Solar Photovoltaic Grid Parity: A Review of Issues and Challenges and Status of Different PV Markets

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Abstract- This paper presents a review of the solar PV grid parity in the global market by analyzing all the factors having an influence on the grid parity, methodology so far adapted to investigate the grid parity and the status of PV markets of different countries. The analysis indicates that solar resources, evolution in PV module cost, progression in electricity prices, environmental cost and grid extension cost are the major factors that affect the grid parity and these factors vary time to time and market to market. Cost reduction of PV modules in global markets has followed the Swanson prediction enabling it to compete for the conventional electricity market. Germany had been leading the PV market but owing to the change in policy and decrease in incentives, its annual PV installation has been decreased since 2013. China introduced incentives based renewable policy that abruptly increased the PV installations in 2011 and now China is leading the solar PV market. Study of different PV markets revealed that PV grid parity dynamically occurs in various segments of power sectors like residential, industrial and commercial sectors at different times. This paper will be supportive for the investors to understand PV market and its constraints, for the solar policymakers to comprehend various policy incentives that would help the solar PV penetration into the current electricity market.

Keywords: Solar grid parity; photovoltaic; Germany; China; Japan.

1. Introduction

The cost of the conventional fossil fuel-based energy resources is increasing with their increasing demand and rapid extinction. Deployment of photovoltaic in different global PV markets has drawn the PV module cost to a level to compete for the conventional market, a phenomenon known as grid parity or socket parity. Owing to the rapid extermination of fossil fuels, prices of traditional grid-based electricity are increasing gradually. To meet the ever-increasing demands of electricity, renewable energy resources and associated technologies are gaining popularity. Among renewable energy resources, photovoltaic (PV) energy is fit to compete for the current electricity market. Solar PV directly converts solar energy into DC electricity [1]. Solar grid parity or socket parity is thought to be a situation when solar PV energy is cheaper than the conventional electricity. Generally, solar grid parity is a situation in a time when the cost of electricity from solar PV (Levelized Cost of Electricity) is equal to or lower than the conventionally sourced electricity such as from grid and is called a static PV parity [2-4] as shown in Figure 1. Defining dynamic PV parity, the net present value of the cost of the whole PV system is compared to the net present value of returns generated by the operation of the PV system [5]. In a broader sense, the definition of solar grid parity is inconsistent and indefinite depending on various parameters and it fluctuates time to time, location to location and customer to the customer [4]. [6] has considered silicon cost $1/W as grid parity. [7,8] has contemplated the manufacturing cost $1/W of solar PV module as grid parity. [9, 10] defines the grid parity as the retail cost of PV module plus the cost of the Balance of System (BOS) while the manufacturer never sells at manufacturing cost but at a retail price after keeping his profit. [11] stated the half of the cost of the PV system goes to the PV module cost while the remaining half is of the BOS that includes the cost of installation, module supporting cost, inverters, switches, wires, and transformers. PV cell technologies with their characteristics parameters and BOS have been studied in detail by [12-14]. Among renewables, PV industry believes that it will dominate the conventional fossil fuel-based energy resources with the development in manufacturing and financing of currently available materials [15]. In view of the decline in PV cost over the years, it is going to be a reality. To reach the real grid parity without subsidies, in 2011 the energy department of US has set a target to bring the cost of PV to $1/W ($ 0.06/kWh) till 2020 [16]. A leading thin-film manufacturer, First Solar, envisages the cost of fully installed PV systems below $1/W by 2017 [17]. Solar shares only 1 % of the global electricity generation [18] but analysts and solar industry foresee 20-30 % share of solar in world energy mix till 2050 [19, 20] as the cost is abruptly declining with increasing solar PV installations. [15] stated that the cost of a solar panel has precipitously fallen 80 % in five years confirming the Swanson's prediction of 20 % reduction in cost with each doubling the shipped volume (cumulative production) [21].

The purpose of this review paper is to define the grid parity in its real sense by evaluating all the possible factors that could affect the time and location of grid parity, to accumulate all the parameters and economics of different PV adopted countries to understand the PV market and grid parity by just one document. The investigation over the grid parity year for a specific country requires reading out its solar PV market, electricity prices, environmental concerns and the availability of sun. Once the solar PV grid parity is achieved, solar PV will dominate the conventional fossil fuels and give ways to the latest grid technologies.

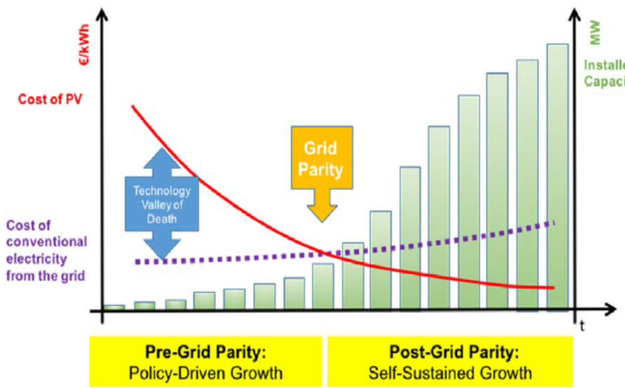


Fig. 1. Solar PV grid parity concept [22]

This paper endeavors to answer the following grid parity research questions:

1. What is the role of grid parity in encouraging solar PV?
2. Which factors drive the solar PV grid parity?
3. What is the status of different PV markets regarding grid parity?

Paper is organized as: section 2 investigates all the parameters and factors that control the occurrence of solar PV grid parity. Section 3 discusses the methodology so far adopted to determine the solar PV grid parity year by various authors for various PV markets. Section 4 and 5 discuss and compare PV markets of different countries to estimate the solar PV grid parity year depending on different constraints. Section 5 gives a discussion and concludes the paper.

2. Driving Factors of Solar PV Grid Parity

As stated in the definition of the grid parity; it is a dynamic situation in solar PV market because of its dependence on various dynamic factors such as environmental cost, solar resources, electricity cost, PV generation cost, and grid related cost. Change in one of the above constraints changes the occurring time of the grid parity. All these parameters are indicated in Figure 2 and how each of them is related to grid parity is investigated below.

