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Internship Report: Solar Energy Policy

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1. Outline

This report is intended to provide information on the use of solar photovoltaic (PV) technologies in New Zealand. The term 'photovoltaic technologies' is used to refer to materials that convert radiation, in the form of sunlight, into electricity. The current use of solar PVs in New Zealand is outlined and the potential of PVs to address an increasing electricity demand, and the implications for New Zealand's energy landscape are discussed. Whilst other kinds of solar energy technology, such as solar thermal and concentrated solar power exist, this report will be focused solely on the application of solar PV systems.

Whilst committed to renewable energy and reduced emission targets, New Zealand does not currently have a national solar energy policy. Therefore, the solar energy policies of some key countries with more established PV markets are discussed and the effects of their implementation are outlined. Through examination of the implications of varying solar energy policies in different countries, this could provide New Zealand with an ideal platform from which to build its own solar energy policy. Insight into common issues, pitfalls and barriers to PV uptake can be gained through examination of how other countries have previously or are currently handling increased PV uptake. This report therefore highlights some policies that have demonstrated success internationally, as well as those that had unanticipated negative effects and how these effects were subsequently mitigated.

2. Introduction

The effects of anthropogenic global warming are becoming more apparent worldwide and there is growing public pressure for action to be taken by government and policy makers to move to 'greener' behaviours and to reduce our overall carbon footprint. It is becoming increasingly important for individuals, particularly those with influence in producing energy policy, to be aware of the changing energy demands on both a national and global scale. In 2016 New Zealand, alongside many other countries, signed the Paris Agreement and committed to reducing its greenhouse gas emissions. Currently, the world is not on track to meet international climate change goals. In 2018 global energy demand increased by approximately 2.3%, the greatest increase in a decade. Consequently, global energy related CO_2 emissions grew by an estimated 1.7% in 2018.[1]

New Zealand's unique geographic environment, combined with its small population, allows it to generate a significant proportion of its electricity from renewable sources. In 2017 New Zealand generated 82% of its electricity from renewable sources and ranked 4th in the OECD for primary renewable energy supply.[2] Hydropower is the major contributor to New Zealand's renewable energy generation, making up approximately 55-60% of the electricity supply.[2] New Zealand is proud of its strong position on using renewable sources to generate electricity, however in terms of net energy consumption, renewables made up only 39.6% of the energy supply in 2017.[2] The majority of New Zealand's energy demand comes from the transport and industry sectors, which rely almost entirely on fossil fuels. However, multiple future projections predict large changes in the net energy demand and importantly, its relative distribution.

Electrification of the transport and industrial sectors is anticipated, which will result in a significant increase in electricity demand. This increased electricity demand is unlikely to be met by hydropower unless consent is given to build additional hydroelectricity facilities. Therefore, the increased electricity demand needs to be met by additional sources. Solar PVs have the potential to help generate these additional electricity requirements. Many countries such as Australia and Germany, which cannot heavily rely on hydroelectricity, have made significant headway in introducing, developing, and successfully integrating solar PV systems into their electricity generation and distribution networks. This integration is continuing to progress, but its initiation was made possible due to a range of state and government policies. Although different in nature, they have functioned to provide incentives for individuals and businesses to use solar PVs.

Given New Zealand's significant solar energy potential (Section 5), solar PVs currently play a surprisingly small role in electricity production in New Zealand, making up only 0.2% of total electricity generation.[2] Solar PVs have shown the most rapid reduction in cost over the past decade than any other energy source and is currently the fastest growing form of energy.[3] According to the Energy Transition Outlook, by 2050 solar power is predicted to make up 40% of world electricity generation and 16% of the global energy supply.[3] Some objections have been made regarding the uptake of PV technology in New Zealand. It has been argued that because New Zealand already produces the majority of its electricity from renewable energy sources, there is no need to provide regional or national incentives to increase PV uptake because we would simply be replacing one renewable energy source with another. The inherent flaw in this type of argument is that it merely addresses a current 'snap-shot' of the energy landscape in New Zealand as it currently stands. It does not consider how energy demand, generation and distribution will change in the future.

Herein, the current use of solar PVs in New Zealand is outlined (Section 4). How New Zealand's energy landscape may look in the future and potential factors that may influence this are also discussed (Section 5). Different types of solar energy incentives and policies which have been implemented in different countries, and the consequences thereof, are introduced (Section 6). The successes and failures of solar energy policies in a range of countries may provide a useful guide for New Zealand to develop its own policy in the future. Even if significant solar energy incentives are not adopted by New Zealand, it is also important that New Zealand takes measures to make sure that the uptake of solar PVs is not actively hindered. This can be achieved by making sure that measures that actively dissuade PV uptake, such as 'solar taxes' which can have hugely destructive effects on the solar PV industry are not implemented. Lastly, different types of new emerging PV technologies and their potential application and impact are briefly discussed (Section 7).

3. Renewable energy policy in New Zealand

The Energy Efficiency and Conservation Authority (EECA) is the New Zealand government agency that focuses on improving energy efficiency in homes and businesses as well as encouraging the uptake of renewable energy. The EECA was established under the 'Energy Efficiency and Conservation Act 2000' (the Act). The Act gave New Zealand a legal means to promote energy efficiency, energy conservation and renewable energy. The EECA is monitored by the Ministry of Business, Innovation and Employment (MBIE), which advises the government on energy policy decisions. The long-term goals of the EECA are set by the government. The document 'Unlocking our Energy Productivity and Renewable potential – New Zealand Energy Efficiency and Conservation Strategy 2017-2022' (the Strategy) was prepared under the Act and is the national strategy on energy efficiency and renewable energy prepared under the Act. It is a guiding document for the EECA and highlights that New Zealand's large proportion of renewable electricity means that electrification is a significant opportunity to decarbonise New Zealand. It acknowledges the significant role electric vehicles, solar PVs and battery storage will play in this transformation. The document is a companion to the 'New Zealand Energy Strategy 2011-2021' (the NZES) which is the government's primary statement of energy policy.

The NZES 2011-2021 sets up a strategy for the energy sector and the role of energy in New Zealand's economy. The overall goal is to 'grow the New Zealand economy to deliver greater prosperity, security and opportunities for all New Zealanders'. The NZES is split into four key priorities for government focus, namely; diverse resource development, environmental responsibility, efficient use of energy and secure and affordable energy.

