DOI: 10.14621/ce.20170202

The Future of Solar Energy

Michelle Jamshidi, Alex Hatch, Andrew D. Lowery, James E. Smith

Mechanical and Aerospace Engineering Department, West Virginia University
Morgantown 26505-6106, West Virginia, USA; Drew.Lowery@mail.wvu.edu

Abstract

Solar energy and its resulting derivatives is the answer and driver behind all the energy we have access to and will continue to use into the foreseeable future. While nuclear plays a part in our energy portfolio, it will be some time before it can displace current programs and then most likely in ways we have yet to realize or embrace. Independent of the designation of renewable and non-renewable, all the current energy we use comes from the sun. For the renewables, wind as well as current solar and thermal cells all rely on the direct impacts of the sun. Clearly, if we are to significantly offset the non-renewables it will be through the direct use of more solar energy through these renewables. The direct use of solar energy should thus be a key in any strategy of offsetting the use of fossil fuels, to produce clean, renewable power. However, in its currently available forms, it is often unreliable due to the way in which it is utilized, particularly since the current processes rely directly on nature. With all the unpredictability associated with solar, it can be difficult to produce consistent, reliable, and thus affordable power.

One of the main features of solar power is the inability for anyone other than highly organized and funded power companies to supply energy into a power grid. Localized sources, homes, businesses, and even communities can create supplemental sources for energy acquisition. Unfortunately, most moderately sized grids are unable to handle large supplemental sources and are even less likely to have the capability or capacity to integrate, smooth, filter, and synchronize these supplemental nodes. The grid, therefore, will need major upgrade planning and control to accommodate the changes in energy sources as well as adding a grid level power storage to smooth out the unanticipated and unplanned power inputs.

Keywords:	Solar power; Renewable energy; Grid integration; Grid storage; Grid damage

Article history:	Received:	07 February 2017
	Revised:	27 October 2017
	Accepted:	30 October 2017

1. Introduction

Energy comes from many different sources, yet ultimately all energy is produced by the sun. Every year about 1.524 x 10^{12} gigawatt-hours of the Sun's energy hits the Earth's surface [1]. In contrast, globally, human beings consume 2.38 x 10^{7} gigawatt-hours, or about 0.0016% of the total energy the Sun produces and sends to the Earth [2]. This solar energy can often be used directly by converting it into electricity using photovoltaic solar cells or through the production and capture of heat using thermal cells. The excess energy from the Sun that reaches the surface of the Earth disperses around the globe, creating localized heating on the rotating surface which, in turn, drives weather patterns and ocean currents. The rest is absorbed by the plants, the ground, or is reflected into space. These factors in ever-changing ways influence the creation of air currents, and ultimately wind, which can be used to drive wind turbines. Figure 1 shows a pie chart of the total energy produced by humans broken down by source. As seen in the figure, only 5.9% of the total energy comes from solar driven devices, such as solar cells (both thermal and photovoltaic) and wind turbines. On a global basis, solar energy provides a small portion of energy production.

In the case of fossil fuels, the sun's impact is less obvious to the layman, but equally as integral as it is to produce all other energy sources. When sunlight reaches plants, its energy is used for photosynthesis, in which the energy provided by photons contained in the sunlight cause movement of electrons within the chlorophyll of the plant. This process leads to the creation of an electron transport chain and, ultimately, the production of adenosine triphosphate (ATP), which is used as energy for the plant. As the plant grows and eventually dies, the energy is stored in more concentrated forms of organic matter, and/or is consumed by animal life. After millions of years of the build-up of this matter, plus the intense heat and pressure caused by the resulting