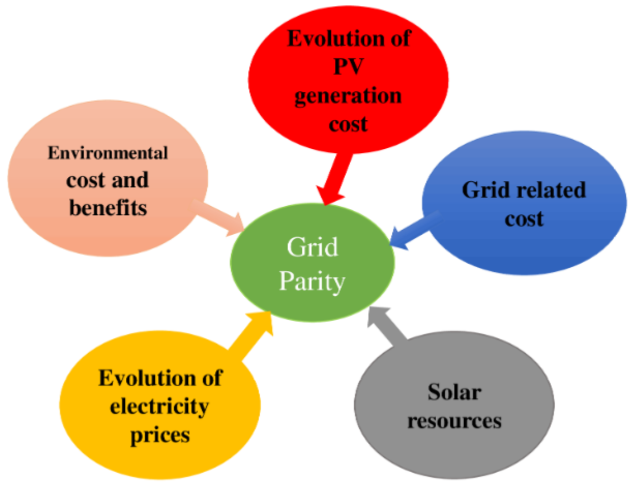


Fig. 2. Grid parity driving factors

2.1 Environmental cost and benefits

Emissions from the electricity generation process are a key factor influencing the occurrence of grid parity. Solar PV has astoundingly low emissions of CO_2 or even no CO_2 [22]. However, it is reported that during the mining, smelting, and purification of the metal and the production of the PV modules, total direct emissions of Cd for mono-Si are 0.9 g/GWh and 0.3 g/GWh for CdTe. One kWh of electricity generated from PV makes 15-50 g of CO_2 [23] and emission saving of CO_2 from one kWh of electricity is 530 g [24]. To reduce the greenhouse emission, environmental concerning authorities and policymakers are encouraging the tax on carbon emissions. In Australia, $23 were initially imposed on 1-ton generation of CO_2 [23] that rose to $25.4 in 2014. The Age [25] reported in its story that after nine months of the implementation of the carbon tax, lignite coal-based electricity generation mitigated by 14 % and reported 28 % increase in renewable-based electricity generation for the same above stated period. Ireland enacted carbon tax of €15/ton of CO_2 in 2010 to achieve green parity. That carbon tax was increased to €20/ton in 2012, which is still implemented there [26,27]. International Energy Agency (IEA) envisaged in its roadmap for solar energy that in 2050 installed capacity of 4600 GW in its 29 member countries would be handy in avoiding 4 gigatons CO_2 per annum [28]. Today, China is the largest emitter of CO_2 with a 14.15 % global share in 2000 that ascended to 28.03 % in 2013 [29].

The government of China is focusing on climate policies to limit the local CO_2 emissions. [30] stated that the implementation of carbon tax promotes energy efficiency and hence encourages the renewable energy resources.

To ensure the replacement of the conventional environment polluting fossil fuel based system with the renewable based environment-friendly energy systems, certain incentives like Renewable Portfolio Standards (RPS) and Feed-in Tariff (FiT) have been introduced and recognized by various policymakers of the different countries [31]. RPS is acting as a crucial instrument to ensure the specific percentage of a utility's electricity to be generated by renewable energy resources. In 28 states of USA, RPS has been implemented to mitigate the dependence on fossil fuels, mitigate carbon emissions and deploy renewable energy resources [32]. Canada, Germany, France, Spain, India and various other countries have adopted FiT to promote renewable energy resources [31].

2.2 Solar Resources

The maximum power that a PV module can deliver is highly dependent on the irradiance received by the PV module [33, 34] and the temperature of the PV panel. Hifsa et al introduced a temperature controller that controls the temperature of the PV module for the indoor PV system and increased the efficiency of the PV system [1, 35]. The maximum power point on the I-V and P-V curves is drastically decreased with the increasing temperature [36, 37]. The region with low irradiance level is not pro to solar PV as the PV modules will not provide its rated output power. To get the required power, more PV modules will need to be installed that will boost the system generated electricity cost ($/kWh) as well. So, solar resource or solar irradiance is the main factor that directly spurs the solar grid parity as no source mean no electricity available to sale & purchase at competitive rates and more sun means better and consistent production of electricity.

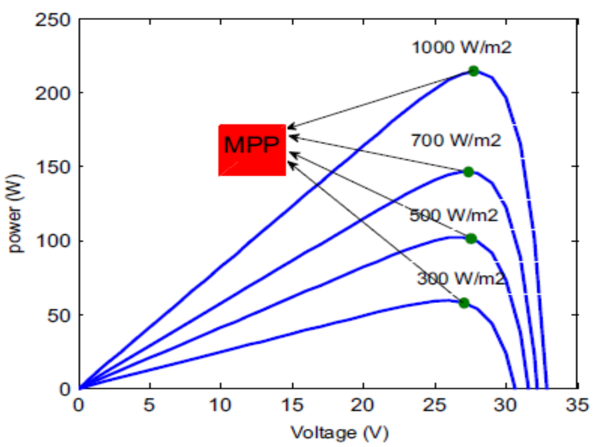


Fig. 3. The power curve of the PV module for varying irradiance [34]

As weather plays a major part in the output of renewable energy resources [38]. The design and model of indoor photovoltaic system prove to be 1.16 times more energy efficient as compared to its equivalent outdoor model for the same conditions. Moreover, extended lifetime is observed because of the indoor conditions [39]. To enhance the solar production, solar trackers and Maximum Power Point Trackers (MPPT) are coupled with the solar systems [1, 35]. Figure 3 shows maximum power at maximum irradiance level. With the reduction in irradiance, output power also declines.

2.3 The Growth in Electricity Prices

Current electricity generating power plants are fossil fuel based so the cost of electricity production varies with the cost of fossil fuels and change in demand and hence classically tend to escalate over time [40]. To assess the future electricity prices, its methodology needs to be considered that consists of two different types like wholesale price and the retail price. Wholesale price is the amount paid by the electricity supplier to the producers while the retail price is the amount paid by the customer to the supplier which is the sum of the wholesale price, supplier profit, grid cost, and the taxes [41]. Hence, the customers pay a retail price for the electricity they use [41, 42]. Moreover, photovoltaic based microgrid systems are proved to be cost efficient through a reduction in peak power consumption, DC-link voltage regulation and power factor compensation [43, 44]. Following three components determine the cost of electricity.

- Procurement cost
- Transmission and Distribution cost
- Taxes

Figure 4 explains the breakdown of electricity prices. Currently, traditional fossil fuel-based power plants are the major electricity producers whose cost of energy mainly depends upon the resource they use like gas, oil, and coal. With the extinction of these resources and heavy carbon taxes on polluting resources, the cost of these resources is escalating over time. Transmission and distribution of the electricity from the power plant to the end users all over the country incur another major cost that raises the electricity prices. With the abrupt increase in electricity demand, demand pattern has been altered from generation-follows-demand perspective to demand-follows-generation perspective [45] by using renewable energy resources and the distributed generation based smart grids [41] that compete for the utility grid prices to reach the grid parity.