New Zealand currently has a target of 90% electricity to be generated from renewable sources by 2025. The 2011 National Policy Statement on Renewable Electricity Generation acknowledges solar energy on the list of renewable energy sources but there are no solar specific policy incentives.

4. Solar energy in New Zealand: Current state of play

In New Zealand, electricity is generated by five major companies, who are also the major retail companies. These generation companies own and operate electric power stations spread throughout the country. National electricity transmission from power stations to substations is operated by Transpower, which is owned by the state. The transmission system includes substations, high voltage cables, transformers, and high voltage overhead transmission lines. Transpower transmits electricity to the 29 distributional (line) companies in New Zealand as well as directly to some large industrial companies. The distribution companies then sell and distribute electricity to retailers who then sell electricity to consumers.

In 2017, 81.9% of New Zealand's electricity was generated from renewable resources. However, renewable sources only make up 39.6% of New Zealand's total energy supply (Figure 1.1).[2] The majority, typically 55-60% of New Zealand's electricity, is generated through hydro power, with geothermal energy for electricity generation making up over 17% of the total electricity demand in 2017 (Figure 1.2).[2] Solar PVs provided less than 0.2% of total electricity generation. Nonetheless, uptake of solar PVs is increasing, with 17 MW of PV installed in 2017, bringing the total up to 69 MW at the end of 2017 with 17,672 connections.[2] The current PV capacity increased to 78 MW in July 2018[2] and has now exceed 85 MW.[4] The uptake of PVs in New Zealand significantly lags that of other developed countries, as does policy on solar energy. Despite some claims to the contrary, in terms of average incident solar radiation, New Zealand receives 2,000 hours of bright sunshine every year. This equates to an average solar resource of ~4 kWh/m^2 horizontal to the ground, per day.[5,6] This is higher than Germany, one of the leading countries in solar energy generation.

Solar energy has several appealing factors. The idea of being able to independently generate, store and manage one's own electricity is rapidly increasing in popularity. This has been driven by frustrations with increasing grid electricity costs and the decreasing costs of PVs and batteries, reducing the net payback time. Additionally, with increased public awareness of anthropogenic global warming and the consequences thereof becoming increasing apparent, there is additional momentum pushing for a greener, renewable energy future.

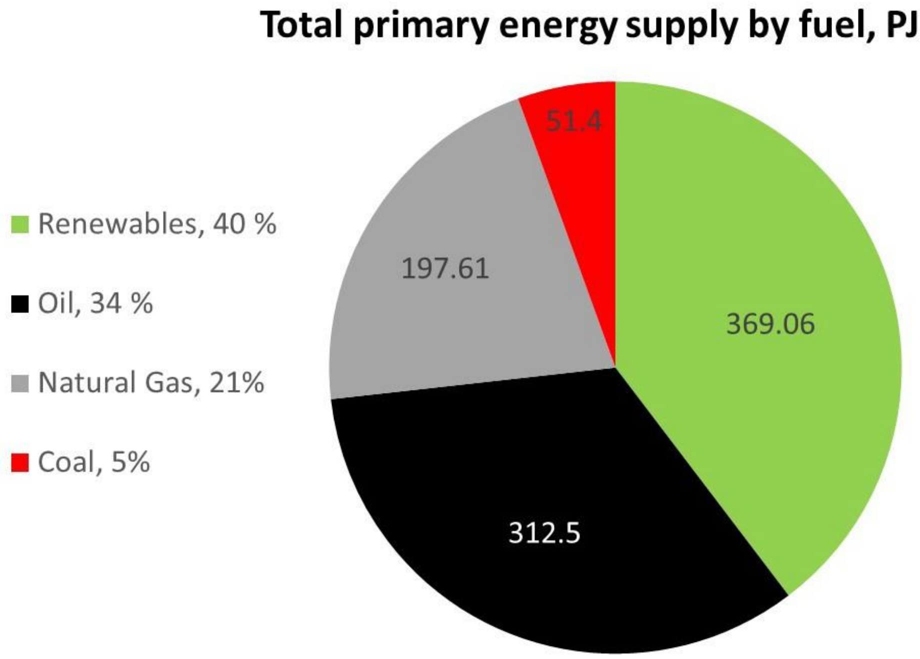

Figure 1.1: New Zealand total primary energy supply by fuel in 2017. Data obtained from 'Energy in New Zealand 2018'[2] (PJ = petajoules)

New Zealand households and businesses with rooftop PV systems that are connected to the grid have the ability to sell any excess electricity back to the grid (Section 6). When rooftop solar PV systems were just starting to be installed, these buyback rates were high, equal or similar to the purchase price of electricity. However, in 2014 major companies such as Meridian and Contact Energy cut the buyback rates to roughly a third of the purchase electricity cost, a reduction from 25¢ per kWh to 7-8¢ per kWh. This was most likely a commercial decision intended to maximise the companies' profits.

Although electricity prices have continued to rise, the buyback rates remain at 7-8¢ per kWh. The sudden drop in buyback rates meant that those who had purchased solar PV systems before the drop had their payback time hugely increased. This made having solar PV systems a less economically sound investment. The buyback rate for renewable electricity generation is lower than in many other countries, who have instead tended to use a feed-in tariff (FIT) system which typically offers a long-term contract with a fixed purchase agreement. FITs and other solar energy policies are discussed in more detail in Section 6.

