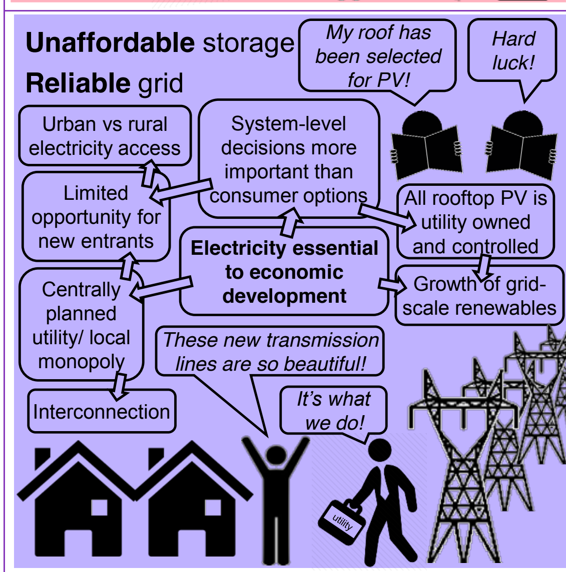


Description

The emerging-markets scenario where storage with solar is unaffordable and the grid is unreliable is consistent with weak regulation, strained utility finances and the widespread use of diesel generators.

In this scenario the utility is given insufficient support from regulators and government. Electricity prices are kept artificially low for political reasons, grid theft is widespread and the utility does not have the financial strength necessary to meet the needs of a growing population. This self-reinforcing cycle sees grid reliability issues worsen and many living off-grid. Grid-access represents a major social faultline between rich and poor both in urban and rural environments.

Those that can afford an alternative rely on diesel-based generators as backup. There is a growing market among more sophisticated consumers and communities for microgrids combining solar with diesel generation – these provide the most effective form of backup. Diesel importers are a potentially powerful lobby group, seeking to influence policy on alternatives, meaning that subsidy support for solar and storage is unlikely.

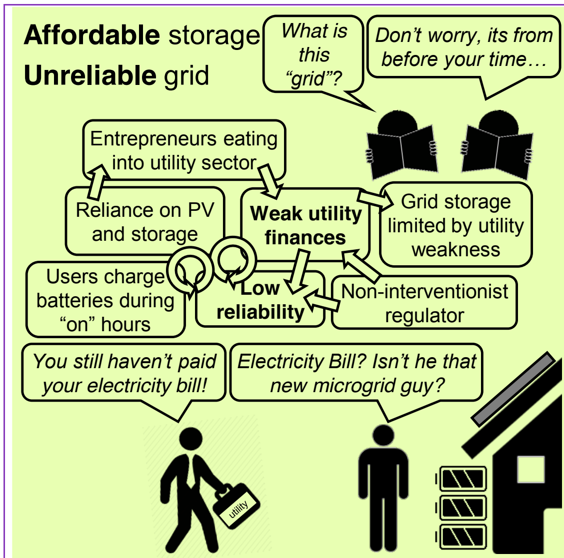


Description

The emerging-markets scenario where storage with solar is unaffordable and the grid is reliable is consistent with a centrally planned utility sector whose effective management is a core political priority.

Cheap and reliable electricity is seen as essential to industrial development, meaning that the government has continually supported and co-invested in the development of infrastructure to meet present and future needs. The result is a grid with significant spare generation capacity and sufficient transmission. Interconnectors to neighbouring countries are also a useful tool in regional politics, heightening the degree to which energy is a government priority.

There is limited opportunity for new entrants. Rooftop solar is considered only if it serves to ease grid challenges and is as a result predominantly owned and controlled by utilities, supported by government mandates. Aside from that renewables – which are adopted wherever they represent the best option economically – are found predominantly in large-scale installations. In the rare cases where it is the only viable option utility-scale storage is also used.

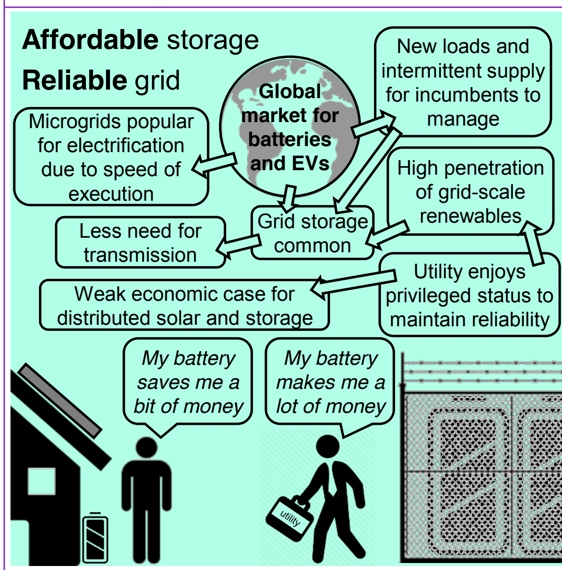


Description

The emerging-markets scenario where storage with solar is affordable and the grid is unreliable is consistent with a 'leap-frog' to a distributed energy-based electricity sector, with the grid only playing a limited supporting role.

In this scenario storage costs have reached a tipping point and it is an affordable option for end-users and communities in need of a reliable source of power. The financially weak utility is poorly positioned to invest in new technology and so the uptake of storage is almost entirely at the grid-edge. This creates further problems for the utility – even if end-users add solar there is a tendency to charge batteries while grid electricity is available (and no regulation to stop them doing so), increasing the peak and making it harder to avoid blackouts.

As grid reliability worsens the appeal of storage increases, as does the addition of solar to further reduce grid dependence and complement the battery. Entrepreneurs offering home systems and community microgrids capture utility market share and, with relatively low per capita electricity consumption, the bulk of demand can be met by distributed systems alone. Utilities' new role is marginalised to supporting energy intensive industries only.



Description

The emerging-markets scenario where storage with solar is affordable and the grid is reliable is consistent with utilities embracing grid-scale storage while solar is economically attractive at both the grid-scale and grid-edge.

Although stationary storage is an affordable option for end-users the reliability of the grid means that there is little incentive for end-user storage – where electricity prices are high the first priority would be the addition of solar. Grid-scale storage, however, is a cost effective option and, given the regulatory emphasis on reliability, should be straightforward for utilities to finance. This results in a situation where rooftop and community solar is common, generally speaking, but storage is centralised.

The addition of substantial grid-scale storage has further implications, easing grid integration of utility-owned wind and solar (which are economically attractive) as well as reducing the need for transmission investments. Assuming neighbouring countries are also benefitting from cheaper storage, the need for interconnectors (and their political 'soft power' implications) is also reduced.

SECTION 8. ROADMAP TOOLKITS

While the scenarios developed in the previous sections can provide insight into what the future may look like, they tell us nothing about what may happen between now and the future to make that scenario a reality. The next phase of the scenario planning exercise addresses this by considering 'transitions' between the scenarios, which then form the basis of the roadmap toolkits.

Figure 22: Scenario transitions and toolkit elements

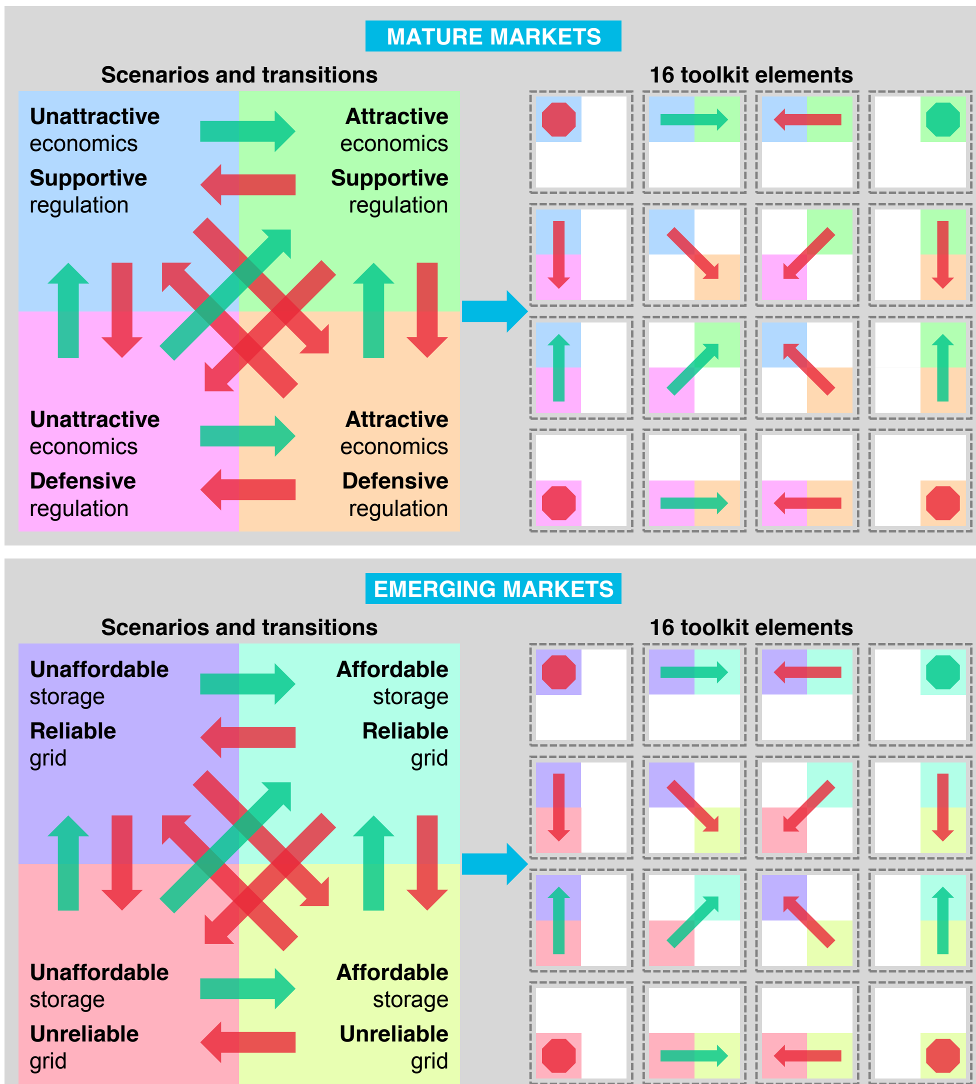


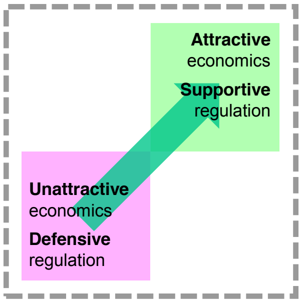
Figure 22 illustrates the principle behind the roadmap toolkits, which is based on examining possible transition pathways between scenarios. We have labelled the transitions as either drivers (green) or risks (red) depending on whether they move towards or away from the most favourable scenario. The definition of the most favourable scenario is subjective – the rationale for the choice in mature and emerging contexts is discussed in the sections below, in which each toolkit is also described in full.

8.1. ROADMAP TOOLKIT: MATURE MARKETS

For mature markets the choice of the most favourable scenario in the context of solar and storage is straightforward: where economics are favourable and regulation is supportive.

Drivers and risks for the "unattractive economics and defensive regulation" scenario

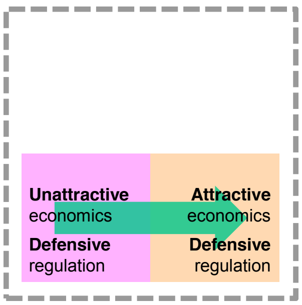
FAILURE OF TRADITIONAL UTILITY MODEL



A severe shortfall in grid capacity – due to chronic underinvestment and growing demand – means frequent blackouts and a sharp rise in electricity prices, causing public outctry and forcing the urgent reformation of the utility sector.

In order to increase system capacity, new regulations are incentivized to encourage non-traditional generators to feed into the grid, including owners of rooftop and community solar and storage systems. The high price of grid-supplied electricity means that the economics of solar and storage are now particularly attractive.

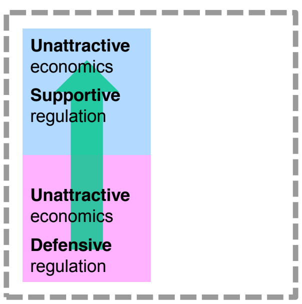
STRONG GLOBAL ECONOMY DRIVES STORAGE INDUSTRY



A sustained period of economic growth globally sees a reduction in trade barriers and increased demand for electric vehicles. As a result a global industry for lithium-ion batteries emerges and battery prices fall rapidly.

Growing demand for electricity sees an increase in prices, further improving the economics of solar and storage but grid codes prevent non-utility actors from fully monetising distributed energy assets. However utilities, protected by regulation, are able to rate-base batteries, supporting the uptake of grid-scale storage technologies.

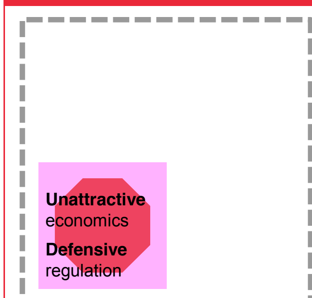
POLITICAL DESIRE TO SUPPORT NEW TECHNOLOGIES



Tension on the global stage means that energy independence – and hence renewables – becomes a priority for the government. Public concerns over climate change align conveniently with this position and a consensus emerges that the electricity sector should be reformed to encourage new entrants and renewables.

Despite the increase in support for solar and storage locally, the defensive stance of governments means that trade barriers prevent technology costs from falling and the economics of solar and storage remain unfavourable in most applications.