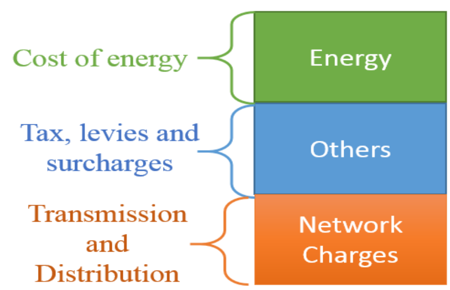
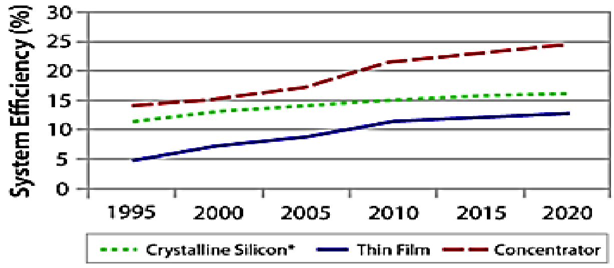


Fig. 4. Breakdown of electricity prices [39]

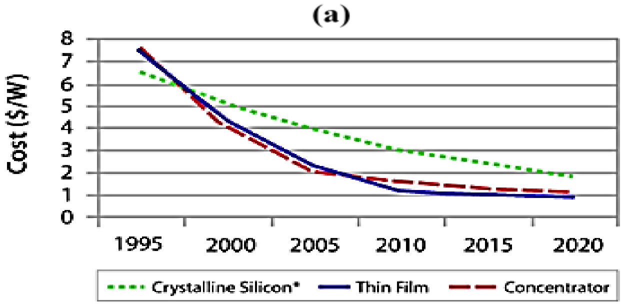
2.4 Evolution of PV Generation Cost

Rapid extinction and increasing environmental damages of conventional fossil fuels have made the conventional electricity extravagant giving its place to other renewable energy resources to accommodate the energy demands. Solar energy is one of the best energies having the ability to compete for the existing electricity market. Owing to the Research and Development (R&D) in solar PV technology, solar modules of efficient and cheap materials having higher conversion efficiency have been developed [46]. Since 1995, how the efficiency of different PV materials has been gradually increased is shown in Figure 5 (a). These more efficient PV materials have driven the PV modules cheaper [47] and thin film PV cost has crossed below $1/W as recorded in Figure 5 (b). Solar PV cells of different materials have been conferred and compared by [14, 48-51] on the basis of their manufacturing process, conversion efficiency, availability of materials and the price.

Powell [52] has outlined the pathways in bringing down the c-Si cost to the $0.50/Wp. With the improvement and development in all above-stated factors, cumulative production and cumulative installed capacity of solar PV modules have gone skyrocketed and the solar PV market is growing to compete the conventional fossil fuel-based electricity market. Swanson's law states that with each doubling of the PV cumulative production, the cost is decreased by 20 % [47] which has been found true. Figure 6 indicates the experience curve of the PV module cumulative production (GW) versus cost ($/Watt) from 1975 to 2015. This experience curve exhibits that in 2015 the cost of PV module has reached much below the Swanson's statement.



(a)



(b)

Fig. 5. (a) Efficiency of PV systems since 1995 (b) PV system capital cost [51]

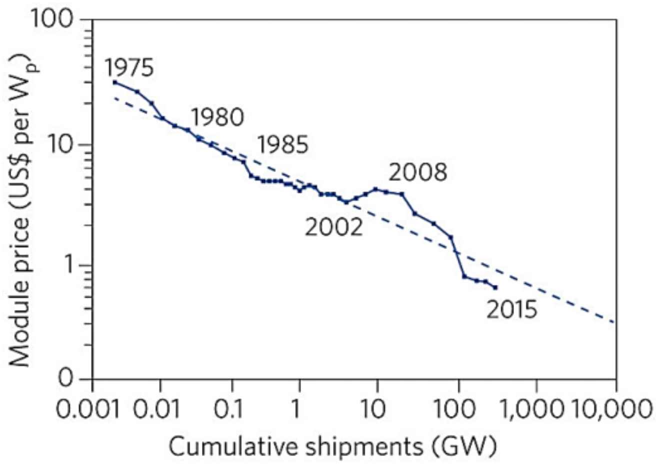


Fig. 6. Swanson's law and experience curve for PV module [15]

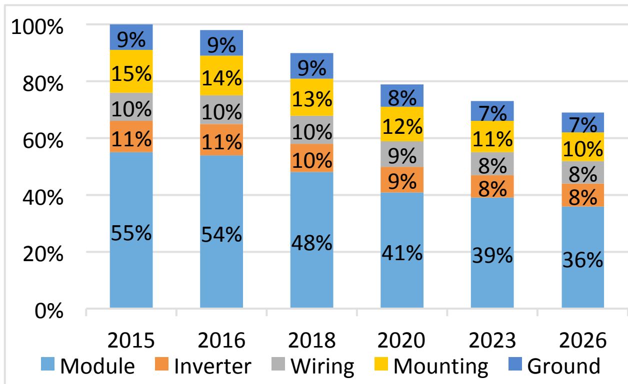


Fig. 7. Cost distribution development for PV system >100kW in the USA and Europe [57]

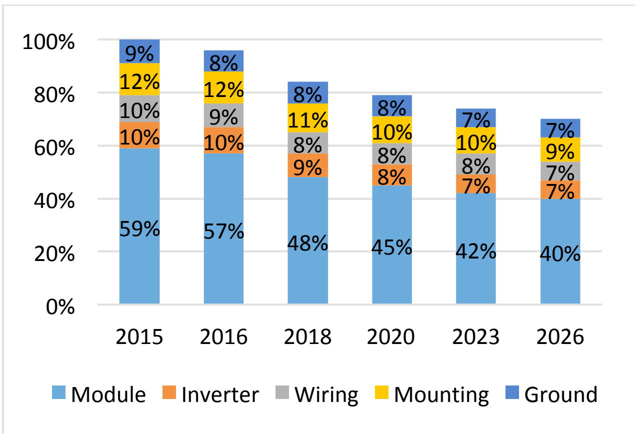


Fig. 8. Cost distribution development for PV system >100kW in Asia [57]

PV system cost is the amassed summation of PV module cost and the Balance of System (BOS) [53] consisting of an inverter, wiring, installation, and ground [54-56]. Discussing the evolution in PV system cost, the cost of the BOS has become a decisive factor as the cost of PV module has been decreased rapidly as shown in Figure 7 while the cost of the whole system is now dependent on BOS which marks two third of the system cost [53, 57]. Figure 7 and Figure 8 show the cost development of PV system larger than 100 kW for the US, Europe, and Asia respectively. Graphs indicate an almost similar cost reduction inclination, about 30 % of the whole PV system for Asia, and 32 % for US and Europe from 2015 to 2026. It is expected that the cost of PV modules will be continued to decline and hence the BOS cost has become crucial in reducing overall system cost.

2.5 Grid-related Cost and Benefits

While discussing the grid parity phenomena, the cost of the access to the electricity grid cannot be ignored. About 1.5 billion people of the world population are without electricity grid access. Most of them reside in areas enriched with solar irradiance [3]. So, islanded solar PV systems are best for these regions that require a microgrid to the sale and purchase PV electricity to and from neighboring PV systems.