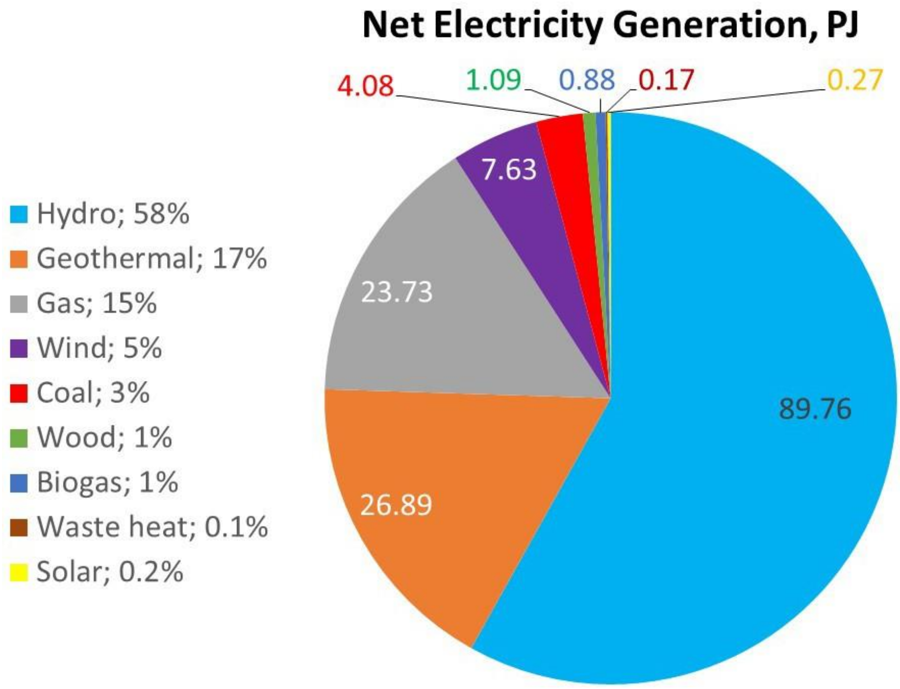

Figure 1.2: New Zealand electricity generation in 2017. Data obtained from 'Energy in New Zealand 2018'[2] (PJ = petajoules)

Solar energy in New Zealand: Solar energy future

The EECA refers to solar PVs as a type of 'disruptive technology' as they have the potential to significantly change the global electricity industry. However, there are still currently both financial and practical obstacles for widespread PV implementation. A household PV system still costs several thousand dollars to install, with a payback time of roughly ten years. A battery is an additional cost, further extending the payback time. Furthermore, currently PV systems are not suitable for all households or buildings, as factors such as location, roof orientation and angle and nearby surroundings which could shade the roof, greatly affecting output. However, increasing technological improvements continue to lower the price of solar PV systems and batteries, making them a viable option to an increasing number of consumers. Likewise, there is significant scientific interest in development of a range of new types of solar PVs. Several the emerging PV technologies possess physical and chemical properties that greatly differ to those of traditional solar panels and may provide alternate, cheaper PV options in the future (Section 7).

In 2017 the consumer energy demand of New Zealand was 590.52 PJ, an increase of 16.01 PJ from 2016 from which 13.50 PJ came from increases in the transport sector.[2] The transport and industry sectors make up the majority of New Zealand's energy demand, using 231.49 PJ and 210.54 PJ, respectively.[2] In the transport sector, 231.26 PJ came from oil.[2] Increased electrification of the transport sector would have a significant impact on energy distribution and total use (Section 5). As stated previously, New Zealand's future electricity demand is predicted to significantly increase. The Te Mauri Hiko Energy Futures report predicts that electricity demand will more than double by 2050. Increasing from its current value of approximately 40 TWh a year to 90 TWh by 2050.[7] A large part of this increase is attributed to electrification of sectors and processes whose energy needs have been traditionally met with fossil fuels or other non-renewable sources. According to the EECA strategy 2017-2022 the greatest potential for New Zealand to reduce its emissions lies in the process heat and transport sectors. Improving the efficiency and reducing the emissions of the transport sector alongside promoting innovative and efficient electricity usage, are among the primary goals of the EECA strategy.

Electric vehicles

Widespread electrification of the transport sector would have a significant impact on the net amount and the distribution of energy in New Zealand and would considerably reduce greenhouse gas emissions.[7] Driving electric vehicles does not result in any emissions and they are significantly more efficient than petrol or diesel vehicles.[8] Electric vehicles convert ~90% of energy from their batteries to motive energy compared to that of ~20-30% for internal combustion engine vehicles.[8] This significant increase in efficiency would greatly reduce total energy demand. Additionally, based on current off-peak electricity prices, charging an electric vehicle is approximately 15% of the cost of running a petrol or diesel car of the same size [8] This is roughly equivalent to paying ~3¢ a litre for fuel.[8] The EECA performed a lifecycle analysis of electric vehicles compared to that of internal combustion engine vehicles. Even when factors such as raw material extraction, battery manufacture, maintenance and shipping were considered, electric vehicles were shown to have 60% fewer climate change emissions over the full life cycle compared to petrol or diesel vehicles.[8]

As discussed previously, the majority of electricity in New Zealand is generated through hydropower and when additional energy is required, non-renewable sources are often used. Instead of using non-renewables, solar PVs stand in good stead to make up this extra electricity demand. Through a combination of rooftop solar PVs and batteries, solar energy could be stored during the day, charging the battery such that it could be used on demand, to run household appliances and/or charge electric vehicles.

An analysis conducted by mysolarquotes.co.nz provides a rough estimate of the solar energy, and hence PV capacity required to charge an electric vehicle.[9] Using a Nissan Leaf from 2018 with a 38 kWh battery capacity and assuming an average daily driving distance of 28 km, you would need 4.4 kWh of solar power per day, equal to 1,752 kWh a year, to meet the energy requirements to charge the vehicle. A 2 kW PV array would be comprised of 10 x 200 W panels and in Auckland would have a rough a daily average solar power generation of ~7.8 kWh. However, daily household solar energy production will clearly vary with location and time of year with the monthly average dropping to 4.46 kWh in June, just below the charging requirements. This does not leave any excess energy for any other household requirements so in this instance electricity would therefore need to be drawn from the grid.

Solar energy storage

Given the variable and intermittent nature of solar energy, installation of solar PVs is best accompanied by a means by which to store the energy generated during the day. This is beneficial to both the consumer and the electricity provider. When accompanied by a battery, electricity generated during the middle of the afternoon, typically when household energy consumption is low, is therefore not wasted and can instead be used later, such as during the evening peak period, when solar irradiance is low. This also benefits the electricity companies by helping to reduce peak electricity demand on the network. However, solar PV batteries are expensive and therefore increase the payback time for PV systems. However, the cost of batteries is decreasing. Lithium-ion batteries have decreased in cost by 79% since 2010,[10] and could decrease by another possible 54% by 2030.[11]

Another means by which excess solar energy could be stored is through hydrogen generation. Electricity generated from solar PVs could be used in the electrolysis of water to generate hydrogen, which in turn could be stored and used for a range of energy needs.

5. International solar energy: Use and policy

Numerous countries have adopted some form of solar energy policy to promote clean energy use and to provide incentives to increase solar PV uptake for both businesses and residential electricity consumers. In 2017, 168 countries had established renewable energy targets and renewable energy policies were found in 121 countries.[1] However, sometimes certain policies have attracted controversy or resulted in unintended, negative effects such as decreasing PV uptake or jeopardising small PV companies.

