MGT-453 Industry dynamics, models & trends
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Electricity Industry : Final Report

Industry analysis of solar photovoltaic electricity and its impact on the electricity industry

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1. Introduction

The power industry is the backbone of present day industrial world which supplies essential power for industrial, manufacturing, commercial and residential customers. As mechanical engineers interested in energy sector, we are motivated to understand the sustainability of power industry, its challenges, opportunities and industry dynamics. Electricity industry is interesting because, the industry is experiencing various dynamics, most prominently in electricity production. There are three primary drivers of change in electricity generation which can be categorized as climate change awareness, increased demand for electricity and peaking of known fossil fuel reserves. In view of the climate change phenomena, there is a great demand for the ‘energy transition’ to shift from fossil fuels to renewable resources. Power industry being the largest contributor to global CO2 emissions[1], it is undergoing rapid energy ‘upgrades’. Energy policies are continuously being amended to control the carbon footprint and to meet the global CO2 emission targets, most notable of which is the Paris climate change agreement in 2016 adopted by 195 member parties[2]. Secondly, the demand for electricity has ever been on the rise ever since its beginning due to growing electrification, industrialization and globalization. Figure 1 shows the electricity generated per year since 1980[3], indicating that the demand has more than tripled by 2018 and it is expected to reach double that of today by 2050. In order to ensure energy security and sustainability, various governments have different energy policies and regulations.

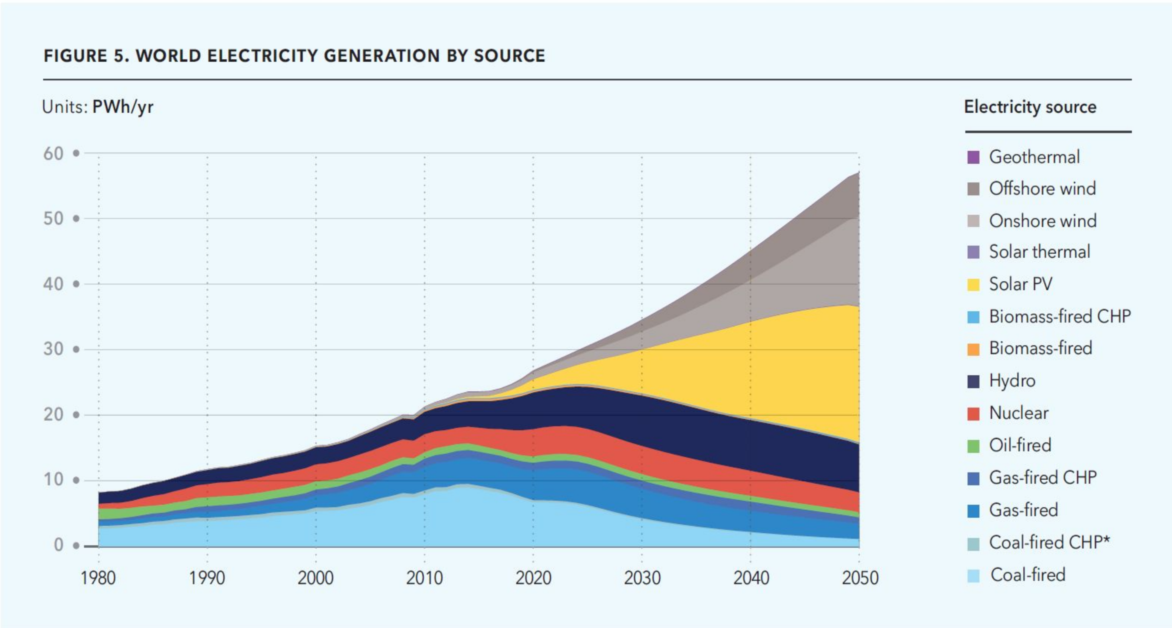


Figure 1: World Electricity production per year [Past trend and Future forecast][3]

As of 2018, nearly 70% of the electricity generated came from nonrenewable resources such as fossil fuels, of which gas is expected to peak by 2029 and coal by 2046, as shown in figure[4]. The depletion of known fossil fuel reserves are leading to increased cost of mining and traditional electricity. Growing electricity demand when combined with depleting known fossil fuel reserves is set to trigger various dynamics in the energy portfolio of the future. As shown in Figure 1, one of the forecasts expects that the additional demand will be met by solar photovoltaics and wind energy with the former taking maximum share.

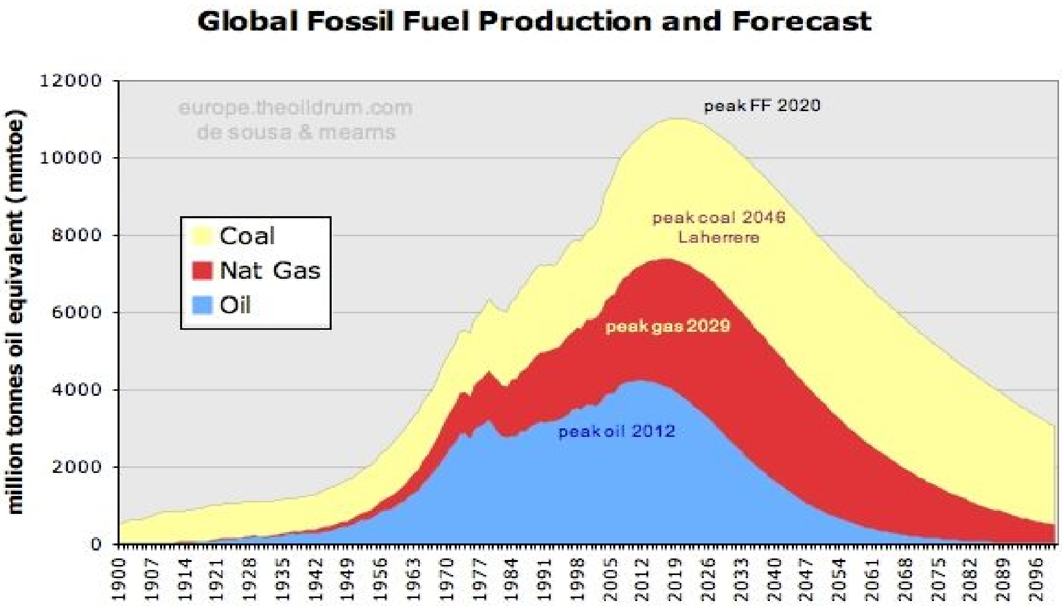


Figure 2: Global fossil fuel production and forecast [4]

1.1. Problem statement

In view of the call for 'energy transition', one natural question arises. ***What is the impact of shift towards renewable energy resources on the conventional electricity industry?*** which mostly derives the fuel from non-renewable resources such as fossil fuels**.** By traditional electricity industry we imply the largest producers of electricity, associated firms and actors. Further, we are ***specifically interested in solar photovoltaic industry*** which has been exponentially growing in the past decade. Solar photovoltaics is a method of producing electricity using solar cells which convert energy from the Sun into flow of electrons through photovoltaic effect. Figure 3 shows the solar PV energy generated over the past decade, indicating the exponential growth of solar Photovoltaics [5].

Given the background, the industry we are interested in this report is the electricity industry. Further, we would like to specifically study the developments in solar photovoltaics and its impact on the traditional power utilities industry. Hence, we first address the electricity industry in detail and present a brief analysis of the industry. Next, we describe the evolution of solar photovoltaics developments and its present status. Then, we present a brief qualitative analysis of the impact of photovoltaics on traditional electricity generation.

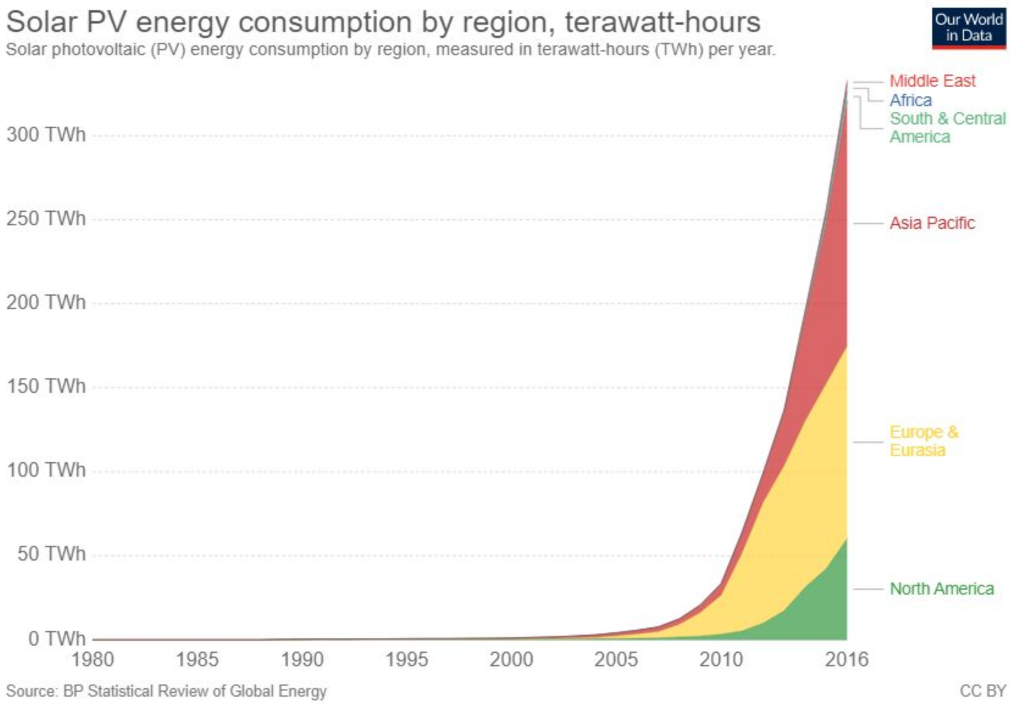


Figure 3: Solar PV energy consumption trend [5]

1.2. Genesis of electricity industry

The history of electricity generation and its birth as an industry inevitably touches upon some history of electricity itself. While static electricity and 'electric current' had been known since the 18th century (Benjamin Franklin's experiments with lightning), it would not be until a few decades later when Michael Faraday entered the scene that conventional ideas of power generation were born. Although Alessandro Volta had come up with electrochemical batteries as a means of 'producing' electricity, Faraday's work on electromagnetic induction gave humankind a seemingly endless supply of electricity. Of course, at this point in time, the average person did not *want* to have electricity. In fact, it was Thomas Edison's founding of the Edison Electric Light Company that created the potential for a centralized power production industry. Until his development of a working and somewhat long-lived incandescent bulb, the only consumers of electric power were industries that required a powerful source of heating (such as in an electrical furnace) or strong and reliable lighting. Although a few individual power plants had existed by that point in time, it took the likes of Edison and his business partner Samuel Insull to create an industry out of the prospect of clean and safe lighting for everybody.