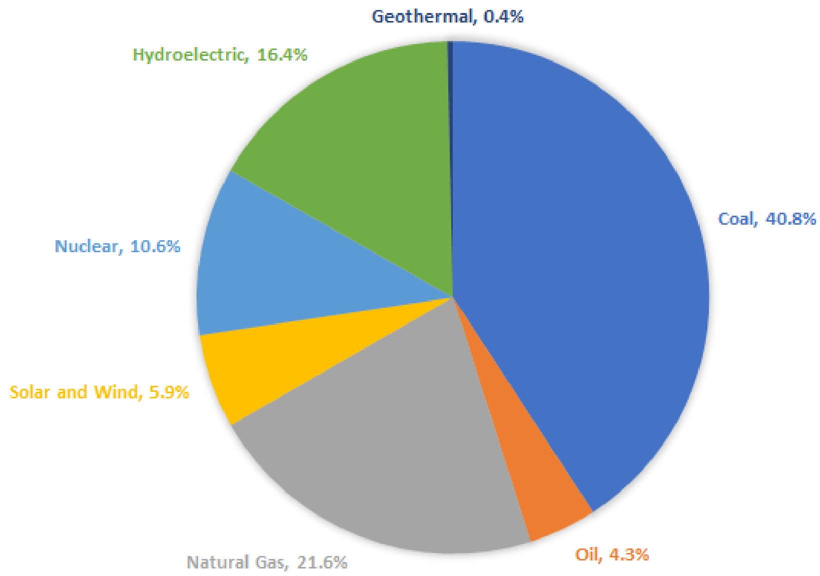

Figure 1. Global electricity production by energy source [2]

overburden, this organic matter can form into fossil fuels such as oil and coal. These processes are of course a result of the same solar energy input, but on an infinitely longer time scale.

Renewable energy, such as the direct use of solar power, has at a first glance many benefits that makes it a more desirable energy source than its fossil fuel counterparts. For example, in comparison to natural gas, oil, and coal, solar energy produces little to no emissions prior to the conversion of photons to electrons and wind or ocean current into mechanical work, and then electrons. Solar energy does impact the global weather patterns and as it is consumed by plant and animal life, the products of that consumption in fact are its emissions. This is a delicate, but highly effective closed-loop process, which balances the solar energy input against the absorption of the same by the living and non-living processes around the globe.

A real advantage for solar is that since the sun's energy is predicted to be around for the next five billion years, it is essentially inexhaustible. Noting that while it takes fossil fuels millions of years to replenish, solar power is available daily and is an obvious, but overly simplified choice. The issue then becomes whether it is available in amounts that are sufficient to localized needs and can it be managed to handle storage and distribution issues caused by the diurnal cycle. Also, it is important to realize that while the total energy available from the Sun is tremendous, it is distributed over the entire planet; thus, capturing it in ways that are sufficient for the localized needs has yet to be handled or even considered for the future needs of the globe, as mankind continues to modernize.

Solar energy conversion is on the increase, producing a total of 148,000 gigawatt-hours of energy during the ten-month period from January to October of 2016, 0.6% of the current total needs worldwide [3]. Solar energy's predicted average growth rate over the 28-year period from 2012 to 2040 is 30.7% per year, significantly more than the total global growth rate of energy of 1.7% per year [4]. Figure 2 and Figure 3 illustrate the predicted growth rate of the total global needs for all energy types in comparison to the growth rate of renewable energies. As seen in Figure 3, while the trend is increasing, the production of solar energy in comparison to the total needs differ greatly. Solar energy does not and is not projected to be close to meeting the increasing rate in energy needs. It is worth noting, however, that as solar power and other renewable energy sources are more widely adopted there is projected to be a dip in the amount of energy created through fossil fuels, particularly coal, as shown in Figure 4. In fact, it was projected that from 2016-2020 the United States will retire as many as 132 GW of coal power plants. However, since the repeal of the Clean Power Plan, which called for the tightening down of standards on fossil fuel power plants, by the new administration it is likely that about half of that will actually see retirement by 2020 [5].

Solar energy is also helping the economy through equipment manufacturing and installations around the world. In the US, the number of solar jobs has more than doubled in the last five years and in the last year alone about 35,000 jobs were created [7][8]. Globally, solar energy manufacturing, design, and maintenance employs roughly 2.5 million people [9]. In 2015 alone, $161B USD was invested in solar energy globally against the derived energy value of roughly $3k USD per kilowatt of installed solar capacity [10] [12]. This large variance is mostly due to the differences between