International solar energy policies are continuing to be developed as the PV and renewable energy market matures. The solar energy policies of some key countries with significant PV capacity are outlined below and both the positive and negative implications discussed. This could provide a useful information base from which New Zealand could build its own solar energy policy. As solar PVs become more established, the need for government support through subsidies or other means decreases. However, these solar subsidies are often an important tool to support and encourage their growth, particularly in newly developing markets. In some cases, national policies are not in place, however sometimes states, cities or other jurisdictions have implemented their own strategies. These can also lead to significant changes and, given the reduced management size, are often easier to implement than nationwide policies.

Types of solar energy incentives

One of the most common policies is the introduction of feed-in-tariffs (FITs). FITs are a type of 'clean energy cashback' scheme designed to function as an incentive to increase investment in renewable energy electricity production. FITs have been shown to be one of the most effective government policies for increasing the uptake of renewable energy technologies and are used around the world.[12] Consumers who generate their own electricity through renewable sources are paid a cost-based price per kWh, dependent on the type of renewable energy and the technology used, typically offered as long-term contracts. FITs are designed to offer cost-based compensation to renewable energy producers and are designed to be reduced over time to encourage technological development. There are both net and gross FITs, which respectively pay consumers for any unused energy that is put back into the grid or for every unit of electricity generated, even if it is used.

Another type of incentive for corporations or individuals to increase their usage of renewables is known as a power purchase agreement (PPA) which is a contract between two parties. In a solar PPA, one party with a solar PV system leases the electricity generated to another party, often a company or a corporation. This allows the buyer to utilise renewable energy without having generate it themselves, avoiding the complications and costs of solar installations. The PPA contract may last for several years. PPAs are found in many countries including the US and China. [1]

Renewable energy auctions, sometimes known as competitive tenders or bids, are also becoming increasingly popular and have helped to lower the cost of renewable energy electricity generation. The government issues a call for tenders to procure a certain capacity or generation of renewables-based electricity. The renewable energy project developers then function as bidders. They submit bids to gain governmental support for renewable energy generation projects that they wish to construct.

Grid integration - myths and reality

There have been a number of studies investigating the potential effects of increased PV penetration on electricity networks.[13–16] One of advantages of PV systems is that excess electricity generated can be sold and fed back into the local network. However, this reversal of power flow can sometimes cause some network issues, typically at the middle of the day in areas with a large PV capacity. However, these effects greatly depend on the extent of PV penetration and the capabilities of the local network and can be greatly mitigated by battery storage.

Integration of variable renewable energy (VRE) systems to an established electricity system will be accompanied by new challenges and questions that need to be addressed if significant PV integration occurs. However, such challenges are dependent on several factors and can be readily addressed with informed planning and procedure, as has been seen in other countries with more established PV markets. It is very important that the breadth and scale of such challenges is not overstated. According to the IEA report 'Getting Wind and Sun into the Grid',[17] integration of variable renewable energy is often 'still marred by misconceptions, myths, and in cases even misinformation' that can have adverse effects of PV uptake.

'Where VRE power plants are small and dispersed over the low voltage grid (e.g. rooftop solar PV), managing the interface between the (high voltage) transmission network and (lower voltage) local networks emerges as a priority. International experiences show that a well-balanced portfolio of wind and solar PV power plants, for example, can have complementary electricity output profiles, which may enable the better use of existing grid assets.'

The Te Mauri Hiko 'The sun rises on a on solar energy future' report stated that electricity distribution networks in New Zealand would be able to handle increased distributed solar. *'By exploiting the natural partnership between solar and battery technology (and the utilisation of inverter capabilities), anticipated voltage constraints in electricity networks could be managed to enable networks to host 9-10 GW of solar.'*[4] They stated that operationally significant solar could be well integrated with batteries. '*A significant amount of energy storage and flexible generation in the form of New Zealand's hydro system provides enough capacity to manage New Zealand's evening peak demand ramp up, even with solar penetration of up to 10 GW.'*[4] The Te Mauri Hiko Energy Future report emphasises that new technologies such as PVs will play a large role in New Zealand's energy future and that our whole electricity network from the power stations to local distribution networks need to prepare for the coming transformation.

It is important for New Zealand to be aware of potential issues that may arise with increased VRE integration such that New Zealand can take appropriate and informed actions. As emphasised by the IEA, '*if such actions are omitted then further deployment of VRE and the security of electricity supply may be jeopardised.'* Likewise, it is imperative that myths, misconceptions and misinformation regarding VRE integration are addressed as these could additionally function to limit their uptake. According to the IEA report, *'...while it is true that new challenges do arise as the share of wind and solar power increases on a power system, in fact these are usually very different from the concerns frequently expressed by those unfamiliar with these technologies.'*

Worldwide

In mid-2018 the total globally installed PV capacity exceeded 500 GW, with 99.8 GW installed in 2018.[18] Solar PVs meet ~2.58% of the global electricity demand.[18] The top 10 countries for PV installation in 2018 and total cumulative PV installation are shown in Table 1.1 (data from PVPS 2019 Snapshot of Global PV Markets).[18] New Zealand's PV capacity is currently only at ~0.085 GW (85 MW), the majority of which was installed in the past two years.[4]

Germany

In 1991 Germany introduced the Electricity Feed-in Act which was designed to promote electricity generated through renewables. It ensured that that grids had access to electricity generated from renewable sources and obligated utilities operating the public grid to pay long term FITs for electricity generated from renewable sources fed into the grid. These tariffs are paid by all consumers of electricity (except those of energy intensive industries) in the form of a surcharge. This act was superseded in 2000 through introduction of the Renewable Energy Act (Erneuerbare-Energien-Gesetz, EEG) to encourage the uptake of renewable energy technologies. It provides renewable energy, technology specific FITs, and grid operators are required to preferentially dispatch electricity generated from renewable sources, allowing smaller enterprises to access the electricity system. The FITs are guaranteed for 20 years and designed to decrease at regular intervals, a process known as 'degression.' This mechanism is designed to promote technological developments and provide incentives for cheaper renewable energy production.