3. Methodology for PV Grid Parity

3.1. Experience Curves Analysis

In history, experience curves have been used to examine the recovery rate of psychological patients with repeated training (learning). Over the last few decades, experience curves have been extensively used to study the past decreasing trend of cost with cumulative production. [21] has reviewed learning curves for different technologies of electricity generation. [58] has assessed the PV module cost reduction using experience curves and stated that a considerable cost reduction would be after 2020 to achieve grid parity. [59] argued that the cost of the Combined Cycle Gas Turbine (CCGT) would be reduced with a gain in experience. A new CCGT of 2250 GW will need to be installed to gain that experience which is unlikely to occur. [60] used the experience curves to analyze the cost reduction of US ethanol production and found 62 % cost reduction in corn production and 42 % cost reduction in ethanol production from 1975-2005. [61] used the experience curves for energy demand technologies and concluded a cost reduction at a learning rate of 18±9 resulting in cheaper energy demand technologies. Refs. [62-64] have used experience curves to find out the solar PV grid parity.

Experience curve is a scatter plot of cumulative production on the logarithmic x-axis versus cost on the logarithmic y-axis. The scatter points exhibit a decaying line showing that with each time cumulative production is doubled, the cost of the product is decreased. Experience curve analysis or the learning curves in solar PV is the study of a decrease in cost with an increase in cumulative production of the solar PV module. Cumulative production is used to estimate the gain in experience or the technology improvement and innovation usually termed “learning by doing” resulting in cost reduction [65, 66]. The decline in cost is because of the improvement of existing technology (learning by doing), innovation of new technology and scaling effect. Swanson’s law states a 20 % reduction in PV module cost if the globally cumulative production is doubled. Learning curve, in literature, is described as shown in Eq. (1)

$$C_t = C_0 \left(\frac{Q_t}{Q_0}\right)^b \tag{1}$$

Where Ct is the cumulative production cost/unit at time t, C_0 is the unit cost in a base year, Q_t is the cumulative production at time t, Q_0 is the base year cumulative production and b is the learning rate (LR) as given in Eq. (2).

$$b = \frac{ln\left({C_t}/{C_0}\right)}{ln\left({Q_t}/{Q_0}\right)} \tag{2}$$

Learning rate (LR) determines the cost of the unit product. If LR is high (PR low), the rate of cost reduction is high while it is low for low LR (PR high).

PR+LR=1

Progress Ratio (PR) = 2b

Learning Rate (LR) = 1-2b

As stated earlier in this section that learning is one of the factors influencing the experience curves. However, regarding solar PV, some authors assume that the local and global learning is the same as the technology is globally shared by international solar PV manufacturing companies. For this reason, authors have taken global data and extrapolated it for their local grid parity assessment [67].

To measure the learning of solar PV, two approaches are used in literature. One is the experience curves for solar PV modules and other is the experience curves for the Balance of System (BOS) consisting of rest of the solar PV system components (inverters, MPPT, charge controller, cables, system installation, and other electronic components) excluding solar modules [68]. In literature, related to grid parity, authors have focused on module cost rather than the overall solar system cost. Learning in module manufacturing is attributed to the learning in designing, installation, and integration of the BOS. [67] has drawn learning curves for solar PV modules considering different progress ratios (75,80,85,90) as shown in Figure 9 that exhibits a reduction in cost with cumulative production of PV modules. With variation in learning rate, the rate of cost reduction is also varied. With greater learning effect (PR=75 %) cost of PV module is rapidly decreased.

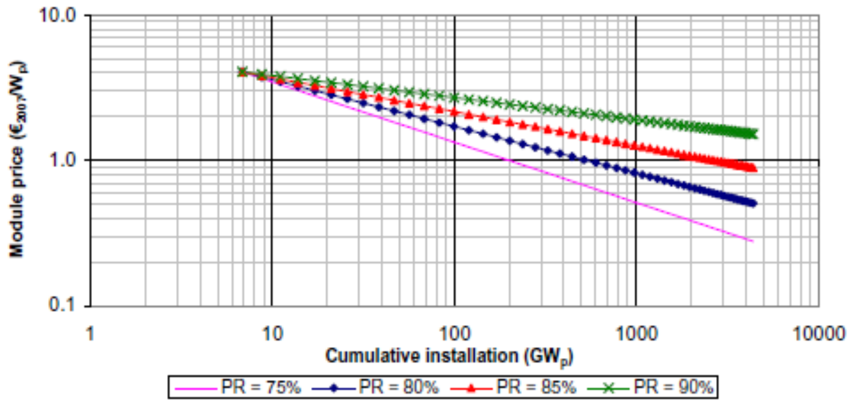


Fig. 9. Experience curves for global PV module cost (2006-2060) [67]

3.2. Levelized Cost of Energy

Levelized Cost of Energy (LCOE) for PV plants is a benchmark [69, 70] and well established method [66] that calculates the cost of energy ($/kWh) under some sensitive assumptions especially when predicted and extrapolated the trend into the future [66, 70-72] for comparing it with energy cost from other sources [65]. Irrespective of the fact that the PV market price ($/kWh) is dynamic [65] depending on solar insolation [73, 74], location, plant lifetime, operation, complexity and efficiency [69, 75]; agents mishandle the sensitive assumptions in measuring the LCOE which is a static measure [65]. For the lifelike assessment of the LCOE for PV investment expenditures; O&M cost, discount factor, carbon cost, fuel cost, decommissioning cost and the electricity generated must be taken into consideration [66, 76-78]. LCOE considers all capital expenditures and operation and maintenance cost to calculate the total system cost and then fraction it with total energy generated. However, the method does not count for any financing risk and financing methods. [65] has given a detailed review of the LCOE for solar PV based power plants. [79] has provided LCOE for PV systems in 143 countries. The general equation for LCOE is shown in Eq. (3) [66, 80].

$$\text{LCOE} = \frac{\text{Lifecycle cost of the project (\$)}}{\text{Lifetime energy generated (kWh)}} \quad (3)$$

LCOE is measured by two generally used methods, “Discounting method” and “annuitizing method” [81, 82]. In discounting method, future actual cost ‘Ct’ is fractioned with electrical energy produced ‘Et’ in the year ‘t’ discounted back at rate ‘r’ as explained in Eq. (4) and (5).

$$\text{LCOE} = \frac{\text{CAPEX+NPV(OMEX)}}{\text{NPV(EG)}} = \frac{NPV(cost)}{NPV(output)} \quad (4)$$

Where CAPEX, capital expenditure (initial investment); OMEX, operation and maintenance expenditure; EG, energy generated and NPV, net present value. Discounted LCOE is expressed in Eq. (5).

$$LCOE_{dis.} = \frac{\sum_{t=1}^{n} \frac{C^t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E^t}{(1+r)^t}} \quad (5)$$

In “annuitizing method” NPV of the cost of the plant over its lifetime is calculated and reintroduced as annual cost using the annuity formula. This lifetime cost of the plant is then fractioned with the annual average electrical output energy of the plant over its lifetime (n year lifetime) as illustrated in Eq. (6).