DEFENSIVE ECONOMICS AND UTILITY PRESERVATION

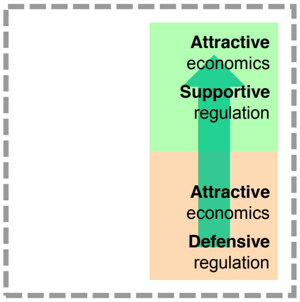


As governments worldwide struggle with the economic slowdown trade barriers are introduced, limiting the growth of a global storage industry. A weak economy means that locally utilities face the threat of flat or falling electricity demand.

Policy and regulation is aimed at keeping utilities in business in order to protect utility jobs and keep the lights on. Renewable energy is seen as expensive and of secondary importance relative to more immediate concerns. Moreover, distributed generation is seen as a luxury and a tax on self-consumption is introduced.

Drivers and risks for the “attractive economics and defensive regulation” scenario

DISSATISFACTION WITH UTILITIES BECOMES POLITICAL



The public is increasingly aware that options such as rooftop and community solar and storage are attractive, but unavailable due to regulation protecting utilities. As such, dissatisfaction over utility prices begins to intensify.

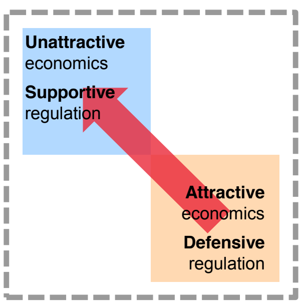
In this environment, any negative headlines within the utility sector – whether on reliability, executive salaries, emissions, rumours of collusion – are amplified to the point of being major scandals. Politicians on all sides see utility reform as a major vote winner and new regulation is introduced to open up the electricity market to new entrants.

ELECTRIC VEHICLES NEED A STRONG UTILITY

The popularity of affordable electric vehicles means that they are now an essential part of both daily life and the wider economy. This new source of demand creates a challenge for utilities and even minor interruptions to the regular supply of electricity are major disruptions for the public and businesses alike.

Utility companies argue that distributed generation brings an increased risk of grid instability and that a well regulated centrally controlled grid is the safest. Given that the importance of electricity now extends to the transport sector the government and public accept this proposition.

MARKET OPENS AND CHEAPER OPTIONS EMERGE

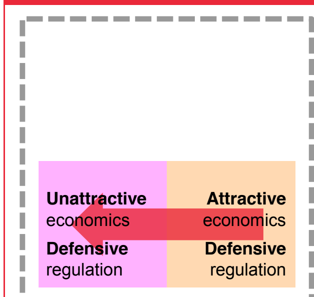


With renewables high on the political agenda, regulators make structural changes to the energy sector, opening the market to new technologies and new players.

While the changes should suit non-utility solar and storage it also opens the door for other options – demand response, power-to-gas, transmission and renewables diversification – which prove to be cheaper in a competitive market.

Electricity prices will decrease due to the increased competition and as a result storage and solar will cease to be an economically attractive option.

RECESSION MEANS BACK TO BASICS



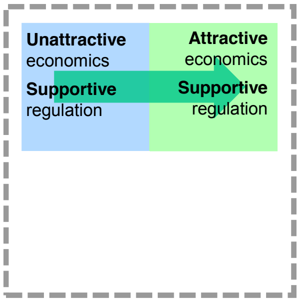
A recession sees low demand for electricity and gas, which translates into low power prices and undermines the economics of solar and storage. Governments introduce protectionist policies, limiting the import of solar and storage systems from abroad which prevents those industries from scaling and decreasing costs.

Consumers, with less disposable income than before, are unwilling to consider investing savings in unfamiliar technologies such as solar, storage and electric vehicles.

The utility incumbents maintain their dominant position, but based on traditional technologies once more.

Drivers and risks for the "unattractive economics and supportive regulation" scenario

CHEAP STORAGE, MORE STORAGE, EVEN CHEAPER STORAGE



Favourable regulation for distributed solar and storage means that even with unfavourable economics there is business-model innovation. As a result, when there are eventually decreases in the price of technology it is efficiently translated into sales.

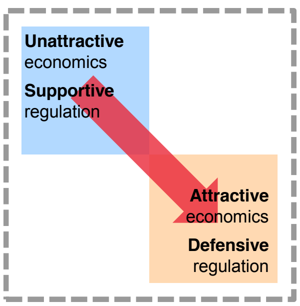
A virtuous circle results, particularly for storage technologies – higher volumes mean reduced prices which lead to even higher volumes. As batteries become cheaper the market for electric vehicles also gathers pace, further enhancing this effect. Non-utility solar and storage becomes an economically attractive combination.

GLOBAL INDUSTRY FAILS TO EMERGE

Despite the favourable regulatory environment, the storage industry fails to make the breakthrough required for distributed solar and storage to be economically attractive. This may be the result of high trade barriers or innovation around competing solutions such as demand response and power-to-gas that decrease the necessity to combine solar with storage.

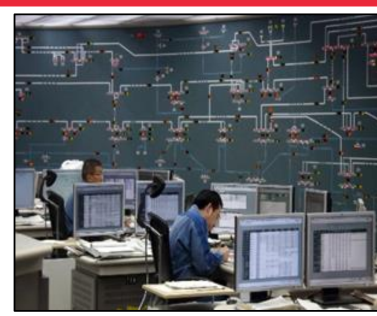
As opportunities decrease, investment in the development of storage technology eventually dries up and existing manufacturing capacity is shut down.

CONTROVERSY AND RE-REGULATION

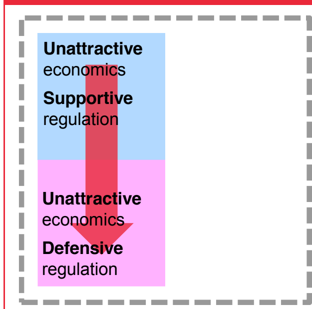


A technology breakthrough leads to a dramatic fall in storage prices. The rapid and unforseen uptake of solar and storage is controversial and disruptive. While many benefit from support schemes for the technology others complain that the government is giving public money to those privileged enough to own their own roof.

A lack of labour certified in the installation and integration of distributed solar and storage leads to a large number of "cowboy" headlines causing reputational damage to the industry. Responding to concerns, the government introduces restrictions on non-utility generation.

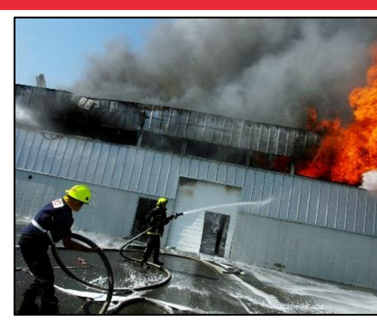


PUSH BACK AGAINST UNSAFE AND UNRELIABLE TECHNOLOGY



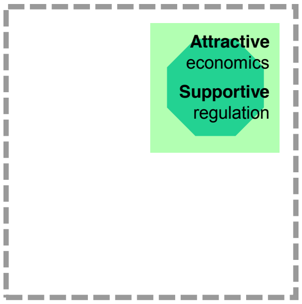
An incident involving storage – such as a fire or similar – will shock public opinion leading to the open questioning the wisdom of subsidising early-stage technologies that are yet to prove their safety.

Reacting to the incident regulators will place restrictions on storage technologies, particularly when located inside or near buildings. As a result opportunities for distributed solar and storage will be stifled due to restrictive regulation.



Drivers and risks for the "attractive economics and supportive regulation" scenario

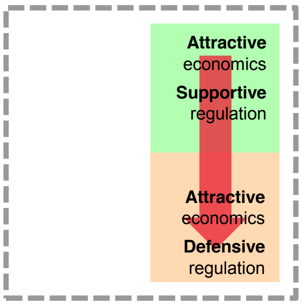
EMERGENCE OF NEW INDUSTRY, PROTECTED BY NEW REGULATION



The market for rooftop solar and storage flourishes. As new players enter the market with innovative business models competition increases and prices go down, further increasing uptake.

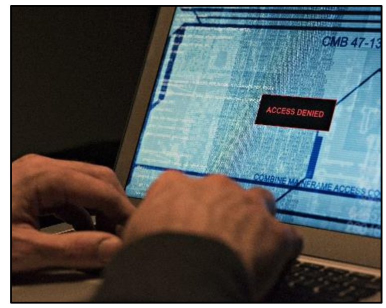
Installation of distributed systems is recognised as a major new source of employment and as such the government introduces further regulation to protect and consolidate this industry. Traditional utilities are forced to plan in line with the new reality.

CYBER-ATTACKS AND SYSTEM FAILURES

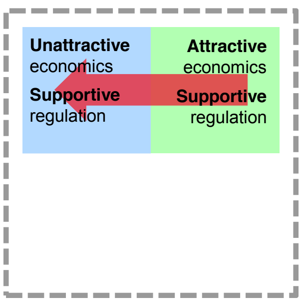


The high uptake of rooftop solar and storage and the challenge of integrating such a large number of systems creates unforeseen problems. A system failure – possibly as a result of poor integration or something more sinister such as a cyberattack – gives rise to concerns that a distributed system is inherently vulnerable.

In such circumstances the role of utilities gains a new appreciation from both the public and politicians and the importance of protecting them is seen as paramount. New regulation is introduced to protect utilities and restrict the uptake of distributed systems.



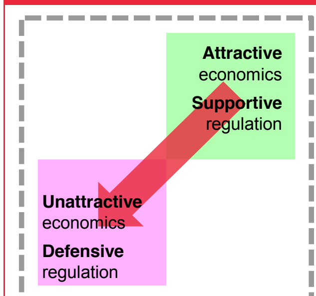
CHEAP GAS MEANS CHEAP OPTIONS



A substantial drop of natural-gas prices worldwide leads to a decrease in grid prices. While this means that distributed generation is generally speaking not competitive, it also means that of the different distributed generation options, those driven by gas are most attractive. While the abundance of gas eases the integration of solar, there is no longer an economic case for storage.

An increase in interconnection may also drive down grid prices in a similar way, undermining the economics of distributed solar and storage.

COLLAPSE OF LITHIUM SUPPLY AND FAULTY ALTERNATIVES



Political factors lead to a collapse in the lithium supply chain meaning that battery prices rocket and storage and solar are no longer economic. Alternative storage technologies are marketed but these are found to be both expensive and unsuitable.

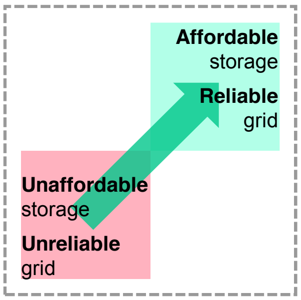
Concerns over dependence on lithium as a commodity and the need to protect consumers from sub-standard alternatives means that utilities are in a strong position. They successfully lobby for a system with both centralised balancing and limits on the uptake of distributed systems.

8.2. ROADMAP TOOLKIT: EMERGING MARKETS

For emerging markets, the choice of most favourable scenario is less straightforward, because an unreliable grid is clearly an undesirable outcome, but would also drive the uptake of distributed storage. However it would be perverse to recommend strategies that would lead to a less reliable grid – so the scenario with affordable storage and a reliable grid was chosen as most favourable.

Drivers and risks for the "unaffordable storage and unreliable grid" scenario

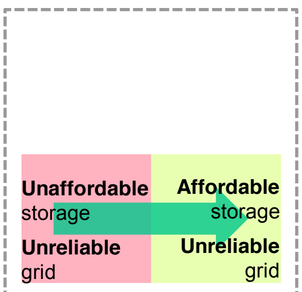
SUBSIDISED STORAGE AND NEW GRID OWNERSHIP



Battery subsidies and technology cost improvements mean that storage becomes a viable alternative to conventional grid reinforcements. Development banks see an opportunity and lead the charge in financing this new infrastructure option. Foreign governments see an opportunity to foster markets for their technology and take strategic stakes in local grids through state-owned enterprises.

The impact is a rapid uptake of grid-scale storage which, coupled with cheap renewables, has the effect of dramatically improving reliability.

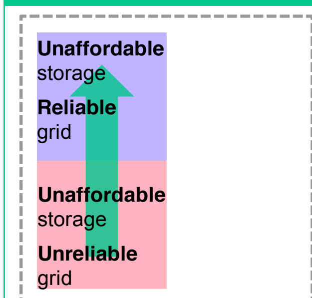
CHEAP BATTERIES AND NEW BUSINESS MODELS DRIVE CONSUMER CHOICE



A growth in global trade sees both the price of storage fall and an increase in individual wealth. The result is an increase in the uptake of distributed storage in order to reduce intermittency and the emergence of business models around community microgrids and other distributed solar and storage applications.

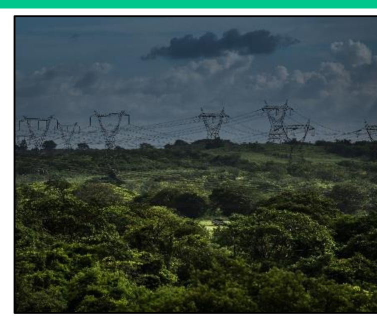
While diesel is still an option for backup power, storage-based systems are considered a superior option for those that can afford them, due to the lack of noise and fumes.

POLITICAL STABILITY, ECONOMIC STABILITY MEANS GRID STABILITY

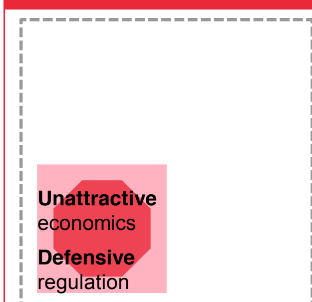


A period of sustained political stability and good governance allows economic growth and enforceable and effective top-down grid planning. In this environment utilities have both a mandate to invest in the grid and the effective cost recovery mechanisms to add meaningful infrastructure.

The result is spending on new generation, smart technologies, transmission and interconnectors. To cover this investment, electricity retail prices rise, meaning that there is also experimentation with demand-response and energy-efficiency business models.

