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Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation

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ABSTRACT

Global energy demand and environmental concerns are the driving force for use of alternative, sustainable, and clean energy sources. Solar energy is the inexhaustible and CO_2-emission-free energy source worldwide. The Sun provides 1.4×10^5 TW power as received on the surface of the Earth and about 3.6×10^4 TW of this power is usable. In 2012, world power consumption was 17 TW, which is less than 3.6×10^4 TW. Photovoltaic (PV) cells are the basic element for converting solar energy into electricity. PV cell technologies, energy conversion efficiency, economic analysis, energy policies, environmental impact, various applications, prospects, and progress have been comprehensively reviewed and presented in this paper. This work compiles the latest literature (i.e. journal articles, conference proceedings, and reports, among others) on PV power generation, economic analysis, environmental impact, and policies to increase public awareness. From the review, it was found that PV is an easy way to capture solar energy where PV based power generation has also rapidly increased.
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1. Introduction

Energy is the driving force for development, economic growth, automation, and modernization. Energy usage and demand are increasing globally and researchers have taken this seriously to fulfill future energy demands [1,2]. Most of the energy demand projections show that current and expected energy sources are not sustainable [3]. Renewable energy can be sources of sustainable power generation. Renewable energy usage has increased in recent years, but is not widespread. As an option for providing power, solar energy is gaining popularity [4]. Today, only 13% of energy comes from renewable sources (biofuel and waste 10%, hydro 2.3% and others: solar, wind, geothermal, heat, among others 0.9%), 81% fossil fuels (oil 32.4%, natural gas 21.4%, and coal 27.3%), and 5.7% nuclear power [3,5]. Fig. 1 shows the worldwide sources of total primary energy supply in 2010.

Fig. 1 further indicates that at present global energy sources are mainly dependent on fossil fuels and the use of fossil fuel is the main reason for global increases of CO_2 density [6]. According to global carbon emissions source [7], carbon dioxide emissions from coal, oil, natural gas, cement, and gas flaring were 43%, 33%, 18%, 5.3%, and 0.6%, respectively in 2012. Emissions of greenhouse gases grew 2.2% per year between 2000 and 2010, compared with 1.3% per year from 1970 to 2000 [8,9]. The world is not capable of absorbing large amounts of CO_2 at the rate it is produced by fossil fuels. As a result, increasing the volume of CO_2 in the environment has increased global warming and further climate change. Global warming and climate changes are challenging all over the world. According to the Intergovernmental Panel on Climate Change (IPCC) report, global warming will continue to increase unless there is a quick shift towards clean energy and cuts in the emission of CO_2. Therefore, if CO_2 emissions continue then acidification and global warming will also continue. Table 1 shows Global CO_2 emissions from 2006 to 2012.

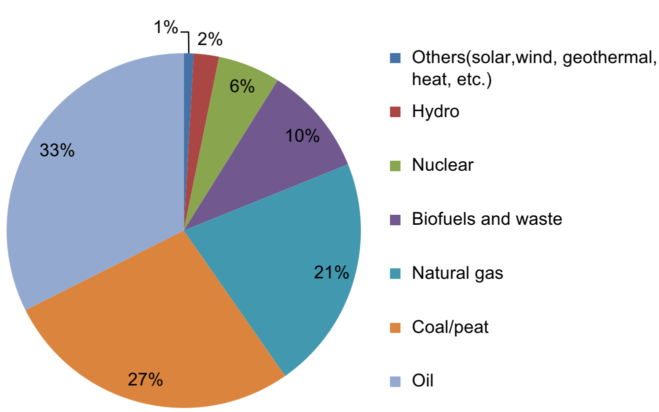

Fig. 1. Shows the sources of world total primary energy supply 2010 [3].

Table 1
The Global CO_2 emission from 2006 to 2012.

Year	CO_2 emission(billion metric tons/year)
2006	30.7
2007	31.5
2008	32.2
2009	32.1
2010	33.7
2011	34.8
2012	35.6

The use of renewable energy provides benefits that reduce emissions of air pollutants as well as greenhouse gases (GHG) [10]. Therefore, alternative sources of energy are needed so that mankind can survive on the Earth without depending on fossil fuels [11]. Solar energy is one of the renewable energy sources that will contribute to the security of future energy supplies [12]. Solar energy has obvious environmental advantages over other energy sources and will not deplete as a natural resource, produce CO_2 emission, or generate liquid or solid waste products [13–15]. Many countries have been forced to change to environmental friendly energy sources and have chosen solar energy as an alternative energy source because it has the least negative impact on the environment to overcome the negative impacts of fossil fuels [13].