$$LCOE_{ann.} = \frac{Ann.\ (cost)}{Avg.\ (output)} = \frac{\left(\sum_{t=1}^{n} \frac{C^t}{(1+r)^t}\right)\left(\frac{r}{1-(1+r)^{-n}}\right)}{\sum_{t=2}^{n} \frac{E_t}{n}} \quad (6)$$

4. Solar PV Markets’ Status

In section 2, it is declared that the grid parity fluctuates time to time and market to market depending on several economic and environmental factors explained in that section. In Figure 10, numerous countries have been placed on an electricity cost versus solar irradiance graph to evaluate their residential PV markets regarding grid parity. Bubble size indicates the PV market size. Germany, Australia, Italy, Denmark, and Spain have already accomplished grid parity before 2012 because of the high electricity prices. Turkey, France, Japan, and Brazil are likely to reach grid parity in 2015 as indicated in Figure 10 where the cost of electricity is above the LCOE in 2015. The countries like Russia, China, India, and Saudi Arabia, where the cost of electricity is already much below the PV LCOE, are far beyond the solar grid parity.

Many countries have analyzed their PV market to search out the grid parity year competing for the conventional grid electricity to cope up with the current electricity market and to estimate the future of the PV market. Some cases of several countries are reviewed below.

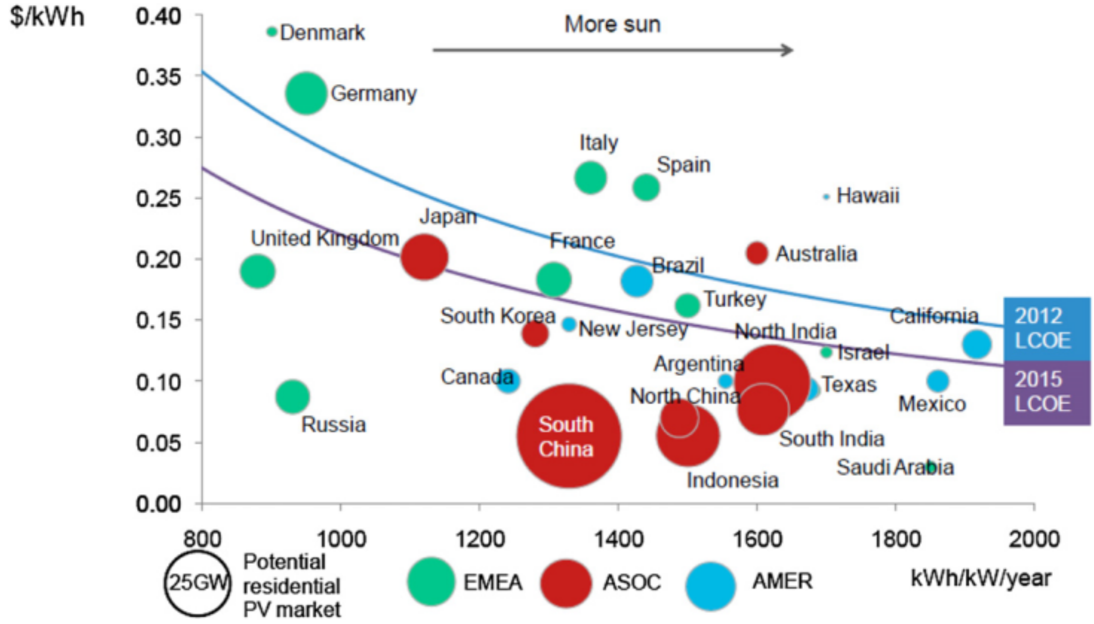


Fig. 10. Residential PV grid parity (bubble size indicates market size) [8]

4.1. Germany

Germany held the leading position in solar PV global market with highest cumulative capacity till the end of 2014 [83]. In 2007, 3.8 GW cumulative capacity was generating only 4 % of its electricity share [67, 84, 85]. [67] conducted experience curve analysis by assuming various progress ratios between 75-90 % for PV modules and attributed it for the BOS to find the grid parity year for wholesale and the retail price for the end users. Learning curves revealed 2013-2014 as the socket parity year if the household installs a rooftop solar system and consumes its electricity at home illustrated in Figure 11. On the other hand, if the PV system homeowner sells the electricity at wholesale price to the grid, grid parity is likely to occur in 2023-2024. Grid parity will occur in the intermediate of these two situations if the owner partially uses the generated electricity and sells the spare electricity to the grid which is a commonly practiced event.

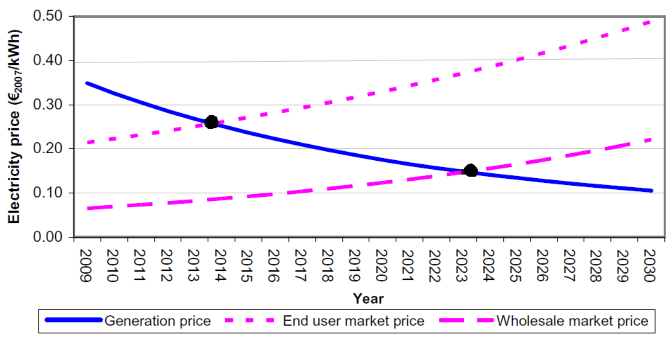


Fig. 11. Grid parity in Germany for wholesale and retail electricity prices [67]

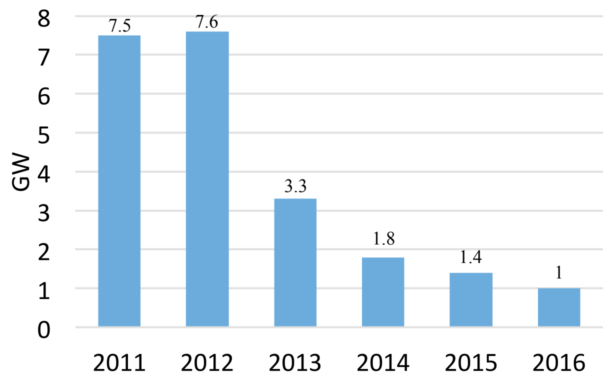


Fig. 12. Annual PV installation in Germany

Energy policies, pro to the renewables and environment, were announced by Germany prior to several other countries [86, 87]. FiT was introduced for PV plants for 20 years in the Renewable Energy Act 2000 and 5 % degraded annually which was further degraded because of the unexpected increase in PV installations [87, 88]. Owing to the handsome FiT of $0.29/kWh in 2011 [89], domiciliary PV installation rose to such an extent [90] that in 2011 large PV plants grasped the grid parity [91]. FiT in Germany exponentially diminished [92, 93] to $0.24/kWh in 2012 [89] and it is expected that the FiT will be eradicated for old erected PV plants in 2020. This uneven decay in FiT for solar PV has lessened the PV installation [94, 95] by 55 % in 2013 while during same era global PV installation increased by 20 % [91]. Figure 12 indicates a gradual cut in annual PV installation in Germany. [96] stated Germany a strong PV adopter than an innovator having 44 % global share in PV installation capacity and 12 % global share in patents. Despite a major reduction in annual PV installation in 2013 and 2014, Germany's cumulative PV capacity was highest till 2014 [83].

