MSc Program
Environmental Technology & International Affairs

The traditional utility business model versus solar energy – the transformation of the electricity system

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
em. Univ.-Prof. Dr. Günther Brauner

Eva Anna Ottlakan

1228442

Vienna, October 2015

Affidavit

I, **Eva Anna Ottlakan**, hereby declare

1. that I am the sole author of the present Master's Thesis, "THE TRADITIONAL UTILITY BUSINESS MODEL VERSUS SOLAR ENERGY - THE TRANSFORMATION OF THE ELECTRICITY SYSTEM", 69 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 21.10.2015

____
Signature

Abstract

In this thesis, we will have a detailed look at how solar energy has impacted the dynamics of the traditional utility business model. Through looking at how solar energy grew in capacity and expanded to scale, we will see how it slowly moves into the utilities' radar. We will have a look at government incentives that supported the initial boost of solar energy, both on the industrial and the residential sides of generators and consumers. As residential solar begins to be paired with energy storage, more and more people have the potential to go off-grid, therefore becoming a major threat to utilities and their revenues. Utilities can react in a number of ways to this potential threat. They could either do nothing about it, or decide that it's a long-term threat only. They can also go out and legally fight back the spill over of solar energy through proposing subsidy cuts on the governmental level. Or utilities can decide to see solar energy and especially residential solar as a business opportunity and invest in it, or alternatively move into providing more consumer services – even as the provider of rooftop solar panel systems. As we see the dynamic between electricity consumer and the utility change, we slowly shift into a new world for electricity – one where the traditional rigid grid transforms into a community grid. We pose the question: is grid defection a short-term possibility? Or do the economics and policy changes point to a different conclusion? What is the future of the traditional utility business model and what role does solar energy play in it?

Table of Contents

List of abbreviations

AEEI – Advanced Energy Economics Institute

BNEF – Bloomberg New Energy Finance

c-Si – crystalline silicon solar cell

CapEx – capital expenditures

Consumer Price Index – CPI

CPUC – California Public Utilities Commission

CSI – California Solar Initiative

DSO – distribution system operator

EEG – Erneuerbare-Energien-Gesetz

GHG – greenhouse gases

GW – gigawatt

HECO – Hawaiian Electric Company

IOU – investor-owned utilities

IPP – independent power producer

ITC – Investment Tax Credit

kW – kilowatt

kWh – kilowatt per hour

LCOE – levelised cost of electricity

LGC – large-scale generation certificates

Li-ion – lithium-ion (battery)

LSE – load serving entity

M&A – merger and acquisition

MW – megawatt

MWh – megawatt per hour

NEM – net metering

NREL – National Renewable Energy Laboratory

O&M – operation and maintenance

OpEx – operational expenditures

POU – publicly-owned utilities

PUC – Public Utilities Commission

PV – photovoltaic

R&D – research and development

RMI – Rocky Mountain Institute

ROI – return on investment

RPS – renewable portfolio standards

SEIA – Solar Energy Industries Association

Si – silicon

SREC – solar renewable energy certificate

STC – small-scale technology certificates

TSO – transmission system operator

Pre-word:

Emphasis of this paper is on the influence of solar energy on the future of the electric utility business model and the transformation of the electricity system, however it is acknowledged here within that it is not the one and only factor affecting the development of said model and system, and there are other factors beyond the study reported herein. Utility as a term within this paper is used to describe an electric utility, either comprising of a generation or a distribution side or both.

1. Introduction: the commercialization of solar energy – a brief history

The introduction of electricity has revolutionized humanity's every day life, with positive effects on things such as education, healthcare, transportation and general comfort. In today's ever-connected world, it's hard to imagine life without electricity. However, a transformation is underway, and the way we've consumed electricity since the discovery of electric forces during the 18th century, through to major inventions in the 19th century which introduced a new wave of industrial revolution, is all about to change rapidly. Harvesting nature's renewable forces to generate electricity has been in the dreams of people for centuries, and we are experiencing this shift right now. The wide-scale adoption of renewable energy sources is rapidly disrupting traditional models for electricity providers, or utilities, with distributed and locally generated electricity decentralising monopolistic business models. Solar energy is uniquely positioned for adoption on all levels of the electricity value chain, from the generation side, all the way down to the consumer's level - all this with rooftop photovoltaic-solutions becoming cheaper and more widely adopted. In this chapter we will have a look at the invention of solar generated electricity and the beginnings of commercial application of said technology.

1.1 The physics behind the solar cell

The history of crystalline solar cells starts in 1952, when Edwin Kingsbury and Russel Ohl of Bell Laboratories published their research titled *Photoelectric properties of ionically bombarded silicon*. Their experiments, starting from 1941, were originally undertaken to find a suitable semiconductor material for use as point contact rectifiers[1] (Braun, 1874). The first photocells were cut from bulk, high-purity silicon (Si), in which a natural potential barrier was found. The existence of this barrier was first discovered in rods cut from melts. One end of the rod developed a negative charge when illuminated or heated: this was named the negative side, or n-type Si. The material of opposite type - positively charged side - was named p-type. The early work was followed by the discovery of the ionic bombardment method of producing photoactive surfaces in p-type Si. In an experiment, the scientists showed the photon efficiency as a function of wavelength of a typical cell (Ohl and Kingsbury, 1952). The first mono crystalline silicon solar cell featured a melt-grown pn-junction and an energy conversion efficiency of less than 1% (Glunz et al., 2012). This was still far away from being capable of generating big loads of electricity.

To shortly summarize the way these cells work, let's imagine the n-type side - the negatively charged side - Si, with properties of four valence electrons. This Si is then doped with phosphorus, which has five valence electrons. Therefore we end up with an extra electron. As a result, this side becomes negatively charged and is called the donor dopant - the one able to donate an electron. The other side, the p-type - positively charged side - Si, also originally having four valence electrons, is doped with boron. Boron has 3 valence electrons, one less than Si, creating holes, and so that side becomes the acceptor dopant. In between these sides is the junction, in other words barrier. When a photon hits the n-type Si, it frees an electron, and since it's connected by an external circuit to p-type Si, it generates a current caused by the movement of electrons from n-type anode to p-type cathode through an external load, and therefore we have electricity. The light energy originally absorbed by the electrons is used up while the electrons power the external circuit. Thus, equilibrium is maintained: the incident light continually creates more electron-hole pairs and, thereby, more charge imbalance. The charge imbalance is relieved by the current, which gives up energy in performing work (Solar Energy Research Institute, 1982). The p-n junction not only forms the basis for the majority of solar cells, but also is the basis for most other electronic devices such as lasers and bipolar junction transistors. Much of the theory of solid-state

[1] Braun noted that current flowed freely in one direction only. He had discovered the rectification effect at the point of contact between metals and certain crystal materials.

semiconductors was worked out during the invention of the transistor in the late 1940's and early 1950s.

Ohl and colleagues also pointed out in their work that these solar cells have optimal temperatures, in which they perform best. In the chapter *Effect of surface temperature during bombardment* they point out that maximum sensitivity results when the target is kept at about 395 degrees Celsius. Above this critical value the cells showed lower back resistances than those at 395 C, and conversely those below the critical value showed higher back resistance but a much reduced photo-response as seen in Figure 1.

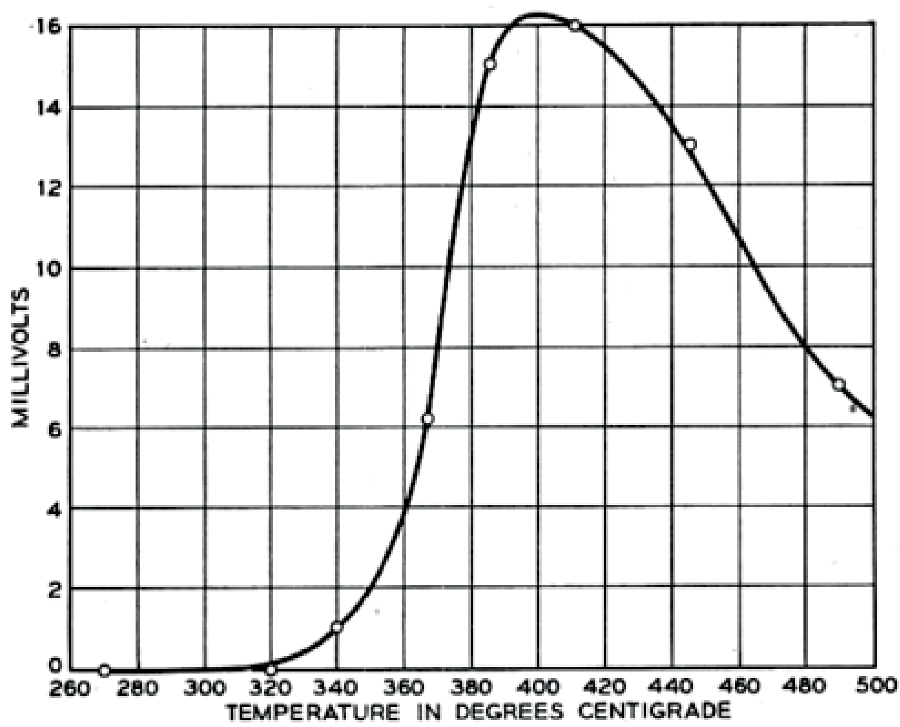


Figure 1: Optimal temperatures of a solar cell. Source: Russel Ohl et al, 1946.

Russell Ohl patented the modern junction semiconductor solar cell in 1946 (Ohl, 1946). The first practical photovoltaic cell, however, was presented in 1954 by Pearson, Fuller and Chapin. Their solar cell had a diffused pn-junction and reached a 4.5% efficiency rate. Later on they switched from phosphorus-doped n-type mono crystalline solar cells to arsenic-doped mono crystalline solar cells, with an outcome of overall efficiency reaching 6% (Chapin et al., 1964). And so begun the race for developing higher and higher efficiency solar cells at lower and lower costs, in the hopes of replacing dirty fossil fuel power sources.

1.2 Commercial application of solar cells

The first ever application of solar power sources was in satellites, when the mono crystalline solar cells won the competition to power satellites. With high efficiency, relative small weight and low costs, it was the ideal candidate to power satellites of the era (Perlin, 1999). Following that, during the 1950s, the space industry had the necessary resources to invest heavily in the research of mono crystalline silicon solar cells.

In 1962, the starfish prime nuclear detonation test in space, carried out by the United States, showed the detrimental affect of radiation on solar technologies placed on satellites. Satellites at the time were operating with n-type cells, as those reached a higher overall efficiency, but after the detonation it turned out that they were more affected by the radiation. Later on this prompted the switch from n-type solar cells to p-type solar cells on satellites, as it was less affected by radiation in space. Space radiation consists of energetic electrons, protons and heavy ions, which could originate from cosmic rays, direct solar emanations and particles trapped by the Earth's magnetic field, forming the 'Van Allen belts'. Today the space industry still heavily relies on solar technologies, so it was imperative to harden satellites against anticipated exposure to space radiation (Conrad et al., 2010). The space industry went on to develop better and cheaper solar cells, and kept focus of research on efficiency rather than volume of production, as the total generated capacity of satellite solar cells never reached a level higher than a few hundred kilowatts. It proved to be the ideal candidate for remote electricity generation in immediate space applications. Down on Earth however, humanity was in need of more and more power arising from a several reasons such as growing population, growing overall GDP per capita, remote areas off the grid and growing electricity demand. The imminent depletion of fossil fuel sources and their increasing prices prompted the industry to seek alternative solutions.

2. Solar at scale

Solar energy was an ideal candidate to replace fossil fuels, as increasing research has been lowering production and installation costs and during operation, the marginal cost of generating electricity with a solar panel is very low, if not non-existent, as solar light as a 'fuel' is free. It's also easily deployable to either ground or roof surfaces, and after installation, requires little to no maintenance. Solar energy growth has also posed a major challenge to utilities, who have been trying to incorporate the costs of government support schemes into their business models, whilst at the same time trying to avoid revenue losses from growing distributed PV generation. Renewable energy investment has been on the rise for several reasons, which we will have a detailed look at in this chapter, analysing the government support and the investment trends that led to the growth of applied solar technologies worldwide.

2.1 Government incentives for solar

Governments have the power to influence and incentivize the markets and investment through several means, such as giving subsidies or setting feed in tariffs for producers or net metering for residential customers. Government subsidies for renewables have been criticized for driving up retail electricity prices (UK Department of Energy & Climate Change, 2015), but the presence of subsidies have also increased investment, created jobs and business opportunities and contributed to the fight against climate change through the use of clean energy technologies. Subsidies are also a great way for a certain technology to reach competitiveness through increasing volume, capacity and R&D expenditure and through reducing costs.

Governments around the world have time after time introduced several measures and legislations that explicitly or sometimes implicitly had a boosting factor for renewables. For example, rules for carbon emissions reductions implicitly favour renewable and clean energy generation with the goal of reducing greenhouse gases (GHG) and pollution. The United States recently activated its 'Clean Power Plan' where fossil-fuelled power plants have the mandate of reducing their emissions through either carbon capture technologies, reducing the polluting output gas, or by replacing generation with clean technologies. Similar measures worldwide have prompted coal and gas plants to shut down, as they were no longer profitable through elongated periods of idleness or just weren't the favoured source of generation anymore due to public pressure (US Environmental Protection Agency, 2014).

The European Union views solar incentives as a vehicle to enable governments of member states to increase the share of PV in the electricity mix of their countries with the highest public benefits and at the lowest possible price tag (Wirtschaft und Infrastruktur, 2012). A good example from Europe is Germany, which had the highest levels of installed distributed PV in the world in 2014, in a big part due to subsidies. In 2000, Germany passed the Renewable Energy Act (Das Erneuerbare-Energien-Gesetz or EEG), which set the goal of achieving to double the share of renewable energy in the country's electricity mix until 2010. It was the first time the country set a priority prescribed by law for renewables to gain share compared to conventionally generated power sources. The EEG also introduced feed-in tariffs (further discussed in a later chapter) to spur residential solar system installations (Bundesministerium für Wirtschaft und Energie, 2014). This led to a radical increase in renewable energy generation in the country. In 2005, Germany became the world leader in terms of cumulative installed solar PV capacity, overtaking Japan for the first time (Internation Energy Agency, 2007). Germany's ambitious energy policy, which is widely known as Energiewende, received a new push in these years, and after the 2011 Fukushima nuclear disaster in Japan, Germany also decided to phase out nuclear generation and to shut down eight of its nuclear power plants immediately. Until 2011, Germany obtained about 25% of its electricity generation from nuclear, using 17 reactors. Today in 2015, this figure has decreased to 17%. To replace the nuclear generation, Germany had to and still has to build more renewable energy sources, and due to the abundant policies supporting this goal, the country has one of the highest retail electricity prices in Europe, regardless of the low wholesale prices (World Nuclear Association, 2015). This is a result of the subsidy tax placed on the retail electricity prices. In the summer of 2014, the German government passed a reform for the EEG to re-boot the energy transition to renewables and to try and decrease any further cost rises to the electricity prices (Bundesministerium für Wirtschaft und Energie, 2015). In 2014, Germany was still the world leader in cumulative installed capacity of solar PV with 38,2GW installed, followed by China with 28.2GW installed and Japan with 23.3GW installed (International Energy Agency, 2015).

As renewable energy installations take off, more and more regulatory uncertainties enter the market. While nations try to balance the grids, which now include increasing amounts of intermittent sources such as solar and wind, they also, at the same time, try to alleviate rising electricity prices. In order to achieve this, the extra burdens to the price such as subsidies, need to be decreased. As of current forecasts and according to research, the future sees no subsidies for solar as costs drop rapidly. This will initially be a blow to the sector, with decreasing new installations, but reports suggest solar energy to recover and regain strength (Bloomberg New Energy Finance, 2015a). Utilities that are coping with growing solar penetration have also started to take measures to curb government incentives, in some cases successfully. These measures will be discussed in a later chapter discussing utility strategies, titled ‘4.1.1 Fight’.

In the following chapters we will have a look at some examples of specific solar incentive methods and programmes. The list is not exhaustive, the varieties of solar incentives are numerous and even minor details for a same type of incentive differ in each country, depending on things such as government resources, market requirements, the level of penetration of solar, weather, the level of solar irradiation and of course general demand for the technology.

2.1.1 Self-consumption schemes

In order to incentivize distributed electricity generation, governments have introduced schemes in which self-consumption is rewarded by premiums or bonuses above the electricity prices. Self-consumption models often intersperse with feed-in-tariffs and net metering schemes, which we will further discuss in following paragraphs. In some cases however, there’s just a single self-consumption incentive in place (European Commission, 2015a). Self-consumption schemes can be therefore understood as an umbrella term for the more specific incentives. Self-consumption measurements can also be adopted as a threshold for subsidies. In Spain, for example, PV systems only get subsidies if the portion of self-consumption is above 70%. This can help to avoid high levels of exported electricity fed into the grid and at the same time minimizing the need for any grid extension.

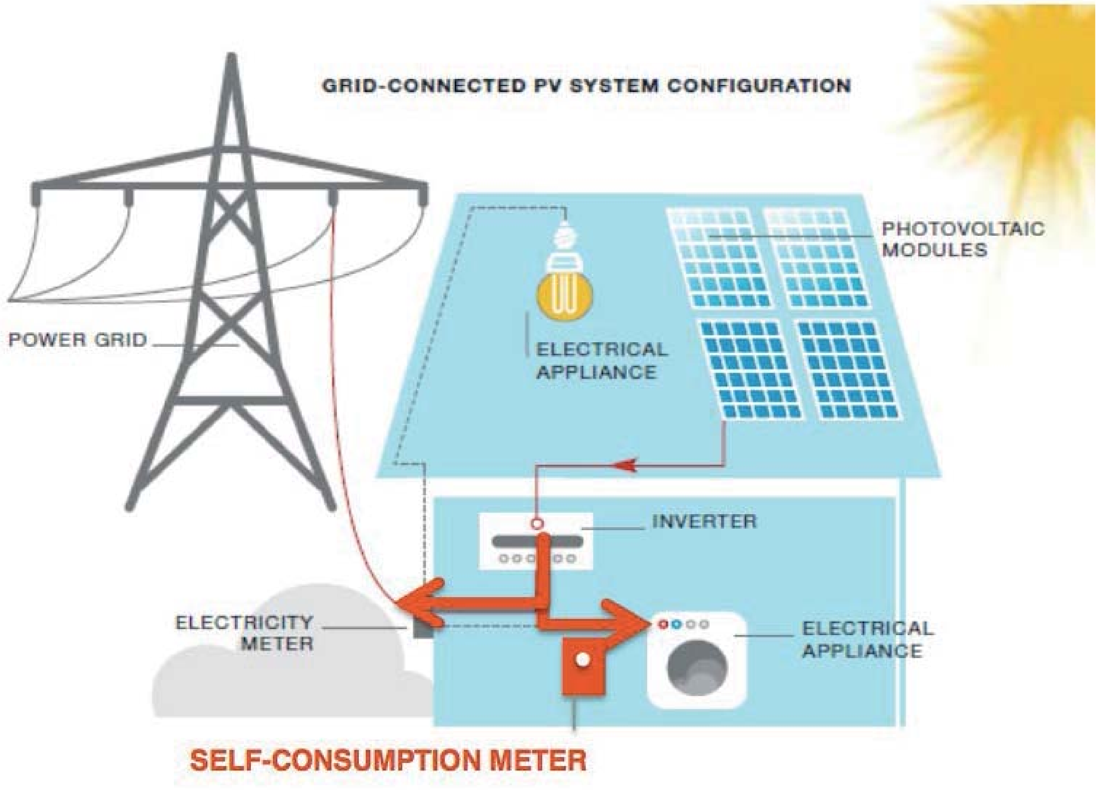


Figure 2: Self-consumption configuration chart. Source: European Photovoltaic Industry Association, 2015.