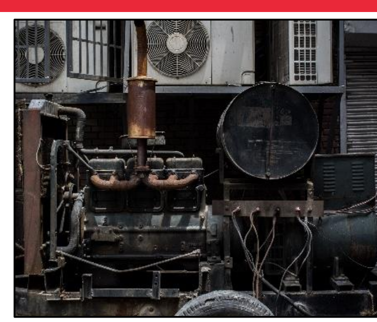


FLAWED GOVERNANCE AND BRAIN DRAIN



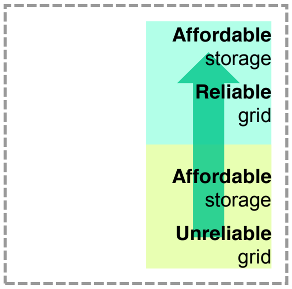
There is a lack of political will to address the various issues that have plagued grid development. Without an effective cost-recovery mechanism the utility struggles to make the investments necessary to bring technicial and non-technical losses under control. The result is poor equipment choices driven by false economy. Rural areas where the costs of grid infrastructure are higher on a per consumer basis are the worst neglected.

To further reinforce the negative cycle, there is a "brain drain" of workers with the skills to implement necessary solutions.



Drivers and risks for the "affordable storage and unreliable grid" scenario

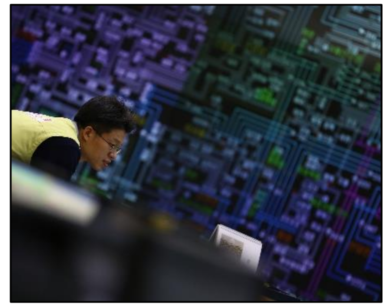
REGULATION AND IT ENABLES SMART INTEGRATION



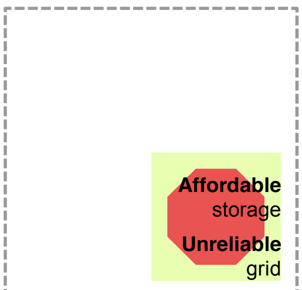
The broad uptake of solar and storage means that there is less strain on the previously over-stretched grid due to an effective decrease in demand.

The government introduces rules to use low-cost smart technologies to enable grid-integration between distributed systems and the grid. Owners of distributed systems and community microgrids are mandated to surrender some control of their battery to the utility.

The result of effective integration is a stable grid that leverages distributed resources to maintain uninterrupted supply.



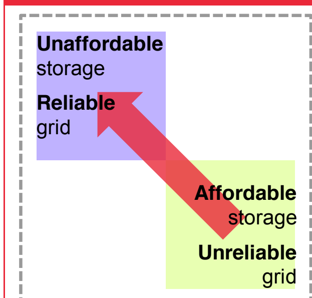
DISTRIBUTED ENERGY DRIVES ECONOMY AS OPPORTUNITY FOR GRID FADES AWAY



While distributed solutions based on batteries propagate, there is continued underinvestment in the grid due to mismanagement and poor incentives. Moreover, the tendency to charge batteries when the grid is available means that even strategies such as load-shedding are ineffective. The grid's reliability worsens to the point that it can't be relied on to provide a full battery charge, so many consumers add solar to complement their storage.

Business models for storage become established. Microgrids are a differentiating real-estate feature. The relevance of and opportunity for utilities is limited.

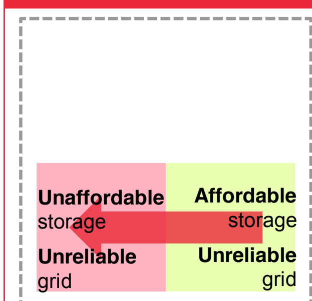
ISOLATIONIST GOVERNMENT FOCUSES ON DOMESTIC SOLUTIONS



A global trend in isolationism means that trade barriers are are erected and the cost of storage increases. By the same token there is also less concern for climate change and cheap coal becomes the option of choice for governments.

Regulation is set around the notion of a centralised coal-driven electricity grid and the result is cheap electricity but high levels of carbon emissions.

THE BUBBLE BURSTS



A severe economic setback, such as a currency collapse, means that imported technologies such as batteries (and PV) are no longer affordable. A period of economic instability compounds this effect by shortening investment horizons both for the utility and consumers. The result is underinvestment in the grid and diesel backup is the only alternative for those that can afford it.

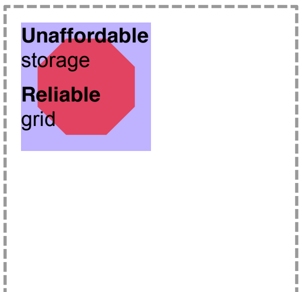
Drivers and risks for the "unaffordable storage and reliable grid" scenario

NEW MODELS EMERGE FOR SELLING STORAGE

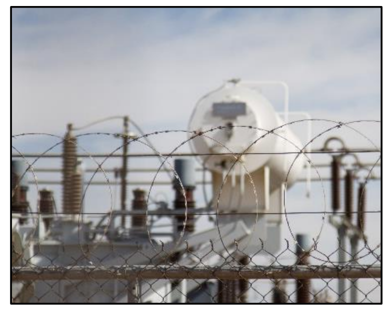
Reacting to increases in electricity prices and falling costs of storage technology, the government introduces a new regulatory framework to allow effective monetization of grid-scale storage. New entrants offer services to utilities generating multiple revenue streams from storage assets. Driven by these new economics, the market flourishes.

This trend is repeated in several countries and the battery supply chain consolidates, pushing prices further down. The high penetration of storage on the grid paves the way for the uptake of more renewables, including solar.

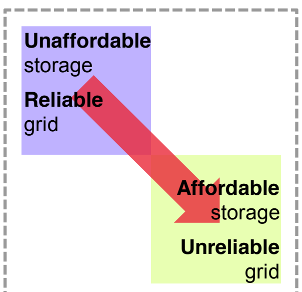
THE GRID IS THE ONLY GAME IN TOWN



Battery technology does not make the necessary cost decreases to reach a tipping point. Subsidised electricity prices mean there is little incentive to invest in either solar or storage. Seeking to limit the disruption caused by intermittency, there are severe connection limits on distributed solar, which stifles the market.



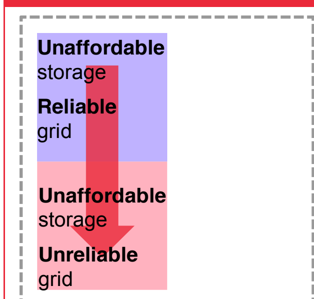
DISTRIBUTED ENERGY FRIES THE GRID, THEN EATS IT



A rapid drop in storage technology costs leads to the rapid emergence of solar and storage microgrids and other distributed energy options. The distributed capacity is poorly managed by the utility and results in some intermittency – which drives more adoption.

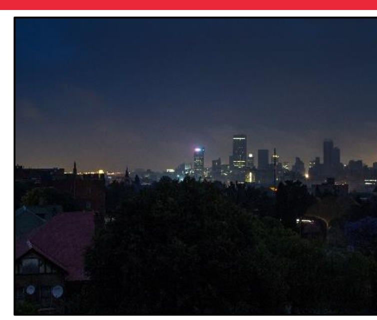
As utility finances worsen, the conventional model seems increasingly outdated and unsustainable. Responding, the government introduces a new set of policies that are based on the premise that the future of energy is in distributed generation.

NATURE OR POLICY OVERSTRETCH GRID



Political pressure to increase electrification, but at artificially low tariffs, means that the grid is expanded too fast and with insufficient funds. Structural changes in economic output and other changes in consumption patterns further overstretch the grid.

Blackouts become increasingly common due to a shortfall in capacity and inadequate distribution and transmission infrastructure. Damage due to servere weather incidents or decommissioning of capacity for political reasons create further disruption from which the utility cannot recover. Grid reliability decreases rapidly.



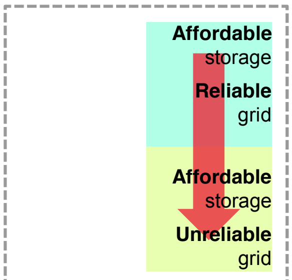
Drivers and risks for the "affordable storage and reliable grid" scenario

SOLAR AND STORAGE IS THE NEW NORMAL

The combination of a stable grid and affordable solar and storage technologies means that utility policy is focused on meeting growing demand in the most economically efficient way possible. Storage and solar is also seen as a means for reducing fuel imports.

The result is a build-out of centralised solar plants and grid-scale batteries. The supply of electricity is cheap and uninterrupted meaning there is little incentive for uptake of distributed options. The traditional utility model is consolidated but based around new technologies.

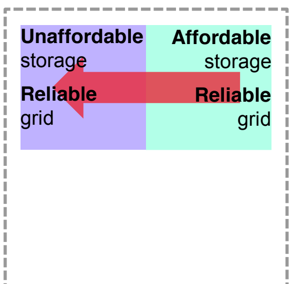
FAILED GRID GOVERNANCE AND ALTERNATIVE OPTIONS



A collapse in utility finances due to unregulated uptake of distributed options by end-users and communities leads to decreased grid investment. The utility pushes the government for protective regulation but their position has little sympathy from the public, who are dissatisfied with an increase in blackouts and are even less inclined to be restricted from choosing alternatives.

New entrants, unconstrained by responsibility to maintain a centralised grid, continue to benefit from the government's slow response to the utility crisis.

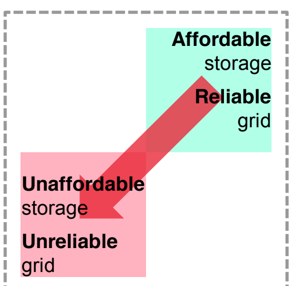
TAX ON FOREIGN TECHNOLOGY AND CHEAP ENERGY



Local content rules for technology mean that cheap storage options from abroad are unavailable or unaffordable. Domestically-sourced batteries underperform and are not seen as realistic alternatives.

Other options, however, do emerge. Increasingly sophisticated models for industrial load-shifting enable effective management of intermittency and wind and solar are found to be less challenging to integrate than expected.

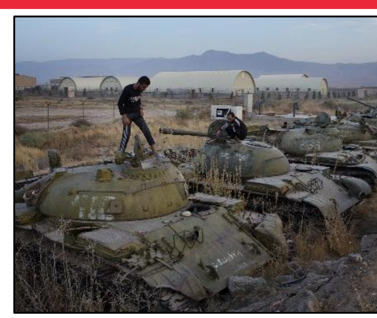
COLLAPSE



Major upheaval leads to economic collapse, undermining the utility business operations and restricting imports.

In the most extreme case this may be due to civil war, but it could also be due the installation of a new government that adopts extreme policies and mismanages the economy through corruption to special interests.

Whatever distributed resources do exist are highly valued for their dependable supply of uninterrupted electricity.



SECTION 9. JAPAN ROADMAP

Japan was a pioneer of rooftop solar with the launch of its Sunshine programme in 1974. The country also is one of the leaders in energy storage. Bloomberg New Energy Finance estimates that it has an installed base of 50,000 residential lithium-ion batteries – the largest fleet globally. Japan's historical progress as well as its outlook for significant uptake of rooftop PV and storage is governed by an interplay between government regulation and market response.

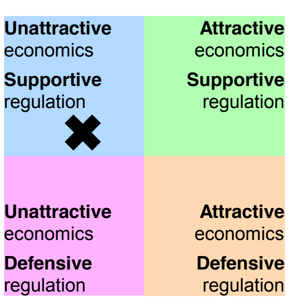
BACKGROUND

Since 1974 resource-poor Japan has been supporting the development and commercialisation of renewable energy technologies

Since the 1973 oil shock, resource-poor Japan has spent significantly in support of R&D and the commercialisation of renewable energy technologies. Rooftop PV installations until 2008 were driven by Japan's 'Sunshine Program', a comprehensive government programme started in 1974 for commercialisation of solar PV technology covering R&D funding all the way to subsidies for residential installations. In November 2009, Japan launched a surplus buyback programme for residential solar accompanied with capex subsidies, which resulted in a surge in installations. The launch of the feed-in tariff (FiT) programme in July 2012 did not significantly affect the residential segment, as the FiT programme treated the purchase of surplus output from residential systems in a similar fashion to the buyback programme.

For storage, the Japanese government launched a subsidy programme for installation of lithium-ion batteries by end users starting in FY2012 – in the aftermath of the Great East earthquake and tsunami of 11 March 2011. Residences that combine the storage system with rooftop PV, are eligible to get a slightly lower FiT rate than the regular surplus buyback programme, but can instead sell the full generation output from the PV system rather than just excess generation. While this arrangement is financially beneficial to the system owner, it doesn't encourage auto-consumption, the primary objective of distributed solar and storage. Nevertheless. the subsidy programme has been very effective in spurring interest from both domestic and international manufacturers. There are currently 144 stationary lithium-ion battery systems offered by 24 vendors registered with the subsidy administrator, likely setting Japan as the market with the most hardware choice as a result.

Figure 23: Japan current scenario verdict



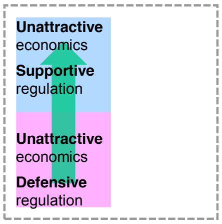
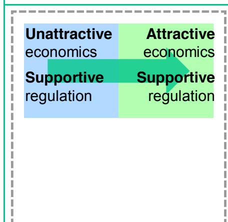
As of June 2015, Japan has an installed base of 8.3GW of PV systems below 10kW, primarily on residential rooftops; with 3.7GW worth of the installations carried out since the launch of the FiT programme. Bloomberg New Energy Finance estimates that the lithium-ion battery subsidy programme has led to over 50,000 residential battery installations.