4.2.China

On solar resources map, China lies in a region where most of its parts are affluent in solar energy resources. On the average, China receives 1200 kWh/m2 to 1600 kWh/m2 which is more than various European countries [97, 98]. By the end of 2013, Chine led the world by manufacturing 67 % of worldwide PV modules that were export-oriented [99] by exporting 95 % of its manufactured PV modules to the world [100, 101] and having global installed capacity of 8 % in late 2012 [102], 11.3 % in 2013 [94], 15 % in 2014 [103] and 22.5 % in 2015 [104]. In contrary to Germany, China was a major manufacturer of PV modules than PV adopter because of the lack of small-scale distributed PV installation. [105] attributed the less development in distributed PV generation to the incentives free PV policies in China. Refs. [106-111] have given different suggestions and recommendations of incentives in policy to promote the distributed PV generation in China. The first FiT for grid-connected PV electricity recognized in 2011 in China was proved to be a PV milestone [112] that raised the cumulative installed capacity abruptly in China in 2011-2012 [113] as depicted in Figure 13.

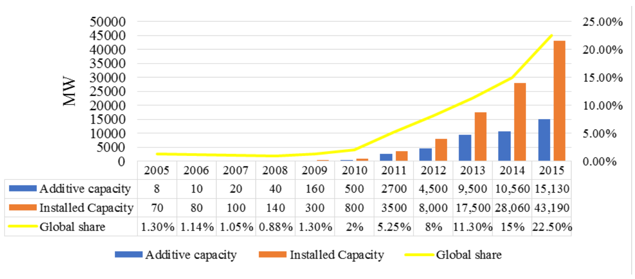


Fig. 13. China's PV capacity and global share (2005–2015)[103,104,113]

Since 2013, China has been at the apex in annual PV installations and at the end of 2015, it also led the global PV market in cumulative PV capacity [114] surpassing the longtime leader Germany. Before 2012, PV FiT was about \$0.18/kWh and after 2012 about \$0.15/kWh [115]. With the establishment of FiT in PV electricity and support from Chinese government, the cost of PV electricity has been dwindled and expected to be continued the same pattern. The cost of electricity from large-scale ground stationed PV system was \$0.09822/kWh in 2012. However, the cost of the conventional fuel-based electricity is growing and expected to overtake the cost of PV based electricity. [116] stated that the price of the PV electricity will approach the grid parity in the next 5-10 years. Figure 14 clearly shows that the solar PV will reach the commercial and industrial grid parity in 2013 (which has come true) and residential grid parity in 2017.

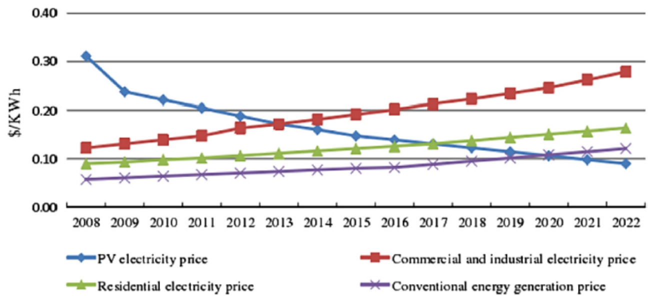


Fig. 14. Estimated grid parity in China [116]

4.3. Italy

Italy, affluent in solar energy, collects daily average radiations of more than 5 kWh/m2 in the south and 4 kWh/m2 in the north [117]. In 2013, Italy held the 2nd place in cumulative PV installation having 16 % share in the global market (Urban et al., 2016). To promote solar energy in the country, contrary to the FiT, Italy announced a new incentive mechanism Feed in Premium (FiP). This FiP incentive mechanism was announced under Conto-Energia (CE) program: CE-1 in 2005-2006, CE-2 in 2007, CE-3 in 2010, CE-4 in 2011 and CE-5 in 2012-2013. 430 % proliferation in the growth of PV volume was recorded in Italy with 9 GW new PV installations in 2011 as compared to 2010 [118]. At the end of 2010, the cost of PV electricity in remote islands in Italy reached the grid parity [119] and after that, the concept got grounds and became a hot research topic. In 2012-13, CE-5, Italy discontinued incentives and subsidies [94] for solar energy: 39 % cut for rooftop solar systems and 43 % for ground-mounted solar systems when equated with the CE-4 incentives [120].

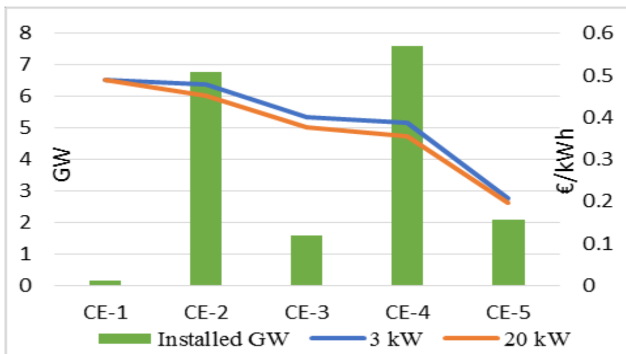


Fig. 15. Installed GW and FiP under all Conto-Energia

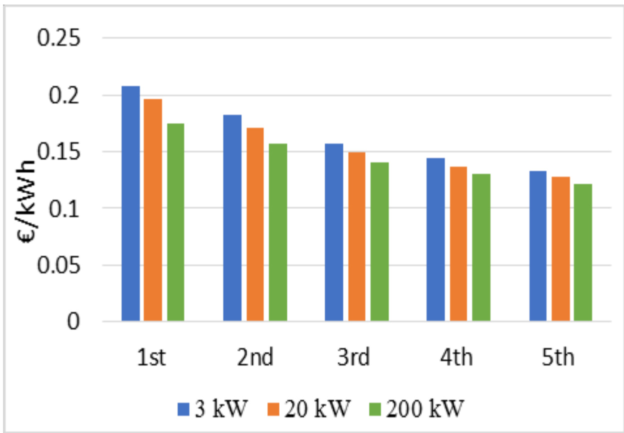


Fig. 16. FiP in 5 semesters of CE-5

Figure 15 shows the PV installations under each CE and indicates how the FiP diminished through each CE. Figure 16 shows the decline in FiP in 5 semesters of CE-5 for 3kW, 20 kW and 200 kW solar systems. An annual 50 % reduction in additional PV installations were recorded in 2012 when compared to the installations in 2011. [118] studied the dynamics of solar grid parity in Italy and stated that, due to the decline in incentives, the grid parity achievement could be delayed in Italy. To early achieve the grid parity in Italy, private investors need to be attracted [118] with a generous FiT.