Table 1.1: Top 10 countries for PV installations and total installed capacity in 2018.[a]

Annual Installed Capacity			Cumulative Capacity		
Ranking	Country	GW	Ranking	Country	GW
1	China	45	1	China	176.1
2	India	10.8	2	USA	62.2
3	USA	10.6	3	Japan	56
4	Japan	6.5	4	Germany	45.4
5	Australia	3.8	5	India	32.9
6	Germany	3	6	Italy	20.1
7	Mexico	2.7	7	UK	13
8	Korea	2	8	Australia	11.3
9	Turkey	1.6	9	France	9
10	Netherlands	1.3	10	Korea	7.9
	EU	8.3		EU	115
	New Zealand			New Zealand	0.085[b]

[a] Values obtained from Reference[18]

[b] Values obtained from Reference[4]

The EEG resulted in the rapid escalation of solar panel producers and service companies, with the solar PV capacity increasing from 6 GW in 2008 to 36 GW in 2013. The EEG is credited with enabling Germany's renewables growth. Germany became one of the global leaders in solar energy. However, from around 2012 the solar industry in Germany began to decline. This was largely attributed to the introduction of significantly cheaper solar panels from China and other countries. This negatively affected Germany PV manufactures as consumers were still able to obtain the FITs using Chinese made PV systems and resulted in the closure of several Germany solar companies and significant job losses. In 2013 the European Commission introduced trade controls to help protect the European market from cheaper Chinese imports. These trade controls ended in late 2018. The German market may turn to focus on integrated system modules and how energy can be stored at home or shared or traded with neighbours. There is a trend toward 'self-supply' and decentralised solar PV production.

In 2017 the EEG was reformed, such that for certain sectors FITs will be discarded in favour of a new, renewable energy auction-based system. Therefore, only renewables installations which have won a tender will receive payments for the power they supply. Smaller installations with a capacity under 750 kW will continue to receive FITs. A trial auction system began in 2015 for large-scale, ground-mounted photovoltaic plants. The reform was designed to increase market exposure to the renewable sector and to improve the relationship between renewables and grid development. It exists alongside the 'deployment corridor' outline in 2013 which specified deployment corridors for renewables development, setting goals for the percentage of Germany's gross power consumption covered by renewables, namely 40-45% by 2025, 55-60% by 2035 and 80% by 2050. The deployment corridor for PV systems is 2.5 GW a year, of which an annual capacity of 600 MW will be auctioned. The remaining amount is made up of multiple, smaller PV systems which are not up for auction. FITs for new installations will be ceased when a total capacity of 52 GW is reached. In late 2018 Germany's total PV capacity was 45.9 GW.[19] The idea behind the reform and the deployment corridor was to better control renewables development and adjust it to grid expansion.

- https://www.cleanenergywire.org/factsheets/solar-power-germany-output-business-perspectives
- https://www.cleanenergywire.org/factsheets/eeg-reform-2016-switching-auctions-renewables
- https://www.cleanenergywire.org/factsheets/defining-features-renewable-energy-act-eeg
- https://www.cleanenergywire.org/news/auctions-set-price-wind-and-solar-debate
- https://www.wolfgang-gruendinger.de/wp-content/uploads/2015/06/6-renewables-pdf

Spain

Initially the solar industry in Spain was promoted through high FITs and in 2008 Spain possessed the second highest installed PV capacity in the world, behind that of Germany. However, in the wake of the global financial crisis, government subsidies were significantly cut in 2008 and restrictions were placed on the allowed installation capacity per year. In 2015 the notorious 'sun tax' was introduced in 2015 by the conservative Popular Party and was frowned upon globally. The 'sun tax' involved a complex set of tolls and charges to grid-connected behind the meter distributed generation, with the idea being to prevent renewables from overloading the grid. The government did not specify exactly how such taxes would be collected but nonetheless the policy and the associated uncertainty effectively brought PV installations to a halt.

In 2018 the newly elected government, Pedro S´anchez's Socialist Party (PSOE) removed the sun tax such that Spanish consumers could now install solar PV systems in their homes and businesses without being hindered by additional fees or complex administrative barriers. Following the introduction of new regulations, demand for solar PV systems in homes and businesses has dramatically increased. Additional factors such as some local authorities issuing lower property taxes on households with solar panels has provided an additional incentive.

'The re-emerging boom in Spanish solar PV is not being driven by subsidies or government tenders but as a result of solar being a highly cost effective proposition for electricity needs.'

- https://www.greentechmedia.com/articles/read/spain-abolishes-the-tax-on-the-sun#gs.12i67z
- https://elpais.com/elpais/2019/06/24/inenglish/1561389834_185650.html
- https://phys.org/news/2018-03-solar-spanish-sun.html

Australia

The high insolation levels in Australia makes it one of the best solar resources in the world and hence solar PV installations have huge potential across the country. In Australia, one in five homes have solar PV installations. There are also a number of large-scale solar farms, with 61 more due to be built in 2019. As of June 2019, there are 2.15 million PV installations in Australia with a combined capacity of over 12.9 GW. Small scale PV systems were responsible for 19.6% of Australia's total clean energy generation and 4.2% of the net electricity. In 2018 Australia had the second highest solar PV per capita of 459 W per capita, second only to Germany. [18]

The federal Renewable Energy Target (RET) introduced in 2010 was critical in supporting the clean energy industry. The RET 'has shown the merit of developing an effective national policy and leaving it alone to let the market work.' The RET aims to reduce greenhouse gas emissions in the energy sector and aims to achieve a minimum of 20% electricity generated from renewable resources by 2020 and is made up of two schemes. The first is the 'Large-scale Renewable Energy Target' (LRET) which financially supports large scale development of renewable energy power stations, such as solar farms. It requires high-energy users to obtain a fixed proportion of their electricity from renewable sources. Large renewable power stations acquire large-scale generation certificates (LGCs) which are then sold to high-end users under the obligation. The Clean Energy Regulator announced in January 2018 that the LRET is anticipated to meet its target before the 2020 deadline. The renewable electricity target remains the same from 2020 to 2030, but high energy users are required to meet renewables obligations through LGCs until 2030. As the percentage of renewables increases, more LGCs will be produced, reducing their cost. There is currently no new policy to replace it and there are fears that the renewable energy movement will lose momentum. *'Most state governments have worked to fill the void left by the absence of a national climate and energy policy. While a strong, consistent national policy remains preferable to navigating a patchwork of individual jurisdictions, state and territory policy measures have been crucial in driving new investment*.'

The second scheme is the 'Small-scale Renewable Energy Scheme' (SRES) which is designed to provide financial incentives for households and smaller businesses to install small scale renewable energy sources, such as solar panels. Small-scale technology certificates (STCs) are issued for a system's power anticipated power generation and larger energy users are required to purchase a fixed proportion of STCs. The values of the STCs decrease every year until the scheme ends in 2030.