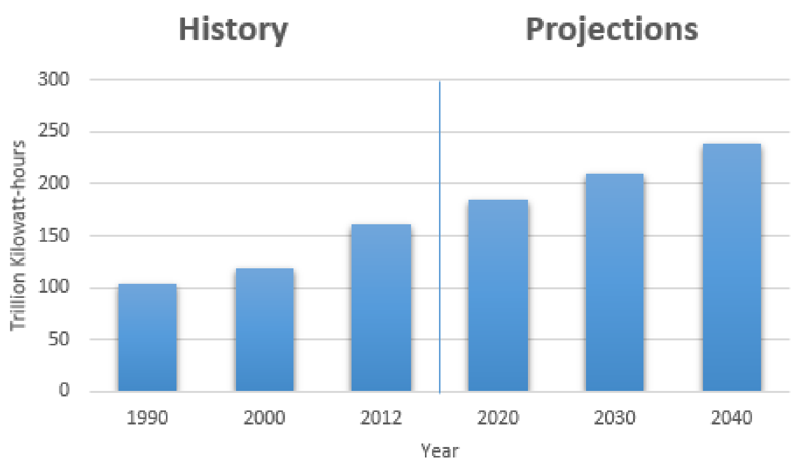

Figure 2. World energy consumption, 1990-2040 [4]

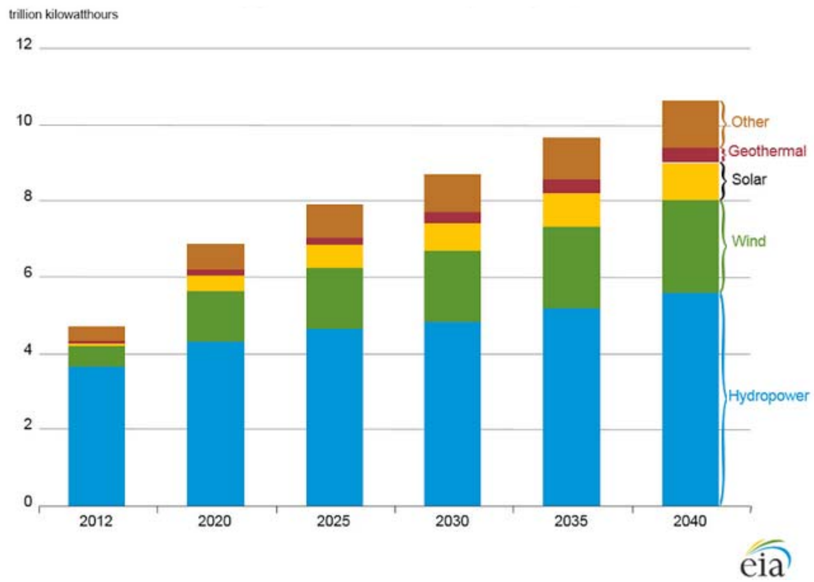

Figure 3. World net electricity generation from renewable power by source, 2012-2040 [4]

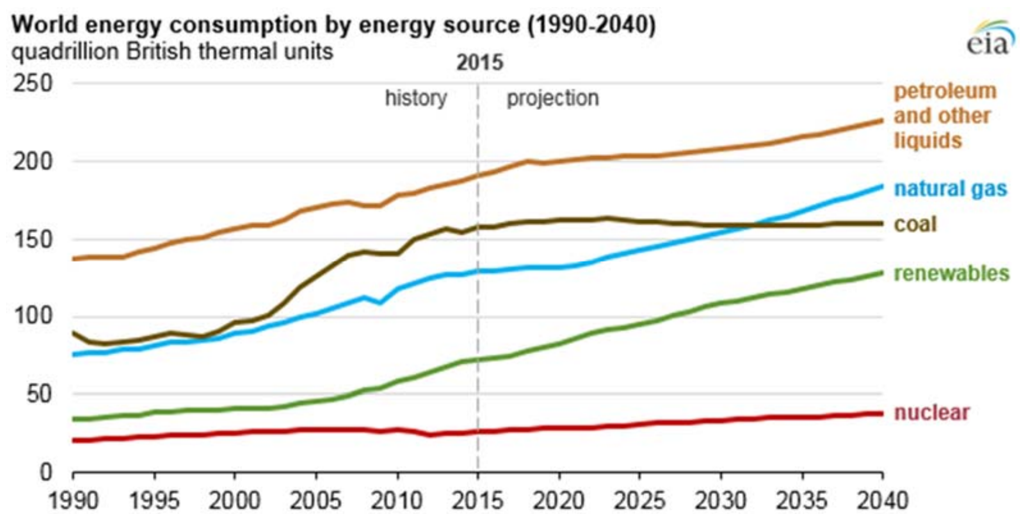

Figure 4. Projected world energy consumption by source [6]