2.1.1.1 Feed-in-tariffs

As mentioned earlier in Chapter 2, feed-in-tariff is a solar subsidy policy, designed to accelerate self consumption of electricity by guaranteeing a minimum payment for each unit of electricity a household generates from renewable sources, or in this case solar systems. These schemes vary from country to country. We've had a look at the German scheme earlier in Chapter 2, where the payment is made after every unit delivered to the grid, similar to a net metering scheme. In the United Kingdom (UK) however, the scheme varies, as payment is made after every unit of electricity generated, regardless of it being exported to the grid or used up entirely by the household. On top of this, the consumer is paid an extra amount if excess is exported on to the grid. In the UK, the average ratio of exported electricity is 50%. In the UK, payments are currently guaranteed for at least 20 years, and are index linked so they increase with inflation (Renewable Energy Consumer Code, 2015). Partly with the use of this scheme, the UK has successfully supported the growth of solar energy system installations since 2010, when the scheme was launched. However, the scheme also costs a lot to the government of the UK. Because of this, since 2010, they have also constantly tried to cut back on the scheme, with a notable occurrence in 2012, when a slash to the scheme was taken to court by solar companies and lobby groups. As an outcome, the measure was ruled unlawful by the Supreme Court of the UK, resulting in the loss of the court case for the Department of Energy and Climate Change (DECC). This year, the new government is again set to carry out a full review of the programme in the second half of 2015 (Bloomberg New Energy Finance, 2015b).

2.1.1.2 Net metering

Net metering (NEM) is the practice of setting the electricity meter for a household to go backwards as well as forwards, depending on the source of electricity said household consumes. If a consumer generates electricity from rooftop-mounted solar panels during the day and generates any surplus, it then feeds that surplus back into the grid, which makes the meter go backwards against any night-time usage, giving credit to the surplus generated. Customers will then only be billed for their net energy use (Solar Energy Industries Association, 2015). Generally, net metering is understood to equate 1KWh of generated electricity to 1KWh of consumed electricity. However some states' or countries' utilities have set the remuneration rate below the retail electricity price, in an attempt to curb revenue losses. Under the NEM model, consumers with distributed generation are using the grid to figuratively store electricity produced at one point of time to consume it at another point of time. This method however, doesn't necessarily reflect the actual value of electricity, which may vary significantly between these time periods. We will discuss the causes of these variations in electricity prices in chapter '3.1 The electricity value chain'. Due to this challenge, several governments have introduced different forms of limits on their net metering (European Commission, 2015a).

Net metering schemes are generally set in law by the government of a state or country and in some cases electricity suppliers can also set their own net metering schemes, making the benefits widely variable. Net metering is said to originate from the United States (US) where Minnesota became the first state to pass a net metering law in 1983 (Trudeau, 2011). As of 2014, most states in the US, precisely 44 out of 50 (US National Conference of State Legislatures, 2014), had some sort of NEM legislation in place (Freeing the Grid, 2015). Utilities generally are obliged to adopt net metering schemes, but the ones that went ahead regardless of legislation requirements, do it to cope with distributed solar through introduced net metering schemes and taking advantage of these systems to better manage their peak loads. The overall existence of net metering is an incentive for ownership of residential solar technologies, but a threat to battery storage technologies, as it uses the grid as a ‘social battery’ by feeding surplus electricity back instead of storing it locally (Lilinshtein and Di Capua, 2014).

A recent story of a net metering scheme dispute between the government and a utility has been related to the state of Hawaii in the United States. In Hawaii, the solar incentives, especially net metering, have boosted PV penetration to a record-high 12% in comparison with the US average of 0.5%, which the utilities are struggling to efficiently integrate (US Energy Information Administration, 2015a). To put that into context, the Government of Hawaii has also recently passed a bill to achieve 100% renewable energy portfolio (or commonly known as renewable energy portfolio standard, RPS) by 2045, of which solar PV will be a big part of (Hawaii State Legislature, 2015). Since Hawaii is a remote island, it is dependent on importing fuels, which has historically contributed to a high retail electricity price (in 2015, Hawaii’s retail electricity price was almost three times higher than the US average (Hawaii State Energy Office, 2015)), so fostering renewable energy investment and installations was imperative to the local government. In April 2015, the local utility, the Hawaiian Electric Company (HECO), requested from the Hawaiian Public Utilities Commission (HPUC) the permission to slash the payments that it is required to give to rooftop PV owners who generate surplus electricity and feed it back into the grid. The lowered incentives would sharply increase the payback period of an installed distributed PV system (PV Magazine, 2015). Utility HECO was arguing that the extra costs generated by the net metering scheme is burdening the residents without solar systems, and contributes to Hawaii continuously having the highest retail electricity price in the United States (US Energy Information Administration, 2015b). At the end of August 2015, Moody’s downgraded HECO’s credit outlook from stable to negative, “due to concerns about the execution risk inherent in transforming its oil-dominated generation base to renewables” (Moody’s, 2015). One suggested solution to Hawaii’s situation has been the possible introduction of variable pricing, which could be favourable by all sides, according to a study by the University of Hawaii (UHERO, 2015). Under current situation, the utility has to remunerate the PV system owner for any surplus electricity at the retail price. Pricing however could be altered to fit everyone’s consumption and supply, introducing a new flexible rate structure.

However, even though the utilities are currently struggling with the growing distributed PV penetration on the island of Hawaii, the popularity of the net metering scheme is clearly visible from local data (Figure below). The first net metering legislation was enacted in 2001 in Hawaii, and since then the incentive program has been made ever more attractive to the local community, by gradually raising both the eligible system capacity and the generation cap (US Department of Energy, 2015a).

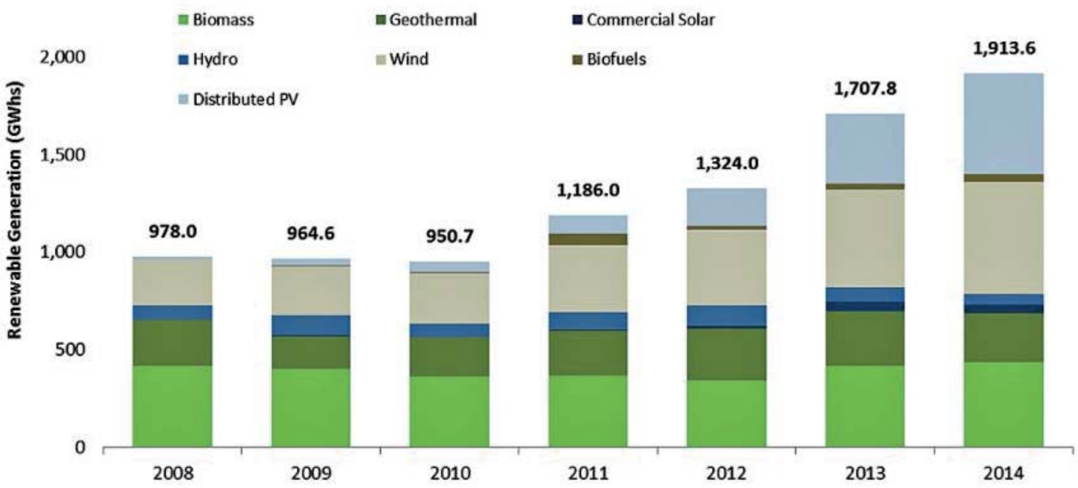


Figure 3: Hawaii renewable energy resource by generation, 2008-2014. Source: HPUC, 2014. HPUC Notes: Kauai Island Utility Cooperative (KIUC) not included in 2014 pending KIUC's annual RPS status report year ending 2014

However, could Hawaiian solar survive without subsidies? Firstly, as already mentioned, Hawaii has the highest retail electricity prices in the United States. In July 2015, the average residential retail electricity price in Hawaii was \$0.30/kWh. In the same period, the US average was \$0.12/kWh (US Energy Information Administration, 2015b). Secondly, Hawaii has a higher than average cost of living relative to other US states (The Council for Community and Economic Research, 2015). Thirdly, the average initial upfront investment for a solar panel system in Hawaii in 2015 (without a federal or state tax credit) is about \$20,000. The solar tax credit equals to about 30% of the initial investment (UHERO, 2014). This investment could be a financial burden for an average household taking into account the first two factors listed above. On top of that, solar panel systems that are not paired with energy storage units only produce consumable electricity during daylight hours. If an average homeowner spends daylight hours away at work, and not consuming that electricity, after work at night-time hours the household still depends on the utility's electricity. Subsidies however, like net metering schemes, make solar panel systems a feasible financial option, as they provide payback after electricity generated but not consumed during daylight hours. Therefore unsubsidised solar energy in Hawaii would only become more competitive at current economics when compared with energy storage units, and even then only over a long time period due to the current high costs of batteries (e.g. the Tesla Powerwall 7kWh will cost $3000 starting in 2016, excluding inverter and installation costs (Tesla Motors, 2015)).

2.1.2 Upfront investment incentives

An alternative to supporting solar energy self-consumption through payments per units of electricity generated is providing help for the initial investment of the system upfront, as mentioned in Hawaii's case earlier. This can manifest in a tax credit, or a cash-back rebate depending on the solar system's capacity and capabilities. These schemes can allow for a growth in number of installations through increasing capacity, as well as renewable energy generation. In this chapter we will have a look at two examples that follow this scheme: solar investment tax credits and cash-back rebates.

2.1.2.1 Solar Investment Tax Credit

In the United States, a solar PV system owner, let that be residential or commercial, has the possibility to claim back a so-called federal solar investment tax credit (ITC) at a rate of 30%. This means that 30% of the initial investment, ergo the cost of the system, can be deducted from the tax bill in a tax year. Hypothetically, if a PV system for example costs $10,000, then $3000 can be claimed back and be deducted from federal taxes. In the United States, individual state investment tax credits also exist and can differ from the federal incentive. The federal tax incentive was introduced in 2005 via the Energy Policy Act that supports all renewable technologies, including solar. Originally this was introduced for only a few years, but in 2008, it was extended for another eight years. The current legislation ends end of 2016 and is scheduled to step-down to 10% from 30%. Some requirements of claiming the tax credit, in the case of solar, is the personal ownership of the system, and the system also has to be new or used for the first time. Expenditures on the solar PV system also include the installation costs (US Department of Energy, 2015b). Solar ITCs can also be claimed by commercial customers, and can be viewed as part of the initial capital expenditures (CapEx) on solar.

Solar ITCs had a great role in boosting investment in solar in the US and can be considered as a major factor in the overall capacity growth in the last decade. However, future of the incentive is in doubt as we approach the step-down date. Nation-wide, several arguments have risen in favour of keeping the incentive in place, or alternatively modifying it and phasing it out gradually over an extended period in order to maintain competitiveness of solar. A recent report by Stanford University raises the issue of solar possibly rendered uncompetitive in the case of the scheduled incentive step down. They suggest a gradual phase-out over the years up until 2024 when the incentive can be removed entirely. In their alternative scenario, solar could keep its competitiveness and stable growth (Comello and Reichelstein, 2015).

A recent report, commissioned by SEIA and conducted by Bloomberg New Energy Finance, came to similar conclusions. According to the report, the ITC step down from 30% to 10% in 2017 would reduce annual new capacity additions by 2GW, but a 5-year extension of the ITC would boost current new capacity additions with an additional 2GW. With this envisioned scenario, the US would add over 22GW of solar to its install base. The report points out how the solar industry is not mature enough currently to endure a phase-out without having major implications on it’s solar energy industry, both on the small-scale and the large-scale sides. By 2021 however, the industry will be strong enough to maintain growth, even after a hypothetical extended phase-out date. The figure below demonstrates the status-quo and the imagined extension scenario (Yozwiak, 2015).

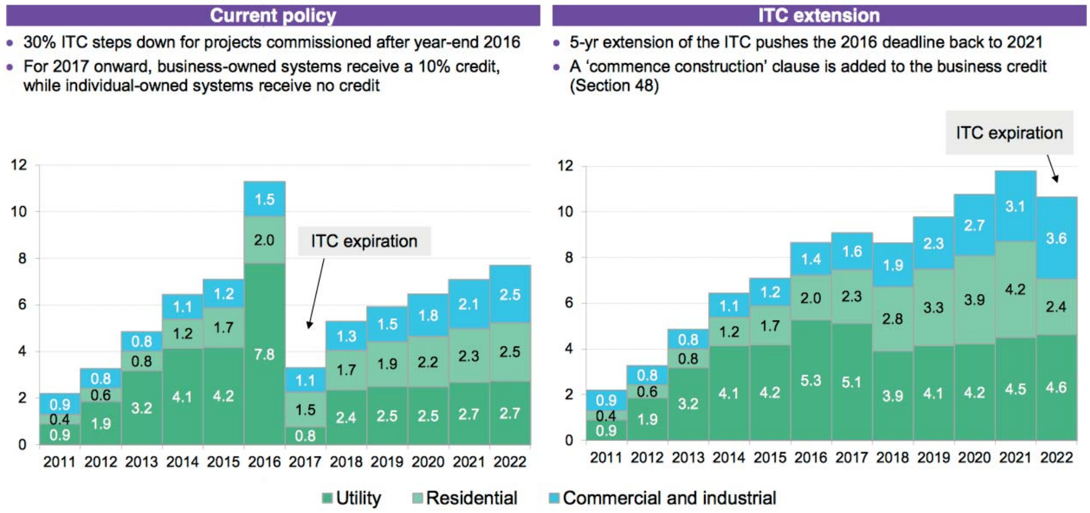


Figure 4: US solar build by customer segment, historical and forecast, 2011-22 (GW) – two ITC scenarios. Source: Bloomberg New Energy Finance, EIA 826, 860, 861, 2015.

A different study, conducted by the Massachusetts Institute of Technology (MIT) suggests the government owned ITC to be replaced by real estate investment trusts (REIT) or master limited partnerships (MLP) as new owners, as this solution would allow solar system owners to avoid corporate income tax or the need of having to go through the tax equity market. The MIT study also concludes, that "investment-based subsidies are less effective per dollar of government cost at stimulating solar generation than price-based or output-based subsidies" (Schmalensee and Bulovic, 2015).

2.1.2.2 Cash-back rebates

Cash back rebates are an efficient vehicle to foster solar energy growth through supporting initial investment through monetary compensations. A good example for this is the California Solar Initiative passed by former Governor Arnold Schwarzenegger. California's solar success story goes back to 1997, when the Million Solar Roofs program was launched, aiming to install solar panels on one million roofs in California by 2018, let those be residential or commercial, through the means of financial grants (Strahs and Tombari, 2006). Out of this grew, what was later cited to be the biggest political success in the US in fostering clean energy technologies: the California Solar Initiative (CSI). In 2006, then Governor Schwarzenegger signed the senate bill that authorized the California Public Utilities Commission's (CPUC) proposed CSI program. According to the programme's handbook, the CSI is “overseen by the California Public Utilities Commission (CPUC) and provides incentives to customers in investor-owned utility (IOU) territories of Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E)” and “provides cash back for solar energy systems for existing homes, as well as existing and new commercial, industrial, government, non-profit, and agricultural properties - within the service territories of the three above-listed IOUs”. These programmes are funded from revenues that come from placing an additional fee on electric and gas ratepayers’ bills (Go Solar California, 2014a).

In 2010, the CSI programme also decided to invest part of the revenues, $50 million to be exact, into solar research and development in order to further accelerate the penetration by bringing down production costs (Go Solar California, 2014b). The CSI has been widely believed to be the primary contributor to the state’s rooftop solar boom (Hallock and Kinman, 2015).

Today, in 2015, the California Solar Initiative has reached a point, where most of its funds have been depleted and the program has closed parts of the funding categories. It no longer accepts applications for rebates from customers of PG&E and SCE, nor from residential customers of SDG&E, only commercial customers’ applications from the latter utility (Go Solar California, 2015). However, distributed solar installations are still on the rise, even without the incentives, as seen in the figure below.

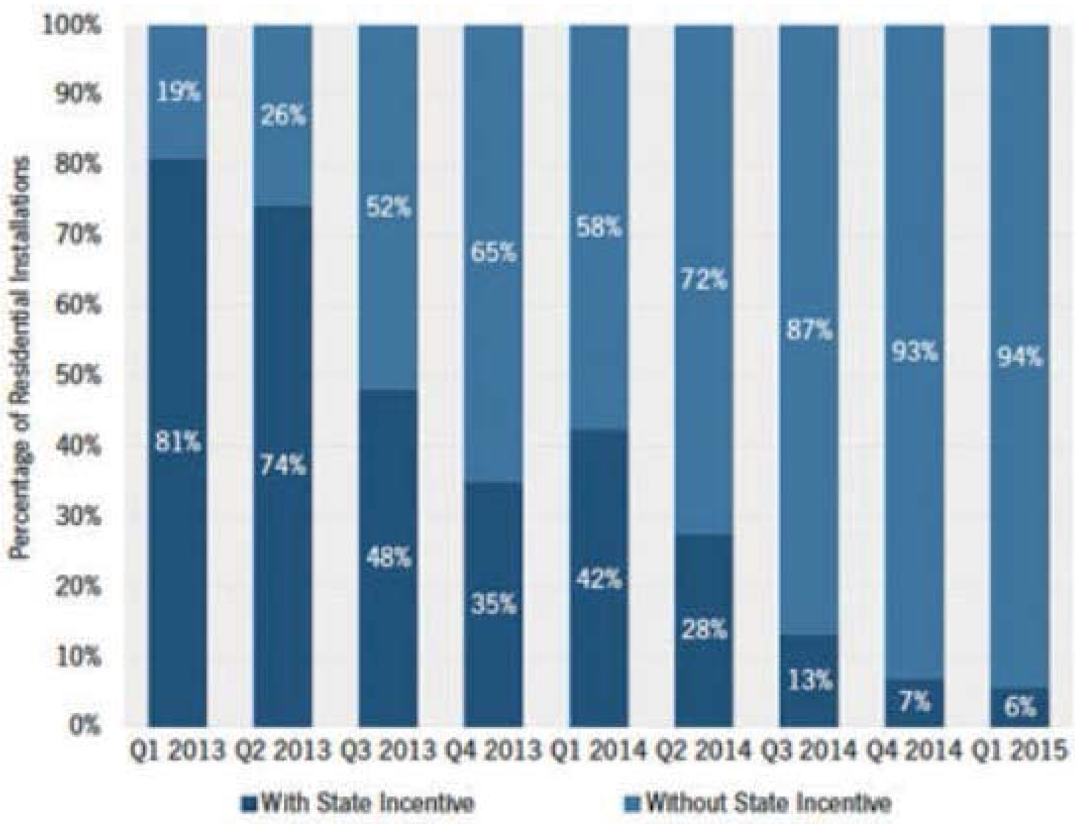


Figure 5: California Residential Installations, Q1 2013 – Q1 2015. Source: SEIA, GTM Research, 2015.

The CSI had an initial goal of installing 1,940MW of solar energy capacity by end of 2016 (Go Solar California, 2014c) and allowing solar growth to reach grid parity or competitiveness with conventional electricity sources by bringing down the costs per watt generated by solar. The following figures demonstrate the progress made on these fronts. As seen on the below figure, California is on the forefront of the solar energy boom happening in the US.

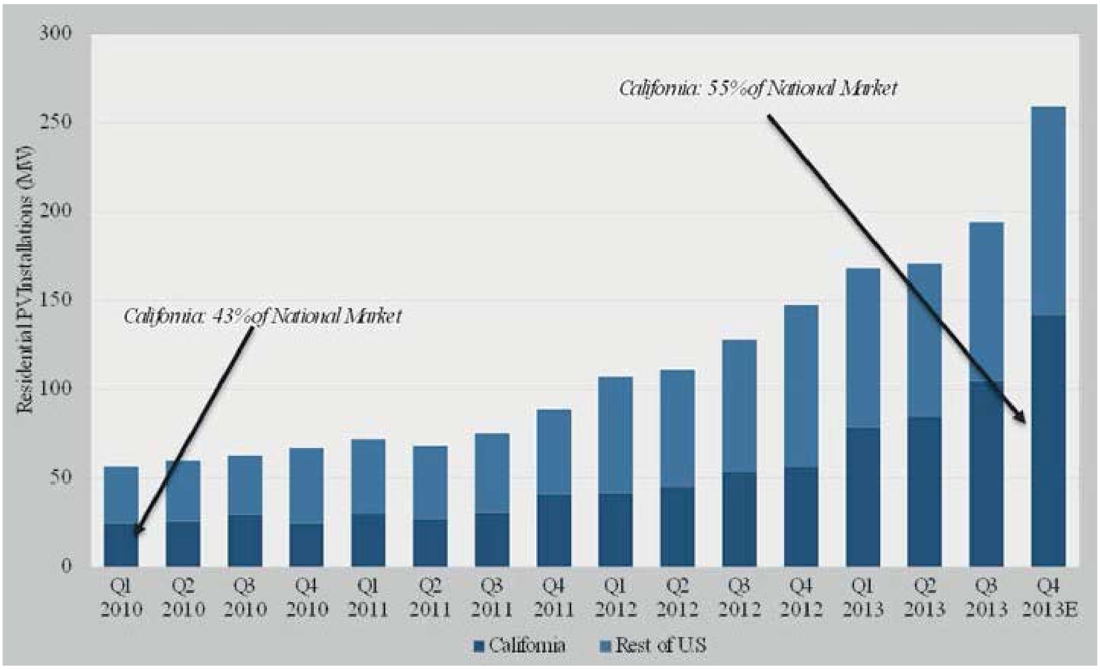


Figure 6: Residential PV installations, California vs. rest of US, 2010-2013. Source: SEIA, GTM Research, 2015.