Photovoltaic (PV) is the direct conversion system that converts sunlight into electricity without the help of machines or any moving devices. It is an inexhaustible energy source. PV systems offer longer service times with minimum maintenance costs. PV elements are scratchy, simple to design, and their construction as stand-alone system provide output from micro-power to mega-power. So, the system is used as a power generation source, for water pumping, in remote buildings, in solar home systems, for communications, for satellites, for space vehicles, for reverse osmosis in plants, and even for megawatt-scale power plants. Parida et al. [16] discussed PV technology, power generation, PV materials, application of PV, environmental impact, different existing performances, and reliability evaluation models, sizing and control, grid connection and distribution. Chaar et al. [17] reviewed PV technology with different types of PV (crystalline, thin film, compound, and nanotechnology). Chen et al. [18] performed a study on PV generation system, energy demand, financial analysis, payback period, internal rate of return, cash flow, the operation cost, as well as capital investment costs for PV generation systems. Tyagi et al. [19] investigated the current global status of PV technology, PV cells materials (e.g. crystalline, thin films, organic, hybrid solar cell, dye-sensitized, and nanotechnology) as well as the environmental impact of solar cells. Most of these papers highlighted cell technology and materials for different PV cells and some other papers highlighted the economic aspects and environmental impacts.

The literature shows that solar energy is a potential field and the policies are essential for the commercial establishment of the PV technologies. This paper presents a review of the technologies, prospects, progress, policies, and environmental impact as well as the cost benefit of PV solar power generation.

2. Cells and modules technology

PV cells generate electricity from the use of direct sunlight in PV systems. Multiple PV cells include a PV module and multiple PV modules are connected in series or in parallel in a PV array system. PV cells have a light absorption property that absorbs photon and produces free electrons through its PV effect. The PV effect converts sunlight to electricity with solar cells. Sunlight is plentiful and is the actual energy that is attracted by PV cells and causes some electrons to gain high energy and move freely. A potential barrier is built-up-in the cell and helps these electrons to produce a voltage that is used to drive a current through circuits [20]. The electrical efficiency depends on the length and intensity of sunlight falling on the system and the type and quality of PV cells and cell materials and components used within the solar module.

According to manufacturing process, mainly there are two types of solar cell: (a) crystalline solar cells and (b) thin-film solar cells. Crystalline solar cells are divided into two types (i) mono-crystalline solar cells and (ii) multi-crystalline solar cells more details can be found in the following Refs [21–27]. On the other hand, thin-film solar cells include (i) amorphous silicon, (ii) cadmium telluride, and (iii) copper indium gallium di-selenite (CIGS) and there has also been work on organic photovoltaic cell and dye-sensitized cells.

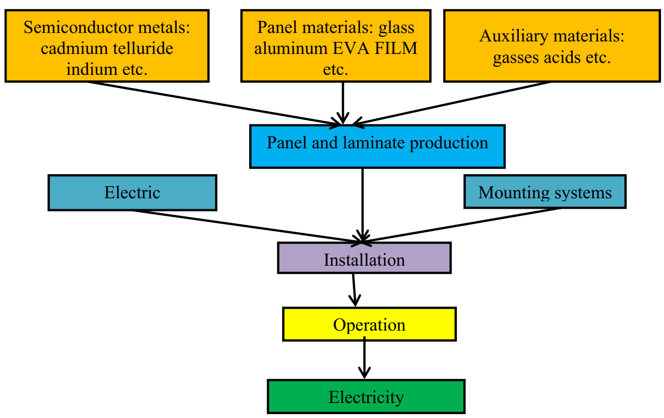

Fig. 2. Steps for the production of thin film PV modules [27].