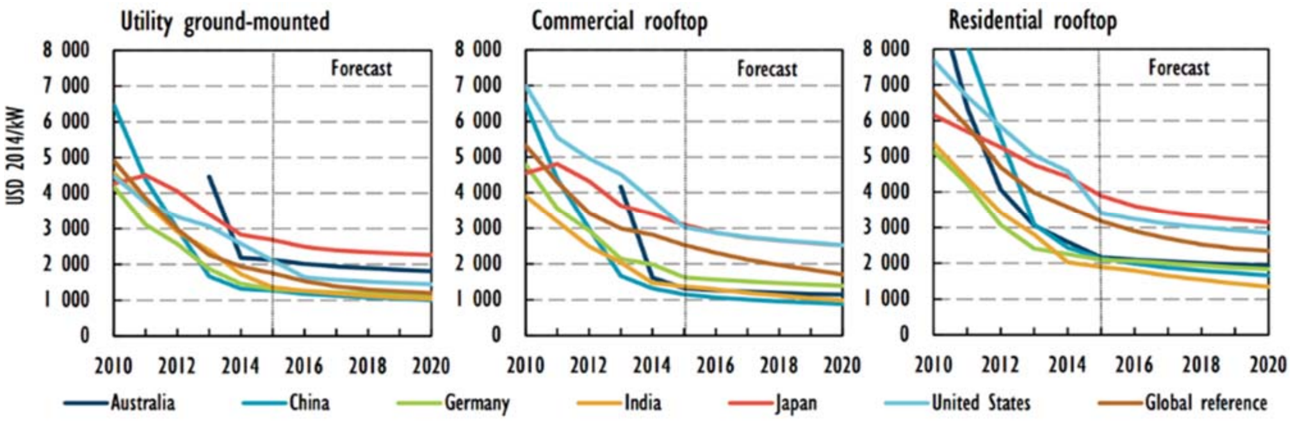

Figure 5. Cost projections of solar PV, 2012-2020 [11]

installations of the panels (roof vs ground mounted) as well as whether the panels are being used in a commercial or residential application. A breakdown of these costs by country along with projections through 2020 are shown in Figure 5. The general trend in these charts show that the installed cost per kilowatt of solar panels is predicted to decrease over time for utility scale, commercial, and residential arrays for different countries and globally.

2. Solar panels

Currently around the world, there is 227 GW of total solar PV capacity installed, which supplies about one percent of worldwide energy needs [14]. With many countries planning to increase their solar production over the next 25 years, solar energy has the potential to become a major source of energy for some localized areas, particularly in those regions where other forms of energy are not economical or desired. While the rise of solar energy has brought new opportunities, there are still some issues that need to be resolved. To begin with, solar energy is highly unpredictable, in that the sun doesn’t always shine every day, or all day. Since the sun is only at its peak for 25% of the day, the grid gets flooded with power during the time of the day regarded as a non-peak time for power consumption.

The fact that the grid experiences a large input of solar power at hours where it simply can’t use the power leads to a wide variety of issues. These include: strain and damage on the grid from residential or community net metering, difficulty in grid management due to unpredictability in solar radiation production, and power waste due to the need for utility companies to curtail some of the power produced during non-peak usage times, plus the need to keep capacity spooled up with conventional fossil fuel generating capacities for the irregularities during the solar cycle, or accept those irregularities and the power fluctuations and interruptions that result.

While it is possible to overcome some of these issues with a modernization of electrical grid systems and an introduction of grid level power storage systems, these advances would represent a significant financial and technological investment for utility companies around the world. Most of these concerns neglect the life expectancy of current solar capture systems, their maintenance, replacement costs, and the environmental impact of their ultimate disposal and recycling. Global production of solar panels will eventually bring the cost down, and the efficiency and reliability up, but this assumes the materials needed for their current production and to produce the more advanced versions will be readily and economically available.

3. Sample Analysis

Due to its relative youth in the field of energy production, having only risen to popularity in the last ten years, there isn’t enough country-by country or even United States (US) state-by-state data to fully analyse the effect of solar power around the globe, or in the US. However, there is a fair amount of accessible data for the state of California in the US that is the result of both government funded research as well as private company transparency initiatives. Data from the following sources was analysed: California Independent System Operator (CAISO) database of solar energy curtailment, Solar Energy Industries Association (SEIA) studies, as well as a study on net metering by Energy and Environmental Economics (EEE). In turn, this data was used to reach conclusions about the entire United States.