The next figure shows that as installations across the US increase, the weighted average system price of PV drops. This negative correlation works the other way around too: as the supply increases, prices tend to drop.

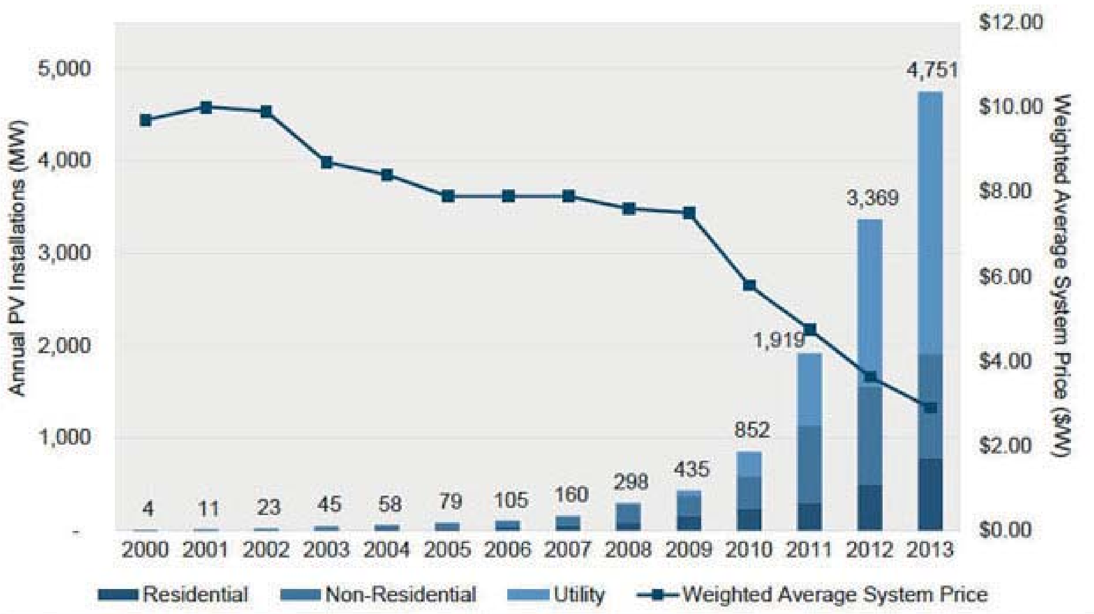


Figure 7: US PV installations and average system price, 2000-2013. Source: SEIA, GTM Research, 2015.

But every coin has two sides. On the following chart, it is clearly visible how the declining solar costs, and growing PV penetration in the residential sector has affected (and will continue to affect through the next five years) the utilities across the US, and especially the ones in California. The chart below shows the potential gross revenue losses to US utilities from residential PV. The losses are due to the distributed nature of the energy source and self-consumption.

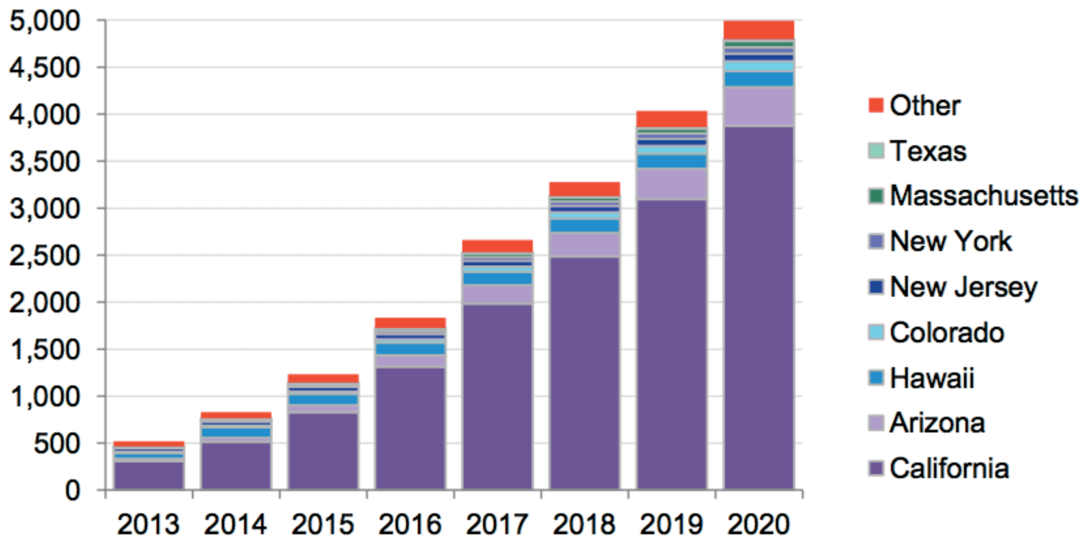


Figure 8: High-level estimate of potential gross revenue loss to US utilities from residential PV ($m). Source: Bloomberg New Energy Finance, 2014. BNEF Notes: "The analysis considers the impact of residential PV relative to 2008 levels (i.e., PV installed since 2008 is included as having contributed to revenue loss). For the unit price that is cannibalised, we take the average summer residential retail electricity price (this likely results in overestimate, as summer prices are typically higher than prices at other times of year). In the case of California, which has multiple tiers, we use the rate of 27¢/kWh, equivalent to the highest tier retail rate. The analysis assumes 2% annual escalation of the electricity price. Assumes all distributed PV is net metered. This only represents potential revenue loss and is not a cost-benefit analysis, which looks at the net gains or losses due to DG." (Lilinshtein and Di Capua, 2014)

2.1.3 Solar renewable energy certificates

Renewable energy certificates for solar or SRECs are a collective vehicle for supporting companies' investment in solar energy, through receiving one certificate, or tradable electricity commodity, per each MWh of generated solar energy. These certificates hence support, or subsidise, the production of clean energy. When an SREC is sold by a utility generating the clean energy, it can be bought by anyone who has not per se generated that clean energy themselves, but therefore show support for that clean energy source, and afterwards sell it on via the markets. The generator receives remuneration for supporting clean energy and the buyer can sell this on in the REC market (U.S. Department of Energy, 2011). REC markets exist in other parts of the world too other than the US, but under different naming, such as large-scale generation certificates (LGC) and small-scale technology certificates (STC) in Australia, which serve the same purpose as RECs do in the US.

RECs in general are designed to meet renewable energy portfolio standards (RPS). These standards are set for utilities or Load Serving Entities (LSEs) to meet the required proportion of renewable energy when purchasing electricity for their loads, whilst specifying a solar energy proportion, or so-called solar carve-out. The standards are also aimed at growing the adoption of residential solar PV systems, through setting a goal of certain capacity of installed solar power by the end of a specific timeframe. In general, RPS policies are more widespread than SRECs, so they don't necessarily come hand-in-hand. More than half of the US states have RPS in place, and only a portion of those states have the use of SRECs permitted. Setting SRECs is in the power of governments, and several US states have already introduced it, with solar PV dominating the technology side or occasionally having solar thermal incentives. Utilities or LSEs purchase the SRECs to demonstrate compliance with RPS policies (Bird et al., 2011).

There are two different markets where these certificates can be bought or sold: voluntary markets and compliance markets. The latter, the compliance market is designed for utilities or LSEs to be able to meet requirements of the RPS. The voluntary market on the other hand is where consumers or institutions can purchase the certificates to match their clean energy needs (Heeter and Bird, 2011).

SRECs have proved to be helpful in fostering initial solar investment, however one characteristic of SRECs is that their price is subject to market conditions, therefore it fluctuates over time (Mann, 2014). This uncertainty creates market volatility, which can be observed in the figure below, showing auction prices per SRECs per states over time.

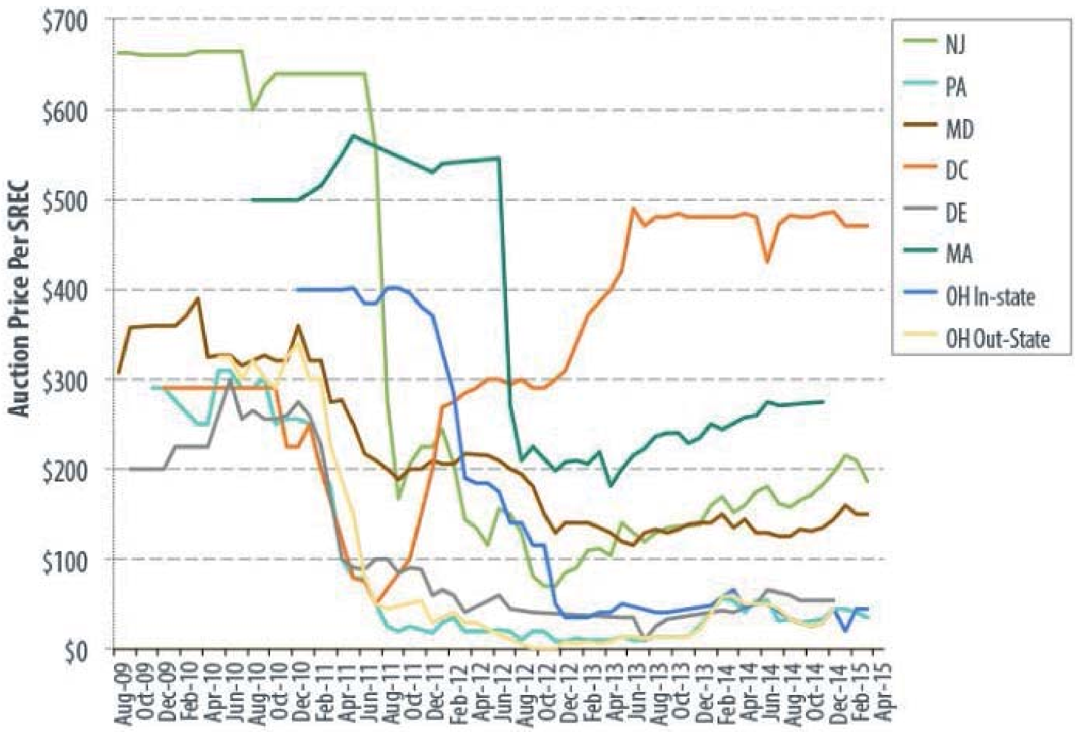


Figure 9: Compliance market SREC weighted average price ($), August 2009 - April 2015. Source: SRECTrade, Flett Exchange, 2015.

Another important factor in SREC trading is the solar alternative compliance payment (SACP), which allows electricity suppliers or utilities that do not buy the required amount of SRECs to pay a fee in order to comply with the RPS. This in turn creates a price ceiling for SRECs, since if the SRECs prices are lower than the set SACP fee, then for the utility it is the sensible option to choose the cheapest of the options. SACPs are also "considered to be a legitimate form of compliance, rather than a penalty for non-compliance". (Pierpont, 2012)

2.2 Solar PV's energy market penetration

After assessing the importance of government support for the initial growth of solar energy system investment and operation, we will now have a look at the numbers behind the outcomes of the policies, which led to widespread growth of both the capacity additions and the financial investment into the solar energy industry.

Through growing investment came growing capacity, and from growing capacity came new financing mechanisms in order to further spur growth. We will have a brief view into this journey, using a couple of specific examples.

2.2.1 Investment in solar

As government support increased over the decades, solar became a more attractive investment opportunity for generation companies and even for larger utilities in some cases. Also with decreasing capital expenditures, the return on investment (ROI) increased, both from the industrial and residential sides of solar energy. Amongst new investment into renewable energy, solar has been the segment that grew most rapidly, gaining a big chunk of the clean energy investment sphere. The figure below demonstrates this growth over the last decade, since 2004.

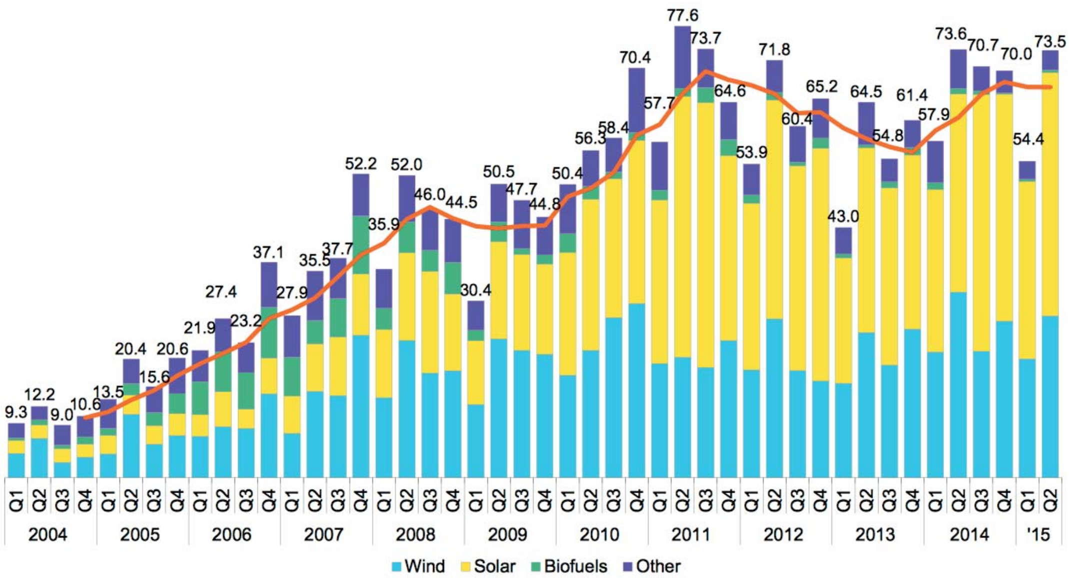


Figure 10: New investment in clean energy by sector, Q1 2004 – Q2 2015 ($BN). Source: Bloomberg New Energy Finance, 2015. BNEF notes: Total values include estimates for undisclosed deals. Excludes corporate and government R&D, and spending for digital energy and energy storage projects (reported in annual statistics only).

In 2014, solar energy investment was estimated at $177.8 billion, including all new investment and acquisition transactions. Global cumulative finances of solar energy between 2004 and 2014 also surpassed the staggering sum of $1 trillion. Solar power will keep expanding in the foreseeable future, with a forecast of $3.7 trillion in investment through 2040 (Bloomberg New Energy Finance, 2015a). Solar energy also has been seeing new players enter the market, with technology companies, such as Google and Apple, retail companies like Wal-Mart, or banks like Goldman Sachs investing into solar due to a government-led US wide clean energy initiative (Fehrenbacher, 2015). Residential solar installations have also increased as a result of declining system costs. The figure below shows the decline in residential PV system CapEx.

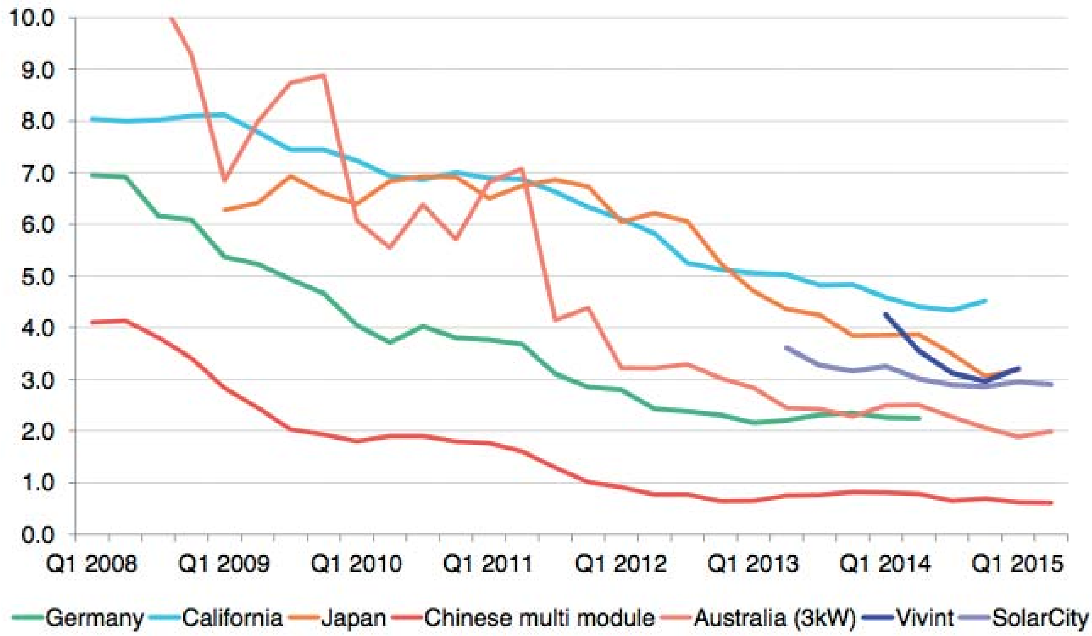


Figure 11: Public benchmarks of residential PV system CapEx, $/W (DC). Source: Bloomberg New Energy Finance, Solarchoice, METI, BSW-Solar, California Solar Initiative, 2015.

An alternative to investing into a solar panel system upfront for households, is renting it. Third party ownership of solar systems is designed to alleviate upfront costs of the said system for residential consumers, by allowing a third party financier to install and maintain the rooftop PV system on the consumer's roof. Third party ownership can either manifest in a power purchase agreement (PPA) or a lease agreement. In the former, an agreement is signed, where the system provider sells the electricity generated by the system at an agreed price to the household where the solar panel is placed. The latter method, the lease agreement, is when a household, instead of buying a solar panel, leases it for a fixed monthly payment and for a certain period of time, regardless of the system's electricity generation.

These practices have yet to gain popularity in the EU, where consumers, in the case of financing shortage, would rather apply for loans to buy the solar panels upfront. Third party financing contracts generally require 20 to 25 years of commitment, which could be a deterring factor, as prices of PV systems gradually decrease over the years, making the direct purchase a possibly favourable option in the future of a household. Also in the EU, current relative lower upfront CapEx costs allow homeowners to go down the alternative routes for obtaining solar systems. In the United States however third party financing has increased PV penetration radically, making access to cheap and clean solar energy fairly easy. (Kollins et al., 2010) A good example of a company using this financing mechanism is SolarCity, a leading residential rooftop PV provider in the US, which has been gaining even more territory with this model. SolarCity, as the owner of the rooftop panel systems is also eligible for a federal investment tax credit, being able to claim 30% of the cost of the system from the government (SolarCity, 2015).

2.2.2 Decreasing costs of PV

The cost of solar PV systems has been decreasing over the last decades, with increasing investment into research and development (R&D) and growing capacity additions. This market dynamic is clearly visible through the experience (or learning) curve of solar PV, where cost reductions are analysed as a function of the market and PV production capacity expansion. The curve typically "describes a quantitative relationship between cumulative production and the 'cost of a unit' of a given technology (measured as either capital cost or cost of energy produced)". From looking at historical data, forecasts for the future can be made on how costs of a technology might further decrease. Solar PV's experience curve is based on the traditional solar cell, the first generation crystalline solar cell (c-Si). However, as new technologies enter the market, and for those fewer historical data is available, a different curve can be seen for the newcomers. Another limitation of the solar experience curve is that it's based on solar PV module prices, as market transparency for production costs is low. Therefore the cost doesn't take into account other costs associated with system installations, such as cables, wiring, inverters or batteries in the case of off-grid systems (Candelise et al., 2013). An example of an experience curve for solar PV can be seen in the figure below.