The story of the birth and growth of an electrical grid in the United States tells us how power generation grew into an industry that was more so related to distribution than simply to generating electricity from fuel --- any good engineer could build a turbine or an engine, but a business would still depend on the distribution network to connect the generator to a customer. The model set by the Commonwealth Edison Company and the General Electric

Company in the US set the tone for many distribution networks that came after in many parts of the world [24].

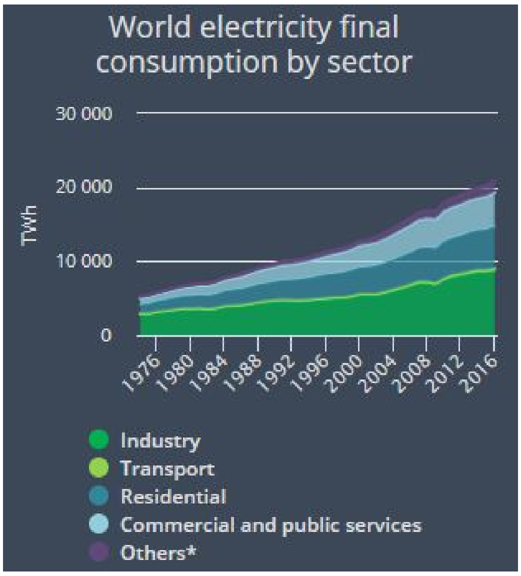
2. Electricity Industry Overview

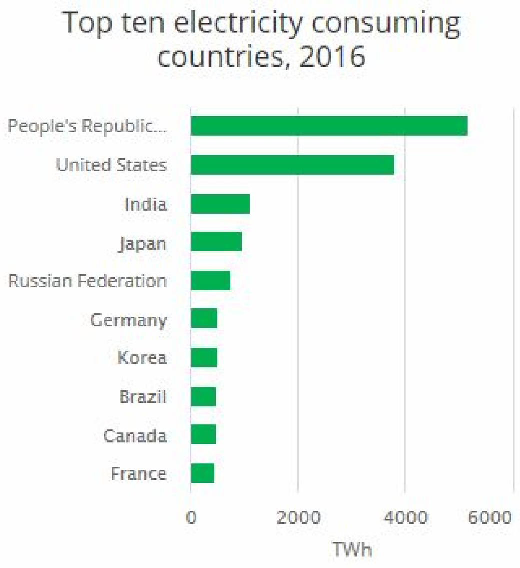
2.1. Scope of the Industry

In this report, we are concerned with the firms and actors involved in delivering electricity to the end users. Typical electricity supply chain includes electricity generation, transmission, distribution and retail. In this analysis, first we present a global overview of the electricity industry including the present market scenario, major firms and actors. Subsequently, we present the industry by analyzing firms and actors in each phase of the electricity supply chain. As the problem statement is more concerned about the electricity generation, we specifically focus on the electricity generation sector.

2.2. Present industry environment

The share of the electricity consumption for industrial, residential and commercial purposes is shown below. Close to half of the electricity consumption comes from industry while the remaining is equally distributed across residential and commercial purposes[6]. Electricity consumption by the region is shown below[7], China is the largest consumer of electricity followed by United States and India.

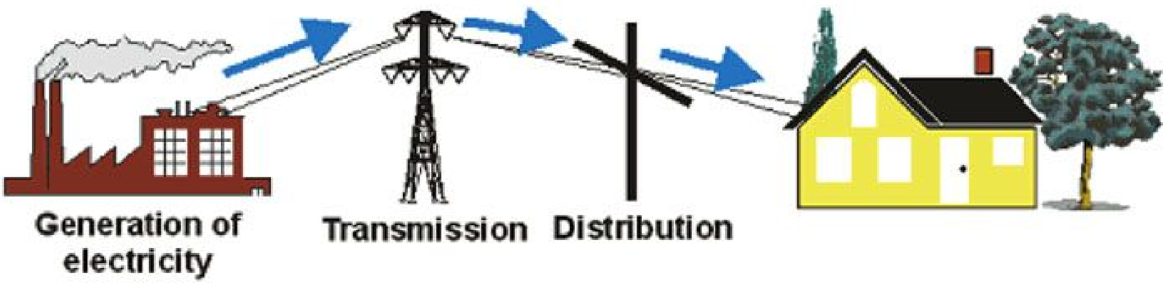




Major firms in the industry by the sale of electricity include State grid corporation of China accounting for $370 billions, followed by Enel(Italy), Uniper(Germany), Électricité de France SA (France), ENGIE(France), Korea Electric Power (South Korea), Tokyo electric power (Japan) etc. Also, major private firms by market capital include NextEra energy (U.S) valued at $76billions followed by Enel(Italy), Duke Energy(U.S), China Yangtze Power, Iberdrola (Spain)[8].

2.3. Working of the Industry

The electricity industry is composed of three basic components: Power generation, transmission and distribution. Power is generated using various mix of fuels which is then transmitted and distributed through power grid.



2.3.1. Electricity generation

Power plants are used to generate electricity. Power plants generally operate with diverse fuel mix which includes both renewable and nonrenewable energy resources. The World energy council classifies electricity generation into 11 categories based on resources which include oil, coal, gas, hydropower, wind, nuclear, solar, geothermal, biomass, Marine and Peat[9]. Alternatively, the sources of electricity generation can be classified into renewables and non-renewables. Non-renewables include fossil fuels and biomass that deplete with increasing consumption. As per international energy agency report in 2018, the share of electricity generated by various resources is shown below. It is observed that renewable sources account for over one quarter of the global electricity generated.

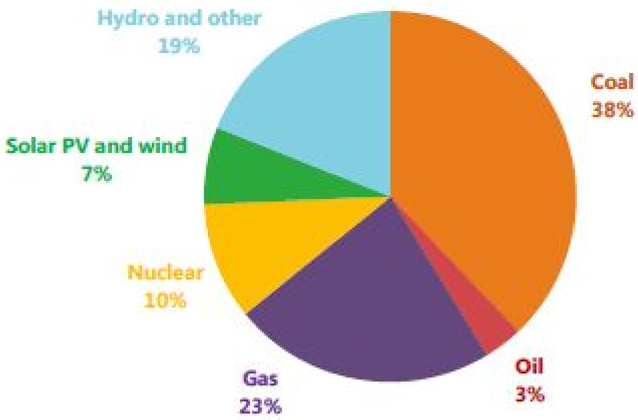


Figure 4: Global electricity generation mix by the fuel resource, 2018[10]

In most countries, fossil fuels account for the majority of electricity production. For example, 69% of the electricity generated in 2014 in the United States comes from fossil fuels with 89% of installed capacity. Power generation capacity also varies depending on the resource availability. Further, each of the fuel resources have a supply chain of their own. For example, fossil fuels have to extracted, processed and supplied to the power plant locations.

This includes vast infrastructure networks of railroads, pipelines, waterways and highways to supply the resources to the power generation facilities.

Power plants generally harvest electricity from mechanical work that is exerted from turbine to a coupled, rotary magnet that spins around copper coils within a generator. Resources such as fossil fuels serve as primary energy resources to generate mechanical power which then is converted to electrical power. Most of the thermal generator used are driven by steam which is generated by combusting fuel. Various fuels are used for producing electricity such as Coal, Crude oil, Natural gas, Nuclear resources and renewable sources. We present a brief overview of the electricity generation by each resource along with its present market share in this section.

Coal is the most abundant fossil fuel, with about 7800 million tonnes of coal consumed every year for various forms of energy production. Majority of the coal used in power production is steam coal or lignite. Presently, about 40% of the electricity production is from coal which is forecast to continue for at least 3 decades. Largest producers of coal are not confined by region. The top 5 producers of coal include China, United States, India, Indonesia and Australia. Further, Russia has the highest coal reserves in European region followed by Germany. Poland produces 90% of the electricity from coal resources. However, In poland, the coal costs have been low compared to the production costs which led to the closure of 4 coal mines in 2015. Further, a decline in hard coal mining is evident in Poland, Germany and other European nations due to the increased cost of production compared to global prices due to depletion of easily accessible deposits and increased labor costs. Consumption of coal for global electrification has huge implications on carbon emissions since coal is the most carbon intensive fossil fuel. There are various methods to mitigate the effect of coal use for electricity production such as carbon capture and storage so that carbon emissions are reduced.