The reasoning for this method is that since California is undoubtedly the solar energy hub of the US, accounting for 52% of all solar capacity in the country, the data for the state would be scalable to draw conclusions about the entire United States [13]. The following data is based on a 7,655.5 MW array that was monitored by California Independent System Operators. Figure 6 shows the daily production from solar energy during the months of May 2016 to November 2016. As seen in the graph, the production of solar energy declines over time as the season changes. As the month's progress through the summer season the general production of solar energy increases, then as the season changes to winter and the days become shorter, the production decreases. The sudden dips in production are most likely due to weather, where clouds and rain were blocking the sun.

Figure 7 shows the curtailment of solar energy from June 2016 to November 2016. When the solar production is greater than the demand of energy, utility operators must restrict certain amounts of the energy to the grid. The bars on the chart indicate the number of megawatt-hours being curtailed on any given day. Figure 8 shows the electricity demands are higher in the summer months. Therefore, the amount of curtailments is lower in the summer. In the winter, the demand is lower so the restrictions on the production of solar energy are higher to avoid over supplying the grid.

Figure 9 is the average production of electricity in California. The graph shows the production of different energy sources during the summer of 2016. In comparison to the other sources, solar is much more time dependent. The yellow section below is the amount of solar being produced during a 24-hour time. Because solar panels only produce energy when the sun is out, there is a portion of the day where there is no production. Currently, on the utility scale, to cover this lack of production, other energy sources must be used to meet the electricity demands. These usage and curtailment trends will be similar for any other location in the world due to the fact that international energy consumption compared to solar production follows what is known as the "duck curve". This describes the fact that energy production from solar is highest during the middle of the day when energy consumption is at its lowest due to most people being at work. This trend then reverses in the evening when consumption is at its highest as people return home from work.

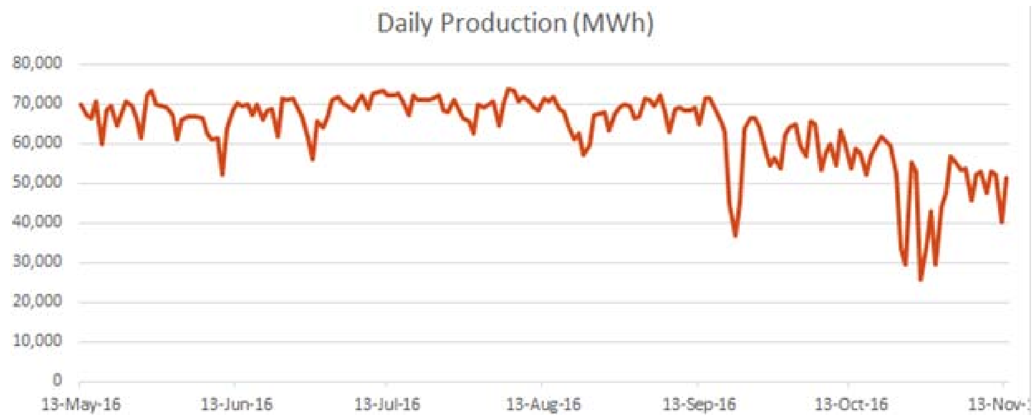

Figure 6. Daily production of utility scale solar array [15]