Measures have also been included to prevent solar tax. In 2015 the Federal Court ruled in favour of a decision that would prevent South Australian Power Networks from charging households with solar panels additional fees. This was an important decision as it demonstrated to all electricity providers that that they *'cannot unfairly charge solar households more to cover the cost of their poor planning for an electricity network changing from fossil fuels to greener energy and lower consumption.'*

Australia has rebates and FITs which have helped to drive the rapid uptake of PVs. Australia does not have nationwide FIT programme. Instead, each State and Territory runs schemes that vary between jurisdictions. For the most part, jurisdictions have a minimum set FIT amount which is paid to residents who export any excess electricity back to the grid generated from rooftop solar PV systems. However, whilst well intentioned, the FITs and rebates have not always functioned as intended.

The Victorian Solar Panel Rebate is a $1.34 billion scheme designed to help 650,000 households save on solar PV installations. It began in 2018 and was designed to significantly subsidise rooftop solar panels for residents in Victoria, offering up to $2,250 per household. As a result, the number of solar

PV installations increased substantially and caused solar installers to purchase additional equipment and hire additional staff to cope with the increasing demand. However, after the first six months the number of PV allocations available was exhausted. Understandably, interested buyers delayed purchasing solar PVs until the next allocation number were opened the following month. This resulted in a huge drop in solar installations and caused solar companies, particularly smaller ones, to suffer and even go into liquidation. In July 2019, the entire month's quota of 3,300 rebates was exhausted in three days. In August, it sold out in two hours. The scheme has been met with significant backlash, stating that it was ruining the solar industry and putting small companies out of business. This is a prime example of how a well-intentioned scheme that was not carefully planned can have damaging, counterproductive consequences. Calls have been made for the scheme to be cancelled or adjusted in different ways. For example, reducing eligibility by changing the minimum household income required to be eligible for the scheme or halving the rebate and thereby doubling the available quota. It has been suggested that Victoria should *'take the approach of the world's most mature solar subsidy scheme, that now used in Germany. When the market is over-stimulated (i.e. demand for the subsidy outstrips the budget), the subsidy is reduced along with a commensurate increase in the number of subsidies available at the new level (and vice versa). This is designed as a self-correcting mechanism that prevents the boom-bust stop-start solar coaster from occurring.'*

- https://arena.gov.au/renewable-energy/solar/
- https://pv-map.apvi.org.au/analyses
- https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2019.pdf
- https://www.cleanenergycouncil.org.au/resources/technologies/solar-energy
- https://www.energymatters.com.au/renewable-news/solar-tax-sa-em5265/
- https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/BriefingBook45p/RenewableEnergy
- https://www.cleanenergycouncil.org.au/advocacy-initiatives/renewable-energy-target
- https://onestepoffthegrid.com.au/d-day-for-victoria-solar-rebate-as-government-holds-firm-on-design/
- https://reneweconomy.com.au/its-time-for-victoria-to-right-the-solar-ship-before-it-sinks-12788/

UK

FITs took effect in the UK in April 2010, and all domestic and commercial renewable energy producers with a capacity of less than 5 MW were eligible. Payments are made for all renewable energy generated, even if it was consumed by the generator. An additional payment is made for any excess electricity fed back to the grid. The FIT rates are scaled depending on the type of technology and are guaranteed for 25 years for solar PV systems, with the tariffs adjusted annually. The number of new installations that can receive a FIT is capped each month, with excess applicants placed on a waiting list. The FITs have encouraged the growth of PV systems in the UK, enabling 800,000 households and 28,000 businesses to generate electricity using solar PV systems. In 2017, 30% of electricity generated in the UK was from renewable sources, with solar energy making up 4.2%. In late 2015 the UK government made the decision to reduce subsidies for household rooftop solar PV installations by 65%. The FIT scheme closed to new applicants in April 2019, causing installations in May to fall by 94%.

There are concerns that ending FITs will result in lost jobs and investment opportunities and would be a step backwards in the movement to reduce greenhouse gas emissions and to meet climate targets. Closure of the FIT scheme means that households that produce excess electricity and feed it back into the grid will not be compensated. The Department of Business, Energy and Industrial Strategy (BEIS) stated that ending the FIT scheme would *'allow the government to develop a system that takes into account the growth of technologies such as batteries and the changing energy landscape.'* Currently no policy has been put in place to replace the FIT scheme but a call for evidence has been launched in order explore new policy opportunities. The Renewable Energy Associations head of policy and external affairs James Court stated *'... it is unrealistic to expect consumers, businesses or developers to continue installing small scale generation. This could be achieved by tax incentives, market enablers, and planning or building regulations, but we are currently left in an unnecessary policy vacuum without any firm proposals put forward by Government.'*

In June 2019 it was announced that UK homeowners who install new rooftop solar panels from January 1st 2020 would be able to sell excess electricity generated back to their energy supplier.

- https://www.greenmatch.co.uk/blog/2018/03/renewable-energy-in-the-united-kingdom
- https://www.theguardian.com/environment/2019/jun/05/home-solar-panel-installations-fall-by-94-as-subsidies-cut
- https://www.ofgem.gov.uk/environmental-programmes/fit/about-fit-scheme
- https://www.power-technology.com/features/end-feed-tariffs-uk-mean-small-scale-renewables/
- https://www.theguardian.com/environment/2019/jun/09/energy-firms-buy-electricity-from-household-rooftop-solar-panels

USA

The potential for significant electricity generation through solar PV in the USA is significant. According to the 2012 SunShot Vision Study, if PVs covered only 0.6% of the country's land area, enough electricity would be generated to fulfil the electricity needs of the entire country.

Most solar PV systems in the USA are connected to the grid and are subject to net metering laws. Net metering allows electricity generated during the day to be utilised at any time. During the middle of the day when solar energy generation is at its highest, any excess electricity generated is fed back into the grid. The electricity meter is run backwards to provide credit against electricity used later, such as in the evenings during peak demand. Given the intermittent nature of solar energy, net metering works particularly well for those with PV systems. It also functions well as a means by which to smooth out the energy demand curve and reduces peak electricity loads. Net metering legislation differs between states. Some states have Renewable Portfolio Standards (RPS) which require electricity providers to provide a certain percentage of their electricity from renewable sources.