2.1. Thin film solar cells

Thin-film technology is mainly thin films of semiconductor materials given to a solid backing material. The semiconductor material layers used are only a few micron (smaller than 10 μm) thick compared to crystalline wafers which are several hundred microns thick. Moreover the possible films deposited on stainless steel substrate allow the creation of flexible PV module; as a results lowering the manufacturing cost by the high throughput deposition process as well as the lower cost of materials. Normally the elements used for thin film cell are Gallium arsenide (GaAs), cadmium telluride (CdTe), copper indium diselenide ($CuInSe_2$) and titanium dioxide (TiO_2) etc. To produce thin film PV panel, the photoactive P/N junction is the combination of two semiconductor elements, CdTe or $CuInSe_2$ and CdS. These elements are directly accumulated on the very thin layers of a cleaned substrate glass that is meant for the vacuum vaporization process. A P/N junction formed is connected in series by auto mated laser and mechanical cribbing processes [28]. Fig. 2 shows the steps of production of thin film PV modules [27].

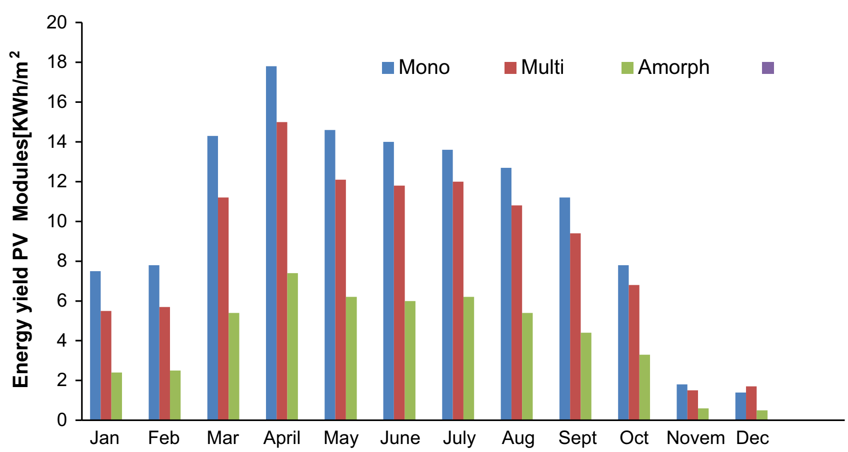

Fig. 3. Efficiency analysis of three cells [33].

Table 2
The generation of solar cell and their materials, cell efficiency and their application area.

Generation	Solar cell materials	Conversion efficiency (%)	Radiation resistance	Reliability	Cost	Application area
I (Crystalline Si)	Single-crystal Si	24.7	Δ	●	o	Terrestrial, space
	Poly-crystal Si	19.8	Δ	●	o	Terrestrial
II (Thin-Film)	Amorphous Si	14.5	Δ	Δ	●	Consumer, Terrestrial
NEXT (Advanced Thin Film)	Poly-Si thin film	16	Δ	o	●	Terrestrial
	II–VI Compound thin film	18.8	●	o	o	Terrestrial
	Concentrator tandem	32.6	●	o	o	Terrestrial, space
Space	GaAs	25.7	o	●	Δ	Space
	InP	22	●	●	Δ	Space
	Tandem	33.3	o	●	Δ	Space
New materials	TiO_2	11	–	Δ	●	Terrestrial
	Organic	2	–	Δ	●	Terrestrial
	Carbon	3.3	–	o	●	Terrestrial

Note: ● Excellent; o good; Δ fairly good.

2.1.1. Amorphous silicon

Amorphous silicon technology is a non-crystalline technology that is one of the earliest and the most popular technologies [29]. The silicon atom normally moves freely from one to another [30]. This free movement in the atomic structure of silicon has a great advantage for electronics. For these properties, it has a higher band-gap (1.7 eV) than crystalline silicon (1.1 eV). The higher band-gap of the silicon atom supports amorphous silicon (a-silicon) cells to absorb the visible spectrum better than it absorbs the infrared spectrum. The substrates of crystalline silicon solar cell are (1) glass or flexible SS, (2) tandem junction, and (3) double and triple junctions. The different performances of substrates are caused by their different properties [31]. The tandem structure of a-silicon cell efficiency is 13% when the air mass is 1.5 [32]. Fig. 3 shows the efficiency of three cells.