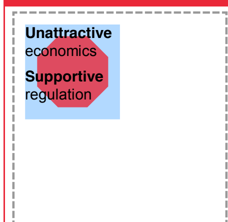
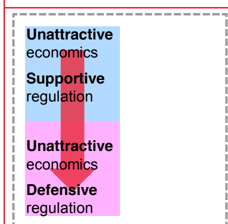
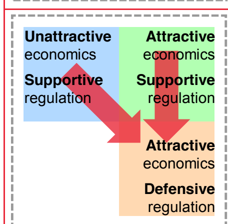
SCENARIO, DRIVERS AND RISKS

Japan is by no means at a standing start in terms of progress on solar and storage. In addition to the subsidy programmes detailed above, there is a process of market reform spurred by the power shortages experienced in the aftermath of the 2011 earthquake that means overall regulation is supportive for distributed solar and storage. Despite the country's large lithium-ion battery industry, the high cost of storage remains a barrier to broader uptake.

Given the above, Japan is best characterised by the top-left scenario of unattractive economics with supportive regulation. Accordingly, the majority of drivers and risks in the roadmap toolkit that are relevant to Japan originate from that quadrant.

Table 1: Key drivers and risks for Japan

Driver	Description
	***Political desire to support new technologies*** Reform of Japan's electricity market is an ongoing process that can be traced back to the Great East earthquake and tsunami of 11 March 2011 and the subsequent power shortages. Japan's electricity retail market is set for full deregulation starting from April 2016. This will spur interest by many new players to engage in electricity retail, including some who are considering offering rooftop solar and storage. While government support for distributed solar existed before the earthquake, the government added a subsidy programme for installation of end-user lithium-ion batteries in 2012.
	***Cheap storage, more storage, even cheaper storage*** While the lowering of trade barriers will accelerate cost decreases in storage technologies, Japan is comparatively well positioned irrespective of the international picture. This is due its sizeable battery industry. A trigger for the scaling of the storage market and industry could be the expiry of the FiT/surplus buyback programme for PV systems below 10kW, which lasts only 10 years. As early as 2019, Japan will have a significant amount of rooftop PV installations whose owners will have a financial motivation to increase their auto-consumption rate, spurring a sudden increase in interest in energy storage.

Risks	Description
	***Global industry fails to emerge*** As discussed above, Japan's domestic battery industry could still achieve the cost-reductions required to allow the market for solar and storage to scale irrespective of the global outlook. However, it is equally possible that this won't happen. Collectively, Japan, South Korea and China represent over 70% of the global lithium-ion industry – if international tensions give rise to reduced trade the result could be the choking of the fledgling storage industry. Another point particular to Japan is that there has been considerable interest in alternative balancing technologies that would reduce the need to add batteries with distributed solar. Power-to-gas and other hydrogen-based options are a particular area of focus for both corporate and government R&D funding.
	***Push back against unsafe and unreliable technology*** Many aspects of Japan's electricity market reform are still in discussion and full implementation has yet to occur. For example, the volume of electricity traded on the wholesale electricity market is still tiny and the number of tradable products very limited. There is also no ancillary services market. These limitations hinder the ability of new electricity retailers relying on aggregation of distributed PV and storage to provide a quality, reliable electricity service. If these newcomers struggle to secure sufficient supplies due to lack of a properly functioning electricity wholesale market, they may even end up causing blackouts. The price of the electricity delivered by aggregation of distributed resources is also not yet fully clear as distribution charges for low voltage networks are yet to be finalised. Overall there is a risk of a high priced poor quality electricity service that could end up turning the general public against the technology.
	***Panic and re-regulation / Cyber-attacks and system failures*** The combination of high electricity prices, supportive regulation and the presence of a domestic industry for batteries means that Japan has the potential to be a leading early market in the uptake of distributed solar and storage. While this can be seen as positive, it also means that Japan could be among the first countries to encounter some of the unforeseen problems associated with integrating significant capacities of solar and storage at the grid edge. Whether these problems are associated with safety, quality or cybersecurity, they could lead to a regulatory backlash severely restricting the uptake of further distributed systems – while other countries learn from mistakes made in Japan.

Japan will have to carry the burden of early-mover disadvantage

Japan is well placed to become a global leader in the adoption of distributed solar and storage. If supportive regulation and subsidies for technology continue then it could simply be a matter of time before the country's storage industry delivers small-scale systems at attractive prices.

However, even with such high levels of support, the path ahead is by no means straightforward. The domestic market may not be sufficient for Japan's storage industry to achieve economies of scale. There are also other government-supported technologies that could undermine the opportunity for solar and storage. Regulatory reform is ongoing and new rules could yet be introduced that are unfavourable to distributed systems generally. Lastly, if Japan is to become a leading market for solar and storage, it will also have to carry the burden of early-mover disadvantage – and possibly be over taken by other nations that have benefitted from lesssons learned in Japan.

SECTION 10. GERMANY ROADMAP

Germany is currently leading the renewable energy sector in Europe and is the most attractive European market for residential energy storage due to high electricity prices and a high penetration of distributed PV. BNEF expects the nation's renewable sector to account for 90% of total generation by 2040, with almost $220bn to be invested in the country until then. Historically supportive of PV, Germany will continue to enjoy even lower solar costs, setting the ideal conditions for the uptake of distributed solar and storage.

BACKGROUND

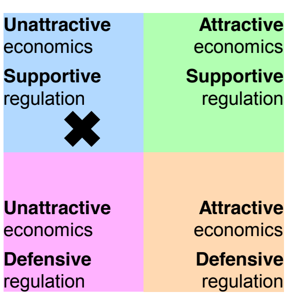
Germany is currently the most attractive European market for residential energy storage due to high electricity prices and penetration of distributed PV

Over the past ten years, Germany's renewable energy sector has grown more than threefold and the country is now an undisputable leader in renewables in Europe and globally. The current energy mix sees renewables accounting for 50% of total capacity, with small scale PV at this time representing 15% and expected to further grow thanks to declining solar costs.

The nation's renewables program is summarised under the *Energiewende* – literally, 'energy turn-around'. The strategy enjoys political support across party lines. The country pioneered feed-in tariffs as early as 1991, and offered them persistently until they were replaced recently by more competitive auctions. In 2013, the country introduced a three-year subsidy programme (KfW programme) for distributed storage financed though a EUR 50m fund. The scheme provides up to EUR 600/kW for the purchase of new battery storage or for the substitution of existing PV systems with energy storage. The programme has contributed substantially to the uptake of energy storage in the country: as of November 2015, around 25,000 systems have been sold, half of them under the KfW programme. Energy storage systems connected to PV systems sub 30kW are also eligible for low interest loans and a grant of up to 30% of the cost of the system.

In 2014, the revision of the Renewable Energy Law (Erneuerbare-Energien-Gesetz - EEG), the consequent decision to phase-out nuclear power by 2022 and to substitute 80% of it with renewable capacity, has lead to completely new challenges. With more renewables entering the grid and affecting power prices, the pressure on existing generation capacity – as well as on the nation's utilities -- has substantially increased. Renewables are already curtailed on a regular basis when the grid cannot absorb their output, and the problem is rising and affecting both transmission and distribution grids. The amount of unused renewable energy generation has risen from practically nothing in 2009 to more than 1.2% of the total in 2014, according to Bnetza data. The bottlenecks of the Energiewende have shifted from capacity build to the transmission grid and the integration of more and more intermittent renewables. The country has therefore put forward a power market reform, foreseeing an energy-only market system with a strategic capacity reserve holding 5% of peak demand.

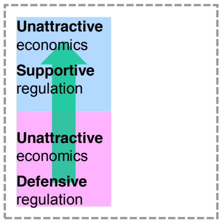
Figure 24: Germany current scenario verdict



SCENARIO, DRIVERS AND RISKS

Given the above, Germany is best characterised by the top-left scenario of unattractive economics with supportive regulation. With its broad political support for a low-carbon energy system, as well as its manufacturing prowess that has already seen promising storage start-ups emerge, the nation is well-suited to remain at the forefront of distribtued solar and storage as the economics for the technology improve. Germany's progress could be derailed if new investment in distributed solar and storage raises safety or reliability concerns that are too much to stomach for a risk-averse public.

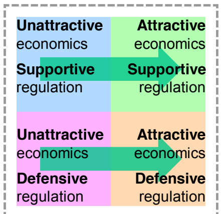
Table 2: Key drivers and risks for Germany

<table>
<tr><th>Drivers</th><th>Description</th></tr>
<tr><td>


</td><td>

Political desire to support new technologies

The “Energy Turnaround” decision to phase out nuclear power by 2022 and replace it with mostly renewable capacity, has set new challenges for the German power sector. With an ever increasing penetration of renewables influencing electricity prices, existing baseload generation is increasingly under pressure. Meanwhile, the profitability of flexible capacity to back up renewable generation, once nuclear phase-out is completed, has also been questioned.

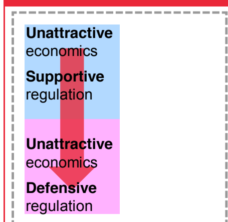
The country has therefore put forward a power-market reform, foreseeing an energy-only market system with a strategic capacity reserve representing 5% of peak demand. Given the wide political backing for the Energiewende and the pressure on the transmission grid, it is quite likely that distributed storage will be seen as an important part of the solution.
</td></tr>
<tr><td>


</td><td>

Cheap storage, more storage, even cheaper storage / Strong global economy drives storage industry

In 2013, Germany announced a subsidy program for storage, which has contributed to the uptake of energy storage in the country with 25,000 systems sold as of November 2015. While the the end of the mechanism may result in a regulatory setback, it is generally seen that the scheme has successfully brought down energy storage costs by developing local expertise and enhancing consumers’ awareness. It remains to be seen if its momentum can continue.

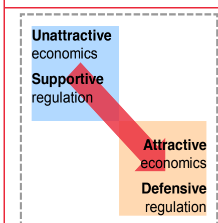
Additionally, Germany is seeing innovation on aggregation and community-level storage which could both also improve the economics of storage. Aggregation startup Caterva enables behind-the-meter storage owners to rent out part of their battery to network operators, while utility MVV has created the StromBank community storage system for households to benefit from storing rooftop PV without installing a battery in their own homes.
</td></tr>
</table>

<table>
<tr><th>Risks</th><th>Description</th></tr>
<tr><td>


</td><td>

Push back against unsafe and unreliable technology

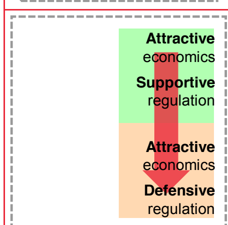
According to a study conducted by Karlsruhe Institute of Technology, many storage systems eligible for the KfW programme are potentially unsafe and at risk of catching fire, as suppliers have failed to comply with industry standards. Among the issues the report highlighted is that many systems are characterised by low quality cells, plastic instead of metal casing and poor quality separators with low temperature limits of 80°C.

This may represent a significant risk for the further development of the solar and storage industry, as policy makers could decide to push back against the storage sector, in the name of public security, should some of these issues manifest in the form of disruption to supply or safety incidents.
</td></tr>
<tr><td>


</td><td>

Controversy and re-regulation

The rapid uptake of PV in Germany has not been without controversy. Taxes represent the 52% of the total commercial electricity bill, for example, but consumers that can afford to reduce their bill through the installation of PV could in theory avoid paying their share of this. Increases in grid prices to offset the lost electricity from owners of rooftop PV are also seen as unfair, particularly on lower income consumers.

To address this, the 2014 Renewable Energy Law (EEG) saw the introduction of a renewable energy surcharge applied to all the new PV systems larger than 10kW, taxed at current rate of 30%, rising to 40% by 2017. Taxing self-consumption is controversial and has itself provoked a major backlash in Germany.
</td></tr>
<tr><td>


</td><td>

Cyberattacks and system failures

The current German legislation sets stricter PV requirements for inverters as they are required to meet controls on the amount of power injected in the grid (active power). This allows the Transmission System Operator (TSO) to have some degree of control on assets, as it can require curtailment of PV at a fixed rate of 70% and enforce frequency control, when it rises above 50.5 Hz.

While such measures may enable grid operators to more easily manage the system, they add additional complexity to the installation of rooftop PV and to some extent reduce the consumers’ sense of independence from the grid.
</td></tr>
</table>

Germany is well placed to further strengthen its position of leader in the renewable sector and to become a leading market for distributed solar and storage.

However, even with such high levels of support, the path ahead is still uncertain. The risk of systems failures from unreliable technology could undermine the opportunity for solar and storage. Regulatory reform and new rules could yet be introduced that are unfavourable to distributed systems generally. Finally, if Germany is to become a leading market for solar and storage, it will also have to carry the burden of early-mover disadvantage – and, as in the case of Japan, take the risk of being surpassed by other nations that have learned from its mistakes.

SECTION 11. UNITED STATES ROADMAP

The residential PV market in the US is growing strongly, and Bloomberg New Energy Finance expects that a total of 11.5GW of residential and commercial solar will be installed by the end of 2015. The nation is also a leading market for grid-scale energy storage, with over 420MW of capacity installed at the end of 2014.

BACKGROUND

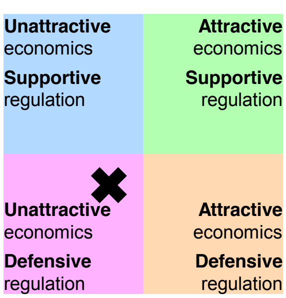
BNEF expects that a total of 11.5GW of residential and commercial solar will be installed by the end of 2015. The rooftop solar market in the US has been supported by two regulatory pillars that have fostered a competitive environment for installers.