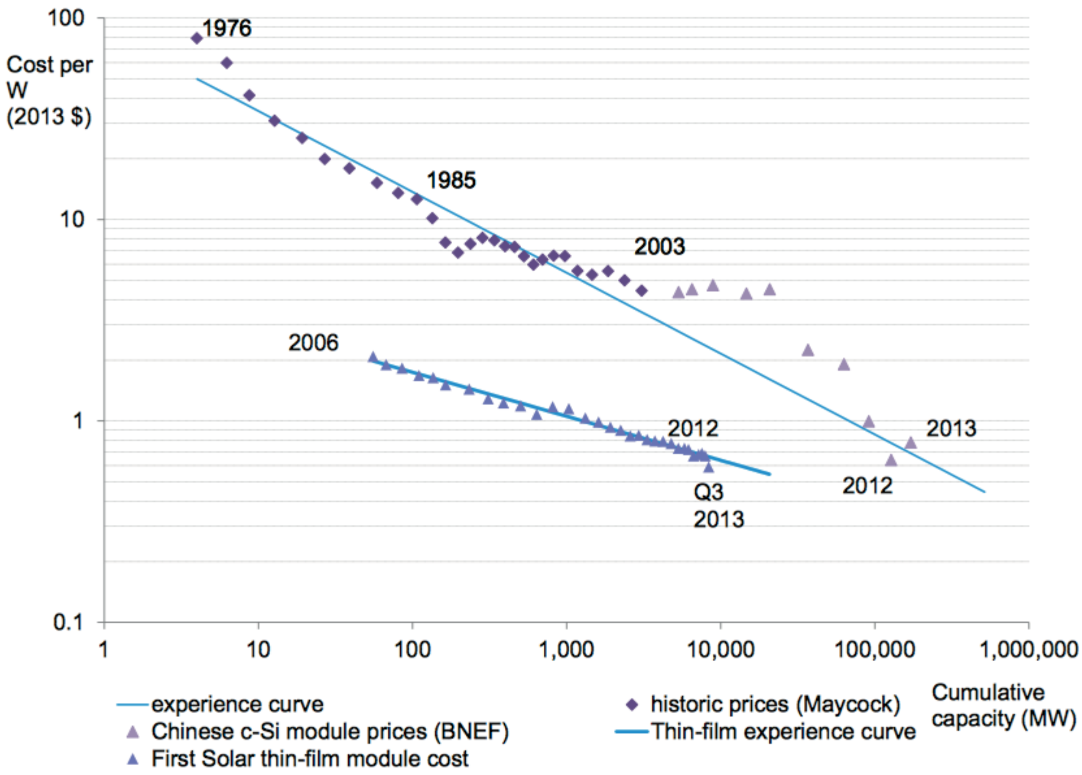


Figure 12: PV experience curve, 1976-2013 (2013 $/W). Source: Paul Maycock, First Solar, Bloomberg New Energy Finance, 2014. BNEF Notes: Prices inflation indexed to US PPI.

Both small-scale and large-scale new PV capacity additions are increasing as we speak due to the falling prices of PV systems. And as the number of distributed PV installations rises over the years, with a positive correlation, the price of PV further drops.

2.2.3 Growing capacity

Global solar energy capacity has been growing rapidly in the last decades with an equally inclining future projection yet to be seen. As discussed earlier, government incentives have been one of the primary boosts to the growth demonstrated in the industry. As of the end of 2014, total installed cumulative capacity of solar energy globally was just over 191GW, with close to 80GW accounting for utility-scale and 46.6GW for residential solar capacity out of the total figure (Bloomberg New Energy Finance, 2015a). The following figure shows the global growing cumulative capacity of solar with projections for the future, also demonstrating an expected growth especially in the Asian regions, with China potentially becoming the biggest player in solar energy.

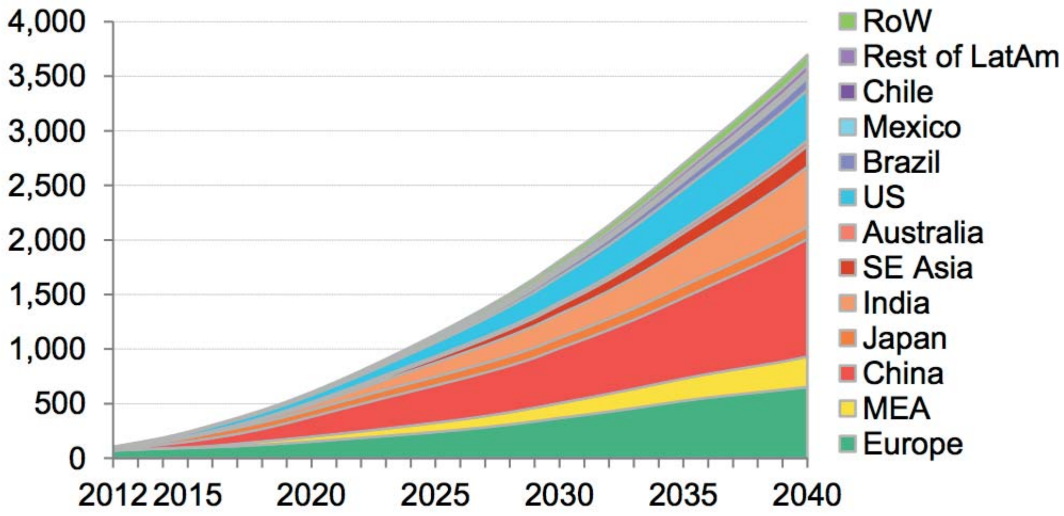


Figure 13: Solar installed cumulative capacity by region, 2012-2040 (GW). Source: Bloomberg New Energy Finance, 2015.

An interesting phenomenon in the residential PV world in connection with capacity is the occasional need for the oversizing of the array-to-inverter ratio of a household's solar system for it to be able to meet peak electricity demand. This occurs when a solar PV system is not connected to a battery storage system, therefore can only consume the electricity generated through solar energy at the moment of generation. During nigh time, when the sun isn't shining anymore, the household relies on the grid to feed its electricity. An oversized system can assure to maximize the electricity output, even under non-ideal conditions, such as shading or lower irradiation. Recent decrease in system and inverter costs have allowed for a higher array-to-inverter ratio and oversizing, without any extra costs. In countries where time-of-use (TOU) utility rate structures are in place, oversizing becomes an even more attractive option for producers and consumers alike. Through TOU schemes, electricity retail price from the grid is generally most expensive during daytime, same time as when irradiation is at it's highest. With the use of oversizing, solar PV systems can generate more electricity exactly when electricity is valued at its highest (Fiorelli and Zuercher-Martinson, 2013). However, with the intensive research going into increasing solar cell efficiency, oversizing as a compensation method could be avoided in the future.

2.2.4 New trends in solar financing: yieldcos and green bonds

Many markets face difficulties when it comes to investing in solar technologies. Through the several financing options emerging in recent years one that has proven to be highly efficient and has been gaining popularity amongst investors in the renewable energy sector are yieldcos. The definition of a yieldco suggests it to be an investment vehicle, an alternative financing model for clean energy projects specifically. According to Forbes, the definition of a yieldco is that it's a separate, public corporate subsidiary set up by a parent energy company, in order to transfer a portfolio of long-term operational energy projects or assets and separate that portfolio from the development pipeline. This allows for the subsidiary to attract investors through a steady and protected cash flow (Forbes, 2014). This financing model also allows for the protection of investment in renewable energy projects similar to the ways of how REITs or MLPs are set up, since through this financing, projects and companies are shielded against governmental regulatory changes. Since 2013 to 2015, the total market capitalisation of yieldcos has reached $27.6bn. However, yieldcos have also seemingly reached their peak of popularity, as current market statistics show a decreasing interest in the model (Liebreich and McCrone, 2015). To date, examples of a yieldco formation through initial public offerings in the US can be seen in the cases of NRG Energy, NextEra Energy, Pattern Energy or Abengoa, where large industry players had the necessity to spinoff assets to raise cash (Urdanick, 2014). The figure below shows the structure of a yieldco spinoff.

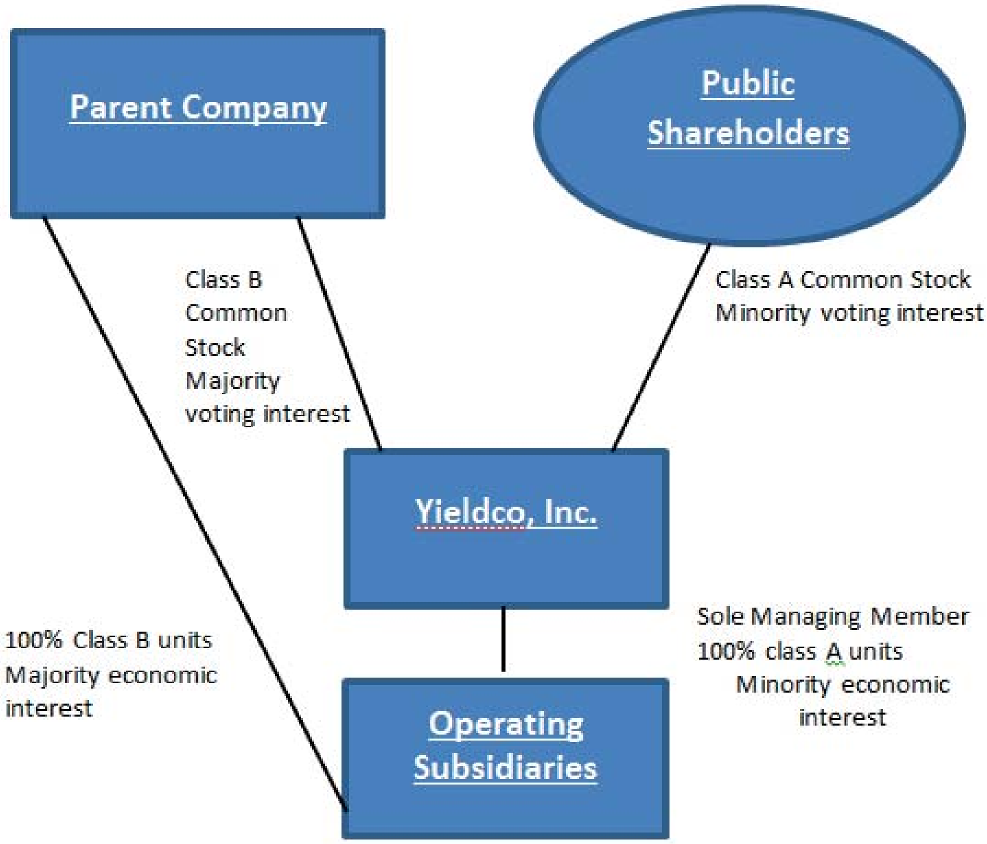


Figure 14: Yieldco structure. Source: National Renewable Energy Laboratory, 2015.

Another interesting trend in investment into solar energy has come from the emergence of so-called green bonds, allowing for an investment to be categorized as originating from clean-energy sources. The definition of green bonds can vary, but according to Bloomberg New Energy Finance, a green bond is a fixed-income instrument that funds projects promoting climate change mitigation or other environmental sustainability purposes (Salvatore, 2014). The first appearance of the term dates back to 2007 and 2008, when the World Bank, along with other organizations like the European Investment Bank, created the concept of labelling debt sold by environmentally friendly projects as 'green' (Reichelt and Davies, 2015). However, the debate continues, as to what we call a green bond, and whilst a bond can be green for one company for say its energy efficiency characteristics, another can view it as a simple unlabelled bond, and its advantages are still debated from a financing perspective. In Davos in 2014, the World Bank called for a doubling of the market, and the market responded (The World Bank, 2014). The figure below shows the growth in issuance of green bonds.

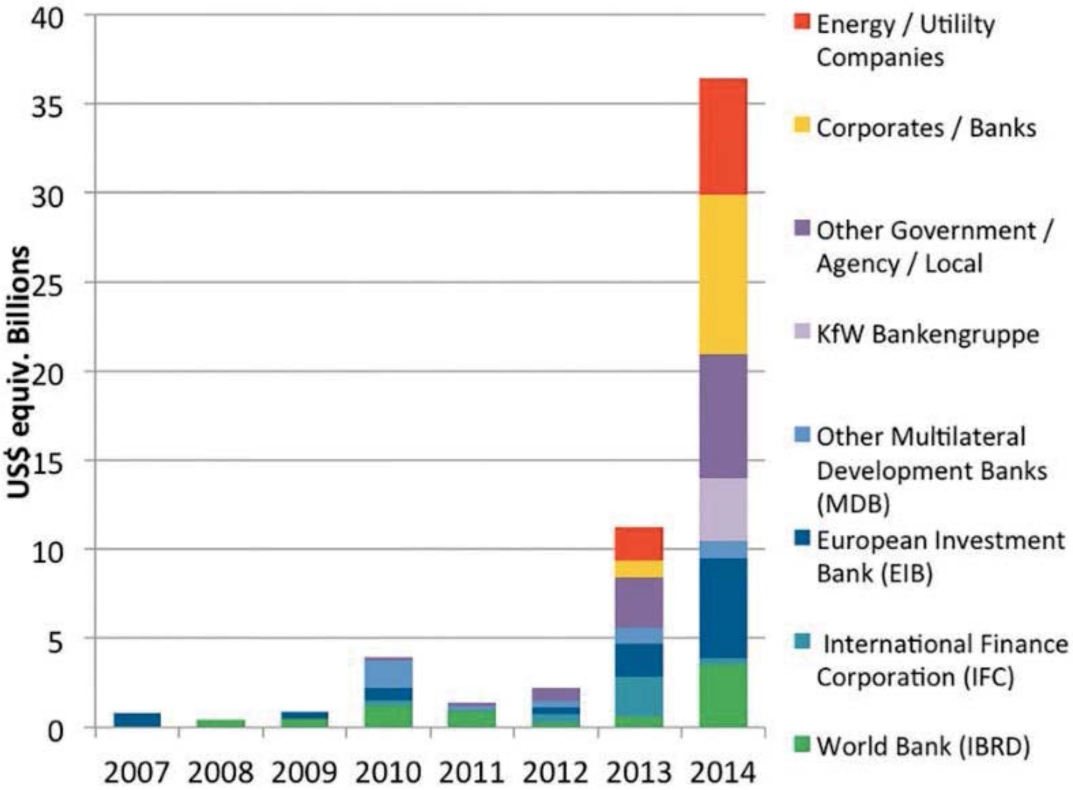


Figure 15: Annual green bond issuance by issuer type ($ billions/year). Source: Bloomberg, World Bank, 2015.

These alternative financing methods, namely yieldcos and green bonds, have provided a new route for renewable electricity generation companies to grow their portfolios and capacity. As the chart above shows, utilities have started to partake in these new financing mechanisms (labelled red in the chart), which also can be viewed as a sign of a changing utility business model, as they adapt to new market circumstances.

2.3 Solar LCOE and reaching grid parity

The levelised cost of electricity (LCOE) is defined as the total cost of installing and operating a power plant represented in dollars of the energy output over it's lifetime, and also taking into account government subsidies and taxes. It therefore aims to calculate the true price of electricity from a generation source, taking into account all factors (National Renewable Energy Laboratory, 2014). It is calculated according to a formula, which can vary depending on the methodology, but one of the more widely used ones is as follows:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

Figure 16: Formula for the levelised cost of electricity (LCOE) in $/kWh. Source: Kost et al., 2013.

Within the formula, 'I_0' stands for investment expenditures in dollars, 'A_t' stands for annual total costs in dollars in year t. '$M_{t,el}$' stands for the quantity of electricity produced in the respective year in kWh, 'i' is the real interest rate in percentage, 'n' is the number of years a power plant operates economically and finally 't' is the year of lifetime (1,2..n). The annual total costs comprise of fixed costs and variable costs that apply to the operation, maintenance, service, repairs and insurance payments of the plant. This calculation method allows for a comparative calculation for technologies on a pure cost basis (Kost et al., 2013). This method is therefore suitable to compare the cost of electricity generated from renewable sources and the electricity generated from fossil-fuel sources. LCOE is an important figure, as it can quantify the point where a technology becomes competitive with another type, which is what we call grid parity in the world of electricity. Grid or socket parity is defined as when the LCOE of a renewable energy source is equal or less to the normal retail price of electricity to consumers, generally including taxes. The European Commission more generally, as already outlined before, defines grid parity for PV systems as a stage of development at which it becomes competitive with conventional electricity sources (Wirtschaft und Infrastruktur GmbH, 2012). This encourages consumers to install rooftop PV panels as a means of saving money on the electricity bills and also contributing to the fight against climate change.

Reaching grid parity can be a milestone for solar energy as a technology as it would represent the point at which it makes sense from an economic standpoint to start to displace fossil-fuel generation in the industry with a renewable energy source like solar. However as utilities turn to cheaper generation sources and try to balance their loads with back-up generation, it is important to note that the overall generation mix of countries worldwide is shifting towards renewables as LCOEs drop, and increasing residential PV penetration is also a threat to the traditional utility business model as grid defection looms closer. This will be discussed in more detail in following chapters.

Declining LCOEs for solar also in turn have an affect on electricity wholesale and retail prices, as more and more solar generation enters the energy portfolios of utilities and independent power producers (IPP) due to the decreasing CapEx of PV. The figure below shows residential grid parity by country compared to 2015 and projected 2020 LCOEs.

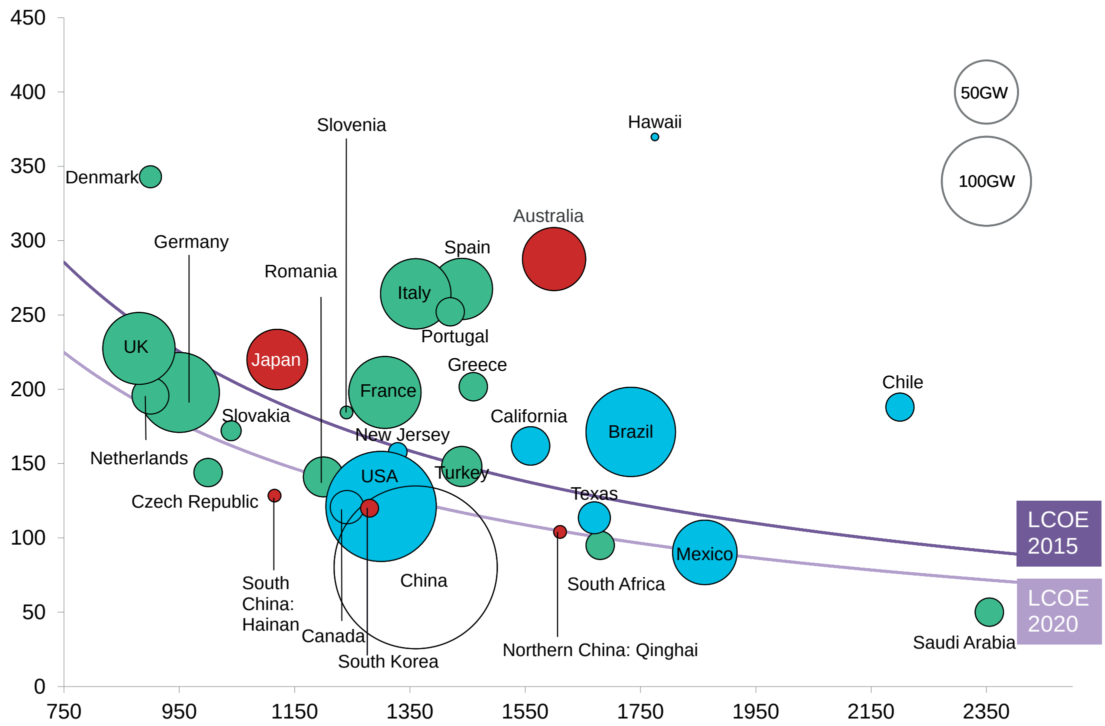


Figure 17: Average residential power price including taxes ($/MWh) by solar energy irradiation (kWh/kW/year) and compared to the LCOEs of solar. Source: Bloomberg New Energy Finance, 2015. BNEF Notes: Weighted-average cost of capital (WACC) for LCOE at 6%. Capex 2015 $2.28/W; for 2020, $1.80/W

In comparison with residential solar systems, commercial systems are usually cheaper on a dollar-per-Watt basis, due to the larger size of the systems and the lower commercial electricity rates. The figure below shows how commercial systems can reach grid parity sooner compared to conventional energy sources in most countries.