Naval sliver cells are made on single crystal silicon solar cells that offer 10–20 times less silicon than others do to reduce silicon consumption. This cell has another advantage that makes it suitable for industrial production and it needs 20–42 times less wafer per MW than other wafer-based cells [34,35]. A new multi-junction a-Si device (micro-morph thin film) is developed that captures the short- to long-wavelengths of solar irradiation to increase efficiency [35]. This cell is formed by a combination of many PV junctions where the layers are one on top of the other. The upper layer is made from an ultrathin layer of a-Si. Further, this layer is used to capture the shorter-wavelengths of the visible spectrum and the microcrystalline silicon is used to convert longer-wavelengths for extra conversion from the infrared spectrum.

2.1.2. Cadmium telluride

Cadmium telluride (CdTe) technology is an attractive and popular thin film technology. For the module produced, a CdS thickness of 0.05 μm and a CdTe thickness of 3.5 μm are required for the highest efficiency of CdTe, which is 16.0% [36]. CdTe has a band-gap of 1.45 eV that is known as the ideal band-gap. CdTe technology is also widely used for high volume production. Different countries have already used this for high volume production, such as Ohio (USA) – 40 MW, Germany – 10 MW, and Abu Dhabi (UAE) – 5 MW. This technology requires a hetero-junction to be used and is proven by First Solar [37] and Antec Solar [38]. However, this technology is popular because of manufacturing process efficiency, price competitiveness, and availability of telluride [31].

2.1.3. Copper indium diselenide or copper indium gallium diselenide

Chalcopyrite compound material like $CuInSe_2$ has a high optical absorption co-efficiency. As a semiconductor material, $CuInSe_2$ is suitable for PV device applications. Gallium (Ga) and sulfur are added to increase the band-gap of $CuInSe_2$. About 25–30% Ga is used where $Cu(In,Ga)Se_2$ (CIGS) produces a band-gap of 1.15–1.20 eV [36]. CIGS is a multi-layer thin-film composite defined as a multi-faced hetero-junction module. This multi-layer thin-film composite has an efficiency of 20% with CIGS [39] and for large structure modules the efficiency is about 13% [40].

We can summarize from this section that the PV module efficiency depends on the PV cells. According to a market analysis, mono- and multi-crystalline solar cells are used commercially for about 90% of the total used PV technologies. Thin film is a promising technology for large-area module production, but its efficiency is not as good as crystalline silicon. Nevertheless, the current progress of this technology has led many industry specialists to believe that thin-film PV cells will eventually dominate the marketplace in the future at a low price.

3. Characteristics and application areas of solar cells

The applications for solar cells depend on characteristics of individual cells in addition to the environmental conditions. The PV industry started with silicon cells and they still dominate the cell technology market with an efficiency rate of 24.7%. Mono-crystalline and multi-crystalline Si cells with bulk-type shape are used as first-generation cells. Second-generation solar cells are amorphous and are low cost but also have a low efficiency rate. Poly-crystal thin-film cells, II–VI, and compound thin film are expected to advance thin film cell technology. Other new cell types are dye-sensitized cells that use TiO_2, organic cells, and carbon cells [24]. Table 2 presents the characteristics of these cells.

We can summarize from this section that the resistance of advanced thin film cells to radiation is excellent. The reliability of crystalline silicon cells is higher than other cells (Table 2), but are more expensive. New materials (TiO_2, organic cells, and carbon cells) and thin film cells are more appropriate for terrestrial applications. On the other hand crystalline and space (Ga As, InP, Tandem) cells are suitable for outer space or non-terrestrial areas.

4. Photovoltaic power generation

PV systems are combinations of many elements such as cells, mechanical, and electrical mountings, among others, where electric power is generated from sunlight irradiation [16]. PV power generation systems are built around a number of solar cells,