In 2018 California introduced revised energy standards for residential and non-residential buildings. Requirements for energy efficiency and renewable energy were introduced. This was the first state-wide mandate to include solar PV in new homes.[1] There has been some pushback against home solar installations from some utility companies. They argued that *'because transmission costs—for line maintenance, tree trimming, and emergency crews, for instance—have traditionally been paid by the kilowatt-hour, solar customers are not contributing their fair share, even though they continue to use the lines (primarily at night). What's more, in order to accommodate solar customers, utilities say they must invest in new technologies that allow them to, for example, scale production up and down based on whether it's a sunny or cloudy day.'* However, it was shown that solar customers had a positive impact on the grid system as they reduced electricity demand. A solar expert at the Michigan Tech Open Sustainability Technology Lab stated that *'solar penetration would have to reach more than 15% of the market before utilities would need to make investments to alter the grid.'*

- https://www.energy.gov/eere/solarpoweringamerica/solar-energy-united-states
- https://www.seia.org/initiatives/net-metering
- https://www.epa.gov/statelocalenergy/state-renewable-energy-resources
- https://www.nap.edu/read/12987/chapter/7#119
- https://www.consumerreports.org/energy-saving/how-utilities-are-fighting-back-on-solar-power/

China

China is the world leader in solar PVs. The rapid uptake of PVs in China was aided by significant FITs.

The cost of solar PV installations decreased rapidly, whilst electricity prices remained fairly constant, which increased the uptake of PV systems. However, the PV uptake was so significant that it left a huge gap in the subsidy scheme. The subsidy backlog was estimated at 120 billion yuan, leaving the finance ministry struggling to support new solar projects. Additionally, with the primary focus being on increasing the PV capacity, planning and coordination with the local grid networks was not given appropriate consideration. This meant that the additional solar capacity was not well integrated into the power system which meant that significant proportions of the solar PV generated electricity was wasted. The National Energy Administration showed curtailment figures of ~20% for the north-west of China, which contains 40% of the country's total PV capacity but also has a low electricity demand and export capacity. In other words, in those regions approximately one fifth of the solar power was wasted. The national average curtailment rate for solar is ~10%.

In 2018 the Chinese central government announced a new policy which significantly cut solar subsidies nationwide and put limits on the size of solar installations. The aim of this policy was to shift the development of the solar industry towards local governments and to help transition the industry from quantity to quality based. Regional governments will be allowed to offer their own incentives, with the idea being to try and help develop zero subsidy projects. This policy came to be known as the 'May 31 Policy' or the '531 Policy'. According to Bloomber New Energy Finance 'China's 13th Five-Year Plan is no longer focused on '*stimulating the rapid build-out of new generation capacity but rather, on how to streamline investment planning and operation of the overall power system while avoiding incurring significant social and capital costs*.' China is currently working on a $88 billion investment to build large scale ultra-high voltage lines to help reduce curtailment rates.

Renewable energy subsidies have been reduced in other countries like Spain and Germany, but in those cases the national energy consumption was relatively stable and renewables were introduced to help replace other non-renewable energy sources. However, energy consumption in China is growing rapidly. Furthermore, in Germany each year the FITs decreased *'so that only the most efficient and technologically advanced entrants could profit.'* According to the Renewables 2019 Global Status Report '*China's decision to constrain domestic demand led to global turmoil as Chinese modules flooded the world market, and trade disputes affected the industry in some countries. Record low auction prices, driven by intense competition and lower panel prices, brought further consolidation. Nonetheless, the year also saw investment in new, more-efficient production capacity and additional advances in solar PV technology.'*

- https://www.climatechangenews.com/2018/08/15/china-solar-industry-struggles-sudden-subsidy-cuts/
- https://www.reuters.com/article/us-china-solar/china-solar-policies-to-boost-quality-ease-

burden-on-government-xinhua-idUSKBN1J800D

- https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report__en.pdf
- https://www.renewableenergyworld.com/2018/12/03/china-hopes-to-lessen-solar-wind-curtailment-in-2019/
- http://greenubuntu.com/go-green-china-is-worlds-top-producer-of-solar-power-edges-out-india-usa/
- https://www.pv-magazine.com/2019/06/08/the-weekend-read-chinas-hard-change-towards-grid-parity/
- https://www.renewableenergyworld.com/2018/06/11/chinas-domination-of-the-pv-industry-veni-vidi-vici/
- https://www.pv-magazine.com/2018/12/08/chinas-31-5-malaise/

New Zealand

New Zealand has policies and guidelines related to renewable energy and decreased emissions goals. For example, the existing target is to have renewable sources contribute to 90% of electricity generation by 2025 and to reduce emissions to 30% below 2005 levels by 2030. However, New Zealand does not currently have any specific policy related to solar energy, with no government subsidies or specific incentives. Kiwibank does offer a mortgage top-up and subsidy called the Sustainable Energy Loan which provides up to $2,000 towards the cost of renewable energy systems.

As discussed in Section 4, in New Zealand, the majority of consumers with PV systems have the opportunity to sell any excess electricity generated back to the grid. However, the buyback rates are set by the electricity companies and are typically much lower than the cost price.

There has also been controversy over what was dubbed as 'solar tax' in New Zealand. In April 2016, Hawke's Bay lines company Unison introduced an extra charge for users in the area with solar panels. Unison justified the move by stating that other consumers had to meet connection costs and that it was done in the interest of fairness. This move was met with widespread disapproval and Greenpeace, Solarcity CEO Andrew Booth (New Zealand's largest solar energy company), and Sustainable Electricity Association of New Zealand chairman Brendan Winitana called the Unison action a solar tax, saying it was designed to discourage solar adoption. Union challenged this description but the Advertising Standards Authority ruled that the word tax was appropriate to describe their actions. The Electricity Authority ruled that the company was not in breach of any rules, a decision that lead to widespread outrage. A petition was launched by Greenpeace who stated that solar energy in New Zealand was being threatened by big energy companies. Solarcity submitted a complaint to the Electricity Rulings Panel regarding Unison's solar tax, challenging the decision made by the Electricity Authority. Solarcity won the right for the solar tax move of Unison to be subject a full hearing.

It is important that New Zealand tries to promote, or least not to discourage, the uptake of PV systems. Disincentives, such as solar taxes, have been met with global disapproval and are seen by the majority as backward thinking.

- https://www.rnz.co.nz/news/regional/300397/new-solar-panel-charge-kicks-in
- https://sustainable.org.nz/sustainable-business-news/energy-solar-tax-debate-exposes-nz-energy-fault-lines/
- https://www.nzherald.co.nz/hawkes-bay-today/opinion/news/article.cfm?c_id=1503459&objectid=11675291
- https://www.solarcity.co.nz/blog/media-releases/solar-tax-and-trustpowers-plans-to-delay-solar-a-desperate-money-making-move-says-solarcity-ceo
- https://www.nzherald.co.nz/hawkes-bay-today/business/news/article.cfm?c_id=1503458&objectid=11792689 the majority as backward thinking.