- The 30% **investment tax credit** awarded to solar projects represents a direct subsidy paid from federal tax revenues. It applies to large-scale and rooftop solar projects, and has been repeatedly extended. It is currently scheduled to expire by end-2016, which is likely to slow the solar market, in particular for large-scale projects that cannot benefit from net metering.
- A total of 44 states had **net-metering programmes** in place in 2013, allowing consumers to sell surplus power produced by their solar systems, often at the retail electricity tariff. Net-metering dramatically improves the economics of rooftop solar and reduces the need for a battery. Net-metering is criticised by some utilities, who argue that it allows solar system owners to avoid paying the costs of maintaining the grid while benefitting from its availability.

Solar tax credits are tradable and associated with significant paperwork, so many of the leading solar installers also offer to finance and handle the monetisation of the tax credit. Around 70% of residential systems installed in 2014 were leased rather than owned outright, with the lease provider also handling installation and monetisation of the tax credit. Banks and leasing providers are increasingly also offering solar loans, meaning that end-user ownership may soon increase.

The US storage market is driven by state-level mandates and electricity market designs that reward applications such as ancillary services, network and demand charge management, and resiliency. Net-metering policies reduce the attractiveness of residential energy storage in the US. However, there is a growing market for commercial and industrial behind-the-meter energy storage. This is being driven by a combination of building demand-charge management, the need for resiliency and the potential to use aggregated storage systems to provide services to utilities and network operators. Of the 262MW of energy storage that Southern California Edison procured in October 2014, 160MW was for behind-the-meter storage.

Figure 25: United states current scenario verdict

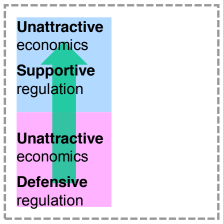
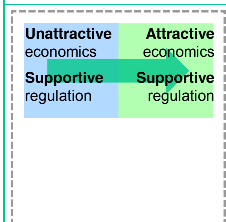
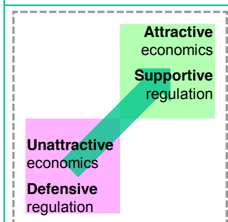


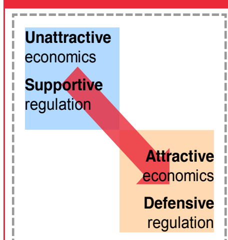
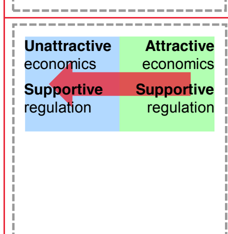
SCENARIO, DRIVERS AND RISKS

The US's recent momentum on end-user PV installations and its leadership in utility-scale storage applications means that it is well placed to take a lead in distributed solar and storage. However, the widely used net metering programmes are likely to be among the biggest stumbling blocks for adding storage to solar, as they force the grid to function as a free, virtual battery.

Given the above, the US is best characterized as having both unattractive economics for PV and storage systems as well as a somewhat unsupportive regulatory framework. However the days of net metering are likely to be numbered, and it is easy to imagine that regulators can shift towards measures designed to support distributed solar and storage just as readily as they have embraced policies such as net-metering that support distributed solar alone.

Table 3: Key drivers and risks for US

Drivers	Description
	***Political desire to support new technologies*** California is leading the way in creating the regulatory framework and incentives to push behind-the-meter energy storage. Besides having mandates for its utilities to procure at least 1.3GW of energy storage by 2020, the state also offers developers funding under the 'Self-Generation Incentive Program' for behind-the-meter storage. Besides such specific measures to support behind-the-meter storage, removing the bias against residential storage that is implicit in net metering programs, without removing the support for distributed generation, would improve regulatory conditions. California is also likely to be a pioneer in this regard, with a stated aim of replacing the net metering regime no later than 1 July 2017.
	***Cheap storage, more storage, even cheaper storage*** Business-model innovation can contribute to improved economics for behind-the-meter solar and storage. Companies such as Stem, Sunverge or Advanced Microgrid Solutions are already running pilot projects in which aggregated customer storage systems provide balancing services and similar. This allows system-owners to benefit from additional streams of revenue that would otherwise be inaccessible. The US is also likely to play a role in future reductions in battery costs, given its support for electric vehicles. Additionally, the country's share of global battery manufacturing should increase with the completion of Tesla's 'Gigafactory', which may lead to cost reductions that benefit the local market directly.
	***Break down of traditional utility model*** The grid in several regions in the US is less reliable than in other developed countries, which is regularly highlighted by extended outages following extreme weather or natural disasters (e.g. Hurricane Sandy). This is encouraging energy storage adoption on two fronts: firstly there is increased availability of grant financing for systems that can provide resiliency, and secondly, individuals and companies place a greater value on backup systems for reliability. The traditional utility business model of centralised fossil power plants has been criticised by some on the left for its environmental damage and by some on the right for restricting freedom of choice. The combination of low reliability, ideological convictions and the American tradition of business innovation means that, in the right circumstances, the US could see a dramatic shift towards distributed solar and storage systems that forces regulatory change.

Risks	Description
	***Controversy and re-regulation*** Supportive policies for increasingly cheap technologies that threaten incumbents can trigger a backlash from those incumbents and lead to the introduction of new barriers. Examples of retaliation against distributed solar have occurred in several US states, most notably Arizona and Hawaii. Both of Arizona's regulated utilities have introduced monthly fixed charges for installed residential rooftop solar, and are lobbying to increase the fee to as much as $18/kW. One of the utilities has also asked to start paying wholesale power market rates for solar power generated under net metering, which is far lower than the residential rates paid previously. Hawaii has moved ahead and replaced net metering while adding a fixed connection charge of $25/month. These examples relate specifically to distributed solar. Distributed solar and storage could trigger a similar reaction.
	***Cheap gas means cheaper options*** The fracking revolution has made natural gas a cheap, abundant and domestic source of flexible power in the US. This allows both utilities as well as industrial facilities to produce energy cheaply, and also offer cheaper power to their customers. Cheaper power prices directly reduce the economic attractiveness of solar and storage. By being both domestic and relatively clean, natural gas is also politically popular. These advantages can pose a unique threat to the acceleration of solar and storage in the US, both individually as well as combined.

The solar and storage market in the US will continue to be fragmented, since most regulation is determined at the state-level and past experiences have shown a wide divergence on policy among states. Key dynamics that will affect the US market more broadly are the presence of domestic battery manufacturing which – like Japan – reduces some of the impact of trade barriers on economics. On the other hand, natural gas is likely to remain cheap in the US for the foreseeable future. A major driver may then be resilience which, coupled with business model innovation, could drive a more dramatic transition towards the uptake of distributed solar and storage.

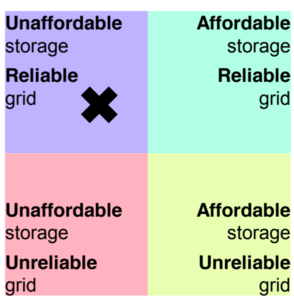
SECTION 12. CHINA ROADMAP

China is currently in the process of drafting its 13th Five-Year Plan and the most recent guidance documents suggest that although there is support for distributed solar, the emphasis for storage is on utility-scale applications that support reliability. If there is a future for rooftop and community solar and storage bundles in China, it will begin in the commercial and industrial sectors, where electricity prices are highest.

BACKGROUND

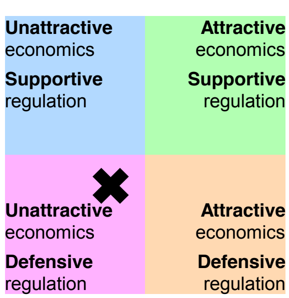
China has the features of both an emerging and mature economy. Average GDP per capita is approximately one eigth of that in Japan and electricity demand is expected to increase by over 250% between now and 2040, driven principally by economic growth (rather than population change). However, its grid, which has been central to decades of economic planning, increasingly resembles that of a mature economy. Although the average minutes lost per customer per year is still high compared to European countries, it is rapidly falling due to ongoing investments by power companies to strengthen and smarten the grid. Reliability differs between rural and urban areas and remains a focus for China's National Energy Administration (NEA), which released the *National Action for the construction of the distribution network (2015-2020)* in July 2015.

Figure 26: China current scenario verdict (emerging market perspective)



China is home to the bulk of the world's PV manfuacturers, with the country accounting for seven out of the top 10 in 2013. By contrast, it is a relatively small player in the storage industry: just three of the top 10 lithium-ion battery manufacturers were Chinese in 2015. With this difference in mind, however, the fact that there is a stronger emphasis on support for solar technologies than storage should not come as a surprise. In 2013, a generation-based subsidy scheme was introduced, offering CNY 0.42 ($0.067) for every kWh of distribution-grid connected PV electricity self-consumed and allowing excess output to be sold to the grid at the price of local desulfurized coal power. This scheme, which is applicable to residential, commercial and industrial users, was updated in September 2014 to include the option of a feed-in-tariff. Returns as high as 14-21% could be achieved in commercial and industrial sectors, where electricity rates are particularly high.

Figure 27: China current scenario verdict (mature market perspective)

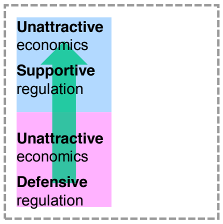
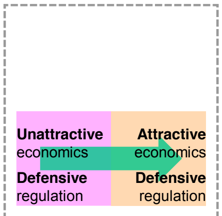


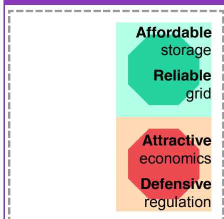
SCENARIO, DRIVERS AND RISKS

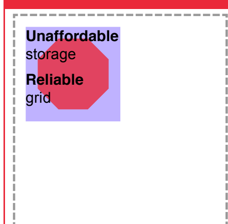
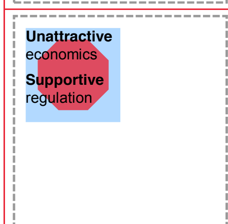
Because China combines features of both mature and emerging economies, the analysis of the country draws on both the mature and emerging markets toolkits. Considering China first as an emerging market, current outage statistics and the policy emphasis on reliability mean that it very clearly fits into the top-left quadrant of unaffordable storage and a reliable grid.

Taking the perspective that China is a mature market, it is fair to say that despite there being some policy support for distributed solar, overall regulation is not favourable for distributed solar and storage. In the rare cases that storage is supported, it is generally for utility-scale applications and economically attractive rooftop solar and storage is some way off.

Table 4: Key drivers and risks for China

Drivers	Description
	***Political desire to support new technologies (mature markets toolkit)*** Since late 2013, the Chinese government has aimed to shift PV deployment from transmission-grid connected (TGC) projects to distribution-grid connected (DGC) installations, to reduce the need for additional investments in the transmission grid. The NEA set an 8GW quota for DGC PV in 2014, which is approximately 10 times the 801MW of rooftop PV connected in 2013. The scope of DGC has also expanded – previously it was limited to rooftop installations but it now includes projects on abandoned land, agricultural greenhouses, intertidal zones, fishponds and lakes. The policy requires grid companies to connect these projects in a timely manner with a service charge of almost zero. While the policy paves the way for rooftop and community solar, future iterations may have provisions for storage.
	***Strong global economy drives storage industry (mature markets toolkit)*** The emergence of a global storage industry with cheaper batteries should coincide with global growth. Although the country does not have a large battery manufacturing industry, a fall in battery prices from non-Chinese manufacturers should also coincide with strong growth in China's commercial and industrial sectors. This is significant because China's commercial and industrial users pay approximately three times more for electricity than residential users. The economic case for end-user solar and storage is likely to be strong in the commercial and industrial sector in China long-before it is in the residential sector – particularly if there is significant growth of economic output.

Risk/Driver	Description
	***Solar and storage is the new normal (emerging markets toolkit) and*** ***Electric vehicles need a strong utility (mature markets toolkit)*** China is currently in the process of drafting its 13th Five-Year Plan for the energy-storage industry. Previously the government has placed a high value on grid reliability. With future economic growth in mind and plans to dramatically increase uptake of electric vehicles there is little reason to see this position change. The *Guidance to Promote the Development of the Smart Grid*, released in July 2015, encourages a certain percentage of energy storage for integration with wind farms and solar plants. This could see a dramatic increase in the uptake of storage, but its impact would be limited to the utility scale.

Risks	Description
	***The grid is the only game in town (emerging markets toolkit)*** The government appears to be in favour of storage technologies that are inherently utility-scale. In September 2015, State Grid announced that it will invest $3.9bn for 30GW of pumped storage capacity during the 13th five-year plan, which would bring cumulative capacity to 70GW. Policy makers are also said to see redox flow batteries as a key technology for grid-scale storage applications. At the non-utlity level, the NEA's *Guidance to Promote the Construction of New Energy Microgrid Demonstration Projects* was released in August 2015 and includes storage as a supporting technology. Although expected to, the guidance does not recommend a subsidy for microgrids.
	***Global industry fails to emerge (mature markets toolkit)*** Despite government support for 'new energy vehicles' China is not a strong global player in the EV lithium-ion batteries industry, with BYD being the main domestic manufacturer of note. Therefore improvements in battery economics is largely dependent on external factors. To address the issue of old EV batteries (and perhaps to also drive down the cost of storage), there have been efforts to explore the possibility of recycling EV batteries for stationary energy storage. However a collaboration between General Motors and State Grid emphasised the challenges posed by a lack of battery standardization which has held these efforts back, particularly when attempting to aggregate to the utility scale.

While the opportunity for distributed solar is increasing, storage is limited to utility-scale applications

Historically, policy in China has favoured centralised generation with reliability the most important measure of success. While the tide appears to be turning in terms of solar, with incentives to shift away from large transmission-level installations to those connected to the distribution-grid, support for storage favours utility-scale technologies and applications. This may be due in part to there being less support for lithium-ion batteries, which are well suited for distributed applications. It could also reflect the relative lack of a domestic industry in that technology.