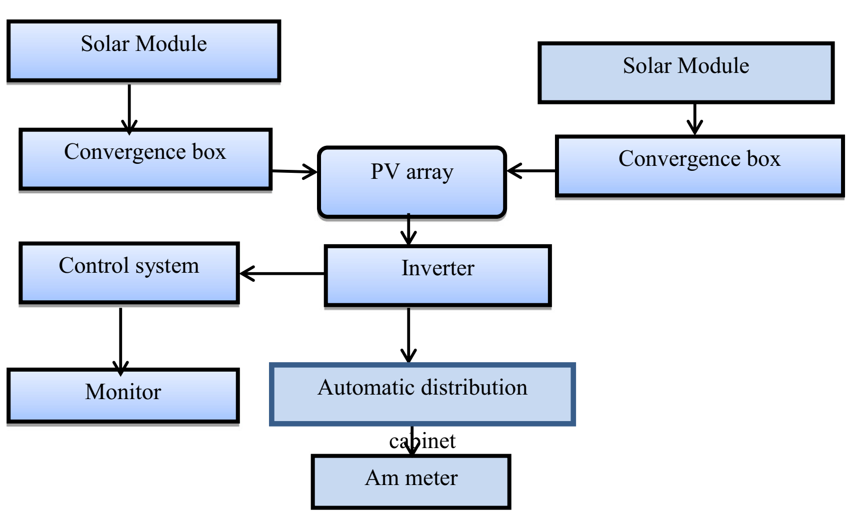

Fig. 4. Schematic representation of photovoltaic power generation system [41].

batteries, inverters, chargers, discharge controllers, solar tracking control systems, and other equipments [41]. Fig. 4 shows a schematic representation of solar PV power generation systems. Some important equipments and their functions are as follows:

1) **Solar cell matrix:** in the daytime, when solar radiation occurs, photons of the sunlight hit the surface of cells, and photons are absorbed by the cell material to create pairs of electrons and holes. If the pairs are mostly near the p–n junction, then the electrons and holes run towards the n-type side and p-type side, respectively. As the two sides of the PV cell are attached through its load, an electric current produces and flows as long as sunlight is available to hit the cell.
2) **Batteries:** for a continuous supply of solar energy, batteries are an important element that is used to load electricity that is produced by the PV power generation system. The following features are essential for batteries:
   i) they do not auto-discharge;
   ii) must have a long lifetime;
   iii) must have a high-discharge capacity;
   iv) have a high storage for charging;
   v) require minimum maintenance;
   vi) must have a high operating range for varying ranges of temperatures; and
   vii) must be low cost.
3) **Charge and discharge controller**: this device is the most important and is used to control overcharges or over-discharges of the battery. Other major factors for battery lifetime are the number of times the battery is charged and discharged and the discharge level of the battery.
4) **Inverter:** the inverter is the most important element of PV power generation systems to convert from DC to AC. There are two types of inverters: square wave and sine wave. Square wave inverters are used for small projects and have a capacity less than 100 W. This inverter is not in high demand because it is a harmonic system with a harmonic value, but they are low cost and simple. On the other hand, sine wave inverter prices are high but can be used for different types of loads [42].

We can summarize this section to indicate that PV systems are made from basic elements as follows: PV panels, cables, and mounting or fixing hardware. An inverter, charger, discharge controller, batteries, and other components for off-grid situations for special electricity meters or in the case of grid-connected systems.

5. Economic analysis

One of the greatest challenges of the PV based energy is its cost effectiveness. For economic analysis, researchers studied the following variables: Net Present Value (NPV), Payback Period (PBP), and the Internal Rate of Return (IRR) [1,18,43–47]. The project is profitable when the NPV is positive. Let T be the life span of the project, CF the net cash flow of the investment project in the n year, and r the discount rate. NPV presents the summation of total net cash flows of the investment project reduced to the present value by discounting. If S is the initial investment in the project, then the NPV of the project is found by [49]

$$\mathrm{NPV} = -S + \frac{\mathrm{CF}_1}{(1+r)^1} + \frac{\mathrm{CF}_2}{(1+r)^2} + \cdots + \frac{\mathrm{CF}_n}{(1+r)^n} = -S + \sum_{j=1}^{n} \frac{\mathrm{CF}_J}{(1+r)^j} \quad (1)$$

IRR is the discount rate that reduces the NPV of the investment project to zero (the rate in question is the maximally acceptable profitability rate, the largest rate the investment project can accept) [48]. It can be calculated by

$$\mathrm{NPV} = -S + \sum_{j=1}^{n} \frac{\mathrm{CF}_J}{(1+IRR)^j} = 0 \quad (2)$$

Payback period presents the number of years necessary to realize the total investment. Generally, two payback periods are calculated: (1) PV module payback period (year), and (2) project payback period (year).