Natural gas is a mixture of hydrocarbons which can exist as a gas or in solution with crude oil. Natural gas is the cleanest and most efficient of fossil fuels for power generation. Hence, gas consumption for power production is set to grow as it can transform the world towards more greener, affordable, sustainable and secure future of energy. Natural gas accounts for 23% of the global electricity produced with top three gas producing nations are the United Nations, Russia and Iran and top three regions with highest recoverable gas reserves being Middle east & north africa, Asia and Europe.

Nuclear reactors are used for producing power mostly fuelled by Uranium, a naturally occurring element in the earth whose traces are found everywhere. However, it is mined significantly in only 12 countries. Over 80% of the Uranium is mined is from five countries namely Kazakhstan, Canada, Australia, Namibia and Niger. Global nuclear power has approximately 10% share in electricity production with the United States and France being major players. Though the United States is the largest producer of nuclear power, it’s share is only 19.3% of power produced in the United States compared to 76% in France making france the only nation with highest nuclear energy portfolio.

Crude oil is another fossil fuels used in power generation with 3% global share. It consists of hydrocarbons formed from sediments rich in organic matter. Oil is mainly used in transportation.

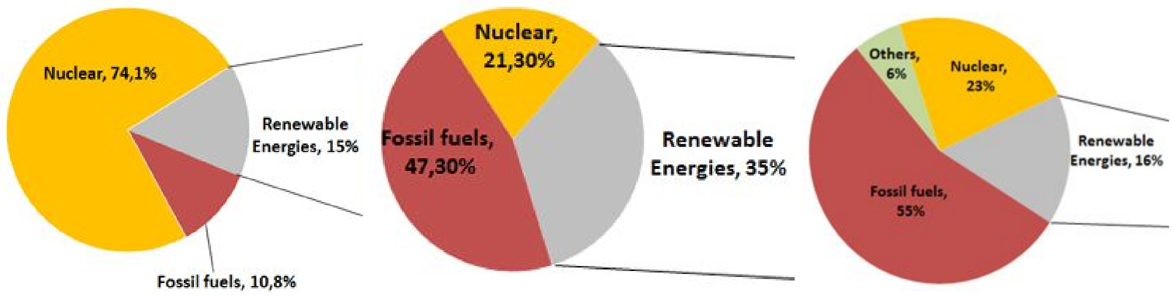
Hydropower is the leading energy resource for the production of renewable electricity with 71% of the renewable market share. Hydropower is harvested when moving water produces the energy required to turn the turbine blades which in turn convert it into electricity. Hydropower is the most flexible of all the renewable energy resources which is capable of meeting both the base load demand and peak demand requirements. As of 2015, the world's leaders is hydropower generation are China, United States, Brazil, Canada and India. There are three types of hydropower plants based on the nature of water storage namely 'run of river', where running river drives the turbines, 'reservoir' where stored water drives the turbines by the virtue of potential head and 'pumped storage' where stored water is recycled by pumping it back to higher reservoir.

Solar radiation is converted to electricity through solar cells which absorb the Sun's energy. There are two main types of solar energy technologies namely photovoltaic and thermal collectors. Photovoltaics collect solar radiation and convert it directly to electricity without the use of heat engine. Solar thermal collectors are generally used for domestic heating or hot water. But large scale solar thermal plants can be used for industrial heating or electricity generation. Global solar energy installed capacity has been on exponential growth making an interesting topic to study and analyze its impact towards shaping the future of energy. As of 2016, Europe leads the world in installed capacity, closely followed by Asia and East Asia. Further, solar energy can play a major role in changing the energy consumption portfolio because it can help reduce the carbon emissions. In addition, it can be used for heating, cooling, lighting, electrical power, transportation and environmental clean-up. We discuss more about photovoltaic industry in this paper in later sections.

Wind energy is another renewable energy source which is used to turn the wind turbines which intern drive the power generators to produce electricity. Wind energy is virtually available everywhere on earth. Although the majority of present installed capacity is onshore, it is possible to have wind turbines installed offshore to benefit from larger resource area with lower environmental impact. As of 2015, wind power capacity has reached 7% of global installed power capacity and 4% of global power production which is significant. China has the largest installed wind power capacity followed by the United States and Germany. In terms of regions, Asia tops the installed wind power generation capacity followed closely by East Asia and Europe.

Electricity generation in Europe

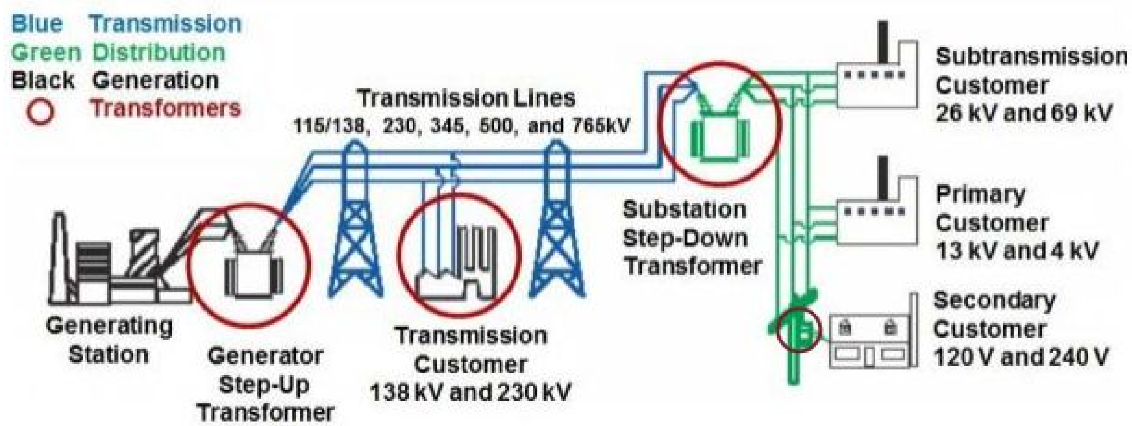
In Europe, various countries have different electricity generation portfolios. Energy mix for France, Spain and Germany are shown in figure[11]. Variation of energy mix across countries is due the resource availability, energy policies set by various governments. Further, global carbon emission targets in view of climate change encourage renewable energy production across all countries. From the figure, we see that renewable energy sources occupy significant share of energy produced. At this juncture, it is pertinent to ask if renewables can improve their share in electricity generation and if they improve what would be the impact on other sectors of the electricity industry. Major companies involved in renewable energy generation by installed capacity are Siemens AG, Vestas, GE Energy, NextEra Energy Inc, Orsted (Denmark), Suzlon etc.



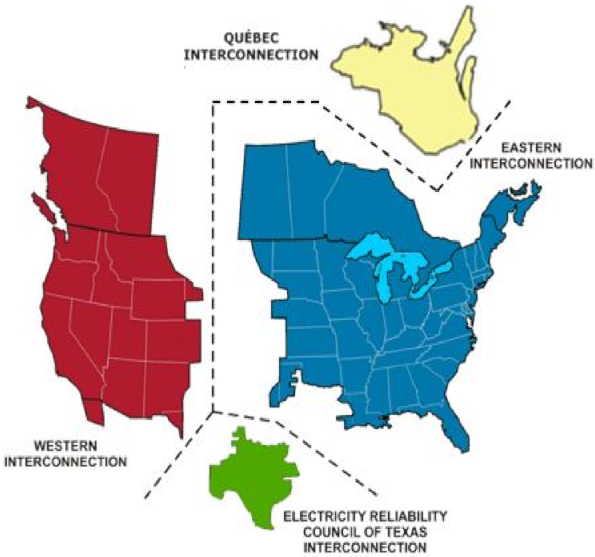
France **Spain** **Germany**

2.3.2. Electricity transmission and distribution

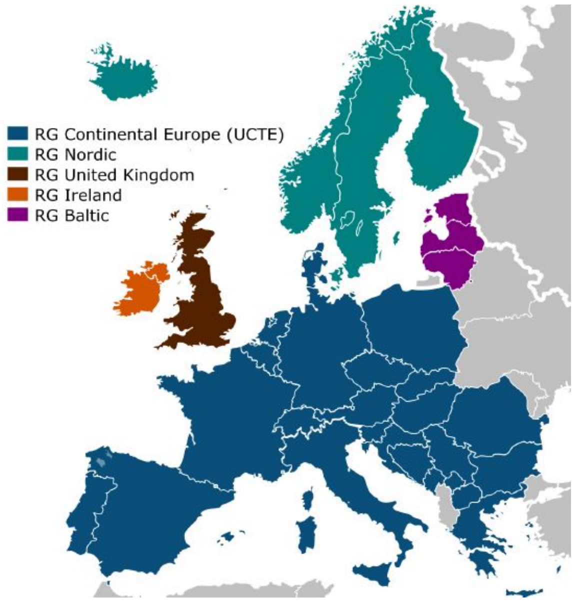
Electricity is generally produced at 5 to 34.5 kiloVolts(kV). and distributed at 15 to 34.5kV. However, the power is transmitted at 69 to 765kV in order to enable transmission over large distances with minimum transmission losses. Hence, power plants generally use step-up transformers to increase their power rating to connect to the transmission system. Transformers play a very significant role in the power transmission and are technically complex to operate. Typical energy supply chain is shown in figure. Another element of transmission is the reactive power transmission. Reactive power is used to stabilize electricity transfer across generators and transmission lines, the sources of reactive power are in close proximity to the demand center so as to avoid losses over large distances.