If regulation does shift to favour distributed storage then the expectation would be that the initial market would be in the commercial and industrial sectors, where grid tariffs are highest and thus economic attractiveness of solar and storage is highest.

SECTION 13. INDIA ROADMAP

For the next 25 years India is expected to have the highest absolute electricity-demand growth of any country in the world, driven by a combination of electrification and population growth. This poses a number of challenges, both technical and environmental. However, the country's high insolation and existing market for backup storage systems means that solar and storage could be an important part of a low-emissions strategy for the country.

As part of Prime Minister Modi's 100% electrification target by 2022, the government has increased its renewables target, which includes 40GW of rooftop solar

BACKGROUND

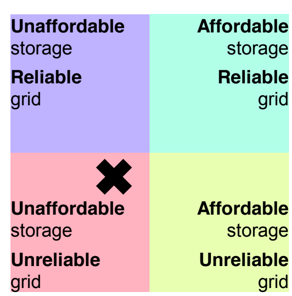
India is home to 1.3bn people and is projected to become the world's most populous country by 2026, according to the World Bank. Around a quarter of the existing population is not connected to the grid and the government wants to achieve full electrification by the early 2020s. India's current power consumption of 936kWh per capita is lower than other large economies, but this is expected to increase with growth of the commercial and industrial sectors and as use and uptake of electrical appliances increases in homes.

India intends to add 100GW of solar power by 2022 (up from the 4.9GW at the end of October 2015). The solar target also includes an ambition to do 40GW of rooftop solar. At the moment, ground-mounted large scale (>1MW) projects contribute 94% of the installed solar capacity.

The low growth in the residential rooftop segment in particular is due to the high cost of storage, which prohibits the use of these systems as a back-up power source during power cuts. This consumer segment also pays lower electricity tariffs than industrial or commercial consumers and hence they may not see a significant immediate gain from reduction in their electricity bills. Another bottleneck in the growth of rooftop solar is the lack of standard loan products or SolarCity-like business models for the residential segment.

Many major states in India have formulated feed-in tariff or net-metering policies to support growth of rooftop solar. There is, however, little effort being put to promote storage solutions. The Ministry of New & Renewable Energy has recently launched an Expression of Interest to support demonstration storage projects for rural applications, microgrids and large-scale grid-connected renewable energy projects. But the first set of these projects are not expected to be commissioned before 2017.

Figure 28: India current scenario verdict



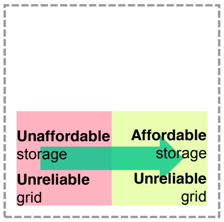
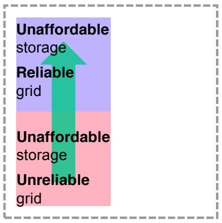
SCENARIO, DRIVERS AND RISKS

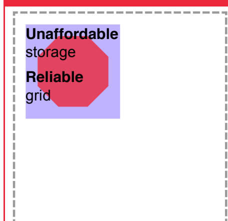
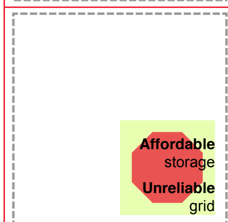
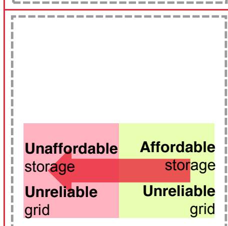
While India has already achieved some of the lowest utility-scale solar costs anywhere in the world, rooftop installations are still at a nascent stage. Artificially low retail power prices hinder the uptake of small-scale PV in India for the time being, with just 281MW of such installations by September 2015. While lead-acid storage system costs are relatively low, once combined with rooftop PV installations the resulting levelised cost of electricity is not low enough to make a proposition affordable for most.

India's grid – particularly on the distribution level – is highly unreliable due to a lack of investment relative to demand growth. The majority of India's state-owned DISCOMs (utilities responsible for distribution and retail) are currently insolvent due to policy decisions such as below-cost tariff rates and acculumated losses over a long period of time.

As a result of these factors India is best characterized by the lower left scenario of unaffordable storage and unreliable grid.

Table 5: Key drivers and risks for India

Drivers	Description
	***Cheap batteries and new business models drive consumer choice*** In urban areas with patchy grid supply, many residential electricity consumers already use lead-acid battery based energy storage systems. The backup power supply industry has also established supply chain in the country and can support further technology development. The existing supply-chain combined with India's market size and entrpreneural spirit may very well accelerate cost reduction for storage faster than other markets.
	***Political stability, economic stability means grid stability*** In May 2015 prime minister Narendra Modi's political party became the first in the past 30 years to acheive an absolute majority. His government has increased targets for renewable energy substantially and is working on improving regulations. This includes steps to unbundle utilities into carrier and retail arms, with the intention to increase competition and service quality on the retail side and infrastructure development and operation on the distribution side. The most important and challenging reform, however, is the reduction of subsidies offered to low-income consumers which would translate into improved power sector finances. The Ministry of Power is also to provide soft loans to DISCOMs to improve grid infrastructure and part of these can be converted to grants if specific targets are met.

Risks	Description
	***The grid is the only game in town*** One of the election promises of the current government is universal access to uninterrupted electricity, which has resulted in programs to extend the grid to all villages in India. While the grid is currently not reliable enough to provide round the clock stable power to all, India has sufficient domestic coal resources for full electrification over several hundred years. Without careful policy coordination, investment may favour centralised coal power plants only, resulting in a reliable grid with relatively cheap electricity tariff rates, limiting economic attractiveness of rooftop PV and storage and other low-carbon solutions.
	***Distributed energy drives economy as opportunity for grid fades away*** Without sufficient grid investment India's cities could face power cuts while millions of people still do not have access to the grid. The government and utility reaction is slow to make improvements there could be time for distributed solar and storage to gain enough traction to become the most relied on source of electriicty. The commercial and industrial rooftop solar market is starting to show promise as retail electricity prices in this segment are high. New business models are also emerging in the rural microgrids and offgrid solution space. With a growth in the economic activity in these areas and a rise in income levels, solar PV and storage solutions can see a rise in penetration levels.
	***The bubble bursts*** Given the relatively low upfront cost of lead-acid batteries, falling rooftop PV costs and India's current poor grid reliability, it is plausible that PV combined with lead-acid based storage systems will become rapidly economical and achieve significant uptake. However shorter lifetime performance of most common types of lead-acid batteries could result in failure of those installed systems. This may then result in the need for more expensive lithium-ion batteries and a slow-down in the market as well as a large number of poorly functioning distributed systems based on outdated technology.

India will have to be careful with the quality of the systems that get installed initially to avoid future market failure

India is well-placed to not only be one of the pioneers of electrification based on rooftop PV and storage, but to also become a major player globally based on market experience developed domestically. However, without the right supporting framework, India could develop a centralised coal-based infrastructure that would be difficult to displace.

To ensure the rooftop PV and storage market flourishes, India's policy makers need to implement supporting policies and coordinate their actions. Specifically, the central and state level government should consider policy frameworks that enable profitable and sustainable business models. For example, they could consider allowing the state-owned DISCOMs as well as national players such as NTPC, India's largest utility, to co-invest in rooftop PV and storage along with private entities based on regulated rate of returns that are passed on to consumers. The government should also consider setting quality standards as well as warranty and service requirements that would entail long-term commitment to the Indian market by any entity.

SECTION 14. BARRIERS

By running a scenario exercise, developing a roadmap toolkit and applying it to a selection of countries we have gained insight into a number of different pathways for the increased uptake of distributed solar and storage. The advantage of this approach is that not just the immediate next steps are considered, but also subsequent developments and risks. There are barriers common to more than one pathway and country, with different timeframes for their impact.

Across the roadmap analysis, there were six barriers that stood out. They are listed in the table below, ranked in order of importance. More details are given in the subsequent subsections.

Table 6: Summary of major barriers for distributed solar and storage

Barrier and rank	Examples	Contributing factors	Short-term impact	Long-term impact
1. Storage costs	• In southern California, storage has negative NPV unless utility rates are above ¢30/kWh • For storage not to be a bottleneck, costs must decrease from ~$1,000/kWh to ~$600/kWh • For 'grid independence' household storage systems costs are $19,000-$33,000	• Lack of industry scale • Installation costs • Technological complexity • Challenge of predicting future costs	High	High
2. Policy and regulation	• Restrictive connection codes (e.g. Hawaii) • Lack of market structure for non-utilities • Self-consumption tax (e.g. Germany/Austria) • Net-metering (barrier for storage only) • Fossil fuel-based electricifcation policies	• Regulatory inertia • Concerns over grid impact of distributed systems • Desire to avoid utility bankruptcy	Medium	High
3. Cheap alternatives to solar and storage	• Discovery of cheap natural gas • Pumped hydro storage • Demand response • Hydrogen technologies (ie power to gas)	• Open markets • High energy prices driving business model innovation • Technology breakthroughs in alternative tech • Fuel cell vehicles	Medium	High
4. Quality and safety issues	• Swedish heat pump market set back a number of years through poor quality installations • Sodium sulphur technology suffered lasting reputational damage after battery fire	• Rapid uptake of new technologies • Bias towards oversizing systems • Lack of accreditation • First-mover disadvantage	High	Low
5. Trade barriers	• Import and export duties • Conflicting technology standards • International sanctions	• Desire to develop technology expertise locally • Recession brings need to develop industries and safeguard local jobs • Geopolitical tensions	Medium	Medium
6. Challenges of distributed resource integration	• Grid failure due to inexperience in relying on a large number of distributed systems • Cyberattacks routed through systems for managing distributed resources	• Rapid uptake of new technologies • First-mover disadvantage • Vested interests exaggerating negative impacts/blame distributed energy	Low	Medium

14.1. STORAGE COSTS

Even where market conditions are favourable to distributed solar and storage, the cost of storage systems remains the barrier. While this can be overcome with the help of subsidies, in the long run the technology will need to be cheap enough for solar and storage systems to be economically viable in their own right.

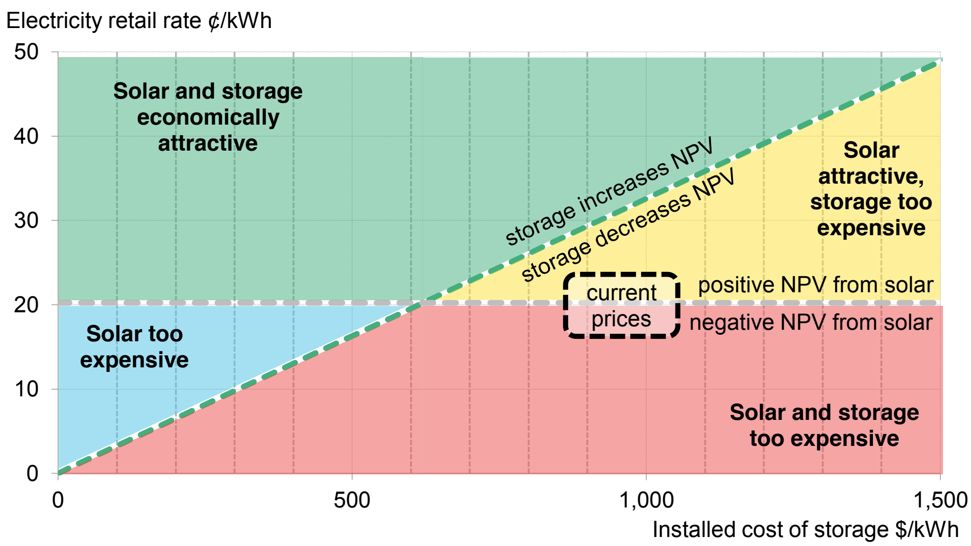
EXAMPLES

The relative sizing between a solar and storage system depends on the use case – whether the objective is to reduce dependence on the utility financially, or to gain independence from the utility completely. In either case storage would need to be significantly cheaper than it is currently for either to be attractive.

Solar and storage as a financial investment

Using a southern California home as an example and assuming no net-metering, Bloomberg New Energy Finance calculations[39] show that a storage system with installed costs of $1,000/kWh **only adds value to a rooftop PV system if retail rates are above 30¢/kWh**. Current residential rates in California are around 20¢/kWh. As figure 27 shows for our example household, solar is just about economically viable even without net-metering. For a combined solar and storage system **it is the cost of storage that is the limiting factor and will be until costs fall below $600/kWh** at which point solar is the limiting factor (though this assumes that the installed cost of solar does not decrease, which is unlikely). While Tesla is currently marketing a suitable battery at $430/kWh in reality the *installed cost* is more likely to be around $875/kWh at the least. Many estimates of installed costs are closer to $1,500/kWh.

Figure 29: Overview of options maximising system NPV for rooftop solar and storage system in southern California household (no net-metering)



Source: Bloomberg New Energy Finance. Note: Household is located in southern California, has an annual demand of 10MWh, a 4kW PV array, a 4kWh battery and flat retail rates (not time of use).

To reduce utility bills, a household with annual consumption of 10MWh/yr might typically install a 4kW PV system with a 4kWh battery. In such a case the installed costs of the PV system, including inverter, would be around $12,000 while the battery is $3,500-$6,000. This might give the impression that the cost of PV, rather than storage, is the barrier, but this is not true for three reasons:

1. Although cheaper, the addition of storage is reducing the overall NPV of the system.

[39] Bloomberg New Energy Finance (Brian Warshay), "US residential PV+storage: case against grid defection", 13 March 2015. URL: https://www.bnef.com/Insight/11721 (paywall)

2. The value that the battery brings is independent of the cost of the rooftop system.
3. Future cost reductions for energy storage at this scale are relatively uncertain – large lithium-ion batteries have cost-trends that span years, compared to decades for PV experience curves.