5.1. PV module payback period

PV module cost ($\$/m^2$) is related to its efficiency, location, and cost at which electricity is sold in the market (in \$/kWh) [49]. The module payback period is given by

$$\text{pay back (year)} = \frac{\mathrm{Cost}\$/m^2}{\eta(5\ \mathrm{kWh/day\ m^2})(365\ \mathrm{day/year})(\mathrm{electricity}\$/\mathrm{kWh})} \quad (3)$$

For an example, the payback period for a 360 $\$/m^2$ module of 15% efficiency at an electricity selling price of 0.40 \$/kWh is approximately 3.3 years. PV module costs was \$300–400m^{-2} or approximately 2–3.5 \$/Wp [18].

5.2. Project payback period

If S is the value of the investment in the T year of the investment project's life span, then PBP can be calculated by [49]

$$\sum_{n-0}^{T} S_n = \sum_{n=1}^{T_p} \mathrm{CF}_n \quad (4)$$

Cost per square meter: the cost of PV materials is often expressed on a per-unit-area basis, but the modules are often sold

Table 3
Specification of the PV.

PV module	Specification
Production capacity	690 KWp
Service time	25 years
Annual O&M	\$16,172
Total investment	\$3,234,375
Inflation rate	2%
Annual derating rate	1.40%
Initial yearly power generation	1178 MWh
Module cost(us\$/watt)	2.40
Discount rate®	6%

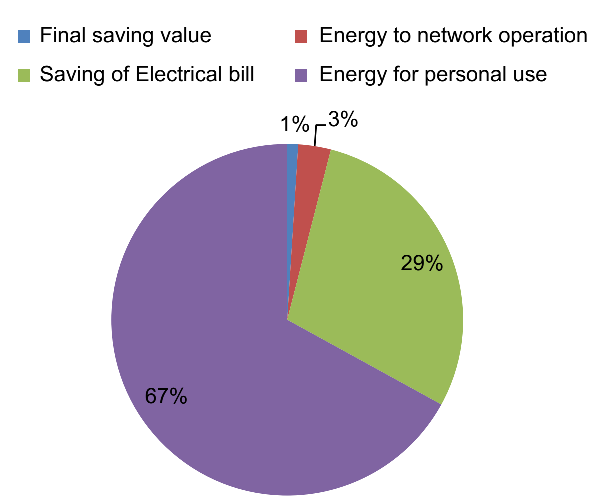

Fig. 5. Photovoltaic system benefits [50].

based on cost per watt ($/Watt) that is potentially generated under peak solar illumination conditions [49]. To convert the cost per square meter to cost per peak per watt, the following equation can be used:

$$\$/\mathrm{Wp} = \frac{\$/m^2}{\eta \times 1000\ \mathrm{Wp}/m^2} \quad (5)$$

where η is the solar module conversion efficiency. A 15% efficient module with a cost of $360/m^2 yields a cost per peak watt of $2.40 [18]. Chen et al. [18] investigated PV generation, energy demand, and economic aspects on Kiribati, a small island in the Pacific. On Kiribati, diesel generators are the main source of electricity. In

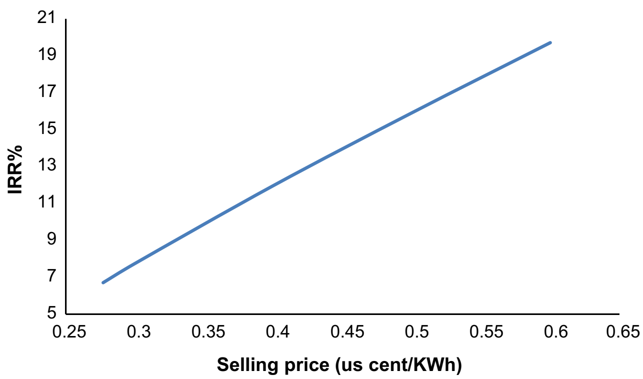

Fig. 6. The relationship between selling cost and the IRR [18].