The network infrastructure involved in transmission and distribution is commonly referred to as power grid. Most of the transmission is achieved through a national grid in most of the places which is constantly being upgraded to connect various geographic locations as well as various power generation sources. Power grids are generally established and work independently. Further, multiple power grids are connected with interconnections to ease the load sharing and to enable the energy trading. For example, the power grid of the United States comprises of four distinct interconnections as shown in figure. European power network consists of many cross border interconnections.



North American power grid interconnections



European power network, Synchronous Areas

Each interconnection operates independently of one another with the few exceptions of direct current conversion links in between. Power demand fluctuates throughout the operation and differs from hour to hour of day depending on the industrial, commercial and residential power consumption cycles, also differs from region to region. Power grids try to meet the fluctuating demand by coordinating with the power generators making communication an effective element in the power supply. Base loading power plants operate at off-peak power demand levels to provide continuous minimum required power to the grid. Peaking power stations come online as the demand increases beyond base-load. Typically, power plants with larger starting times such as nuclear and coal power plants which takes upto 12 hours to start are used to meet the base-loading power demand and faster to start power sources such as natural gas power plants are used for meeting the on-demand peak power requirements.

The United States bulk electrical transmission and distribution consists of 360,000 miles of transmission lines with 180,000 miles of high voltage lines connecting about 7000 power plants. Similarly, European network of transmission system consists of approximately 194,000 miles of transmission lines connecting all of European power grid.

Major global players involved in the development of grid infrastructure are ABB Limited, Alstom SA, Mitsubishi Electric, Eaton, General Electric Company, Hitachi Limited, Siemens AG, Toshiba Corporation and OSRAM Licht AG, among many others.

Power distribution is the final stage of electricity supply to the end-users. Distribution system can either directly link into high power transmission lines or can be fed by sub transmission networks. Electricity distribution is achieved through two methods namely conventional substation and intelligent substation. Substations are crucial elements of power grid since they not only provide links between generators but also between transmission, distribution lines to end-users.

A group of localized power generation and distribution of energy is called micro grids. Micro grids generate energy in modular fashion, hence operate independent of the main power grids. Micro grids are very effective to serve the peak local demands, hence can serve in augmenting the main power grid capacity.

The developments on electricity distribution sector are driven by digital technology and semiconductor high-speed devices coupled with intelligent substations relying on digitalization and IT infrastructure. Global equipment manufacturers in this sector include Alstom Power, ABB Power Products, E-T-A Elektrotechnische Apparate GmbH, G&W Electric Company, GE Power and Water, Schneider Electrical Distribution, Pennsylvania Breaker, Toshiba, Siemens AG Energy, TE Connectivity Ltd. (Formerly Tyco Electronics Ltd.) etc.

2.3.3. Electricity retail and trading

Electricity is the only commodity that is consumed contemporaneously as it is being produced. Hence, the aggregate generation of electricity must be matched to the aggregate demand all the time. This results in a product with marginal cost of production and transmission costs that fluctuate rapidly. Electricity retail includes firms that buy electricity from generators and sell it to households and businesses. Trade between companies, traders, suppliers, distributors and customers that are connected to the transmission network happens in wholesale markets. In most of the markets, electricity trade is driven by surplus or deficit in energy production which varies depending on demand and supply of electricity. Relative price differences across markets also drive competition, hence electricity trade. Electricity trade is most efficient only if there exists interconnections between surplus producing plants to power deficit plants. However, companies involved in this industry are highly regulated by the government in terms of price controls etc. In addition, the industry is often subsidized at various phases. For example, renewable energy sources such as photovoltaics are subsidised to meet the carbon emission targets set by various governments.

2.3.4. Regulation and ownership

Major actors in the industry include regulatory bodies, regional organizations and private owners. The industry has a regulatory body as part of the department of energy within the government. For example, the Federal Energy Regulatory Commission (FREC) is an independent regulatory body with U.S Department of Energy which regulates electricity transmission. Similarly, In Europe, the rules for the electricity markets are set by independent national regulatory bodies. At European Union level, the Agency for the Cooperation of Energy regulators (ACER) defines guidelines for transnational electricity markets. Further, the European Network of Transmission System Operators for Electricity (ENTSO-E) is a network of transmission system operators across Europe.

2.4. Environmental factors

For the major part of its existence, the electricity generation industry does not seem to have been impacted much by cultural perceptions or external pressures --- the fortunes of each business have depended for the most part on the availability of natural resources and economic considerations. That is to say, for any one country, its energy mix is defined almost exclusively by the presence of natural resources (coal, oil, natural gas, river water, uranium ores etc.). That said, there have been protests and general opposition towards, for example, hydroelectric power even in the mid-20th century, especially where the projects would have tended to affect the environment of the region's inhabitants. One famous example was the (somewhat) recently constructed Three Gorges Dam in China, where although the project never seemed to be in any serious danger of obstruction, the ecological impacts associated with projects of such massive scale were brought into the spotlight. In India, the Narmada Bachao Andolan (which translates to the 'Save Narmada Andolan') is a long standing movement against the construction of hydroelectric power projects on the river Narmada, having existed in an organised fashion since the early 1980s [25].

The concept of climate change and action against it, especially in the political sphere, developed around 1980, although the issue of human impact on the environment had been identified and studied since the 19th century [26].

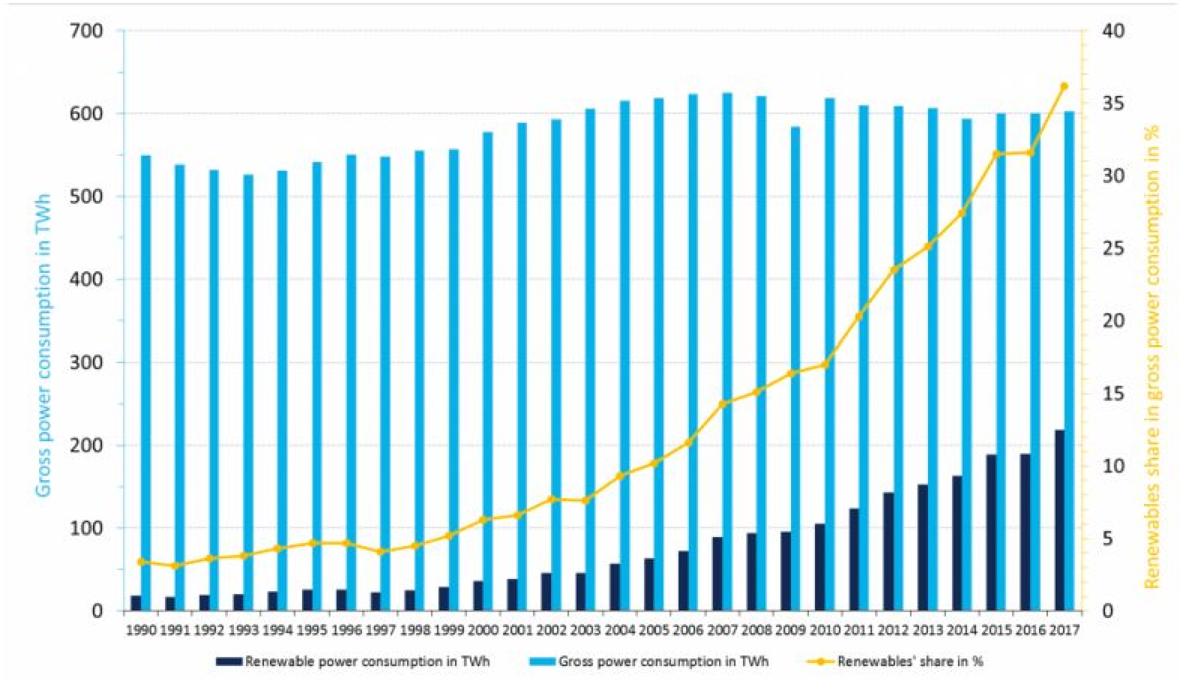
We can obtain some idea of the growth in popularity of climate change measures by looking at the German energy mix over the past 3 decades. We choose Germany for a few reasons: their primary natural energy resource is coal, and so the majority of their power generation has historically been from coal fired plants. With a small and saturated hydroelectric potential, we can construe all increases in wind and solar installations as being correlated to the effort to scrap coal and nuclear based power. Germany has also been very proactive in their energy transition, often being seen as a leader in the path towards the Kyoto Protocol pledges. On the other hand, France, for example, having a low availability of fossil fuel resources, rely primarily on nuclear power, which is already carbon neutral, making an energy transition to renewables a less powerful prospect there.

Germany's energy transition policy, called the Energiewende, currently mandates a share of renewables in electricity production of at least 35% by 2020, and at least 80% by 2050, with intermediate milestones along the way. While they might still miss the target set for the share of renewables in primary energy consumption, they seem well on their way to achieving their 35% target for renewables in power production. According to data from the AG Energiebilanzen, renewable energies in 2018 accounted for 35% of the German power production, most of which was from wind power (14.3% onshore, 3% offshore), followed by photovoltaic and biomass at 7.1% each [27]. A complete picture of their targets is indicated below.