Solar and storage as a means to reduce grid dependence

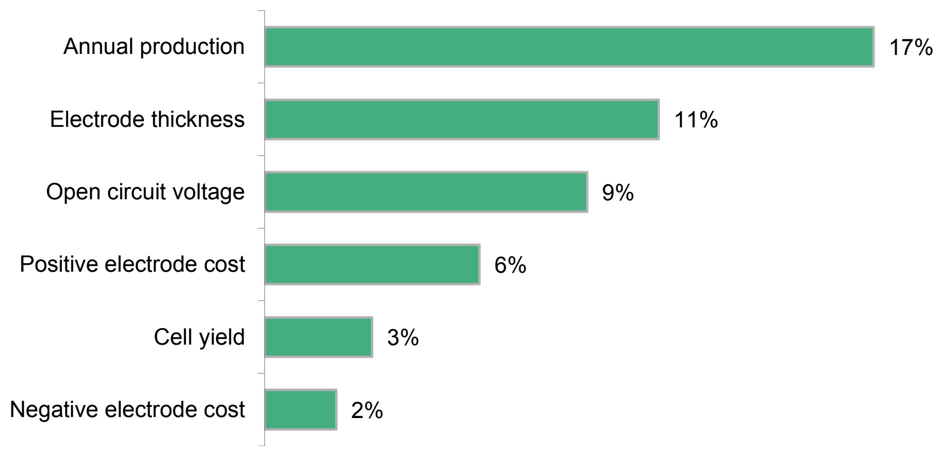
If the objective is to achieve essentially complete grid independence then storage costs have an even more significant impact because of the need to oversize a system for the days of the year with highest consumption. For an annual consumption of 10MWh, Bloomberg New Energy Finance estimates that the example Southern Californian household would need 16kW of PV accompanied by 22kWh of storage to make it through the longest period without sufficient sunshine that can reasonably be expected. At current prices this equates to $48,000 of PV and $19,000-$33,000 for the storage system as an initial investment.

Clearly **this is not affordable for most households**. Although complete grid independence is an extreme example and partial independence is a more realistic goal, it illustrates the potential for costs to climb in non-economic applications.

CONTRIBUTING FACTORS

Figure 30 summarises the findings of a sensitivity analysis run using Argonne National Laboratories BATPAC model, there is significant potential for the reduction of lithium-ion battery costs from a number of variables.

Figure 30: Sensitivity of lithium-ion battery costs to changes of individual variables



Source: Argonne National Laboratories, Bloomberg New Energy Finance

The cost reduction of 17% for annual production is based on an assumption of economies of scale associated with increasing production from 30,000 to 500,000 units. This demonstrates the benefit of a non-fragmented industry that can leverage these economies of scale. This is much more likely to occur in a globalized storage industry that can benefit from low trade barriers (which are discussed further below) rather than a fragmented industry only serving select markets.

In addition to these battery-level cost estimates, it is important to examine the system-level costs. At present installation and balance-of-system costs contribute 50% of the cost of a fully installed system. For the rooftop solar industry, the equivalent costs fell as a result of installer experience and competition as the market grew. Since distributed solar and storage is currently a relatively small market, these costs have not yet been driven down for storage.

IMPACT

At present prices and in most situations distributed solar and storage is not as attractive economically as distributed solar alone, so it is essential for storage costs to decrease if it is to be widely adopted on an economic basis. Where the application is grid independence batteries are currently unaffordable for all a but a few. Therefore storage costs have a high impact in the short term.

While storage and solar costs are both expected to decrease over the course of the coming decades, historical learning rates suggest that battery costs will fall slower than those of photovoltaics. Even if cheaper than today, the storage component of a combined solar and storage system is likely to account for a higher proportion of the total system cost in the future. It may be that the storage industry's relatively small size at present will allow cumulative output to double more rapidly than for solar and enable costs to fall more quickly. However it is still possible that storage costs will have a high impact in the long term.

14.2. POLICY AND REGULATION

The impact of regulation has been a central part of the analysis presented in this work, and so naturally it appears high on the list of barriers that need to be addressed for the distriubuted solar and storage to reach its full potential.

EXAMPLES

Regulation can be a barrier to the uptake of distributed solar and storage in a variety of ways. Many regulatory regimes reflect a traditional framework built around the assumption of large-scale centralised generation – this includes **restrictive connection codes** for new generation in competitive markets, or in vertically integrated markets the **lack of a market structure for non-utilities to monetise distributed generation**. Other regulatory barriers are those introduced explicitly to reduce uptake of distributed generation systems. In Germany and Austria the introduction of a **self-consumption tax** reduces the financial benefit of owning rooftop PV and storage. Italy and Spain are discussing the introduction of similar measures. Similarly, in Arizona **connection charges** have been introduced for owners of grid-connected solar systems.

Net-metering has a fairly nuanced status – it improves the economics of owning a rooftop solar system but significantly reduces the incentive to add a storage system. If the economics of distributed solar and storage are not attractive this is a moot point, since cost is a much more significant barrier.

CONTRIBUTING FACTORS

There are a number of factors that lead to the maintenance and introduction of policies and regulation that blocks the growth of distributed solar and storage.

On a very fundamental there is an inherent **inertia** to introducing new frameworks, especially when compared to the pace of technology change. Energy regulation is a complex field with a wide variety of factors – economic, technological, social, environmental, political and legal – to be taken into consideration, which slows the process of change. For example, the genesis of Japan's forthcoming energy market liberalisation can be traced back to the earthquake of March 2011. The new rules will come into force in April 2016, over half a decade later. During that period the cost of solar modules has fallen by more than 50%.

The other major factor that contributes to the introduction and maintenance of regulatory barriers to distributed solar and storage is **concerns over the impact on incumbent utilities**, whether they are technical, operational and financial. The withdrawal of net-metering in Hawaii is an example of how such fears can lead to changes in regulation that are unfavourable to distributed systems. There the incumbent utility HECO, 16% of whose customers have net metered rooftop solar, argued to the regulator that such systems were creating a number of challenges that jeopordised grid reliability. Opponents have claimed that such concerns are exaggerated and are instead intended to justify delaying new systems from being connected to the grid.

IMPACT

Examples from Germany and Hawaii show that utility barriers already have a significant impact on the uptake distributed solar. However, even with these regulatory barriers removed the distributed solar and storage needs to be economically viable to have an impact. Therefore regulatory barriers have a medium impact in the short term.

Assuming that the cost of storage will continue to decrease then regulation will become the major barrier to the uptake of solar and storage systems in the same way that regulation is currently a barrier to distributed solar in many markets. Therefore regulatory barriers have a high impact in the long term.

14.3. CHEAPER ALTERNATIVES TO SOLAR AND STORAGE

It goes without saying that solar and storage – whether individually or in combination – are not the only option to meet future electricity needs. Indeed it is very unlikely that solar and storage will be adequate on their own. However, alternative solutions could reduce the future opportunity for distributed solar and storage – and in some cases this could lock-in high-emission centralised options to the detriment of the environment.

EXAMPLES

Figure 31: Floating solar installation in Japan

Source: Bloomberg

Natural gas accounts for 43% and 29% of generation in Japan and the US respectively, but less than 4% in India and 2% in China. It has several advantages as a generation fuel – it can be stored, it is suitable for dynamic use in peaking applications and, where a gas grid exists, can also power distributed generation systems such as microturbines and fuel cells. While it is not a clean fuel, its emission intensity is lower than that of coal, which means that it is often – whether rightly or wrongly – supported from an environmental perspective. All of these factors mean that cheap natural gas can undermine the case for distributed solar and storage in more than one way.

A high penetration of centralised **pumped hydro storage** could – on a system level – reduce the need to add storage to solar by allowing the grid to act as a battery for intermittent renewables. This would be reflected in electricity pricing regimes that do not incentivise storage. Recent stories of floating solar being added to hydropower reservoirs are also interesting. For example in April 2015 it was announced that the 250MW Balbina dam in Brazil would have 350MW of floating solar added as part of a government-supported pilot project. This direct integration of pumped hydro storage with PV could mean an increase in centralised solar generation.

Similarly **demand response** and **power-to-gas** would not diminish the opportunity for solar, but they would reduce or eliminate the need for accompanying storage systems by offering an aggregated or centralised alternative – which would also be reflected in pricing regimes available to owners of distributed solar.

CONTRIBUTING FACTORS

There are a number of contributing factors that apply across more than one of these alternatives to solar and storage.

Figure 32: A Nest smart thermostat

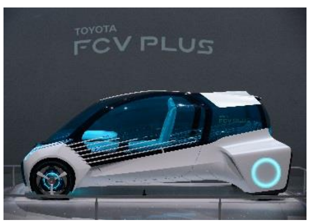
Source: Bloomberg

Technological breakthroughs can improve the economics of competing alternatives. For instance, the development of fracking and horizontal drilling techniques have led to a substantial decrease of gas prices in the US – these techniques may be applied elsewhere to similar effect. The development of smart thermostats is also an example where technology could change the economics of an alternative solution – in this case by enabling higher penetration of automated demand response.

Generally speaking, **open markets**, while enabling solar and storage, also enable competitive alternatives. The PJM capacity markets, for example, have enabled substantial uptake of demand response (the latest four-year ahead auctions saw more than 11GW contracted). At the same time, **high energy prices drive business-model innovation** as was the case with the emergence of the ESCO business model in Texas in the 1970s. Of course, new business models could work in favour of solar and storage, but they may also enable competing alternatives.

In the case of power-to-gas, the major contributing factor would be the development of economically viable hydrogen **fuel cell vehicles**, which at present are less competitive than electric vehicles but have been the subject of significant research, particularly in Japan.

Figure 33: A Toyota concept fuel cell vehicle



Source: Bloomberg

There are also factors that apply to alternative solutions locally. The opportunity for pumped hydro storage is highly dependent on local geography, as is the supply of natural gas. Whether demand response is viable depends on local demand profiles. This means that in certain locations solar and storage will certaintly not be the most competitive solution – however, its principal advantage is that it is more broadly applicable than the majority of these alternatives.

IMPACT

At present distributed solar and storage is one of a number of promising options that could significantly impact the future of energy. However there is no option so obviously superior that support for solar and storage will be withdrawn. Therefore the current impact of alternatives can be described as moderate.

In the long run, certain technologies or business models will either develop faster than solar and storage and win out entirely or be undercut as PV and battery costs fall. A risk could be that before that time arrives, infrastructure is developed around a centralised solution that then prevents the uptake of distributed solar and storage. Therefore the cheap alternatives to solar and storage could be a significant long-term barrier.

14.4. QUALITY AND SAFETY ISSUES

There is no future in solar and storage if systems underperform or, even worse, are unsafe. Assuming that distributed solar and storage can deliver high performance safely, then the issue of quality and safety becomes one of protecting consumers from substandard installations and ensuring that avoidable issues do not hamper or even kill the development of the sector.

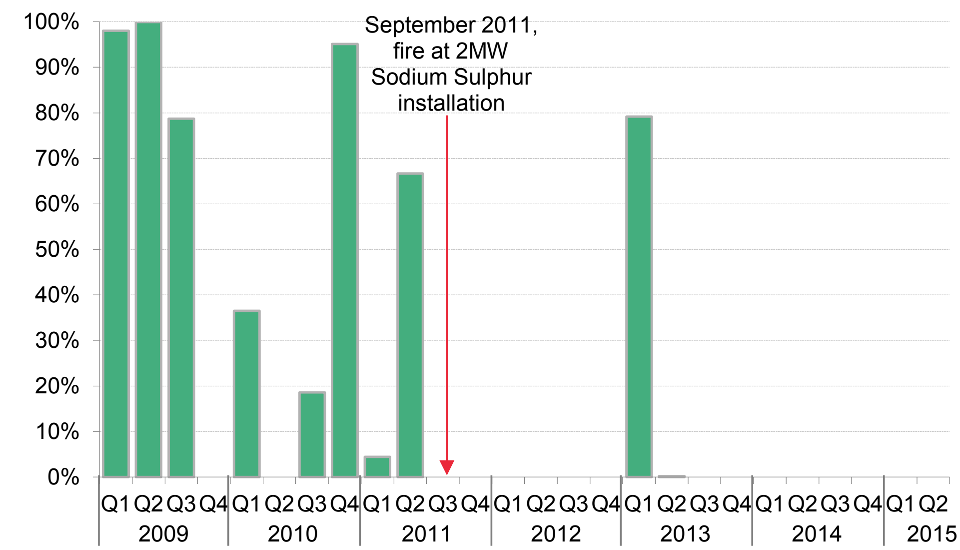
EXAMPLES

As a technology choice, distributed solar and storage bears several similarities to heat pumps. Both are substantial investments intended to reduce utility bills and require skilled installation at a building or home. The **Swedish heat pump market** is one of the world's most developed, but its growth was hampered by reputational issues stemming from poor quality installations. Heat pumps received considerable government R&D funding in the wake of the 1974 energy crisis and by the early 1980s the market had started to gain popularity. By 1985 a total of 50,000 units had

Quality issues with early installations set the Swedish heat pump market back by about a decade

been installed, with a boom driven by a combination of subsidies and high energy prices[40]. However, during this period the technology gained a poor reputation due to low quality and poorly sized systems. For the next ten years sales averaged around 2,000 units per year and it was not until the early 2000s that the market began to pick up again – partially as a result of new government subsidies but also because of the formation of a national heat pump association by the industry in order to set and maintain standards for quality for both technology and installers. While heat pump penetration in Sweden is among the hightest in the world, the initial issues relating to quality set the industry back by around a decade.