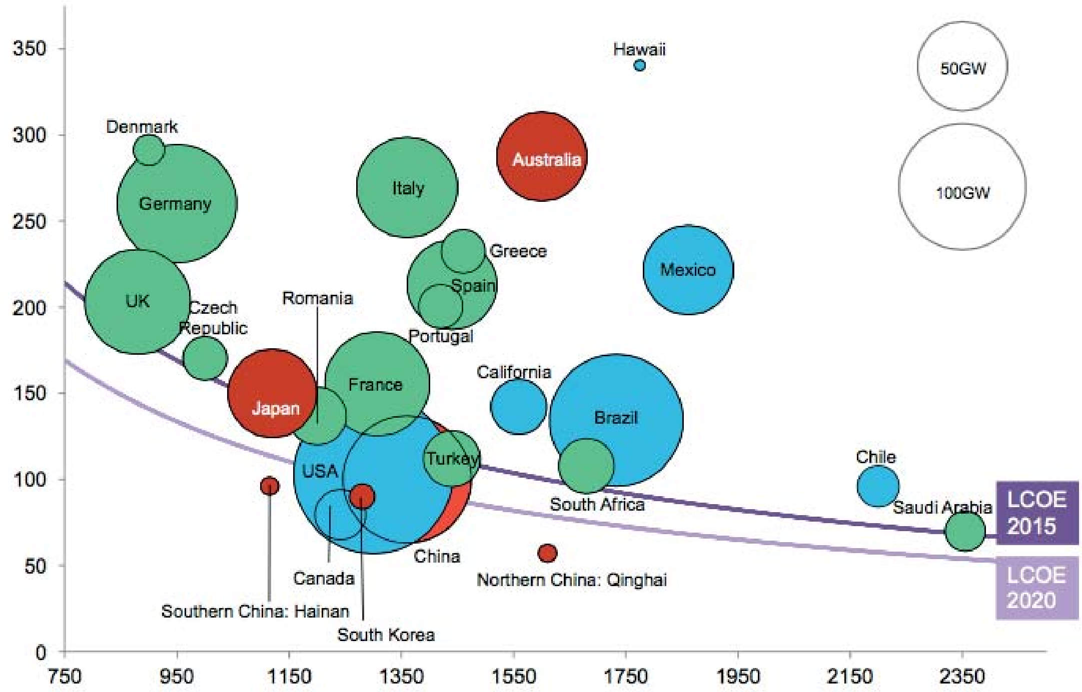


Figure 18: Average commercial power price including taxes ($/MWh) by solar energy irradiation (kWh/kW/year) and compared to the LCOEs of solar. Source: Bloomberg New Energy Finance, 2015. BNEF Notes: Weighted-average cost of capital (WACC) for LCOE at 6%. Capex 2015 $1.71/W; for 2020, $1.35/W

3. The threat of solar for the traditional utility business model

After having a detailed look at the economics and scale of solar energy, we will now put it into context for utilities. Solar energy and especially the distributed segment of it has recently emerged in utility rhetoric as one of the threats posed to the traditional utility business model, as generation becomes localised, and revenues for utilities are lost in the competition. To understand this dynamic, in this chapter, we look into how the relationship between the electricity producers and consumers builds up, what market forces drive the supply and demand, and how renewable energy, specifically solar, is changing this old dynamic.

3.1 The electricity value chain

To have an overall picture of how the electricity flows and to understand that the way we consume electricity is changing, we have to have a look at how the system is built up. The electricity value chain has three basic parts: generation (which is the upstream part of the system), transmission (the intermittent grid) and distribution (which is the downstream part of the system). Electricity is originally generated at a power plant that can be publicly or privately owned, and can come from either conventional sources (coal, gas, nuclear etc.) or renewable sources (solar, wind, hydro etc.). Amongst the players on the generation side, we differentiate between independent power producers (IPP), publicly owned utilities (POU) and investor-owned utilities (IOU). The electricity generated in the power plants is fed into the transmission system, which consists of high voltage electricity lines, owned and maintained by the transmission system operator (TSO). The transmission grid is connected to the distribution grid through transforming into lower voltage for smaller customers or directly feeds the power to large industry consumers who use electricity at high volumes and voltages. Moving on, the distribution grid for lower voltage consumers is operated by the distribution system operator (DSO), who delivers the electricity to either households, commercial customers like office buildings, or smaller industries such as factories. Traditionally the electricity value chain was owned and operated by one large monopoly, taking part in generating, transmitting and distributing electricity to end-users. Electricity in the traditional monopoly is generated then sent to consumers via transmission lines and consumed at a fixed price rate of electricity. Deregulation and decoupling of the generation and supply side from the transmission side however, introduced suppliers or retailers, who supply the electricity to the consumer and have the direct relationship. Utilities as per definition, could mean only the suppliers, or in case of integrated utilities, could mean both the owners of the generation and the supply side. Decoupling of the system however, as we already mentioned, prohibits utilities from owning any part of the transmission system at the same time as owning the generation and the distribution side. We will further discuss the decoupling mechanism in chapter ‘3.2 The changing role of utilities’.

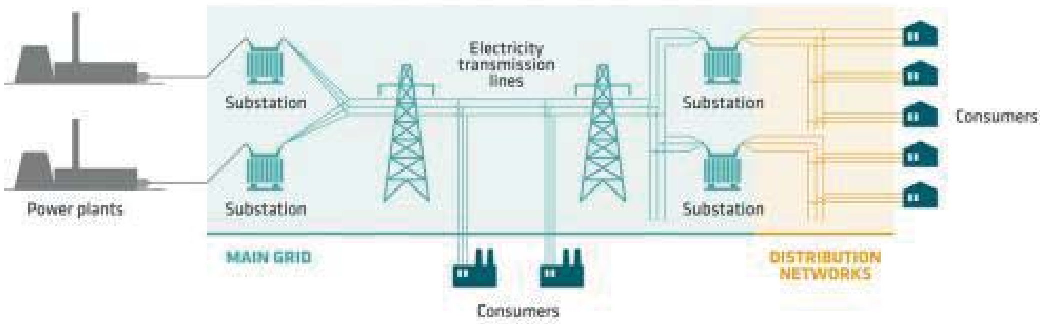


Figure 19: The electricity value chain. Source: Elering, 2015.

In the current set-up of the system, when electricity is generated it is then generally entered into a power market by the power generators through bidding on a set time basis, be that hourly or half-hourly etc. The electricity demand of households changes over the course of a day, and even over the course of the year. For example, during a winter day at 7pm, electricity demand would be much higher than during a summer day at 10am. These times are what we call peak and low point, respectively. In the markets, standard assumption is that bidding always happens at the breakeven price, which is equal to the operational expenditure (OpEx) of the producers. OpEx is the capital invested into everyday maintenance and operation (O&M) of a power plant, such as workers’ salaries, fixing errors, feeding fuel etc. This assumption is in place, because if power producers overbid, they might risk losing out on the demand ranking, and if they underbid they might sell the generated power at a lower price than their OpEx in case their bid sets the electricity price in that time slot. This happens because power producers are ranked in an increasing order by their OpEx or marginal cost, namely in the merit order, and demand will be met by the fewest possible producers with the lowest marginal costs.

When solar players enter this market, they have the lowest bidding prices, because they also have the lowest OpEx, which could in cases be close to zero. This is due to the fact that maintenance and every day operation of a solar plant is very low compared to a conventional power plant's O&M costs, where they have to feed in the fuel (coal, gas etc.) to generate electricity. All of these supply sources create a supply curve, or so-called dispatch curve (US Energy Information Administration, 2012). This is shown in Figure 20 below.

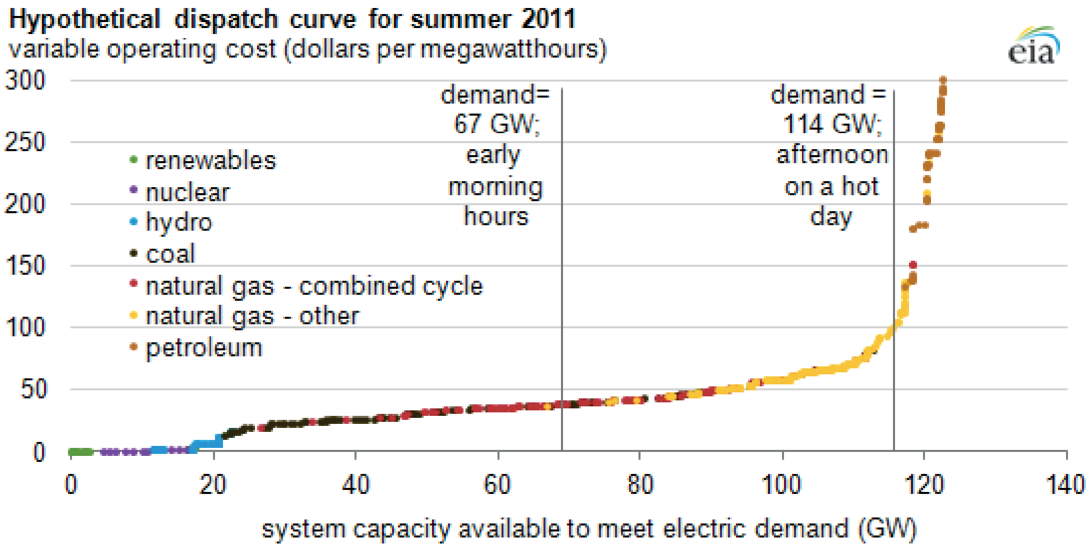
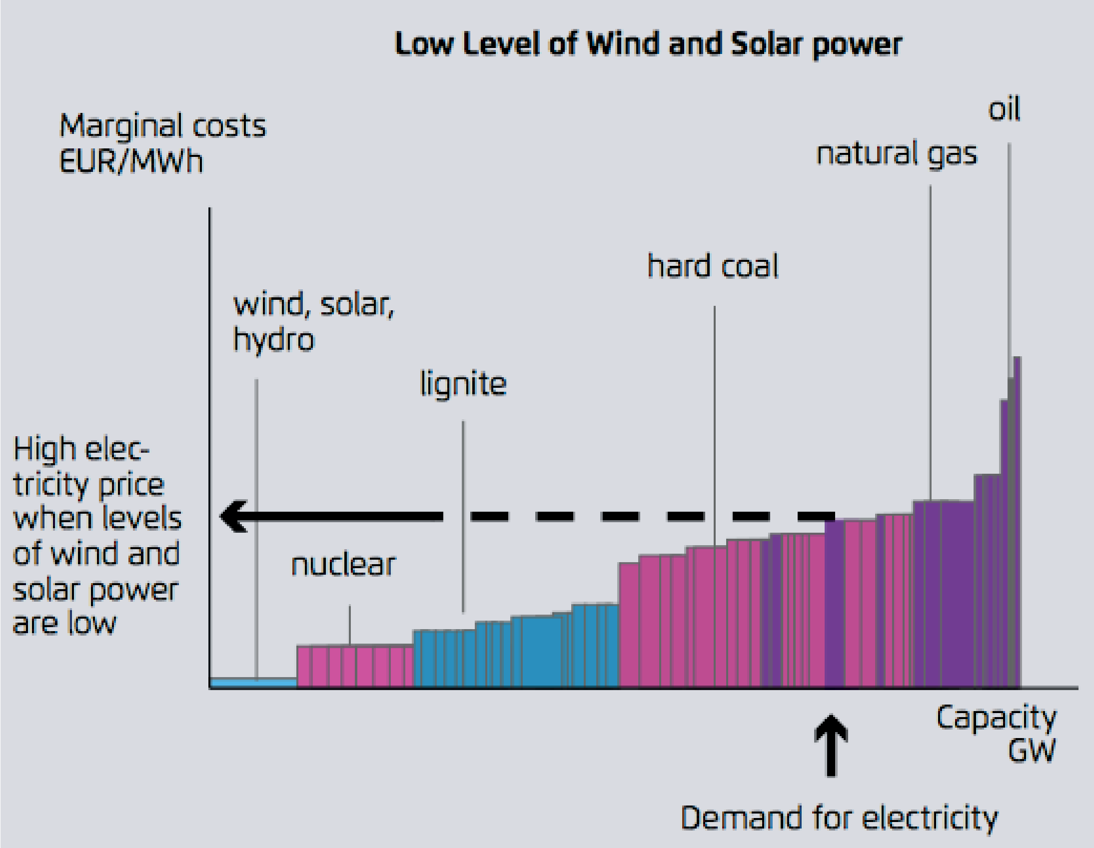


Figure 20: Supply and demand of electricity in the bidding market. Source: U.S. Energy Information Administration, 2011. EIA Notes: The dispatch curve above is for a hypothetical collection of generators and does not represent an actual electric power system or model results. The capacity mix (of available generators) differs across the country (U.S.); for example, the Pacific Northwest has significant hydroelectric capacity, and the Northeast has low levels of coal capacity.

In addition to these conditions, if in a state or country, solar energy is subsidized by the government, it then allows that company to bid at a minus price, taking into account the subsidies it will later receive from the government, given they've generated the required amount of electricity (Turner and Buckley, 2015). At any given time, demand is what sets the price of the electricity, and the price will be the marginal cost of the highest bidder/generator that is required to be switched on to meet overall demand. Solar plants would be switched on first as they generate electricity at lowest OpEx (at zero), then we'd historically have nuclear, then coal and then natural gas and oil at the end coming into the market or onto the grid, as shown on the chart below. However, recent merit order could look slightly different in some cases due to the lower gas prices in some regions like the US, where coal and gas can swap places in the merit order (US Energy Information Administration, 2015c). If the required demand can only be reached if all of these plants are switched on, then the price of electricity has to meet the marginal cost of the highest bidder for all of them to break even.

Even though solar has the lowest OpEx, it also has the highest CapEx currently from the afore-mentioned power plants. That means that the initial investment into the building of a solar plant is much higher than for a coal plant at current cost conditions, but afterwards it functions at a close to zero operational cost compared to conventional plants. If more solar generation comes into the electricity mix of a state or country, then the wholesale price of electricity (meaning the price of electricity without taxes and levies) becomes lower since overall OpEx is lower, and demand can be met by several cheaply operating solar power plants. Figure 21.1 and 21.2 demonstrate this scenario.

21.1



21.2

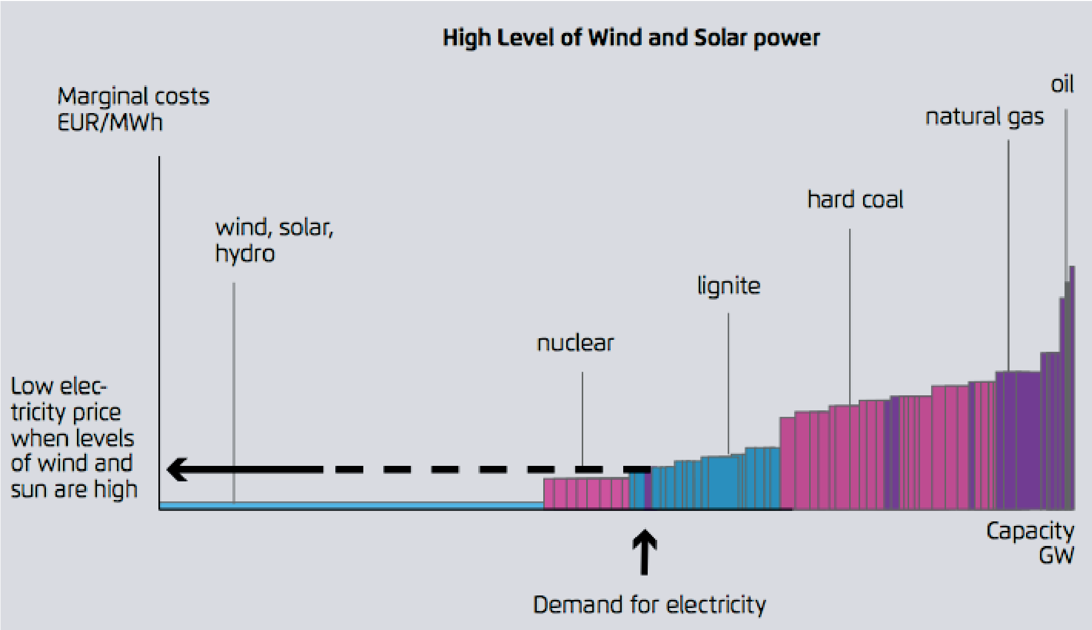


Figure 21: Merit order of a market without (21.1) and with (21.2) abundant intermittent renewables. Sources for Figure 21.1 and 21.2: Agora Energiewende, 2014.

Electricity supply rates are not always flexible, meaning the consumer or end-user will sign an agreement to receive the needed supply of electricity and the price will be at the agreed fixed rate. If the wholesale electricity price is higher than the fixed rate, the utilities that supply electricity would have to sell at a loss (Michaels, 2004). If the wholesale price of electricity is low, then the generation side is hurt. Supplier-only utilities however would be able to profit on a lower wholesale electricity price, as they buy up electricity at a lower rate and sell at a fixed, possibly higher rate. The benefit on the retailer side though is only short-term, because if there's a competitive market in place then the retailer has to adjust the retail price of electricity to match the competition's offer. The benefit of an integrated utility, meaning comprising of both generation and supply sides, is that even if the generation side is hurting from low prices, the supply side can still be doing better and therefore offsetting the drop in revenues.

In these bidding markets, only the top bidder or generator wouldn't receive any revenue, as the wholesale electricity price is set at its marginal cost line. However the last generator, the top bidder, also has the market power, and can ask for any price. This is a dangerous game though, as it’s hard to forecast for sure if you’ll be the last one in the bidding game.

An alternative to fixed electricity retail rates is time-of-use (TOU) pricing, which means the utility sets different prices depending on what time of the day, or which day of the week the electricity is consumed. These rates in the US are generally applied to commercial consumers, but can be adopted voluntarily by residential customers as well. For commercial consumers, to higher rates coincide with office working hours, and lower rates are granted during night period and weekends or holidays. This pricing scheme helps utilities gather back lost revenues from net metering policies and distributed PV penetration.

In the European Union, the Power Exchange market is where all the bidding takes place. The suppliers bid in to buy power that hopefully meets demand and generators bid in to sell power. These markets are designed to be partly day-ahead-markets, meaning they close at a certain time before the end of the day, and all bids had to be made for the following day. If as a supplier, you overbid the demand, assuming demand will be higher, and it actually turns out to be lower, you go back and try to sell that power. The market is then oversupplied, and plants that are overproducing electricity will have to be sent on standby mode by the TSO. If you as a supplier underbid so to say, or underestimate your required demand, you will need to enter the intraday spot market to buy additional power. In these cases the grid operator might need to use back-up energy to cover for this demand, and this will also come with a fee to be paid by the supplier with the wrong forecast. Solar power has introduced unpredictability into this market, both from the large-scale generation side, and from the residential demand side with rooftop PV. Solar is however only one driver of the oversupply spiral in the electricity market, mainly because of problems with forecasting solar due to unpredictability of long-term weather patterns.

A further player in the electricity value chain is the regulator, which, as per its name, regulates the overall electricity market and value chain. It makes sure that the price of electricity reflects demand and supply and that end users are protected and their needs are met in the overall supply chain. The regulator can also set a renewable energy target or quota which then has to be met by the supplier, either by generating or buying up the electricity it provides, and have a certain percentage come from, in this case, renewable sources.

At the moment there is no incentive from an end-user point of view to consume electricity in line with the needs of the grid. In order to better manage the overall system, we need to change the way we get charged for electricity. This is where smart meters or energy management services come into play. It's a territory that utilities or suppliers are starting to move into and could potentially cover for lost revenues through the aspect of better managing the supply and demand and through providing new services. We will further discuss this in chapter '4.1 Fight, flight or adapt', where we will also look at other new strategies utilities are taking to cope with distributed solar PV.