	2015	2016	2020	2030	2040	2050
Greenhouse gas emissions						
Greenhouse gas emissions (compared to 1990)	-27.6 %	-27.3 %	minimum -40 %	min -55 %	min -70 %	largely GHG-neutral -80 to 95 %
Increase in share of renewable energy in final energy consumption						
Share in gross final energy consumption	14.7 %	14.8 %	18 %	30 %	45 %	60 %
Share in gross power consumption	31.5 %	31.6 %	min 35 %	min 50 % (2025: 40-45 %)	min 65 % (2035: 55-60 %)	min 80 %
Share in heat consumption	13 %	13.2 %	14 %			
Share in transport sector	5.3 %	5.2 %	10 % (EU goal)			
Reduction of energy consumption and increase in energy efficiency						
Primary energy consumption (compared to 2008)	-7.8 %	-6.5 %	-20 %			-50 %
Final energy productivity	1.4 % per year (2008-2015)	1.1 % per year (2008-2016)	2.1 % per year (2008-2050)			
Gross electricity consumption (compared to 2008)	-3.7 %	-3.6 %	-10 %			-25 %
Primary energy demand buildings (compared to 2008)	-15.6 %	-18.3 %				around -80 %
Heat demand buildings (compared to 2008)	-10.1 %	-6.3 %	-20 %			
Final energy consumption transport (compared to 2005)	1.3 %	4.2 %	-10 %			-40 %

German Energiewende.. Accessed 9 June 2019. [12]

Perhaps what is most inviting about the German example is that it lends some credence to the notion that significant portions of electricity production can indeed be supplanted by renewable resources --- when Germany first began investing in wind turbine farms, they had their fair share of nay-sayers, arguing the case that wind power would be unpredictable and that it would not serve as a viable backbone for their electricity infrastructure. In 2018, wind power accounted for over 17% of the entire electricity production. Since they are also actively investing in PV installation, the German energy situation should definitely be monitored over the next few years as an example.

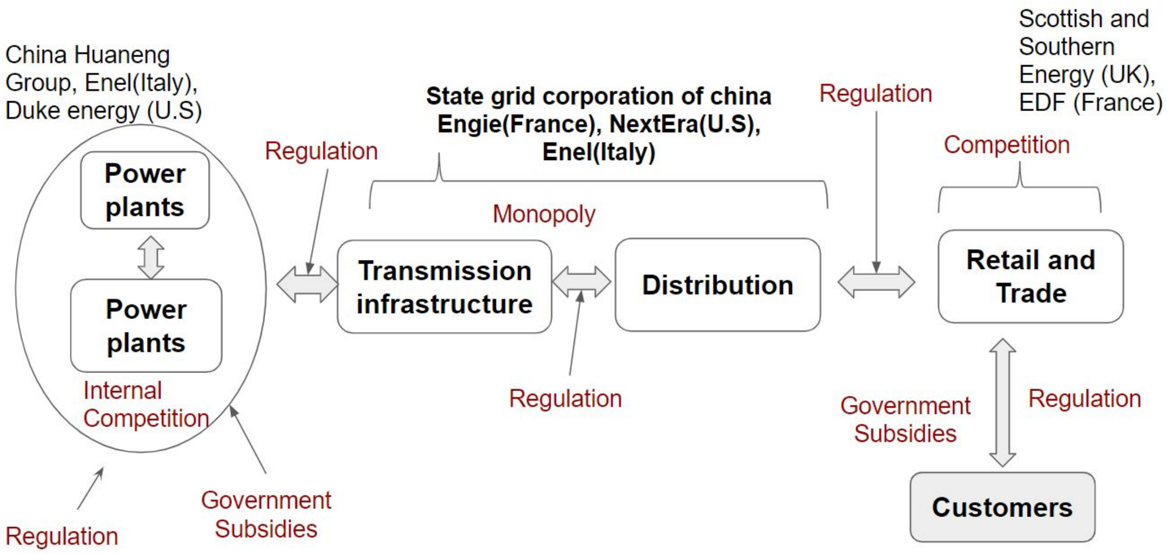


Share of renewables in German power consumption, Accessed 9 June 2019[13].

3. Analysis of Electricity Industry

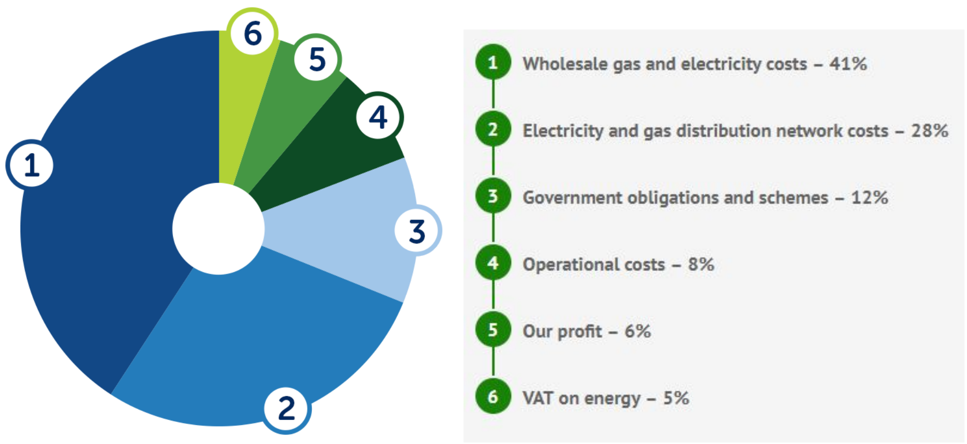
3.1. Value chain analysis of Industry

The industry can be analyzed from the perspective of network industries since the process of supplying electricity to the end user involves sub-sectors organized in sequential manner as depicted in the figure below. Power is generated in various power plants according to the resource availability and energy policies. The big companies in this sector are geographically separated resulting in low competition. The developments in this sector are concerned with the addition of new capacity to meet the growing demand and adjustment of energy fuel mix to optimize the cost and efficiency. Therefore, the dynamics of new entrants like solar photovoltaics is governed by their competing ability with existing power generation resources in terms of cost and efficiency. Further, companies in power generation are regulated with strict requirements in setting up power plants, connections to existing grid infrastructure. Since the investments in power generation are huge, the entry barriers for new companies are very high in power generation. However, government incentives play a crucial role in the establishment of renewable energy plants. For example, China is the market leader in the solar PV capacity installations as well as the manufacturing of solar cells which is solely driven by the Chinese government policies.



The transmission and distribution infrastructure is mainly owned and maintained by large monopolies across the globe. Major developments in this sector are concerned with continuous expansion of grid infrastructure, increasing interconnections between various grids to enable energy trading. Further, the digitalization started bringing in new concepts in grid infrastructure such as smart grids, micro grids. Since the companies in grid infrastructure are monopolies, there is not much competition from external agencies. However, the grid infrastructure establishment, maintenance and improvements are supported by various private corporations such as Siemens, ABB Ltd etc. There is a high level of competition between the private companies for maintaining and expanding the grid infrastructure.

The companies involved in retail and trading of electricity generally buy electricity from the power generators, use the existing grid infrastructure to supply the electricity to end users. Further, end users are charged per kW of electricity consumed depending on the hour of connectivity and the overall consumption. Government provides various subsidies to the end users in the final retail price of electricity. Typical distribution of costs across the network are shown in the figure below from one of the UKs biggest retailers[14]. Power generation accounts for 41% of the overall cost of electricity followed by grid costs which account for 28%.



3.2. Policy and Regulation

The dynamics of power generation are heavily dependent on the government energy policies and regulations. In a perfect market competition, the sustainability of various fuels for electricity production and distribution will be decided by the cost of production and security of supply. A case where market decides the prices though ideal is often distorted by government subsidies and incentives. In contrast, with the centrally controlled energy policies to meet various objectives such as reduced carbon emissions, the price levels will be unsustainable unless subsidized by the government.

3.3. Digitalization

The effects of digitalization on the industry though primarily concentrated in the area of electricity retail, inevitably affects the entire industry. Smart grid infrastructure which includes smart meters, smart appliances is used switch power sources depending on the cost of electricity which varies from time to time according to demand. Availability of big data for the customers makes it possible to adjust the consumption levels and to select various power generation sources to optimize the costs. In addition, the availability of customer consumption patterns makes it possible for the big data companies to distort the existing profits across the value chain.

3.4. Trends

Latest trends in energy generation are driven by two distinct factors. Firstly, the demand for electricity varies depending on the household and industry requirements and changes from year to year. Secondly, nations are driving towards sustainable energy generation while minimizing carbon emissions. Hence, there is an increasing interest in renewable energy resources. The demand for global electricity increased by 4% in 2018 driven by factors such as growth industrial sector, change in weather conditions etc. It is claimed that the majority of growth in demand in the United States in 2018 which accounts for 17% of the global demand is due to hotter summers and colder than average winters. Figure shows the growth in energy generation during the period 2017-18 by the resource. It can be seen that renewable energy sector accounted for 45% of growth in electricity generation with solar photovoltaics contributing to about 15%.