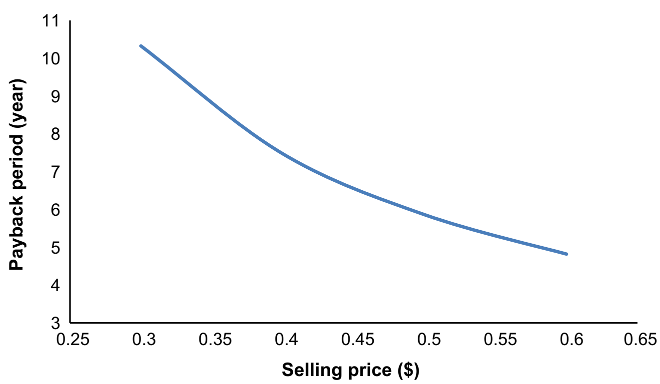

Fig. 7. The relationship between payback time and electricity selling cost of the PV system [18].

Betio, there is one diesel generator with a capacity of 1200 kW and three other diesel generators at Bikenibeu with available capacities of 1350 kW each. With the existing solar irradiation conditions, we found that the maximum PV power generation on sunny days is 530 kW which occur for 12 h. On cloudy days, the maximum PV power generation is 340 kW for 14 h. For financial analysis, Table 3 lists the parameters used and shows in consideration of initial yearly power generation 1 at 178 MWh with an annual electricity producing rate of 1.4% and adjusting for inflation on annual operation and maintenance costs which pushed the rate to 2% annually. Fig. 5 shows the photovoltaic system benefits and Figs. 6 and 7 represent the relationship between selling cost and IRR, payback time and electricity selling cost respectively.

The sunlight comes to the surface of the Earth directly and indirectly by passing through various reflections and deviations in the atmosphere. On sunny days, direct irradiance components are about 80–90% of the solar energy while on a cloudy or foggy period it is zero [51]. Chen et al. [18] investigated and analyzed cloudy and sunny days effect on the power generation, energy savings, and other economic aspects. They found that the sunny and cloudy days were 218 and 147, respectively, in 2010 when electricity production was 706,800 kWh and 471,200 kWh, respectively. PV was the alternative source of diesel generators where the PV based electricity production results in fuel cost savings. They found that the fuel cost savings for sunny days and cloudy days were USD167, 246.00 (US767/day) and USD66, 258.00 (USD451/day), respectively. Therefore, there is a great effect of sunny and cloudy days on fuel cost savings when fuel cost savings for sunny days is higher (316/day) than for cloudy days (Fig. 8). Fig. 9 shows energy losses with and without PV systems. The energy loss saved by PV systems is 67 MWh (i.e. US$26,800.00).

From this, we can see that there is a considerable solar energy production capacity of about 1178 MWh by calculating capital costs that have been invested, the annual operations and maintenance (O&M) costs, the discount rate, and the de-rating factor of PV systems. The IRR is 6.7%, 7.74%, 11.96%, 15.9%, and 19.70%; and the payback time is 11.32, 10.32, 7.47, 5.86, and 4.82 years, correspondingly and in regards to the selling price (US cent/kWh) 0.277, 0.30, 0.40, 0.50, and 0.60. This PV system can save US$ 220,875.00 for fuel costs and US$26,800.00 for power loss reductions yearly [18].

From the above section, it is clear that the economic feasibility is an important factor but PV based power generation costs are higher than for other conventional systems. Therefore, cost reduction is essential for these technologies to be widely accepted. These cost reduction efforts should be focused on module manufacture, cell efficiency, and balance-of-system (BOS).

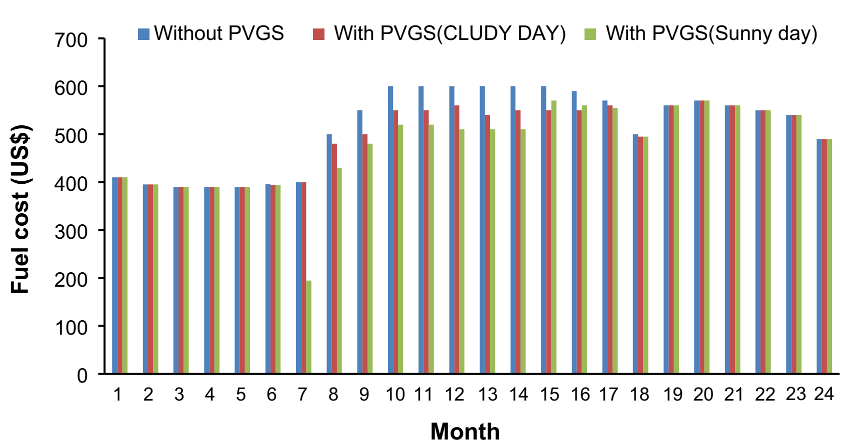

Fig. 8. The daily fuel saving comparison between PV system (in sunny days and foggy days) and without PV system [18].