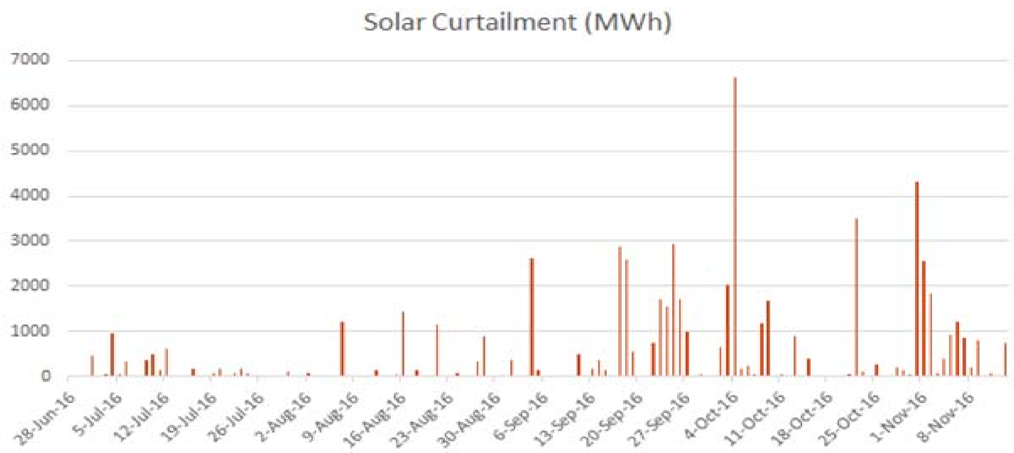

Figure 7. Daily solar energy curtailment of utility scale array [15]

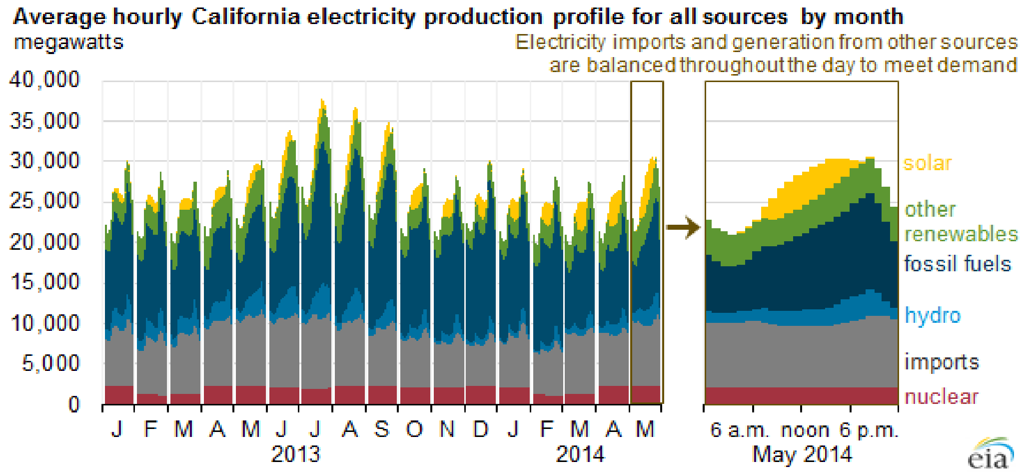

Figure 8. Hourly electrical requirements by month [16]

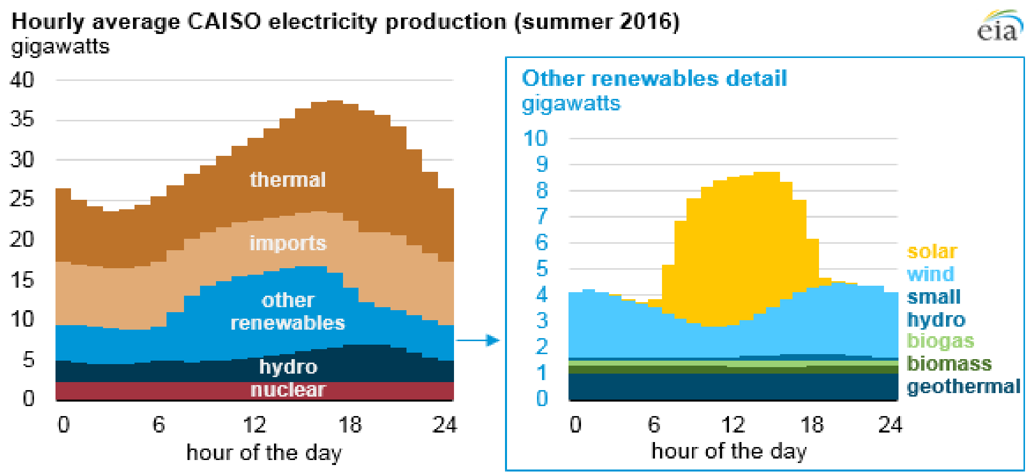

Figure 9. Hourly Average Electricity Production by Hour in California [17]

4. Conclusions and recommendations

As the movement for increased use of renewable energy grows, the supply of solar energy will continue to affect the power grid. As it currently stands in California, renewable energy provides about 26% of the state's electricity with plans to increase that number by nearly 50% by 2030 [18]. In fact, all across the globe other countries have made similar goals for 2030 to raise their renewable energy production, such as Germany's increase to 45% and China's increase to 20% [19], [23]. While these goals are well intended, changes must be made to accommodate this energy source. From the solar production graph, seen back in Figure 6, the daily production can spike high or drop low on any given day. While the general trend shows that the solar production is less in winter months, there still are multiple instances where the production drops far below the average trend line. This shows the unpredictability of solar energy.