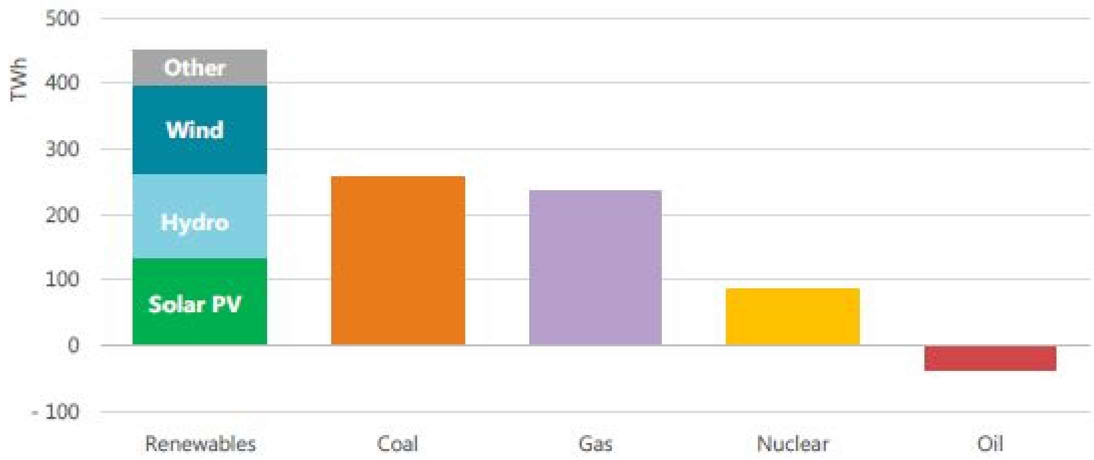


Figure 5: Growth in electricity generation by resource in 2017-18 [15]

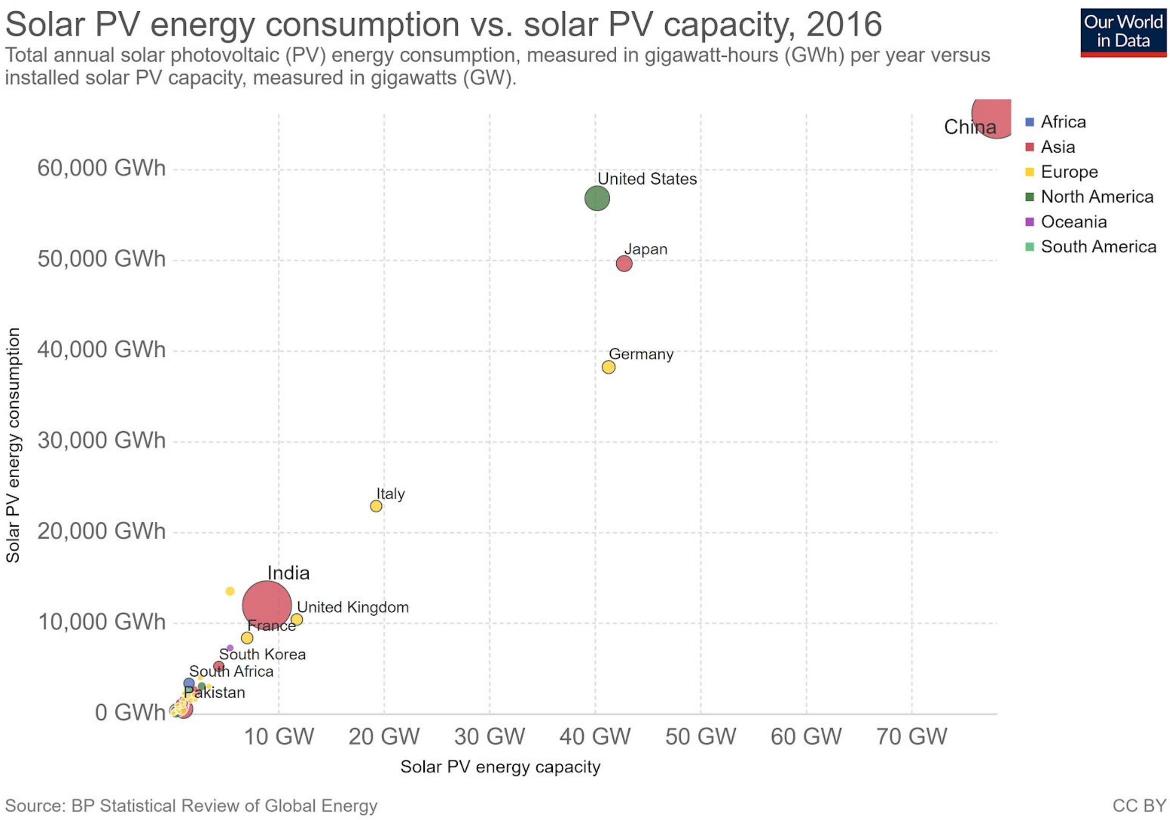
4. Solar Photovoltaics for electricity generation

4.1. Scope of Solar Photovoltaics

In this report, we are concerned with the response of major power utility companies such as China Huaneng group, Enel, EDF etc. with respect to solar photovoltaics for power generation since our problem statement deals with the effects of solar photovoltaics on specifically electricity industry. In addition, we also look at the new entrants in power generation apart from big agencies described before. Similar to the other forms of power generation, photovoltaics industry involves firms and actors involved in solar photovoltaics across the world including firms that are supplying physical products like solar cells, solar panels and companies involved in installation of solar power.

4.2. Global Photovoltaic electricity scenario

Photovoltaics industry is part of the global renewable energy sector. As of 2017, the total global installed capacity is 402GW with year on year growth rate of 29% [16]. China alone accounts for 131GW of installed capacity, followed by the USA (51GW) and Japan (49GW) and Germany (42GW). Other notable solar PV electricity producing countries include Italy (20GW) and India (18GW). Further, solar PV represents about 2.1% of the global electricity supply. As per global trends on renewable energy investments report of 2018[17], total investments in renewable sector accounted for $280 billions of which solar power installations recorded highest investments, accounted for $153.7 billions with 18% growth rate. Solar PV growth is driven by decreasing cost of solar electricity compared to other renewable sources. The average price of crystalline silicon modules continues to fall by approximately 15% year on year leading to lower solar power generation costs. Further, most of the investments in this sector are driven by developing economies such as China, India and Brazil which account for $115 billions in 2017 out of global total $153.7 billions. As noted by various agencies[18], China drives the dynamics of solar power generation. The state of the solar power generation capacity across the globe is summarized in the consumption vs capacity graph given below.



4.2.1. Solar Photovoltaics in China

China is the world's largest market for solar photovoltaics driven by government energy policies and subsidies. As per an International Energy Association report[19], China accounts for 54% of the global solar PV installed capacity in 2017. Though solar photovoltaics accounted for only 1.8% of the total power produced in China in 2017, it has been growing at 75% year-on-year. China Huaneng Group, the largest power generation company in China has been adding solar PV capacity year on year in an incremental manner. In 2016, of the total 10 TWh produced by China Huaneng group's subsidiary, Huaneng Renewables, a significant 0.5TWh is from solar photovoltaics with a growth rate of 26%, lead to increased revenues for the company as a whole[20].

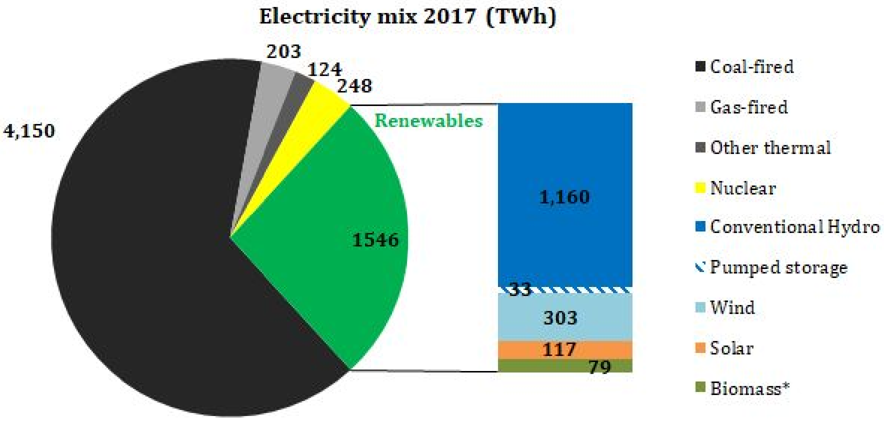


Figure 6: Electricity mix of China

The market share of solar panels for various countries indicated in the Figure below, shows that China is a global leader not only in production of solar power but also in the manufacturing of the solar panels. However, the push for solar PVs in China is mostly driven by government subsidies which may not last for long since Chinese government has an accumulated $17.6 billions in payments for solar PV subsidies as of 2019[21]. Grid parity (the costs of solar PV comparable with the other forms of available grid electricity costs) has become a reality due to the reduction in costs of solar power in various places. However, in China, this is not the case since the costs of other forms of electricity is very low due to 'non technical costs' such as land costs, taxes etc.