4.4. Spain

With respect to global solar radiations, Spain leads Europe by receiving average 1640 kWh/m2 radiations annually at the horizontal surface. Photovoltaic, in Spain, has the potential to meet future energy needs and face the environmental challenges [121]. The boom in PV installations came in 2007-8 when Spain owned more than 70 % grid-connected PV systems in Europe [121]. Under the Royal Decree (RD) 661/2007, attractive FiT was presented for the PV systems [122-124] that abruptly boosted the solar PV capacity in Spain as can be seen in Figure 17.

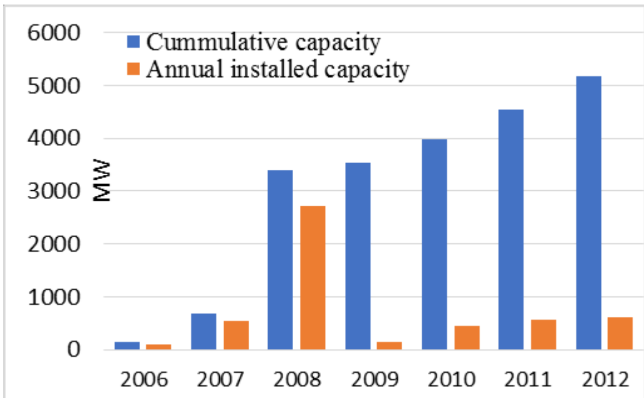


Fig. 17. Annual and cumulative PV capacity in Spain

0.44 €/kWh was awarded to new PV installations under RD 661/2007 when electricity cost was €0.075/kWh [125]. Spain installed 2.6 GW PV capacity in 2008 that was the half of the global installations that year [126]. 392 % proliferation was seen in 2007 with 2.7 GW additive PV capacity accumulating to 3.397 GW in 2008. In September 2008, FiT was restricted to €0.32/kWh under RD 1578/2008 that limited the new PV installations in 2009 and onward. In 2009, PV installation was only 155 MW.

4.5. Japan

Japan started PV installation in 1990 with 24 MW cumulative PV capacity and kept increasing with a little pace until the Fukushima Daiichi nuclear disaster in 2011. Japan introduced weak RPS incentives in 2003 that was little help in solar PV deployment; Japan diverted its attention toward renewable energy and set renewable energy policies in 2012. Till 2012, Japan spent money more than Germany on R&D but solar PV could not be deployed faster than Germany. An aggressive FiT was introduced in 2012 that brought abrupt success in PV installations; 42 Yen/kWh was offered to less than 10 kW PV systems that gradually reduced to 31Yen/kWh in 2016. Japanese government set a target of 28 GW till 2020 and 53 GW till 2030 [120]; 2020 target has already been achieved as the cumulative capacity in 2016 was 42.7 GW as shown in Figure 18.

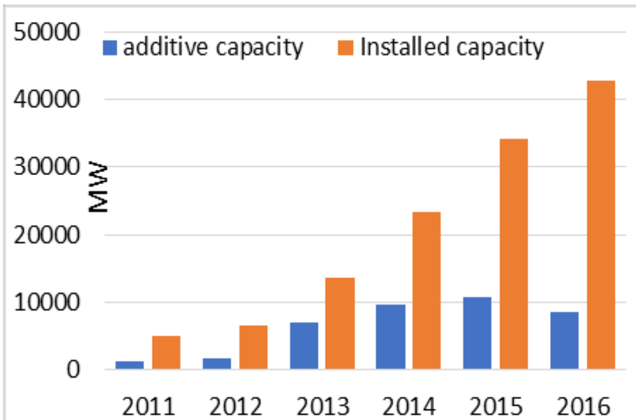


Fig. 18. Annual and cumulative PV capacity in Japan

Japan recently ranks third in cumulative global PV installations. Viewing the progress rate in PV installations, the 2030 target is expected to be successfully achieved before the desired date. The boom in PV installations came in 2013 when Japan installed an annual 6.9 GW PV capacity, 9.7 GW in 2014 and 11 GW in 2015 [83, 103, 114]. 89 % of the Japanese PV installation is rooftop and homebuilders PV systems [127]. Residential grid parity achievement in Japan is shown in Figure 19.

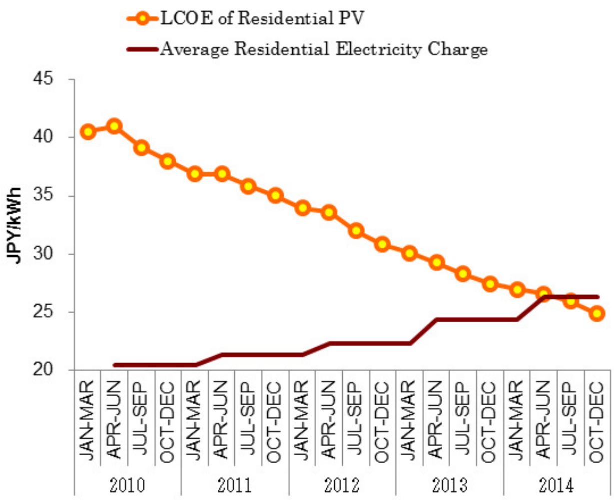


Fig. 19. Residential grid parity achievement in Japan

4.6. Malaysia

In Malaysia, the sun shines more than ten hours a day with solar irradiance from 1400 kWh/m2 to 1900 kWh/m2 [128]. After a gradual reduction in the oil production of its own reservoirs, Malaysia focused on solar energy [129]. Sustainable Energy Development Authority (SEDA) determines the FiT in Malaysia with an objective of achieving early grid parity. Using FiT rates, SEDA determined 2027 to be the solar grid parity year in Malaysia. [62] performed experience curve analysis with different progress ratios and determined 2026 as the solar grid parity year for Malaysia as revealed in Figure 20.