When distributed solar enters into the picture, demand to suppliers go down, since electricity is generated locally for households. This poses a risk of loss of business for suppliers, and integrated utilities are also hit on the generation side as they are not running at full capacity. A remedy for this is the introduction of capacity markets by the government. This phenomenon will be further detailed in coming chapters.

3.2 The changing role of utilities

The traditional utility business model is under transformation, and there are several examples globally to illustrate this change. We are gradually moving away from a centralized and regulated utility and electricity generation to a distributed and localized electricity generation, where consumers are more than just end-users and ratepayers, but rather active participants in the energy system: so-called 'prosumers' (producers and consumers). Utilities haven't had as much flexibility so far as private start-ups to experiment in new services for customers, and this was mainly due to regulations (Trabish, 2015). With the growing penetration of distributed energy generation technologies, such as solar PV, and changing residential power demand, utilities have to face and embrace change if they want to properly tackle the threats and ensure future revenues. Reports such as the recently published paper on California's electricity system by the AEEI (Advanced Energy Economy Institute, 2015), envision new business models in the future of utilities. According to the AEEI, the utility business model of the future will enable a more integrated, "plug-and-play" electricity system.

To understand the way utilities' roles are changing, we need to first look at where they started. Traditional electricity generation is based on fossil fuel sources. This allows for the infrastructure, the investment and the power to concentrate from the top down. Coal, oil and gas have specific resources and are not abundantly available for everyone. Companies and governments inject capital into these projects and then distribute the energy arising from the burning of these fuels in power plants. The end-consumer is merely a participant in this process, which creates natural monopolies, owning all three parts of the electricity value chain: generation, transmission, and distribution. When renewable energy generation enters the picture, the energy source is abundant and is distributed. Sun, wind, water is available to everyone for free. Once you set up a local electricity generation system in your household and you become not just a consumer, but a 'prosumer', it changes the whole dynamic of the energy consumption model. Excess energy can also be transferred to others via a connected, socialised, 'smart-grid'. This phenomenon has been well demonstrated by economist Jeremy Rifkin in his book 'The third industrial revolution', where he proposed that power play is shifting towards a lateral distribution, away from a top-down hierarchy (Rifkin, 2015). This phenomenon has also been noted down by other thinkers, and has risen as a characteristic of forecasts of policy analysts – also known as the democratisation of energy. It's the same concept as when the automobile democratised transport and the internet democratised access to information. Renewables also have the power to democratise access to electricity (TheEnergyBlog Team, 2014).

The shift towards a new utility model started with deregulation waves across the globe during the 1990s. In Europe the biggest event was the UK electricity market deregulation in 1990, followed by several other countries.

In the US, the regulatory struggle stems back to the first financial crisis of 1929, after which the need for state regulation in large utility holding companies arose. In 1935 the Public Utilities Holding Company Act (PUHCA) was passed, forcing utilities to only serve a single state or a smaller geographic area, hence making it easier for state legislation and the Federal Energy Regulatory Commission (FERC) to keep control and oversight of these businesses and their electricity prices (Code, 1935). The act was a step towards enhanced regulation, which by the end of the century actually required some deregulation to ensure natural market forces.

As monopolies emerged in the energy-sphere, the need for deregulation further increased. Unbundling of the electricity value chain became a necessity, in order to ensure low electricity retail prices and fair competition in the market. Unbundling in this case meant the separation of generation and distribution from the transmission side of the value chain. Regulators remained a separate independent entity, in charge of keeping this structure as transparent as possible. The unbundling brought with it the rising competition within electricity distributors and a further decreasing electricity retail price for consumers. It also assured that the market responded flexibly to ever-changing supply and demand of electricity, and to the changing energy mix on the generation side.

One demonstration of the ongoing changes in the role of the utilities is the legislation passed by the European Union in 2011, namely the EU Third Energy Package, which seeks to develop a more harmonised European internal energy market through opening up markets, integrating and upgrading networks and empowering consumers through opening up trading across the EU and finally bringing price convergence. The regulation also created the ENTSO-E (the European Network of Transmission System Operators for Gas or Electricity), which has the role of “facilitating and bettering cooperation between national TSOs across Europe in order to ensure the development of a pan-European transmission system in line with European Union energy goals” (National Grid, 2015). One of the main aspects of the Third Energy Package is unbundling, which is, as mentioned earlier, the separation of electricity supply and generation from the transmission networks. If a single company operates a transmission network and generates or sells electricity at the same time, it may have an incentive to thwart competitors' access to infrastructure. This prevents fair competition in the market and can lead to higher prices for consumers (European Commission, 2015b). A single energy market has to be achieved through market coupling that uses implicit auctioning to allow use of interconnection capacity for trading between markets. However, this process has been slower in being implemented than expected, and has led to nations introducing so-called capacity markets due to worries about future capacity shortfalls. In these markets, the government pays for generation plants of certain capacities to stand-by on the sidelines, in case any amount of unforeseen electricity demand needs to be fulfilled. So to put it simply, these plants receive their revenues from the capacity they have available not the capacity they actually generate. These plants tend to be low CapEx conventional energy sources, such as coal, as they are cheaper to build.

This overall threatens the formation of the single energy market, as countries would rather fire-up their own back up plants that they are already paying for, than import electricity from abroad. Example of current capacity markets in Europe can be seen in France and the United Kingdom (Rooze and Lawn, 2013).

3.3 Electricity demand trends

Electricity demand has generally been perceived to correlate strongly with the growth of wealth in GDP. However, as rural areas become electrified, everything is improved from health care to education to day-to-day comfort of households. Electricity brings about the elimination of petroleum lit lamps or heating with wood, which both produce serious harmful exhaust smoke and are dangerously flammable as well. Electricity has historically meant a better lifestyle, a cleaner, healthier one. However, recently new trends have emerged, where electricity demand has been on the decline, even when coupled with GDP growth. After the financial crisis of 2008, electricity consumption has been declining in the developed parts of the world like Europe. Rising electricity prices also contributed to decline in electricity usage. Other important factors are in play too, such as increasing energy efficiency measures. LEDs are estimated to reduce electricity usage by up to 80% if city streetlights would be replaced. In the US, the Department of Energy calculates that only by replacing a 60W incandescent light bulb with a 15W compact fluorescent bulb, 75% of electricity can be saved (McCrone, 2015). The apparent slow death of the lighting industry is also a sign that as energy efficiency measures come into play, and long-life LED bulbs replace the short-life incandescent bulbs, profits of lighting companies drop sharply (Webb, 2015). And energy efficiency isn't only affecting lighting, but also computation, and electrical home appliances, such as refrigerators and washing machines. The European Union has also introduced a target date for 2020 by which time at least 80% of all households in the EU should be equipped with smart meters that regulate electric or gas heating efficiently. As countries adopt such measures, the overall electricity consumption becomes more conscious and sustainable on an individual and community level. As residential solar panels paired with localised energy storage enter this equation, grid defection becomes a potential threat to utilities, as off-grid self-consumption grows. The figure below shows the correlation between lower or higher GDP and electricity consumption between 1980 and 2012.

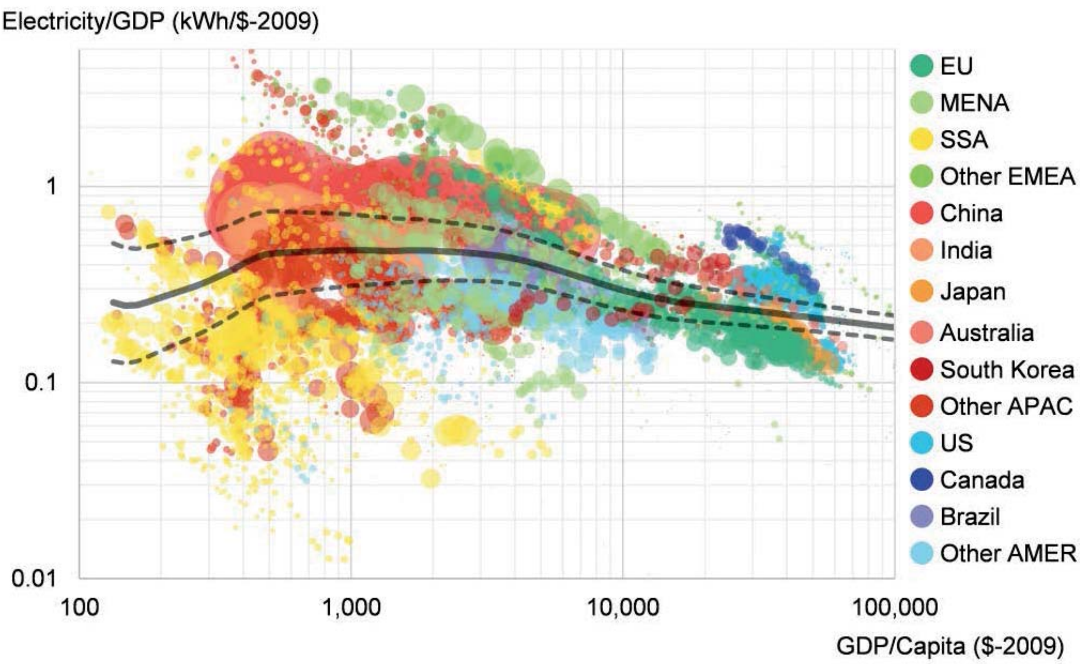


Figure 22: Electricity consumption/GDP versus GDP per capita, 1980-2012. Source: Bloomberg New Energy Finance, IMF, World Bank, EIA, Eurostat, US Census Bureau, US Bureau of Economic Analysis, 2015. BNEF Notes: Size of bubble is representative of country population. Both X and Y scales are logarithmic. EU=European Union, MENA=Middle East and North Africa, SSA=Sub-Saharan Africa

3.4 PV penetration and the utility death spiral

As demonstrated earlier in the chapter on government support for solar, in the US, states with high penetration of PV include the states of Hawaii and California. These states have both adapted to circumstances that favoured the increase of PV penetration in their energy portfolios. These circumstances were either a geographical disadvantage, like in the case of Hawaii, where the conventional source fuel for electricity generation, being locally unavailable fossil fuel, had to imported. This in turn contributed to the increase of the electricity retail prices to one of the highest amongst US states. In the case of California however, advantages of its geographical location having one of the highest ratios of insolation in the US helped the government's case for supporting clean energy and battling air pollution. Utilities had to both adapt to these changes, and even participate in further growing PV penetration like in California, or as in the case of Hawaii, went along the route of fighting PV penetration through proposing cuts to the government's net metering scheme.

Growing PV penetration has not only affected utilities on the revenue side from both generation and distribution perspectives, but also from a financing side. Utilities often turn to the method of issuing bonds, in order to finance new investment. These bonds are traditionally low risk, low interest rate and therefore low yield bonds that are highly rated. This year however, has seen these bonds being downgraded. For example, Barclays in the US downgraded the entire utility bond market, and cited specifically the threat posed by growing PV penetration as a reason, which is a good example where we can see the market reacting to the solar-posed risks to the utility industry (Aneiro, 2014). Another instance of utilities losing credit ratings this year was when Moody's changed Hawaii's electric utility's credit outlook to negative, as discussed in an earlier chapter of this paper.

As we move along the hypothetical experience curve of PV, we reach a point when both homeowners and business owners realize that it's cheaper to make their own power than to buy utility power, and this is when adoption accelerates (Cinnamon, 2013). This adoption is then further accelerated when a homeowner or business owner, yet without solar panels, sees that their neighbor owns rooftop PV technology. Assuming that neighbor has done the calculations and concluded that it's financially reasonable to install rooftop PV panels, then that other homeowner is further incentivized to invest. This spillover affect jointly with government incentives and cost reductions increase residential PV penetration and pose a serious threat to utilities, as grid defection looms closer.

Through the process of self-consumption, passive consumers of electricity from the grid are transforming and becoming active 'prosumers', as mentioned before (European Commission, 2015a). This new phenomenon, and the factors affecting the traditional utility business model discussed in this chapter can be seen clearly in the so-called 'utility death spiral'. The definition of this is understood to be when consumers of the electricity from the grid turn to self-consumption through distributed solar PV, therefore decreasing the number of consumers. This in turn poses a loss of revenue for the utility, which has to compensate for the losses with an increase to the retail electricity rate, through spreading out their fixed and operational costs over that group of lower number of active consumers. This price increase drives more and more people to go partially or entirely off the grid, therefore causing the utility business model to collapse in a death spiral. As the traditional ‘user pays for the grid improvement’ model breaks down with residential customers exiting, the market for utilities becomes hollowed out. This recently emerged theory and trend has brought the attention of utilities to start the implementation and adaptation of new business models that integrate solar energy into their future plans.

3.5 Remote threats: alternatives to the grid

As utilities face imminent threats of grid defection from increasing distributed solar generation and market uncertainties from utility-scale solar, there are various other factors that start to pose a yet remote, but potentially also harmful effect on the traditional utility business model. In this chapter we will briefly discuss some of these ‘remote’ threats.

3.5.1 Solar start-ups and micro grids

As more research and capacity is helping solar costs to keep dropping, smaller companies, so-called start-ups, have emerged in the solar scene. Taking advantage of the distributed nature of solar technology, some of these start-ups aim to deliver electricity to remote areas of the developing world, where national utilities are either non-existent, or have yet to expand their transmission grid. We’ve seen examples of start-ups, such as M-KOPA, a Kenyan company, which delivered electricity to 200,000 homes, to an equivalent of about 1 million people that live off-grid across East Africa. The company reached this in just a few years, being launched in 2012, with the use of distributed solar technologies, that can easily be installed on rooftops with lowered upfront costs and come with a pay-as-you-use mobile payment service (M-KOPA, 2015). The mobile payment makes it easy to reach rural areas far away from cities with any appropriate infrastructure in place (M-KOPA, 2015).

Remote areas that are not connected to widespread national grids also have the option of creating so-called micro grids, which can be understood as a smaller version of a national grid, having a small generation side and a small-scale distribution side with few connected homes or businesses. The transmission also happens at a lower voltage. There have been examples of villages investing collectively in a micro grid, or a local business taking advantage of the opportunity and helping to provide electricity in areas that have lived without it up until then. These projects help the electrification of millions of people, but from a business strategy point of view, they are taking away possible expansion territories from the large utilities.

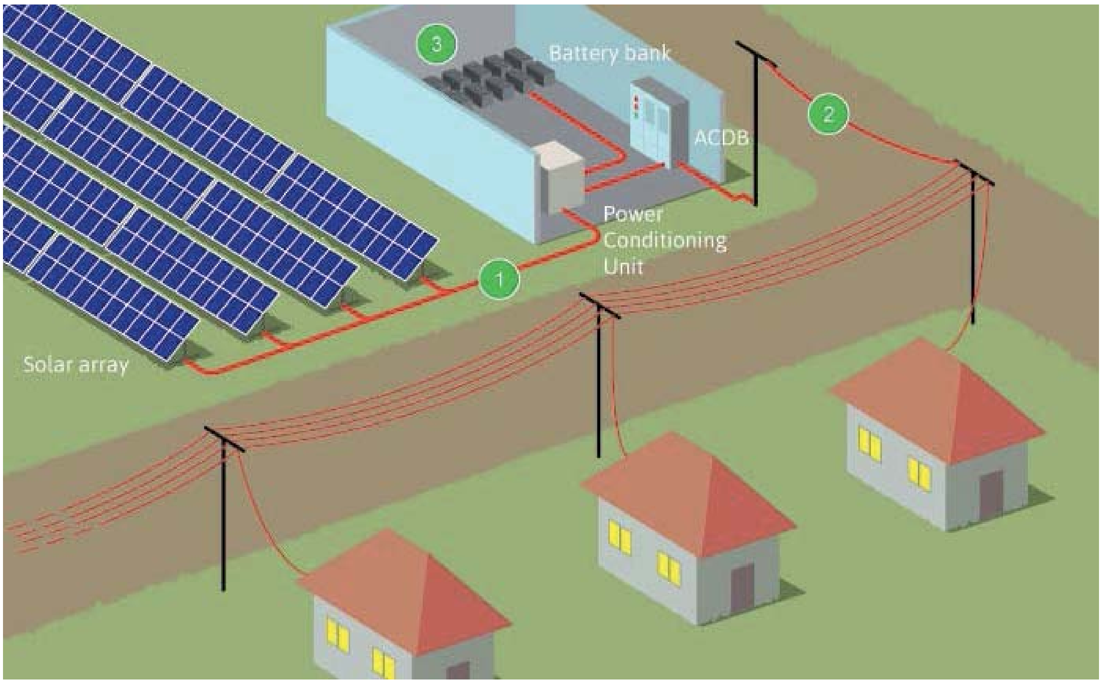


Figure 23: Hypothetical set-up of a micro grid. Source: Tata Power Solar, 2015.

3.5.2 Residential energy storage systems

In today's world of distributed solar electricity generation, most of the power generated is either lost or fed back to the grid, and applications to store energy locally are generally unfeasible due to their relative high costs. Lithium-ion (Li-ion) batteries are the preferred technologies in residential applications, but the current economics of a household storage system has yet prevented its high penetration. Falling prices of Li-ion batteries however provide the opportunity of more wide-scale usage of said technologies in the future. Going off-grid for a household in today's world would require an oversized battery, in order to keep up with its electricity demand. The demand curve of a household currently contains huge amounts of capacity curtail (waste) over the year, due to small storage options. At current economics, it makes sense to stay on-grid, whilst at the same time, if also feasible, invest in an energy storage system. In some countries where the retail electricity price from the grid is much higher than the sum paid to homeowners for the excess electricity from their rooftop PV system they sell back to the grid, storage can make sense, since it can reduce a homeowner's dependence on the grid, but it still cannot eliminate it entirely. For that scenario we would need largely oversized batteries. In countries with beneficial net metering schemes, battery storage makes even less sense for a household, as the grid acts as a de facto ‘social battery storage system’. In addition, there are also electrical safety concerns regarding energy storage, and just like their smaller counterparts used in electronics, the batteries have an infinite shelf life and deplete after a few years, bringing about the need of replacement.

Some countries have favourable policies in place when it comes to energy storage, and some policies, such as net metering, act as a natural deterrent for households, from an economic standpoint. Some utilities have gone as far as proposing and advocating for fees in cases of PV plus storage systems, therefore in a way penalising self-consumption. An example of key policies affecting end-user energy storage is the initiative led by the European Union, called stoRE, which aims to “facilitate the realization of the ambitious objectives for renewable energy by unlocking the potential for energy storage infrastructure”. This project mainly focuses on large-scale energy storage facilities such as pumped hydro energy storage (PHES) and compressed air energy storage (CAES) plants, which allows efficient energy storage on the large-scale generation side of the grid. There’s been similar initiatives in countries like Austria and Germany, in some cases accompanying this with residential subsidies (European Union, 2014). Europe’s leading market for energy storage is currently in Germany. Germany’s Energiewende goals along with the country’s grant programme, implemented by KfW development bank, have successfully contributed to the installation of about 15,000 residential storage systems by the end of 2014 (Bräutigam et al., 2015). This also brings along the concept of not only PV grid parity, but battery parity, which is demonstrated in the figure below. The figure forecasts that PV plus battery systems could become competitive with retail electricity prices in Germany before 2016.