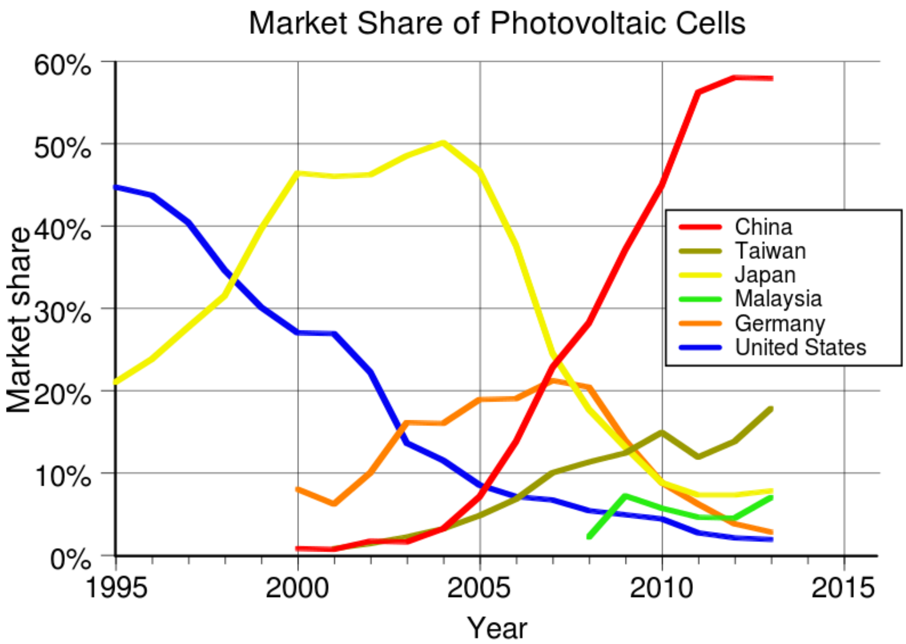


Figure 7: Market share of solar photovoltaic cells

4.2.2. Solar Photovoltaics in Europe

In Europe, Germany accounts for the maximum installed capacity(42GW), followed by Italy(20GW), UK(13GW) and France(8GW). As noted before, the second largest electricity producer in the world by sales is Enel, Italy. Enel green power which deals with the renewable energy resources based utilities produces about 11GW of renewable energy of which solar PV consists of only 9% of total capacity. In 2017, Germany added about 1.8GW of capacity whereas Italy added only about 0.4GW capacity.

EDF subsidiary called EDF renewables operates an installed capacity of 2.4GW as of 2019 globally[22][23]. Further, it has acquired French solar developer LUXEL which has an existing operating capacity of 1GW[24].

Though various governments have been supportive of the solar PV installations, there have been various retroactive measures in this regard. For example, Spain imposed various measures citing weaker economic conditions which lead to 50% reduction in revenues for the solar PV producers[19]. Similarly, Italy reduced Feed in Tarrifs on solar PVs. Further, Belgium imposed grid connections tariffs for compensating the losses in grid revenue.

Regarding the photovoltaics relevance, one of the most important factors is the energy policies set by the government. The policies vary across the nations depending on the social, political and economical situations. In the case of Europe, southern countries can take advantage of more solar hours than the northern ones. One particular case that takes our attention is the case of Spain which has more solar hours and radiation quality compared to most of the European countries. However, the utilization of solar power can be less productive than the north countries due to the policy, regulation and political system.

In **Spain**, since 2015, a Solar Tax has been levied on the photovoltaic industry, to avoid the investment and development of the renewable energies in favor of the traditional ones, possibly born of arrangements between traditional electricity generators and presidential election campaigns. Due to weak economic conditions, the government was not interested in making favorable conditions for the new renewable industries like photovoltaics . However, it was announced that the solar tax would be scrapped in late 2018[28], and the country has reported a significant increase in PV electricity generation in the past year[29].

Regarding to the regulation in **Germany**, from its Renewable Generation Energie Law, *Erneuerbare Energien Gesetz EEG,* in 1998, Germany has become one of the global leaders in clean energy production. In the field of solar energy, the German country remains at the forefront of research, registering today one of the highest photovoltaic energy productions and, what is better, it has an internal market that keeps growing. The only problem to put to its development has to do with its photovoltaic industry, brilliant a few years ago, but literally nonexistent today as a result of the thriving competition of cheap Asian-made equipment. In any case, it is not at all a bad curriculum for a country that is far from being the one that enjoys more hours of sunshine per year. The production of electricity from the thousands of solar panel systems installed in recent years has contributed, together with other energies such as wind or geothermal, to boost renewable energy to the status of the main pillar of the German energy system. The Law of Renewable Energies introduced in 2000 has until today been the main legal tool for the development of solar self-consumption in Germany. Since its inception, the law guaranteed producers a fixed price compensation (feed-in tariff) for the spill of their energy in the general network during a period of 20 years, as well as an auction system for large companies, producers, which has been key in the growth of the sector. The situation is beginning to change, however. Following the trend of the latest updates introduced in the EEG, the most recent amendments to the regulations introduced at the beginning of 2019 have made it clear that the German federal government considers that the market is over-subsidized and, consequently, measures have been introduced as the reduction of the amount of compensation for some months a year for systems of 40-750kW, posing, however, a greater offer of renewable bidding for a total of 4GW for the next 2 years. Germany is expected to be one of the markets with the highest growth in solar storage systems with batteries, one of the true technological challenges of the sustainable energy model and one of the main future goals of the German government.

Regarding regulation in **France,** the country has traditionally relied on nuclear energy for its consumption, with almost three quarters of its power coming from power stations scattered throughout the country. However, the closure of more than a dozen of these nuclear power stations scheduled for 2035 is accelerating the race to fill the gap left by nuclear energy and it is here where renewables seek their place. In their favor they have years' worth of central government incentives: tax benefits, interest-free loans for investment in renewables, subsidies, as well as a policy of redistribution of discharges to the network. Although the role of local and regional governments in the distribution of renewable energy for heating and air conditioning is essential, in France the use of the network for the transmission of electricity from renewable sources is governed by a single general electrical legislation, without existing express regulation for renewables. Recently, and in order to stimulate self-consumption figures that were still considered insufficient, the French government presented in 2015 the Law of Energy Transition for Green Growth (992/2015 relative to the Transition energy), which, among other measures, introduced plans to improve the energy efficiency of buildings or the simplification of procedures, in a clear gesture of support for self-consumption. As in Spain, the current law establishes two possibilities for self-consumption, without surpluses and with surpluses, with the difference that the purchase of surplus discharges into the network is guaranteed for 20 years, at a price higher than the market price and without existing obligation to sell surpluses to the national network (EDF and local distribution companies). For large stores, the option will remain an auction system. The French government has committed to increase its budget for renewables by about 71,000 million euros until 2028, with the aim of tripling the production of wind energy and quintupling the photovoltaic energy for that date.

The situation of renewables in **Portugal,** has been volatile in recent years. What seemed like a stable development scenario in which incentive mechanisms for renewables existed - compensation for discharges, tax benefits, subsidies for investment in renewables - collapsed during the worst part of the economic crisis in Portugal (between 2010 and 2014) and the consequent rescue of its economy. This has caused that since the crisis and until less than a year ago, our Portuguese neighbors lack significant support plans to promote the generation of renewable energy with the exception of some oriented to experimental technologies and co-generation plans. In terms of incentives, these have been fundamentally related to the expansion of the scarce existing transmission network, with the objective that the country gained in development capacity for new projects of photovoltaic energy. In recent times, however, it seems that the time for these new projects has arrived. The new energy plan of the Portuguese government -Roteiro para a Neutralidade Carbónica 2050-, establishes very ambitious objectives, among them, to cover in 2030, 80% of the country's electricity demand with clean energies and to electrify 65% of the Portuguese economy by 2050. This transformation would drastically reduce the country's current dependence on imported energy, which stands at around 75%. However, there is still concern that Portugal has a transmission network that will make future renewable electricity projects viable, especially in the south of the country (Bajo Alentejo and Algarve). Not in vain, this goal still takes much of the efforts of the Portuguese administration through its energy services regulator (ERSE), which has recently renewed its network expansion plan. In Portugal, photovoltaic self-consumption is governed by Decree Law 153/2014 and ordinances 14/2015 and 15/2015. Until that year, the energy produced by the photovoltaic systems could not be used for self-consumption, but rather the energy had to be poured - and therefore sold - into the grid. With the modification introduced by these regulations, the door was opened to self-consumption and the market could start offering photovoltaic kits for residences and companies. Some industrial associations critical of the current Portuguese legislation have positioned themselves against the model introduced by this regulation, arguing that it prioritizes the consumption model without surpluses against the possible benefits obtained by the sale of surplus of energy.

The development of renewables, and in particular of photovoltaic energy in **Italy,** was created in the core of the great development of renewables in Europe after the entry into force of the Kyoto Protocol (2005). So much so that by 2013 the transalpine country had already banned in referendum the development of new nuclear power plants and, thanks to a national incentive plan - and a traditionally very high electricity bill - was already one of the most important markets in the world in renewables together with Germany. Only in photovoltaic, the country represented in that year more than 20% of the installed power in Europe. Although the incentive program had to come to an end in 2013, the market has remained in good health. One of the reasons, in addition to the already mentioned high price of electricity, are incentives such as the "scambio sul posto" (net balance or net-metering in English) or energy efficiency certificates, which have remained in force. At the beginning of this year, the Italian government presented an integrated climate and energy plan ("Piano nazionale Integrato per l'Energia e il Clima 2030") that foresees that electricity from photovoltaic sources supposes more than half of the energy renewable energy by the end of the next decade. For this, the transalpine government foresees an evident investment effort in a country that, being mountainous, has in the hydroelectric power its main source of renewable energy. According to some experts, the challenge will not be so much a matter of incentives, which already exist, but the adaptation of regulations and clarity in authorization processes. The policies of the Italian government are also aimed at doing away with coal between 2025 and 2030. To do this, it plans a number of renewable energy auctions that, in order to compensate for the losses of dispensing with coal, will take place from this same year. From everything explained above, it can be deduced that Spain is not a pioneer in the promotion of renewable energy and self-consumption although the new regulations on self-consumption have positioned our country closer to its European partners, at least in terms of self-consumption. In its future evolution, it is worth taking into account a figure that well illustrates the photovoltaic potential of our country: producing one megawatt of photovoltaic energy in Spain is much cheaper than in other neighboring countries. This factor, together with the abundance of sunshine enjoyed by the country, describes a potential that should be reason enough to move towards an energy model based on solar and other renewable energy, a system that will free us of 40,000 million euros in foreign oil and gas that we import every year. The benefits in terms of environment, employment and external deficit would be substantial. As the photovoltaic market continues to introduce new developments in the country, the reasons for consumers to seriously consider the transition to photovoltaic solar energy will increase.