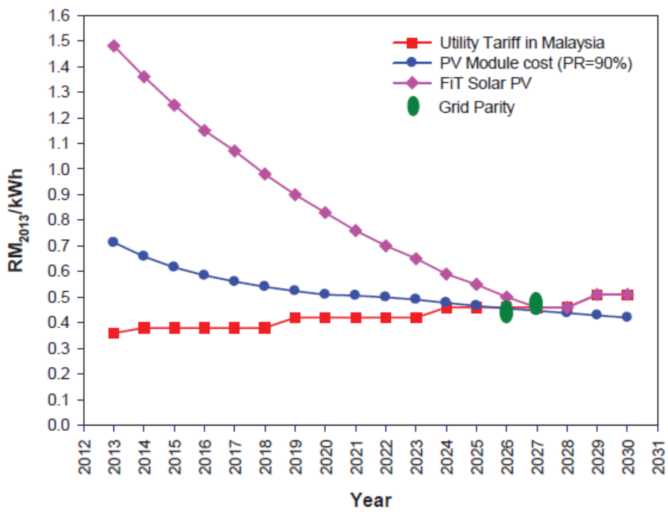


Fig. 20. Solar PV grid parity for Malaysia [62]

4.7. India

Power sector of India is coal-dominant where 84 % of electricity is produced by coal among conventional energy resources [130]. Energy demands of the country are regularly increasing and till 2020, annual 20 GW of electricity will be required to meet the ever-increasing energy demands [131]. [132] estimated solar potential available in India and stated that the 0.1 % of the country's land would be enough to meet electricity demands. Research conducted in Delhi stated that solar residential rooftop systems (SRRS) have the ability to deliver 49% of overall solar energy [133]. To provide electricity at competitive rates (grid parity), India in 2010 has set a target of installing 100 GW solar energy till 2022 [134, 135]. The cumulative solar capacity of India is increasing every year in accomplishing the set target of 2022 as shown in Figure 21. With increasing solar PV installations, cost per kWh diminished astonishingly. In 2011, price per kWh was INR 17.91 [136] that reduced in 2015 to INR 4.63 and [137] has concluded that soon it would be in parity with coal-based grid electricity of the country.

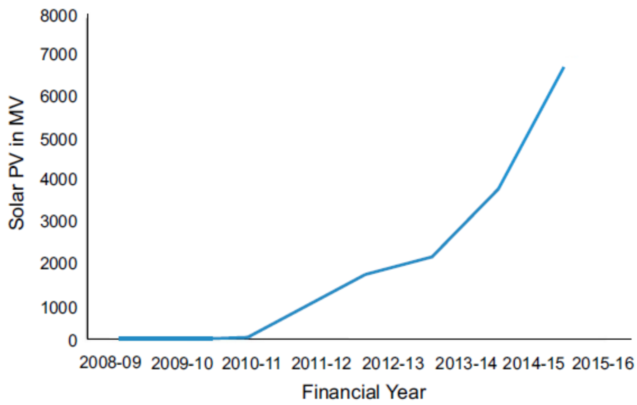


Fig. 21. Cumulative solar capacity in India 2008-16 [137]

4.8. Netherlands

[138] used the LCOE method to calculate the cost of electricity generated by solar PV system of 2.5 kW, 6 % discount rate, 25-year lifetime and 1 % O&M cost. He found it to be €0.173/kWh while the retail price of electricity in the Netherlands was €0.23/kWh. Hence, the grid parity in the Netherlands was achieved in 2012. Olson et al [139] also stated 2012 as the solar grid parity year in the Netherlands for a residential PV system up to 5 kW. A comparison of various PV markets has been presented in Table 1.

5. Comparison of Different PV Markets

Table 1 shows the detailed comparison of different PV markets regarding the methodology used to determine the grid parity and the date of grid parity achievement in the residential, commercial and industrial sector.

Table 1. Grid parity achievement in different PV markets

Reference	Country	Approach	Remarks
Bhandari et al. [67]	Germany	Experience curve analysis	Learning curves revealed 2013-2014 as the socket parity year if the household installs a rooftop solar system and consumes its electricity at home. On the other hand, if the PV system homeowner sells the electricity at wholesale price to the grid, grid parity is likely to occur in 2023-2024.
Zhao et al. [116]	China	LCOE	[116] states that the solar PV will reach the commercial and industrial grid parity in 2013 (which has come true) and residential grid parity in 2017
Biondi et al. [118], Pauli et al. [140]	Italy	LCOE	[118] stated that, due to the decline in incentives, the grid parity achievement could be delayed in Italy. To early achieve the grid parity in Italy, private investors need to be attracted with a generous FiT.
Kimura [141]	Japan	LCOE	[141] calculated the LCOE 26.0 yen/kWh in September 2014, whereas the cost of electricity in that year was 26.3 yen/kWh. In 2014, Japan achieved the solar PV grid parity.
Dahlan et al. [62]	Malaysia	Experience curve analysis	Using FiT rates, SEDA determined 2027 to be the solar grid parity year in Malaysia. [62] performed experience curve analysis with different progress ratios and determined 2026 as the solar grid parity year for Malaysia.
Sharma et al. [136], Goel et al. [137]	India	LCOE	In 2011, price per kWh was INR 17.91 [136] that reduced in 2015 to INR 4.63 and [137] has concluded that soon it would be in parity with coal-based grid electricity of the country.
van Sark et al. [138]	Netherland	LCOE	[138] used the LCOE method to calculate the cost of electricity generated by solar PV system of 2.5 kW, 6 % discount rate, 25-year lifetime and 1 % O&M cost. He found it to be €0.173/kWh while the retail price of electricity in the Netherlands was €0.23/kWh. Hence, the grid parity in the Netherlands was achieved in 2012

6. Discussion and Conclusion

Solar PV grid parity being a dynamic market situation varies time to time and location to location depending on diverse factors; such as the amount of sun, electricity prices, PV cost, subsidies, incentives and transmission, and distribution costs. The countries (location) with greater irradiance have high tendency to reach the grid parity as it draws the LCOE from solar PV down to compete for the market. The market with high grid electricity prices grasps the LCOE from solar earlier making the grid parity unquestionable. Either the high electricity prices or the low PV cost, both are the situations that are pro to grid parity. In literature, (see Figure 1) it was found that the electricity prices have exponentially growing function while the PV cost trend is exponentially decaying. The intersection of both these trends brings the grid parity. Incentives like FiT play a vital role in bringing grid parity. Study of various PV markets revealed that the market giving FiT to solar systems for a specific period achieved the grid parity earlier along with record additions in PV installations. It is considered that the PV market growth before grid parity is driven by the policy. Once the grid parity is achieved, the market should be self-sustained without any subsidies and FiT incentives. It was seen in various PV markets that after the denouncement of the FiT, PV installations lessened every year which made the concept of grid parity more complex and suspect.

The cost of the PV modules has been declined gradually for the last decade and expected to retain the decreasing trend. So, the cost of the PV solar systems is vulnerable to the cost of BOS (installation cost, module supporting cost, inverters, switches, wires, and transformers) which is necessary to be as low as PV module cost to achieve the grid parity.

Some of the authors calculated the LCOE from the solar PV system and compared it with the cost of electricity from the grid to know whether the grid parity has been achieved or not. China, India, Italy, and Germany have achieved grid parity under certain circumstances for various segments of the solar PV market. Such as China, leading the global PV market has approached grid parity in commercial and industrial segments of the PV market in 2013 and the residential segment is expected to approach parity in 2017. In Italy, self-consuming rooftop solar systems have achieved grid parity in 2013-2014 while the wholesale PV will attain it in 2022-2023. The presented paper covers all the fields related to solar PV grid parity; factors affecting the grid parity including different PV markets' situations can be comprehended by this review paper.

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