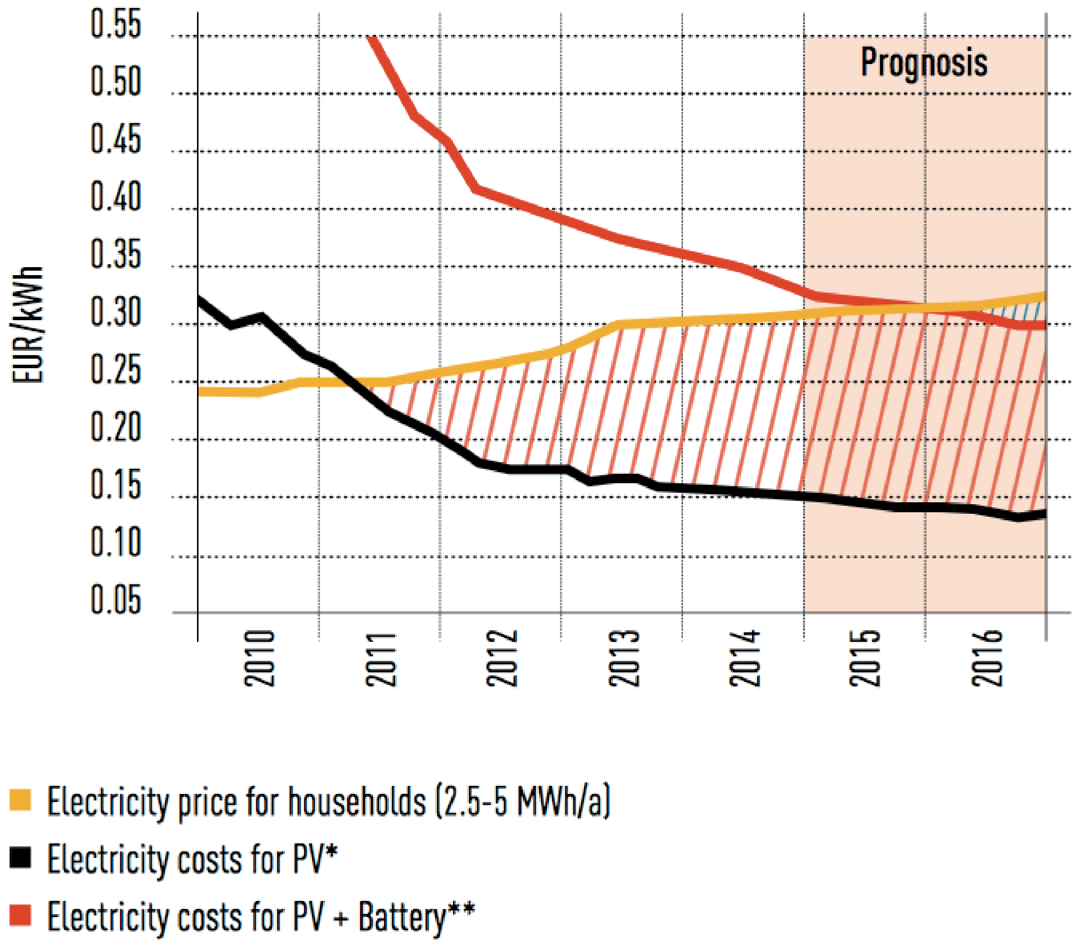


Figure 24: From grid parity to battery parity. Source: Germany Trade & Invest, 2015.

In other parts of the world, like Japan, the government went even further and in 2015 decided to offer high subsidies for residential Li-ion battery storage systems, paying up to two-thirds of the initial investment back to the homeowner. Japan turned to such measures because since the 2011 Fukushima disaster it has been battling acute energy problems, and energy storage could help manage peak demand periods. In other regions such as California and Puerto Rico, the governments have started using mandates to compel utilities to deploy energy storage capabilities (Colthorpe, 2014).

Recently we've seen interesting players enter the battery market such as Tesla Motors with its 'Powerwall' for residential application and 'Powerpack' for utilities, with a goal of making batteries a mainstream consumer product. Tesla has been building a battery 'Gigafactory' as well, which will be able to deliver these batteries in high volumes on demand. The factory is due to be finished in 2016. Other types of players include start-ups like Sonnenbatterie in Germany. As more and more companies enter the market, the economics of PV plus storage becomes better and grid defection comes one step closer to reality. The figure below shows a typical household, where battery storage can manage the intermittent aspect of renewable powers such as solar, where generation is only available during daytime.

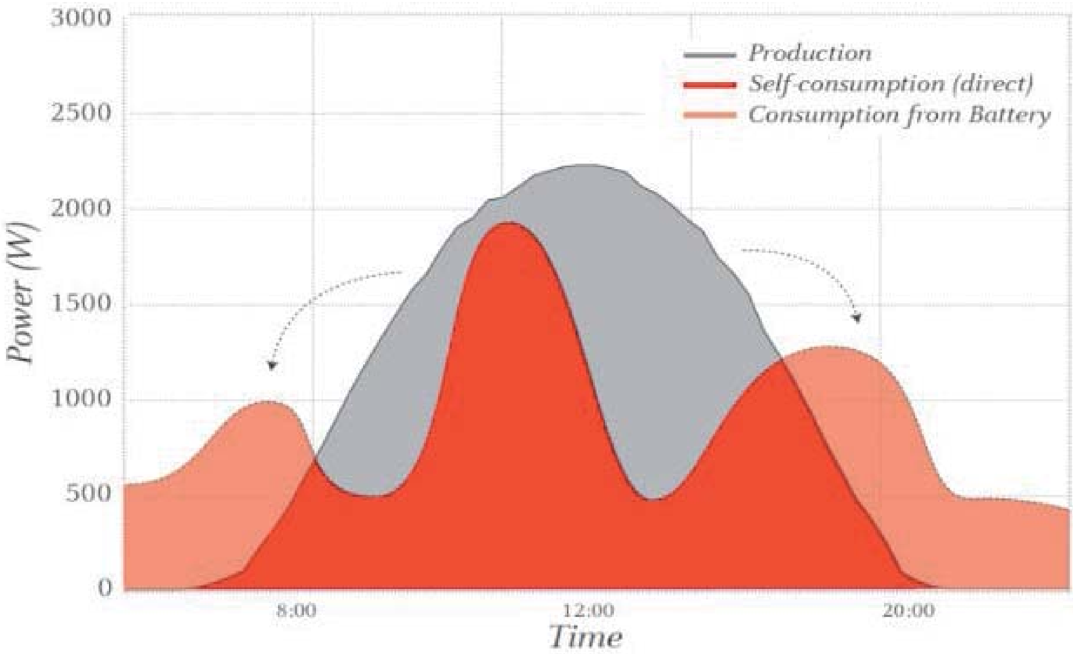


Figure 25: Effects of electrical storage on direct self-consumption (W/t). Source: European Commission, 2015.

As visible on the chart above, a large portion of daytime PV production is lost, unless paired with a battery storage system, or fed back into the grid through a net metering scheme, hence making the case for battery storage systems.

4. Future of the utility business model – possible strategies and outcomes

Utilities have been strategizing and restructuring to adapt to all these changes in the way we generate, distribute and consume electricity. The common themes for new utility business models are for example offering downstream services, providing system flexibility (such as making revenue through capacity markets) or investing in utility-scale renewables. There are numerous other alternative routes a utility can go down that's looking to cut back its losses originating from distributed solar growth.

4.1 Fight, flight or adapt

An important aspect of the decision a utility has to make when deciding which strategy to adopt, is in fact if that utility is regulated or unregulated. The revenues of unregulated entities are more volatile because they depend on weather and energy demand. Regulated utilities on the other hand have their pricing set by the regulators but don't always have the freedom to invest in new assets or businesses due to state regulation. Some utilities tend to be a hybrid between these two states, and have different assets with different levels of regulation. However, revenues and strategies depend largely on which bucket the utility or generation asset falls into. We've already discussed in detail throughout the thesis the threats and the possibilities that utility strategies are facing, but below we will outline the greater picture with a few examples.

4.1.1 Fight

When a utility realises the threat to its business is tangible, it has the option to legally fight back distributed generation. It can do this via seeking changes to rate structures, such as introducing time-of-use pricing, or through requesting caps on net metering, therefore limiting the amount of electricity that can be fed back into the grid. These measures, if passed by legislation have the power to make PV a less attractive option for investment. We've seen examples for these in the case of the Hawaii utility for example in earlier chapters.

4.1.2 Flight

A utility can also devote little or no attention to the threat of distributed PV. There can be several reasons for this. One option could be that the utility hasn't made its strategies public just yet. Another reason for no action could be that the territory the utility operates in has no substantial penetration of solar PV, therefore doesn't have the need to consider alternative business models. Also, if a utility is decoupled, and has its generation side separated from the distribution side, it's protected from the volatility in electricity wholesale prices. However, if a utility operates in a 'flight' mode, it could continue to increase its retail prices with no new energy management services, and that could lead to consumers going off-grid in order to save money and have better management over their energy consumption.

4.1.3 Adapt

The third, and most productive strategy from a revenue point of view for utilities is to adapt to the possible changes, and pursue new strategies that don't go against, but rather build in PV into their business models. For utilities first of all, demand-side management can be very important. Current structure of the grid and metering systems allow little to no visibility on household electricity consumption habits. Once smart meters are installed, both consumers and grid operators have the opportunity to regulate the electricity flow in a more sustainable way. Time-of-use pricing also provides the utility with extra revenue from electricity when it has the highest value, since peak and off peak electricity price differences would help customers better manage demand and would be favourable for utilities as well. In connection to this, utilities also have the option of moving to a management business model from a volume business model: providing for example only 30% energy and the rest in services compared to providing 100% energy to consumers like as of current structure. Another option for utilities would be to start providing new services or even bundled energy service packages, which we will discuss later in this chapter.

An interesting case in the world of new utility strategies is the New York model, where the utility becomes purchaser of energy from thousands of small generators such as households, and the revenue received is from the kWh sold through its system, regardless of where it's generated (State of New York Department of Public Service, 2015). This way the utility acts more like a manager or a middle-man of the energy distribution system, rather than the main player.

Utilities can also partake in the transformation of the electricity system, through passively investing in renewable energy portfolios. On the other hand, through active investment, a utility can merge or partner with renewable energy companies directly or invest in new technologies, such as energy storage or grid enhancement. To go down the route of providing new services, the utility has also the option of partnering with such companies that already operate in the field, therefore reducing the risk by relying on the established expertise of the partner company. (Lilinshtein and Di Capua, 2014)

4.1.3.1 New services: the connected home

As utilities begin to adapt to the changing landscape of electricity consumption, a new trend emerges, known as the connected or smart home. The traditional electricity consumption is where the household buys the electricity from the grid for a fixed price and then uses it without having the ability to better manage their consumption in an efficient way. This is where utilities can come into the picture, pairing with private enterprises in order to provide consumer services in the form of smart metering. Smart metering allows for greater demand side flexibility and allows for information flow and certain control from the utilities to end-users. This way not only can consumers better manage their consumption, but also utilities can have more information on electricity demand and better manage their generation side. In this new market, there's plenty of room for new players, as we've seen in recent trends, where companies not traditionally known to partake in electricity management have entered the market, such as telecommunications companies. Examples of these are Deutsche Telecom in Germany or Telefonica in Spain. But the market also allows for new start-ups or even technology giants to make their way into the world of connected home, such as Nest, which was acquired by Google, or Apple launching a new home electricity appliances management kit, the HomeKit (Liebreich, 2015).

4.2 Goodbye grid?

Finally, after having a look at all aspects of the relationship between the traditional utility business model and solar energy, the question is: can we expect the world's population to one-day go off-grid and resort to individual electricity generation, maintaining their own little 'ecosystem' of generation and storage? To answer the question, we have to take into account a few aspects. To start with the positive outlook for grid defection, the increasing amount of installed small-scale and distributed solar capacity is one indicator, as are the falling costs of solar technologies and battery technologies. If we assume, that at one point, an individual household can generate its electricity from solar panels, and store excess output in batteries at an economical rate, which is under the retail electricity price, then grid defection becomes the evident option (Figure 10). Grid defection can be seen as a long-term threat rather than a short term one, as economics of energy storage for households are poor at the moment. At current prices, grid defection makes no sense for a consumer, but with the changing dynamics, we could reach this point in the future, and at a large enough scale, that could mean the end of the traditional utility business model. The figure below shows the levelised cost of electricity for solar-plus-battery versus the utility retail price projections in the United States. According to the figure, Hawaii has already reached grid parity pre 2014, and other states such as California are forecasted to reach it in the next 15 years (Bronski et al., 2014).

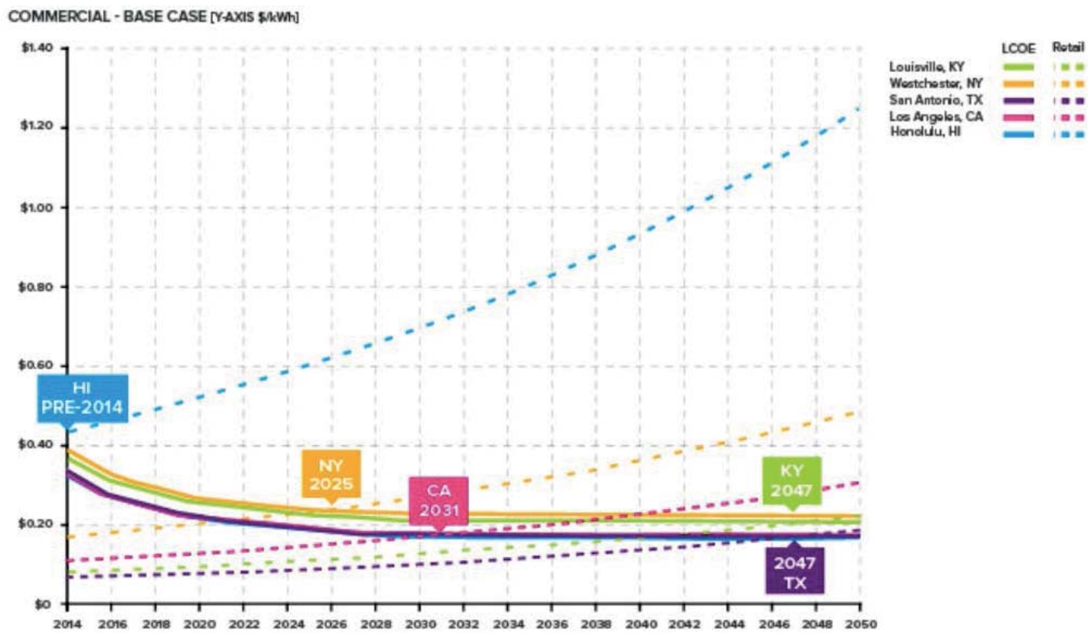


Figure 26: Solar-plus-battery levelised cost of electricity versus utility retail price projections in the US. Source: Rocky Mountain Institute, 2015.

Another possible future scenario is partial grid defection, where a consumer takes advantage of the government and utility support and uses the grid as a ‘social-battery’, meaning that any excess electricity is fed back and distributed amongst other consumers by the utility. This way the household is still partially dependent on the grid, mostly during night-time when solar panels don’t generate electricity. Until economics point to feeding back into the grid, rather than investing in battery storage, grid defection will not become an option for end-consumers. As of 2014, energy storage forecasts 2.3GW of capacity for 2020. Even if we look at 2014 PV data, which shows around 184GW of capacity globally, it’s clearly visible that the capacities don’t match for us to assume total grid defection to be a possibility in the near future (Bloomberg New Energy Finance, 2015a). Grid defection therefore can be seen as a long-term threat rather than a short term one, as economics of energy storage for households are poor at the moment. Another deterring factor for defection can be low retail electricity prices. US retail rates in real price have been dropping since 1960, and utilities that notice the potential threat of defection, have the opportunity to further decrease prices in an attempt to go against storage. Some countries have outright gone against grid-defection already today by introducing for example taxes on self-consumption, like in Germany, which poses a potential barrier to the wide-scale spread of energy storage and therefore grid defection.

A golden mid-route, from a consumer point of view, would be to reach grid-defection on a community level, rather than on an individual level. The potential in community-based schemes to meat peak demand is much higher than on an individual defected household level. A single consumer has a very high peak load and individual generation thus becomes uneconomic at current price levels. You would need about 100 consumers to have a lower statistical peak load: 1 consumer uses up to 15 kW of electricity on average, however, 100 consumers would need about 100 kW in total. An example for efforts supporting community-level grid defection is in Holland, where bulk PV purchases allow for lowered distributed technology investment costs. Such and other new options that arise for consumers are further transforming the electricity system and society's relationship with the grid.

Conclusion

After having a detailed look at the relationship between solar energy technology and the traditional electricity value chain, we can conclude that their dynamic is changing the way we generate and consume electricity. The electricity system as we know it is shifting rapidly to a new structure, where we all, utilities and consumers alike, are active players in this change. Starting from the first commercial adoption of solar cells in the 1950s, through to wide-scale mainstream adoption of solar energy in the last decades, we have seen governments, companies and end-users change their relationship with renewable energy and solar energy in particular. The initial boost to any new and expensive technology can easily commence through governmental support, both from the ideological and the financial sides. After solar energy received that boost globally, private companies have also started moving into this new profitable area of technology. As investment grows, system costs fall and capacity grows, more and more end-users take part in accelerating the technology spill over. The fight against climate change, and possibly already the United Nation's COP21 meeting in Paris in December 2015, will only further boost the renewable energy industry, and propel us towards a clean and brighter future. Electrification of rural areas of the developing world has also created a new opportunity for renewable and clean energy to spread. As we move away from the big monopoly-favouring centralized traditional grid, we are now starting to look at households as their own little world of being a de facto micro grid. Consumers become more aware of their environment and the importance of energy efficiency. Utilities get deregulated and unbundled and competition grows and drives electricity prices further down. We have already seen solar energy disrupt the wholesale electricity market with shifting the merit order. Electricity demand trends are changing globally too as developing nations shift in wealth and become developed. Distributed energy technologies like solar energy paired with battery storage possibilities give the option for consumers to become 'prosumers' – producers and consumers in one. Utilities have to realise that grid defection could become a possibility in the future, even if not in the short-term but in the long-term scenario. And this realisation is what leads them to the adoption of new strategies, may those be active or passive. Some utilities have gone down the path of passively not acknowledging the threat that distributed solar may pose in the future to their businesses. Some utilities have even gone down the passive-aggressive path of fighting government initiatives and support for solar plus energy storage, through measure such as curtailing net metering schemes or proposing cuts to feed in tariffs. And some utilities, which realised that this shift in dynamics may well as be an opportunity for their businesses to grow, have gone down the path of not only adapting to these changes, but becoming active players in it. The traditional utility business model is changing as we know it, and the players that see the connections between the new trends are the ones that have the opportunity to realise this early enough to rise as the future's main energy players. Solar energy has arrived and matured and it's about to become mainstream.

Bibliography

Advanced Energy Economy Institute, 2015. Toward a 21st Century Electricity System in California - A Joint Utility and Advanced Energy Industry Working Group Position Paper. [Online] http://info.aee.net/hubfs/PDF/aeei-toward-21ces-ca.pdf?t=1439494418628, - accessed: 10.21.15.

Aneiro, M., 2014. Barclays Downgrades Electric Utility Bonds, Sees Viable Solar Competition. Barron's. [Online] http://blogs.barrons.com/incomeinvesting/2014/05/23/barclays-downgrades-electric-utility-bonds-sees-viable-solar-competition/ - accessed: 10.20.15.

Bird, L., Heeter, J., Kreycik, C., Bird, L., Heeter, J., Kreycik, C., 2011. Solar Renewable Energy Certificate (SREC) Markets: Status and Trends. [Online] http://apps3.eere.energy.gov/greenpower/pdfs/52868.pdf - accessed: 10.21.15.

Bloomberg New Energy Finance, 2015a. New Energy Outlook 2015 - Solar. [Online] https://www.bnef.com/core/new-energy-outlook - accessed: 10.21.15.

Bloomberg New Energy Finance, 2015b. Policy dashboard [Online] www.bnef.com/policy - accessed: 10.20.15.

Braun, F., 1874. Uber die Stromleitung durch Schwefelmetalic. Ann. der Phys. Chemie 153, 556–563.

Bräutigam, A., Rothacher, T., Staubitz, H., Trost, R., MacDougall, W., 2015. The energy storage market in Germany. [Online] http://www.gtai.de/GTAI/Content/EN/Invest/_SharedDocs/Downloads/GTAI/Fact-sheets/Energy-environmental/fact-sheet-energy-storage-market-germany-en.pdf - accessed: 10.21.15.

Bronski, P., Creyts, J., Guccione, L., Madrazo, M., Mandel, J., Rader, B., Seif, D., Liliental, P., Glassmire, J., Abromowitz, J., Crowdis, M., Richardson, J., Schmidt, E., Tocco, H., 2014. The Economics of Grid Defection. [Online] http://www.rmi.org/electricity_grid_defection - accessed: 10.21.15.