Figure 34: Sodium sulphur batteries as a % of MW utility-scale storage project announcements, 2009-15



Source: Bloomberg New Energy Finance

Safety is potentially a major barrier, particularly if batteries are to be situated inside buildings. A **fire at a 2MW sodium sulphur installation** in 2011 led to the manufacturer NGK Insulator voluntarily suspending their sodium sulphur battery operations. A subsequent investigation found that the fire was caused by a single defective cell that led to a domino effect but that there was no issue inherent to the technology. Both the defect and the subsequent domino effect could have been avoided with stricter quality control and the addition of firewalls. However this did not limit the damage to the technology's reputation – as Figure 34 illustrates, the fire represented a watershed moment for sodium sulphur technology with it going from a dominant choice in the nascent utility-scale storage market to almost zero activity since.

CONTRIBUTING FACTORS

Technology vendors and installers are naturally biased towards oversizing systems

The two examples highlighted above are both inherent to new technologies where there is limited experience and skills to meet a **rapid growth in demand**. Similarly to heat pumps, solar and storage combinations should be sized correctly, however this is not necessarily in the best interests of the vendor or installer, who will naturally be **biased towards selling the largest system possible**. This is exacerbated if there is a **lack of accreditation**. Some issues, however, are difficult to predict, and the issues experienced by NGK Insulator with sodium sulphur batteries are an example of **first-mover disadvantage**.

[40] J. Lund, B. Sanner, L. Rybach, R. Curtis, G. Hellström, "Geothermal (ground-source) heat pumps: a world overview", 2004. URL: https://pure.ltu.se/portal/files/2200656/art1.pdf

IMPACT

The examples provided both relate to nascent markets and can be broadly characterised as ‘teething problems’. Therefore their short-term impact will be high in the specific markets where issues arise, but in the long-run one would expect problems to be resolved (as was the case with heat pumps in Sweden) and thus quality and safety issues should be of limited importance in the long-term as the market matures.

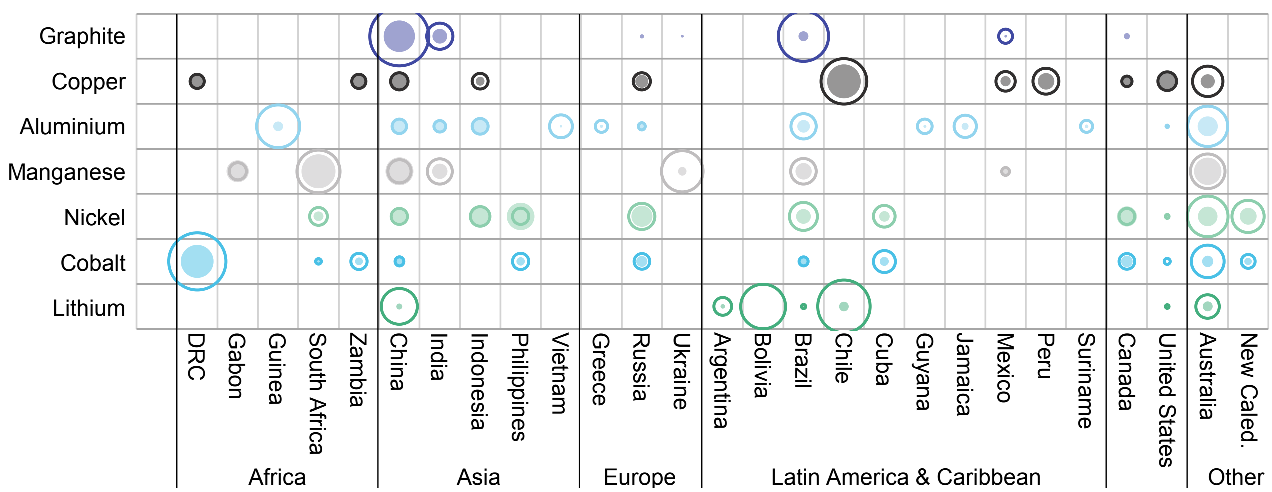
14.5. TRADE BARRIERS

As discussed in Section 14.1, trade barriers could lead to a fragmented storage industry that does not fully benefit from economies of scale, which would hamper the development of the market for distributed solar and storage as well as related technologies such as electric vehicles.

EXAMPLES

There are numerous examples of financial barriers on international trade. Most obviously this can mean **import and export tariffs** but common examples are import quotas and subsidies for **domestic** industry, which can all distort the development of emerging industries. For example, the subsidisation – at a city level – of upstream LED manufacturing in China in 2009-10 led to severe global overcapacity and financial difficulties for many Taiwanese manufacturers in the subsequent two years. It is not difficult to foresee similar scenarios for storage.

Figure 35: Production and reserves of critical materials for NMC lithium-ion batteries in selected countries



Source: US Geological Survey, Bloomberg New Energy Finance. Note: Area of hollow rings represent reserves as a proportion of known global reserves, shaded area represents annual extraction x 20 as a proportion of known global reserves. DRC stands for Democratic Republic of Congo, New Caled. stands for New Caldedonia.

There are also non-financial barriers, such as **conflicting technology standards** and accreditations intended to lock out competition from foreign rivals. A very obvious example where this has had an impact is in the electricity sector where, at the grid-level conflicting frequencies and voltage levels are the consequence of historical differences in technology standards, as are the different plugs and sockets seen throughout the world. Differences in how solar and storage systems should be integrated with buildings and grids could have a similar impact.

In the most extreme cases, **international sanctions** could hold back the industry. While this may appear far-fetched, a battery consists of a diverse range of specialist materials sourced from around the world (Figure 35), and a shortage in any one of these could also prove disruptive.

CONTRIBUTING FACTORS

While economists generally agree that trade barriers are a source of economic inefficiency, there are a number of reasons that they can arise. An obvious example is the **desire to develop technology expertise locally**, particularly if the technology is of strategic importance (as could be the case for both solar and storage). Economic **recession** can also lead to political pressure to reduce foreign imports to protect local jobs. **Regional or global tensions** could also be a motivating factor behind the introduction of trade barriers.

IMPACT

Trade barriers could limit the extent to which the storage industry will scale and push down costs. Having said that both Japan and the US have domestic battery manufacturing and are set to be important early markets for distributed solar and storage, meaning that some progress can still be made even if international trade slows. Therefore the impact of trade barriers could be moderate in both the short-term and long-term.

14.6. CHALLENGES OF DISTRIBUTED RESOURCE INTEGRATION

Distributed resource integration is an umbrella term that captures the broad range of issues that could arise in adding and effectively managing significant volumes of distributed solar and storage on the network.

EXAMPLES

By their nature these are issues that are difficult to predict without existing examples of grids with high penetrations of distributed solar and storage. While the nature of some problems is clear, some are the ‘unknown unknowns’ associated with any pioneering system. This may be the result of software reacting unexpectedly to utility signals, cascading technical failures or difficulties associated with microgrids islanding and re-connecting with insufficient warning.

One issue that may arise is that of **cybersecurity**. If well integrated a distributed system should be more resilient than a centralized one – as is the case with the world wide web. However if poorly integrated distributed resources could provide numerous points of entry to a grid management system, leading to increased vulnerability from cyberattack. Reselience is a potential driver of distributed solar and storage, but if cybersecurity issues arise resilience may also be used as an argument for restricting the integration of the technology.

CONTRIBUTING FACTORS

The challenges described arise from **a rapid uptake in new technologies** coupled with inexperience in operating a system based around these technologies. As with the quality and safety issues, this is an example of **first-mover disadvantage**.

It is also worth recognising that if there are issues associated with grid integration of solar and storage, they truly become barriers if scaremongering and **exaggeration of negative impacts** by vested interests result in a change in policy or regulation.

IMPACT

These issues are less relevant if the penetration of solar and storage on the grid is small and they therefore have a low short-term impact. As penetration increases, challenges of distributed resource integration could become a barrier in those markets that are facing these challenges first. Slower-moving markets will probably have sufficient experience to cope with whatever problems may arise. Therefore the long-term importance of this barrier is medium.

SECTION 15. RECOMMENDATIONS

The barriers outlined in the previous section hold valuable lessons for policy-makers, regulators and businesses keen to maximise the benefits of distributed solar and storage. This section recommends strategies for overcoming those barriers.

15.1. BUSINESS STRATEGIES

Several business strategies can help reduce costs and build the foundation for a growing industry. They include:

- **Create manufacturing scale:** An important part of the successful cost reductions in PV was the technological convergence towards c-Si cells and the modular nature of the technology, which allowed a rapid learning curve as the same process is repeated millions of times. Repeating this will be more difficult for storage due to competing Li-ion technologies, but it is likely a key to achieve rapid cost reductions.
- **Pursue synergies with the EV industry:** Closely related to cost reductions from manufacturing scale is the strong link of storage with battery-powered EVs. Because both are applications for very similar if not identical battery packs, both represent a demand centre for the same manufacturers. Creating strong EV markets is therefore likely to boost economies of scale and reduce battery costs, creating a self-reinforcing cycle.
- **Encourage start-ups to experiment with different business models.** Residential and community-level solar and storage are retail and service businesses. The same technology provides a different service to the consumer in different circumstances – a financial return, a crucial back-up from an unreliable grid, a lifestyle statement, or just a back-up for a stormy day. It is not yet clear how the technology will be installed, owned, financed, delivered, and how it will fill its owners pockets. Experience shows that start-ups often play an important role in figuring out how best to answer all the questions above.

15.2. POLICY AND REGULATORY STRATEGIES

Policy and regulation is important to create a level playing field that allows solar and storage to profitably scale. Interventions in this area could include:

- **Reform electricity markets to support distributed generation**: Distributed generation is generally not owned by utilities. In many jurisdictions, utilities are now arguing that distributed solar is subsidised competition undermining their profits. Distributed solar and storage in combination is likely to intensify this conflict, as it allows customers to further reduce payments to the utility while keeping the grid as a valuable back-up option. Regulatory frameworks that mitigate these conflicts will be important in the years ahead. New York State's Reforming the Energy Vision is an especially interesting approach to addressing these issues.
- **Reform electricity markets to fully compensate storage:** Storage provides a variety of services, such as back-up resource in case of blackouts, renewables integration, grid balancing, frequency regulation and demand response. Distributed solar and storage, combined with the right business models, can provide all of these. However markets and mechanisms for providing compensation for storage services are underdeveloped in many jurisdictions.

- **Fine-tune regulation to incentivise solar and storage in combination:** The net metering programmes that have proven popular in the US act as an accelerator for small-scale PV, but reduce the incentive to add storage capacity to the system by guaranteeing purchase of any excess electricity at favourable rates. Smart policies designed to boost solar and storage should support the package rather than the components. Storage could, for instance, be incentivised through a discount on fixed grid charges for residential solar owners, if they exist.
- **Invest in R&D:** R&D is essential to enable industry to realize continuous cost reductions into the future. Cooperative programs that partner industry, academia, and government research are the most likely to result in new technologies that successfully enter the market. Given the number and complexity of publicly funded research programs in various countries (as described in part in Section 4), it is vital that these research efforts are coordinated, with targets harmonized and results shared as much as possible. It is also imperative for R&D policy-makers to deeply understand the current market dynamics and state of the technology, in order to make public R&D programs maximally relevant.
- **Where grids are unreliable, nudge users from grid-powered storage towards solar-powered storage:** Emerging economies without a reliable grid suffer from the opposite problem of net metering. Residential storage that is charged with grid electricity is likely to be more affordable than a combined system with solar, and solves the customers' immediate problem of power outages effectively. Regulators therefore should consider ways to incentivise adding solar to the system.
- **Reduce diesel subsidies.** Ending artificially low fuel prices for the most obvious competitor to solar and storage in the context of unreliable grids would allow a fair comparison between the costs of grid-supplied electricity and a solar-with-storage system.
- **Define standards for quality:** Underperforming systems **could chill consumer and investor interest in distributed solar and storage,** While quality concerns may be mitigated by business models that bundle the product with a financing solution or maintain ownership with the service provider rather than end-consumer, minimum quality standards could help promote rapid adoption..
- **…and safety:** There are already concerns that many storage systems eligible under Germany's incentive programme may be at risk of catching fire. The best economics and reward systems are unlikely to convince consumers to install batteries if they put their houses at risk. The reputational damage even of rare incidents may be sufficient to slow down technology adoption substantially. Both regulators and the industry should agree on and enforce stringent safety standards.
- **Reduce or eliminate trade barriers**: At present, the batteries required to store solar power are mainly produced in Korea, Japan and China.. This concentration means that in many places, solar and storage equipment is either mainly imported or will at the very least compete with imported products. Keeping trade barriers low will therefore increase competition, reduce costs and should lead to a broader uptake of the technology.

15.3. OTHER STRATEGIES

Other strategies include:

- **Education and training:** Selling, installing and maintaining solar and storage systems will require a skilled work force that considers distributed technologies a natural part of the power system. Once trained, such workers can also contribute to the positive perception of the industry. Creating appropriate training courses is in the interest of both the industry and the regulator.

- **Leverage the local context**: The same solar and storage combination will be popular for different reasons in different places. Environmentalists may see it as a cure for climate change, central-government sceptics as a monopoly breaker, community leaders as an important local asset, and emerging-market regulators as a supporter of grid reliability. Finding the ‘right’ reason to support solar and storage and building coalitions with the groups most interested in it will likely be necessary to create a sustainable support framework.
- **Learn from early adopters**: Countries such as Germany or Japan and states such as California that already have a high penetration of residential solar are likely to be among the first to gain considerable experience with solar and storage. This means they will probably also be the first to hit speed bumps along the way. Policy-makers elsewhere should take note when they do, and adjust their own regulations ahead of time.

ABOUT US

Contact details

David Sandalow	dsandalow@columbia.edu
Colin McCormick	cfmccormick@gmail.com
Bloomberg New Energy Finance	sales.bnef@bloomberg.net

Copyright

Disclaimer