On days where solar energy produces significantly less than the average daily production, utility companies must immediately increase the amount of energy being produced from traditional energy sources. If there is not enough electricity supplied to the grid to meet the demand, then there can be blackouts in some areas. These backup power plants need to be running always in the event of the renewable energies falling short of the demand. Problems can also occur when too much energy is being produced and the demand is lower than the supply. If too much electricity is in the grid, it can cause major damages to the system. To prevent the grid from being fried, operators must restrict the amount of solar energy by turning off solar farms.

In the past when electricity was just coming from natural gas and coal power plants, the supply was more constant and predictable. Now with the solar and wind, the energy supply fluctuates more and must be under watch to adjust the supply based on the electricity demand. There are multiple ways to offset this such as using more of the constant energy producing renewable resources. As seen back in Figure 8, renewable resources such as geothermal, biomass, and hydropower are much more constant in daily production. For that reason, they would make a much more reliable source of renewable energy. Another option would be to install batteries for solar farms. While batteries can be extremely expensive, it would make solar energy a much more reliable source. If the batteries were charged to full capacity, grid operators could use the energy as needed based on the demand. This would also mean that solar energy would be used not just during the day, but in the evening when the energy demand is at its highest. Another storage option would be to use a system called pumped-storage hydropower which stabilizes the electricity grid by reducing the amount of energy supplied during peak production and balancing the load on the grid [21]. This system works like a battery in that the excess energy from solar panels can be used to pump water to a higher reservoir and is stored there until needed. The water stored can be released at any time where it runs through a generator and puts energy back into the grid [20]. Efficiencies for this system range from 80-85% roundtrip, with some systems known to surpass these values [22].

The practice of net metering has also taken its toll on the energy infrastructure of California. A recent report by California Public Utilities Energy Commission Energy Division has predicted that net metering within the state of California is likely to cause at least $1.1B USD in damages to the power grid by the year 2020 [24]. These damages are mostly due to the mechanical stresses put on service lines by feeding power from homes to the grid, opposite of the direction intended when the grid was originally designed.

On a larger scale, net metering could account for more than $2.5B USD in damages across the entire US by 2020 as the popularity of solar power continues to grow. With this cost looming over their heads, most utility companies are having issues with finding a solution. This is mostly due since 43 states have laws mandating utility companies to allow net metering. With these laws in effect in most of the country, power companies have little control over how they handle customers who choose to send power back into the grid. This results in the power companies having to raise rates for everyone in their service area to make up for the damages and additional costs associated with their net metering customers [25].

In general, there are two main ways to approach the problems caused by net metering. First, there could be a total overhaul of power grids across the country to modernize them and prepare them for the continuing growth of solar energy. This would include having more reliable weather forecasting technologies to better predict when and how much power the solar arrays will produce at any given time, more specially trained grid operators that can handle the unreliable and peaky nature of solar power, and the introduction of grid level energy storage, most likely in the form of high capacity batteries.

For this approach, the batteries alone would cost nearly $1k USD per kWh and would need to be replaced frequently, resulting in a multi-billion-dollar expense. Not to mention the expenses associated with training operators and developing control software for the grid. Another option is to institute a solar leasing type program through the power companies. This program would work similarly to other solar lease programs currently instituted around the US. The power company would front all the costs associated with the installation of the home's solar array and then would be paid back by the consumer in monthly instalments that are the same amount as their power bill before the solar array was installed. With this arrangement, the power companies could make enough money back from the installation to cover the costs associated with net metering without having to raise rates for other customers who choose not to. This also benefits the customer by allowing them to have all the benefits of having a home solar array, such as the increased property value, without having to front the capital to have it installed privately.