Bundesministerium für Wirtschaft und Energie, 2015. 2014 Renewable Energy Sources Act: Plannable. Affordable. Efficient. [Online] http://www.bmwi.de/EN/Topics/Energy/Renewable-Energy/2014-renewable-energy-sources-act.html - accessed: 10.15.15.

Bundesministerium für Wirtschaft und Energie, 2014. Das Erneuerbare-Energien-Gesetz [Online] http://www.erneuerbare-energien.de/EE/Redaktion/DE/Dossier/eeg.html?cms_docId=71110 - accessed: 10.16.15.

Candelise, C., Winskel, M., Gross, R.J.K., 2013. The dynamics of solar PV costs and prices as a challenge for technology forecasting. Renew. Sustain. Energy Rev. 26, 96–107. doi:10.1016/j.rser.2013.05.012. [Online] http://www.research.ed.ac.uk/portal/files/10537606/1_s2.0_S1364032113003158_main.pdf - accessed: 10.21.15.

Chapin, D.M., Fuller, C.S., Pearson, G.L., 1964. A New Silicon p-n Junction Photocell for Converting Solar Radiation into Electrical Power. J. Appl. Phys. 25, 676.

Cinnamon, B., 2013. Solar Incentives Are Dead, Long Live Solar. GTM Res. [Online] http://www.greentechmedia.com/articles/read/Solar-Incentives-are-Dead-Long-Live-Solar - accessed: 10.20.15.

Code, U.S., 1935. PUBLIC UTILITY HOLDING COMPANY ACT OF 1935. United States Code, United States.

Colthorpe, A., 2014. Japan launches subsidies for lithium-ion battery storage. PV-Tech. [Online] http://www.pv-tech.org/news/japan_launches_subsidies_for_lithium_ion_battery_storage - accessed: 10.19.15.

Comello, S.D., Reichelstein, S.J., 2015. The U.S. Investment Tax Credit for Solar Energy: Alternatives to the Anticipated 2017 Step-Down (No. No. 3280). [Online] http://www.gsb.stanford.edu/faculty-research/working-papers/us-investment-tax-credit-solar-energy-alternatives-anticipated-2017 - accessed: 10.21.15.

Conrad, E.E., Gurtman, G.A., Kweder, G., Mandell, M.J., White, W.W., 2010. Collateral Damage to Satellites from an EMP Attack. Fort Belvoir. [Online] http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA531197 - accessed: 10.21.15.

European Commission, 2015a. Best practices on Renewable Energy Self-consumption (No. SWD(2015) 141 final). Brussels. [Online] http://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v6.pdf - accessed: 10.21.15.

European Commission, 2015b. Market legislation [Online] https://ec.europa.eu/energy/en/topics/markets-and-consumers/market-legislation - accessed: 10.10.15.

European Union, 2014. stoRE - Final Publishable Report. [Online] http://www.store-project.eu - accessed: 10.21.15.

Fehrenbacher, K., 2015. Apple, Walmart, Coca-Cola, others commit to White House climate change pledge. Fortune. [Online] http://fortune.com/2015/07/27/apple-walmart-coca-cola-others-commit-to-white-house-climate-change-pledge/ - accessed: 10.21.15.

Fiorelli, J., Zuercher-Martinson, M., 2013. How oversizing your array-to-inverter ratio can improve solar-power system performance. [Online] http://solectria.com//site/assets/files/1472/solectria_oversizing_your_array_july2013.pdf - accessed: 10.21.15.

Forbes, 2014. Understanding Solar Yieldcos. Trefis Team. [Online] http://www.forbes.com/sites/greatspeculations/2014/06/17/understanding-solar-yieldcos/ - accessed: 10.21.15.

Freeing the Grid, 2015. Introducing Freeing the Grid 2012 [Online] http://freeingthegrid.org/ - accessed: 10.17.15.

Glunz, S.W., Preu, R., Biro, D., 2012. Crystalline Silicon Solar Cells - State-of-the-art and future developments, Comprehensive Renewable Energy. Freiburg. doi:10.1016/B978-0-08-087872-0.00117-7. [Online] http://linkinghub.elsevier.com/retrieve/pii/B9780080878720001177 - accessed: 10.21.15.

Go Solar California, 2015. The California Solar Initiative - CSI [Online] http://www.gosolarcalifornia.ca.gov/csi/index.php - accessed: 10.19.15.

Go Solar California, 2014. Californi Public Utilities Commission California Solar Initiative Program Handbook August 2014. [Online] http://www.gosolarcalifornia.org/documents/CSI_HANDBOOK.PDF - accessed: 10.21.15.

Hallock, L., Kinman, M., 2015. California ' s Solar Success Story. [Online] http://www.environmentcalifornia.org/sites/environment/files/reports/CA_Solar_Success_scrn_FINAL_7-7-2015.pdf - accessed: 10.21.15.

Hawaii State Energy Office, 2015. Hawaii Energy Facts & Figures. [Online] http://energy.hawaii.gov/wp-content/uploads/2011/10/HSEO_FF_May2015.pdf - accessed: 10.21.15.

Hawaii State Legislature, 2015. A bill for an act related to renewable standards - HB623 HD2 SD2 CD1. United States of America.

Heeter, J., Bird, L., 2011. Status and Trends in U.S. Compliance and Voluntary Renewable Energy Certificate Markets (2010 Data). [Online] http://www.nrel.gov/docs/fy12osti/52925.pdf - accessed: 10.21.15.

Internation Energy Agency, 2007. Trends in photovoltaic applications: Survey report of selected IEA countries between 1992 and 2006. doi:10.1021/ac50054a041. [Online] http://www.iea-pvps.org/index.php?id=92&eID=dam_frontend_push&docID=156 - accessed: 10.21.15.

International Energy Agency, 2015. Snapshot of Global PV Markets 2014. [Online] http://www.iea-pvps.org/fileadmin/dam/public/report/technical/PVPS_report_-_A_Snapshot_of_Global_PV_-_1992-2014.pdf - accessed: 10.21.15.

Kollins, K., Speer, B., Cory, K., 2010. Solar PV Project Financing: Regulatory and Legislative Challenges for Third-Party PPA System Owners. [Online] http://www.nrel.gov/docs/fy10osti/46723.pdf - accessed: 10.21.15.

Kost, C., Mayer, J.M., Thomsen, J., Hartmann, N., Senkpiel, C., Philipps, S., Nold, S., Lude, S., Noha, S., Schlegl, T., 2013. Levelized Cost of Electricity Renewable Energy Technologies. [Online] https://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/study-levelized-cost-of-electricity-renewable-energies.pdf - accessed: 10.21.15.

Liebreich, M., 2015. Bloomberg New Energy Finance Summit 2015. New York. BNEF. [Online] http://about.bnef.com/content/uploads/sites/4/2015/04/BNEF_2014-04-08-ML-Summit-Keynote_Final.pdf - accessed: 10.21.15.

Liebreich, M., McCrone, A., 2015. Yieldcos - Two big questions. BNEF. [Online] http://about.bnef.com/content/uploads/sites/4/2015/07/McCrone-Liebreich-Yieldcos?two-big-questions.pdf - accessed: 10.21.15.

Lilinshtein, J., Di Capua, M., 2014. Fight, flight or adapt: How are US utilities coping with distributed PV? [Online] https://www.bnef.com/Insight/9718 - accessed: 10.21.15.

M-KOPA, 2015. 200,000th Home Connects to M-KOPA. M-KOPA. [Online] http://www.m-kopa.com/press-release/200000th-home-connects-to-m-kopa/ - accessed: 10.20.15.

Mann, W., 2014. Solar Renewable Energy Certificate Markets: Assessing the Volatility Impact. Washington University in St. Louis. [Online] https://economics.wustl.edu/files/economics/imce/whitney_mann_-_final.pdf - accessed: 10.21.15.

McCrone, A., 2015. Electricity demand - the blue whale in the room. BNEF. [Online] http://about.bnef.com/content/uploads/sites/4/2015/05/McCrone-electricity-demand-the-blue-whale-in-the-room.pdf - accessed: 10.21.15.

Michaels, R.J., 2004. Vertical integration and the restructuring of the U.S. electricity industry. [Online] https://www.michigan.gov/documents/energy/Restructuring_paper_2004_411701_7.pdf - accessed: 10.21.15.

Moody's, 2015. Rating Action: Moody's changes Hawaiian Electric Industries and Hawaiian Electric Company outlooks to negative. [Online] https://www.moodys.com/research/Moodys-changes-Hawaiian-Electric-Industries-and-Hawaiian-Electric-Company-outlooks--PR_332798 - accessed: 10.21.15.

National Grid, 2015. Third Energy Package [Online] http://www2.nationalgrid.com/UK/Industry-information/Europe/Third-energy-package/ - accessed: 10.19.15.

National Renewable Energy Laboratory, 2014. Levelized Cost of Energy (LCOE). Syst. Advis. Model. [Online] https://www.nrel.gov/analysis/sam/help/html-php/index.html?mtf_lcoe.htm - accessed: 10.20.15.

Ohl, R.S., 1946. Light-sensitive Electric Device. US2402662 A.

Ohl, R.S., Kingsbury, E.F., 1952. Photoelectric properties of ionically bombarded silicon. [Online] https://ia800904.us.archive.org/0/items/bstj31-4-802/bstj31-4-802.pdf - accessed: 10.21.15.

Perlin, J., 1999. From Space to Earth: The Story of Solar Electricity. aatec publications, Michigan.

Pierpont, B., 2012. Limiting the Cost of Renewables: Lessons for California Climate Policy Initiative. [Online] http://climatepolicyinitiative.org/wp-content/uploads/2012/06/Limiting-the-Cost-of-Renewables-Lessons-for-California.pdf - accessed: 10.21.15.

PV Magazine, 2015. Hawaiian utility bids to slash net metering payments [Online] http://www.pv-magazine.com/news/details/beitrag/hawaiian-utility-bids-to-slash-net-metering-payments_100019142/#axzz3kJIkuho0 - accessed: 10.19.15.

Reichelt, H., Davies, C., 2015. Getting to Know the Green Bond Market. [Online] http://treasury.worldbank.org/cmd/pdf/GettingtoKnowtheGreenBondMarket_PensionFundService.pdf - accessed: 10.21.15.

Renewable Energy Consumer Code, 2015. Feed-in Tariff Scheme 1–10. [Online] https://www.recc.org.uk/pdf/feed-in-tariff-scheme-guidance-for-consumers.pdf - accessed: 10.21.15.

Rifkin, J., 2015. A Smart Green Third Industrial Revolution 2015-2020 Digital Europe: The Rise of the Internet of Things and the Economic Transformation of the EU. Eur. Invest. Bank 1–14. [Online] http://www.eib.org/attachments/general/events/20150302_momentum_for_europe_rifkin_en.pdf - accessed: 10.21.15.

Rooze, J., Lawn, M., 2013. What has the internal electricity market done for you? [Online] https://www.bnef.com/Insight/8286 - accessed: 10.21.15.

Salvatore, J., 2014. Green bonds market outlook 2014. BNEF. [Online] http://about.bnef.com/white-papers/green-bonds-market-outlook-2014/content/uploads/sites/4/2014/06/2014-06-02-Green-bonds-market-outlook-2014.pdf - accessed: 10.21.15.

Schmalensee, R., Bulovic, V., 2015. The Future of Solar Energy. MIT Energy Initiative. [Online] http://mitei.mit.edu/system/files/MIT Future of Solar Energy Study_compressed.pdf - accessed: 10.21.15.

Solar Energy Industries Association, 2015. Net Metering. [Online] http://www.seia.org/policy/distributed-solar/net-metering - accessed: 10.10.15.

Solar Energy Research Institute, 1982. Basic Photovoltaic Principles and Methods. Technical Information Office. NREL. [Online] http://www.nrel.gov/docs/legosti/old/1448.pdf - accessed: 10.21.15.

SolarCity, 2015. SolarLease options for home [Online] http://www.solarcity.com/residential/affordable-solar-lease - accessed: 10.15.15.

State of New York Department of Public Service, 2015. Staff White Paper on Ratemaking and Utility Business Models. [Online] http://t.co/fz0Ks1hQh7 - accessed: 10.21.15.

Strahs, G., Tombari, C., 2006. Laying the Foundation for a Solar America: The Million Solar Roofs Initiative Final Report October 2006. NREL. [Online] http://www.nrel.gov/docs/fy07osti/40483.pdf - accessed: 10.21.15.

Tesla Motors, 2015. Tesla Energy [Online] http://www.teslamotors.com/en_GB/presskit/teslaenergy - accessed: 10.14.15.

The Council for Community and Economic Research, 2015. Cost of Living in Honolulu, Hawaii by Expense Category [Online] http://www.payscale.com/cost-of-living-calculator/Hawaii-Honolulu - accessed: 10.12.15.

The World Bank, 2014. World Bank Group President: This Is the Year of Climate Action [Online] http://www.worldbank.org/en/news/feature/2014/01/23/davos-world-bank-president-carbon-pricing - accessed: 10.12.15.

TheEnergyBlog Team, 2014. Hannover Messe 2014 - End usage and the democratization of energy. Siemens. [Online] https://blogs.siemens.com/theenergyblog/stories/2102/ - accessed: 10.20.15.

Trabish, H.K., 2015. Why can't utilities innovate like startups? Util. Dive. [Online] http://www.utilitydive.com/news/why-cant-utilities-innovate-like-startups/404045/ - accesse:d 10.20.15.

Trudeau, L., 2011. Net Metering. Minnesota Department of Commerce. [Online] http://www.infigenenergy.com/about-us.html - accessed: 10.21.15.

Turner, M., Buckley, D., 2015. Negative pricing in the GB wholesale electricity market. Baringa Partners LLP. [Online] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/441809/Baringa_DECC_CfD_Negative_Pricing_Report.pdf - accessed: 10.21.15.

UHERO, 2015. Efficient Design of Net Metering Agreements in Hawaii and Beyond. [Online] http://www.uhero.hawaii.edu/assets/Net_Metering.pdf - accessed: 10.21.15.

UHERO, 2014. The Costs and Benefits of Installing Solar PV [Online] http://www.uhero.hawaii.edu/news/view/274 - accessed 10.15.15.

UK Department of Energy & Climate Change, 2015. Controlling the cost of renewable energy [Online] https://www.gov.uk/government/news/controlling-the-cost-of-renewable-energy - accessed: 10.15.15.

Urdanick, M., 2014. A Deeper Look into Yieldco Structuring. Natl. Renew. Energy Lab. [Online] https://financere.nrel.gov/finance/content/deeper-look-yieldco-structuring - accessed: 10.15.15.

US Department of Energy, 2011. Quick Guide: Renewable Energy Certificates (RECs). NREL. [Online] http://www.nrel.gov/docs/fy11osti/52105.pdf - accessed: 10.21.15.

US Department of Energy, 2015a. Net Metering Program Info - Hawaii [Online] http://www.energy.gov/savings/net-metering-28 - accessed: 10.20.15.

US Department of Energy, 2015b. Residential Renewable Energy Tax Credit Program Info - Federal [Online] http://energy.gov/savings/residential-renewable-energy-tax-credit - accessed: 10.1.15.

US Energy Information Administration, 2015a. Hawaii’s electric system is changing with rooftop solar growth and new utility ownership [Online] http://www.eia.gov/todayinenergy/detail.cfm?id=19731 - accessed: 10.19.15.

US Energy Information Administration, 2015b. Electric Power Monthly: with data for July 2015. [Online] http://www.eia.gov/electricity/monthly/pdf/epm.pdf - accessed: 10.21.15.

US Energy Information Administration, 2015c. Net generation from electricity plants for all sectors, annual [Online] http://www.eia.gov/electricity/data/browser/#/topic/0?agg=2,0,1&fuel=vtvo&geo=g&sec=g&linechart=ELEC.GEN.ALL-US-99.A~ELEC.GEN.COW-US-99.A~ELEC.GEN.NG-US-99.A~ELEC.GEN.NUC-US-99.A~ELEC.GEN.HYC-US-99.A~ELEC.GEN.WND-US-99.A&columnchart=ELEC.GEN.ALL-US-99.A~ELEC.GEN.COW-US-99.A~ELEC.GEN.NG-US-99.A~ELEC.GEN.NUC-US-99.A~ELEC.GEN.HYC-US-99.A~ELEC.GEN.WND-US-99.A&map=ELEC.GEN.ALL-US-99.A&freq=A&ctype=linechart&ltype=pin&rtype=s&maptype=0&rse=0&pin= - accessed: 10.20.15.

US Energy Information Administration, 2012. Electric generator dispatch depends on system demand and the relative cost of operation [Online] http://www.eia.gov/todayinenergy/detail.cfm?id=7590 - accessed: 10.20.15.

US Environmental Protection Agency, 2014. Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units 79, 34829–34958. [Online] http://www2.epa.gov/sites/production/files/2015-08/documents/cpp-final-rule.pdf - accessed: 10.21.15.

US National Conference of State Legislatures, 2014. Net Metering: Policy Overview and State Legislative Updates [Online] http://www.ncsl.org/research/energy/net-metering-policy-overview-and-state-legislative-updates.aspx - accessed: 10.16.15.

Webb, A., 2015. LED Lights. Bloom. QuickTake. [Online] http://www.bloombergview.com/quicktake/led-lights - accessed: 10.20.15.

Wirtschaft und Infrastruktur GmbH, 2012. Definition of grid-parity for photovoltaics and development of measures to accompany PV applications to the grid parity and beyond. Intell. Energy Eur. [Online] https://ec.europa.eu/energy/intelligent/projects/en/projects/pv-parity - accessed: 10.21.15.

World Nuclear Association, 2015. Nuclear Power in Germany [Online] http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Germany/ - accessed: 10.17.15.

Yozwiak, M., 2015. How extending the investment tax credit would affect US solar build. BNEF. [Online] http://about.bnef.com/content/uploads/sites/4/2015/09/2015-09-15-White-Paper-How-extending-the-ITC-would-affect-US-solar-build.pdf - accessed: 10.21.15.

List of figures

http://apps3.eere.energy.gov/greenpower/markets/certificates.shtml?page=5 - accessed: September 12, 2015

Figure 10: New investment in clean energy by sector, Q1 2004 – Q2 2015 ($BN). Source: Bloomberg New Energy Finance, 2015. [Online] http://about.bnef.com/content/uploads/sites/4/2015/07/BNEF_Clean_Energy_FactPack_Q2-2015.pdf - accessed: September 1, 2015

Figure 11: Public benchmarks of residential PV system CapEx, $/W (DC). Source: Bloomberg New Energy Finance, Solarchoice, METI, BSW-Solar, California Solar Initiative, 2015. Q3 2015 PV market Outlook.

Figure 12: PV experience curve, 1976-2013 (2013 $/W). Source: Maycock, P., First Solar, Bloomberg New Energy Finance, 2014. [Online] https://www.iea.org/media/workshops/2014/solarelectricity/bnef2lcoeofpv.pdf - accessed: September 10, 2015

Figure 13: Solar installed cumulative capacity by region, 2012-2040 (GW). Source: Bloomberg New Energy Finance, 2015. New Energy Outlook 2015 – Solar.

Figure 14: Yieldco structure, Source: National Renewable Energy Laboratory, 2015. [Online] https://financere.nrel.gov/finance/content/deeper-look-yieldco-structuring#references - accessed: September 10, 2015

Figure 15: Annual green bond issuance by issuer type ($ billions/year). Source: Bloomberg, World Bank, 2015. [Online] http://treasury.worldbank.org/cmd/pdf/GettingtoKnowtheGreenBondMarket_PensionFundService.pdf - accessed: September 1, 2015

Figure 16: Formula for the levelised cost of electricity (LCOE) in $/kWh. Source: Fraunhofer Institut for Solar Energy Systems ISE, 2013. [Online] https://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/study-levelized-cost-of-electricity-renewable-energies.pdf - accessed: October 5, 2015

Figure 25: Effects of electrical storage on direct self-consumption (W/time). Source: European Commission, 2015. Best practices on Renewable Energy Self-consumption (No. SWD(2015) 141 final). Brussels. [Online] http://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v6.pdf - accessed: August 30, 2015

Figure 26: Solar-plus-battery levelised cost of electricity versus utility retail price projections. Source: Rocky Mountain Institute, 2015. [Online] http://www.rmi.org/electricity_grid_defection - accessed: September 20, 2015