One of the key shortcomings of solar power is its limitation in the times at which it can be used. We consider as an example the case of Germany's power production profile in May, indicated in the figure below (gray portions indicate the electricity generation by traditional resources, and the yellow portions indicate the power production by solar PV). Over the day, we note that the electricity generation from PV is centered around noon, and dies out towards night time as the sun sets. However, there is always a 'base load' that must be generated, and we note that the majority of this base load is generated from fossil fuels. While PV solar power does a good job of supplying for the peak power demand during the day, it is observed that it contributes little to the 'base load' requirement at other times. In ideal situations, the argument for shifting completely towards PV power would be that excess production during the day would be stored using pumped hydro storage and recovered using a turbine once the sun has set. However, especially in Germany, it is clear that there is not much potential for pumped hydro storage, and even elsewhere, it is limited by the availability of natural geographical resources. This tends to suggest that in many countries, PV is simply not poised to substitute fossil fuels entirely, but may help conserve fossil fuels for future reserves and to offset some of their emissions potential. Of course, in such situations, it is possible that other means of energy storage might be considered (such as energy storage in hydrogen), but such storage methods may or may not use electricity (and thus PV power) as an input --- considering the same example of hydrogen, Fischer-Tropsch synthesis methods utilizing solar thermal energy are competitive with electrolysis methods involving PV.

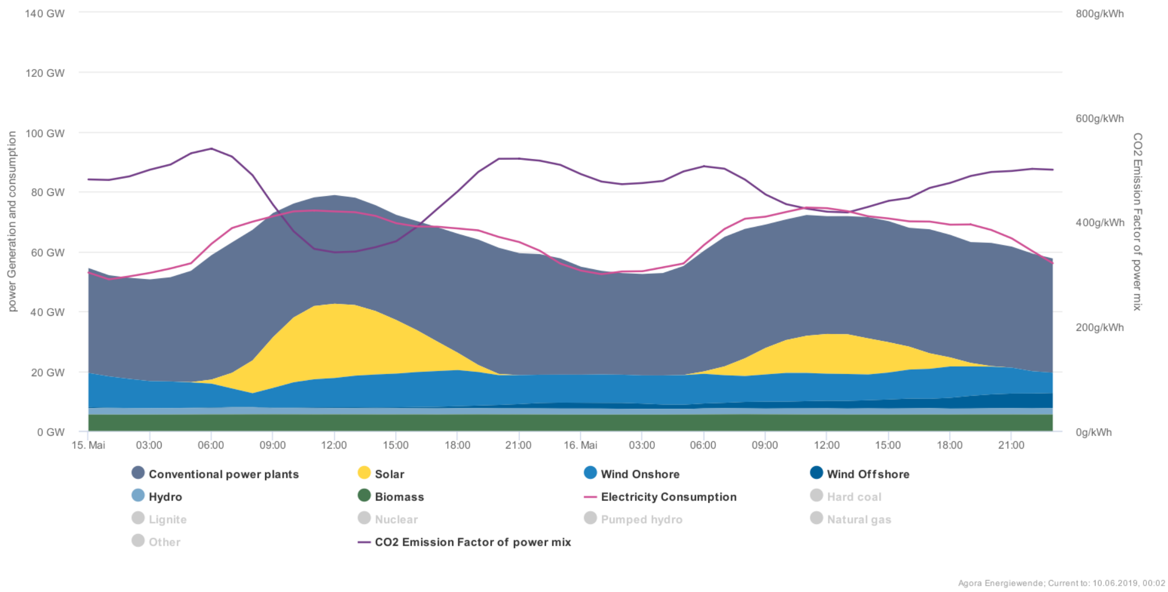


Figure 8: German Electricity production and consumption between 15 and 16 May, 2019[25]

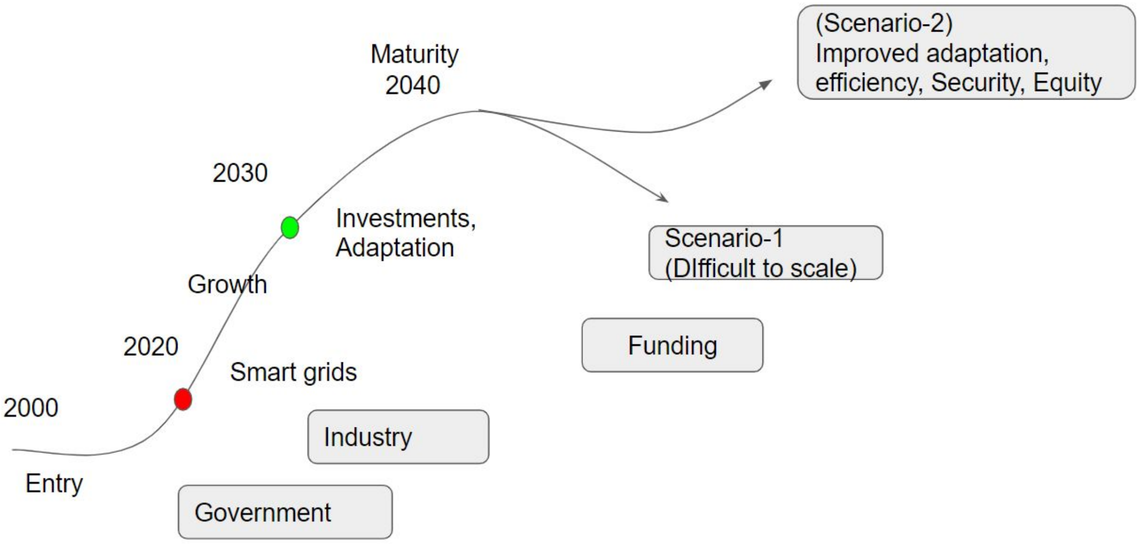
Today, the photovoltaics industry is a market worth several billions of dollars, most of it built around cheap silicon semiconductor materials. There is no reason to indicate that this industry will face any significant threat in the near future --- sunlight is a ubiquitous natural resource, and the cost of solar panels and modules decreases steadily with time. As such, PV is likely to grow and offset the aforementioned variable load or peak load in various developed and high-growth developing countries, and might even go beyond and supplant the sources providing the 'base load' in suitable countries --- Switzerland, for example, has a high potential for pumped-hydroelectric storage, and thus has the potential for replacing some of its nuclear power plants with solar PV farms. However, in the long run, we expect that the future of PV will depend on the development of alternative storage methods that would enable at least short term electricity storage (although ideally, some form of long term storage would also be required). As already mentioned, a prime example is hydrogen based storage, which remains fairly underdeveloped today due to cost constraints and material limitations. Commercial battery technology is simply too low in energy storage density and expensive to be viable for mass electricity storage, and is thus unlikely to help in offsetting the dependence on traditional resources for the base load. As such, we can consider that one of two scenarios could come to pass:

a) The potential of PV exceeds the developed capacity for storage, and the world must continue to depend on traditional energy resources, either fossil fuels or nuclear power for most countries. Over a much longer timeframe, the disparity might be overcome by further improvements in storage technology. However, we must also consider the problem that the 'energy solution' has a ticking clock dictated by extreme climate change, and past the point of no return, incentives for switching to alternate energy sources might also decrease.

b) The PV industry is bolstered by the development of suitable storage methods, and allows for the continued growth of the industry until PV becomes a major portion of the net electricity generation of most countries. In this case, we can expect that the presence of the PV industry will have significantly impacted the existing electricity generation industry, since a large chunk of fossil fuel or nuclear power plants could conceivably be replaced.

5. Discussion

From our research of photovoltaic electricity, we observe that the growth of the industry is primarily driven by China. As suggested by the data, the world's second largest power utility company Enel added only 0.4GW of solar PVs in past year when compared to China’s 54GW. Further, the major power utilities group in China has only 0.5TWhs of solar PV production when compared to 60TWh of solar power produced in China in 2016. This suggests that the largest power utility companies are not investing in solar PVs though the growth rate of solar PV installations is significant. From further analysis, we note that the government subsidies are driving the growth of solar PV installations across the globe primarily in China and Germany. This is depicted in the industry life cycle diagram given below as the present scenario. Since, the market share of solar PVs is significantly lower as of 2019, growing solar PV installations have not attracted much attention from the big power utility companies. However, the cost of solar cells has been decreasing significantly over the past decade. As often described in literature, the energy mix is governed by Energy trilemma which suggests that the adaption of power generation resource depends on Energy security, Energy equity and environmental sustainability. Energy security of solar PVs depends on the availability of solar power which varies depending on the time of the day and also varies from season to season in a given year. Solar energy being renewable source provides environmental sustainability. However, the cost of production, transmission and distribution at large scale have not been favorable. At this juncture, we see two different scenarios for the future of solar PVs, shown in the figure below. We see the continuation of growth of photovoltaics due to further investments in this sector in the coming decade. Further, this regime will be marked by acquisition of existing private entities by the big power utility companies such as EDF acquisition of LUXEL.



In the first scenario, due to various factors such as costs of production and security of energy supply, it would be difficult to scale further beyond a critical point. In the second scenario, improvements in efficiency, reductions in cost of solar cells would enable the solar PV to be a cheaper alternative.

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