The clamour to use more renewables, while logical at first glance, has an inherent set of problems not unlike those that create any new industrial process. Trying to force or mandate these new systems into existence prior to them being vetted to the science and engineering community is likely, as has happened in the past, to cause unnecessary hardships and economic stress. Even when concerns for the environment are the driving interest cost usually becomes the driving factor, since it is the total package from conception to death (sustainability) that determines the total cost. In these new and exciting programs, a long-term evaluation, including cost, environmental impact, life expectancy, and sustainability is needed that looks at all the consequences before a final decision is implemented. Finally, the consumer should have some of the final consideration, since if the source of power does not meet their needs than costly changes will be required, often obviating the original touted benefits of the new system.

References

[1] Larson, Richard B. & Volker Bromm. "The Universe's First Stars." *Scientific American*. December 2001: 70.

[2] *Key World Energy Statistics*. Rep. Paris: International Energy Agency, 2016. Print.

[3] Dunn, Dianne, Jennifer Barrick, et al. January 2017 Monthly Energy Review. Rep. U.S. Energy Information Agency, 27 Jan. 2017.

[4] EIA. International Energy Outlook 2016. Rep. U.S. Energy Information Administration, 11 May 2016.

[5] "Projected 2016-2020 Existing Generating Unit Retirements Under EPA 111(d) Proposal." *Southern States Energy Board*. Southern States Energy Board.

[6] "U.S. Energy Information Administration." *Today in Energy*, U.S. Department of Energy.

[7] Gillespie, Patrick. "Solar Energy Jobs Double in 5 Years." *CNNMoney*. Cable News Network.

[8] United States. The Solar Foundation. *National Solar Jobs Census 2015.* Washington D.C. 2016. Print.

[9] Hettipola, Sharmin. "Fact Sheet: Jobs in Renewable Energy and Energy Efficiency (2015)." EESI. Environmental and Energy Study Institute, 6 Nov. 2015.

[10] FS-UNEP. Global Trends in Renewable Energy Investment 2016. Rep. FS-UNEP Collaborating Centre, 2016.

[11] France. International Energy Agency. *Renewable Energy Medium-Term Market Report 2015.* Paris. Print.

[12] IEA. Renewable Energy Medium-Term Market Report. Rep. International Energy Agency, 2015.

[13] Comstock, Owen. "California Has Nearly Half of the Nation's Solar Electricity Generating Capacity." *U.S. Energy Infomration Administration*. U.S. Department of Energy, 5 Feb. 2016.

[14] "A Snapshot of Global PV." *International Energy Agency Photovoltaic Power Systems Programme*. IEA.

[15] "Daily Wind and Solar Curtailment Report." *California ISO*. California Independent System Operator, 2016.

[16] Bredehoeft, Gwendolyn, Robert McManmon, and Tyson Brown. "California Continues to Set Daily Records for Utility Scale Solar Energy." *USEIA*. US Energy Information Administration, 25 June 2014.

[17] Comstock, Owen. "Natural Gas Generation and Electricity Imports Used to Follow Load in California." *USEIA*. US Energy Information Administration, 7 Sept. 2016.

[18] California Energy Commission – Tracking Progress. *Renewable Energy - Overview*. State of California. 2017.

[19] Sawin, Janet L. "Germany Leads Way on Renewables, Sets 45% Target by 2030." *Worldwatch Institute*. Worldwatch Institute.

[20] "Pumped Storage Hydropower." *Energy Efficiency and Renewable Energy*. U.S. Department of Energy.

[21] Yang, Chi-Jen. "Pumped Hydroelectric Storage." *Storing Energy*. Oxford: Elsevier, 2016. 25-37. Print.

[22] Levine, Jonah G. "Pumped Hydroelectric Energy Storage and Spatial Diversity of Wind Resources as Methods of Improving Utilization of Renewable Energy Sources," page 6, University of Colorado, December 2007.

[23] China. National Energy Administration. *The 13th renewable Energy Development Five Year Plan (2016-2020)*.

[24] "California net energy metering (NEM) draft cost-effectiveness evaluation." Energy and Environmental Economics, Inc. 26 Sept 2013. Print.

[25] Energy and Environmental Economics. Introduction to the Net Energy Metering Cost Effectiveness Evaluation. Rep. California Public Utilities Commission Energy Division, Mar. 2010.