6. Technology developments

Traditional solar panels are made from crystalline silicon wafers and make up roughly 95% of the global market.[20] The increased production scale of these PV cells, combined with improvements in manufacturing processes has driven their cost down. Work has also focused on improving their efficiency. Currently, commercial crystalline silicon panels have an efficiency of around 15-22%, with recent reports from champion laboratory of efficiencies of 26.7%.[21] Although improvements have been made to the efficiencies of crystalline silicon solar panels, it is important for policy makers to be aware that these efficiencies cannot increase without restriction. There is a limit to the maximum possible efficiency of single junction monocrystalline silicon solar cells of 29.4%,[21] known as the Shockley-Queisser limit. Given 'real world' factors such as temperature, environment and structural imperfections, and the ideal nature of the Schockley-Quiesser model this limit may be approached, but not reached. Likewise, efficiencies measured in a laboratory on a small unit will be higher than those of commercial scale panels measured under non-standard conditions.

It is important to note that whilst crystalline silicon panels currently dominate the market, they are far from the only functioning PV technology. There are a wide range of new PV technologies which convert sunlight to electricity via different means using different materials. One class of solar cells are known as 'thin-films' which typically have lower efficiencies than traditional silicon panels. However, they are flexible, light weight and some can be printed 'roll-to-roll' like bank notes, allowing vast quantities to be made rapidly. These types of cells have potential to be more readily integrated in new buildings and various devices or surfaces. Other types of more complex (multijunction/tandem) solar cells exist, which through a combination of different materials and additional components can have very high efficiencies and exceed the Schockley-Quiesser limit. These tend to have slower, more complex manufacturing processes and use rarer materials and hence are often more expensive.

It is important to be aware that although the current market is dominated by crystalline silicon panels, extensive research is ongoing into new types of PVs. Although these are unlikely to entirely replace traditional cells in the near future, they may see an increased market presence and target niche areas where the specific properties of a particular type of cell are desirable, such as thin-film cells directly integrated into the structure of new buildings.

7. Implications and outlook for solar energy in New Zealand

The energy landscape of New Zealand is likely to change significantly in the coming years. Electrification of transport and industrial sectors will help to reduce greenhouse gas emissions. To meet the increased electricity demand and reach our renewable energy goals, additional renewable electricity generation will be required. Solar PVs have the potential to help make up a significant proportion of this electricity. New Zealand currently has a significantly underutilised solar energy potential. Therefore, solar PV uptake by households and businesses could be greatly benefited though supportive government solar or renewable energy policies. The success of such policies in other countries has been illustrated and provides examples and guides from which New Zealand may develop its own policies.

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9. Additional links

- https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf
- https://www.transpower.co.nz/resources/te-mauri-hiko-energy-futures
- https://www.temaurihiko.co.nz/updates#targetText=The%20Sun%20Rises%20on%20a,about%20solar%20in%20New%20Zealand
- https://eto.dnvgl.com/2018/
- https://ww.iea.org/publications/insights/insightpublications/Getting_Wind_and_Sun.pdf
- https://www.cliffordchance.com/briefings/2018/11/renewable_incentivesguidetowardhtml

10. Bibliography

1. REN21, Renewables 2019 Global Status Report. 2019; https://www.ren21.net/gsr-2019/.
2. Energy in New Zealand 18; 2018.
3. DNVGL, Energy Transition Outlook 2018 A global and regional forecast to 2050; 2018.
4. The run rises on a solar energy future - Te Mauri Hiko; 2019.
5. Liley, B. Oh solar me-o: NIWA gives you something to sing about! 2009; https://niwa.co.nz/news/oh-solar-me-o-niwa-gives-you-something-sing-about (accessed 22nd August 2019).
6. Meduna, V. 'Wind and solar power - Solar energy'. 2006; http://www.TeAra.govt.nz/en/wind-and-solar-power/page-3 (accessed 22 August 2019).
7. Te Mauri Hiko Energy Futures; 2018.
8. EECA, Benefits and considerations of electric vehicles. https://www.eecabusiness.govt.nz/technologies/electric-vehicles/benefits-and-considerations/ (accessed 27th August 2019).
9. Hoare, K. The number of solar panels you need to charge an electric vehicle. 2019; https://www.mysolarquotes.co.nz/blog/electric-vehicles/the-number-of-solar-panels-you-need-to-charge-an-electric-vehicle/?keyword=kWh (accessed 27th August 2019).
10. BloomberNEF, Tumbling Costs for Wind, Solar, Batteries Are Squeezing Fossil Fuels. 2018; https://about.bnef.com/blog/tumbling-costs-wind-solar-batteries-squeezing-fossil-fuels/.
11. Irena, Renewable power: Sharply Falling Generation Costs; 2017.
12. Solangi, K.; Islam, M.; Saidur, R.; Rahim, N.; Fayaz, H. Renewable and Sustainable Energy Reviews, **2011**, *15*, 2149–2163.
13. Watson, J. D.; Santos-Martin, D.; Lemon, S.; Wood, A. R.; Miller, A. J.; Watson, N. R. *IET Generation, Transmission & Distribution,* **2016**, *10*, 1–9.
14. Watson, J. D.; Watson, N. R. Impact of residential PV on harmonic levels in New Zealand. 2017 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe). 2017; pp 1–6.

15. Santos-Martin, D.; Lemon, S. *Solar Energy*, **2015**, *120*, 549–564.
16. Tobnaghi, D. M. *International Journal of Electrical and Computer Engineering*, **2016**, *10*, 137–152.
17. IEA, Getting Wind and Sun into the Grid; 2017.
18. Agency, I. E. Snapshot of Global PV Markets; 2019.
19. Wehrmann, B. Germany's solar power capacity approaching 52 GW support cap, industry warns. 2019; https://www.cleanenergywire.org/news/germanys-solar-power-capacity-approaching-52-gw-support-cap-industry-warns (accessed September 3rd 2019).
20. Sinke, W. C. Renewable Energy 2019, *138*, 911–914.
21. Nayak, P. K.; Mahesh, S.; Snaith, H. J.; Cahen, D. *Nature Reviews Materials,* **2019**, *4*, 269.