6. Potential analysis

Solar energy attracts more attention when compared to other renewable energy sources. Solar energy is abundant, free, and environmental friendly. PV systems offer promising sources of renewable power generation and zero CO_2 emissions. Figs. 10 and 11 show worldwide historical development and increase in cumulative installation. We found that Europe has the most PV installations of any other region in the world. Global PV installation in 2011 and 2012 was 30,191 MW and 31,095 MW, respectively. The global PV cumulative installation is about 102,158 MW up to 2012 [52]. China and Taiwan are the largest cell and module producers in the world (Fig. 12) [53].

The world photovoltaic market still depends on mono- and multi-crystalline silicon solar cells. This crystalline silicon solar cell occupies about 90% of the PV market [54]. Thin film solar cells are not now commercially available in the market due to their low efficiency levels. Multi-junction thin film cells are more attractive because of their higher efficiency levels and large production value. Fig. 13 shows that different types of cells share PV production. Multi-crystalline solar cells have the highest share at 53% and mono-crystalline solar cells have a 33% share. Fig. 14 shows that China and Germany have chosen free space multi-junction PV technology.

For crystalline silicon wafer-based PVs, there are many advantages such as high conversion efficiency, abundant silicon materials, and is a commercially well-known technology. However, there are some limitations to crystalline silicon such as a high quantity of silicon is needed and has a costly purification process. On the other hand, the thin-film solar PV has some advantages such as lower production costs, needs less semiconducting material, and has a simple and easy production process. However, the disadvantages of the thin-film technologies are low efficiency and need more surface area as well as it is made from rarely available materials (e.g. Tellurium) and are hazardous to humans. Different and new techniques are used for the use of new cell development mainly for reducing costs and increasing efficiency. At present, multi-junction PVs are the best technology available based on the aforementioned criteria [57]. In the multiple-junction solar cells there are different band-gaps to capture all solar spectrums that increase efficiency and initiate commercial use [58]. In accordance with installation conditions, the building integrated of PV systems produced about 31% and 29% of PV based energy in Germany and China respectively [56].

We can summarize that multi-junction solar cells are the most promising technology with a high efficiency and are suitable for large-scale production. Fig. 14 indicates that multi-junction solar cells are a preferable technology in Germany and China.

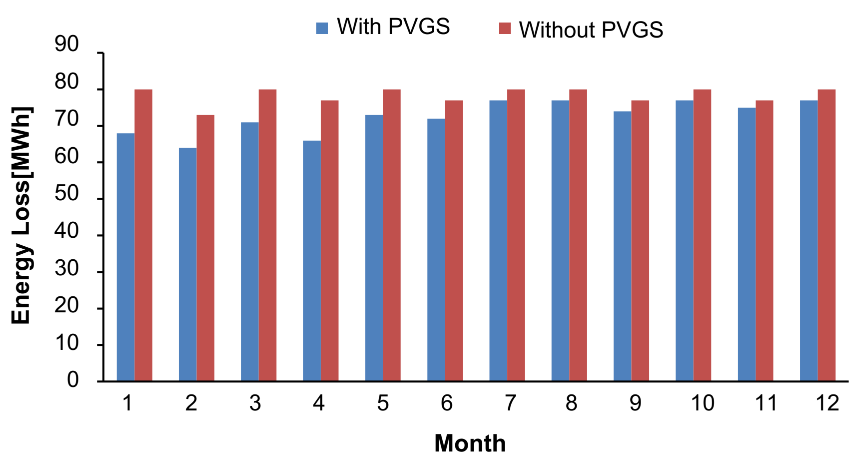

Fig. 9. Monthly energy loss comparison between PV system and without PV system [18].

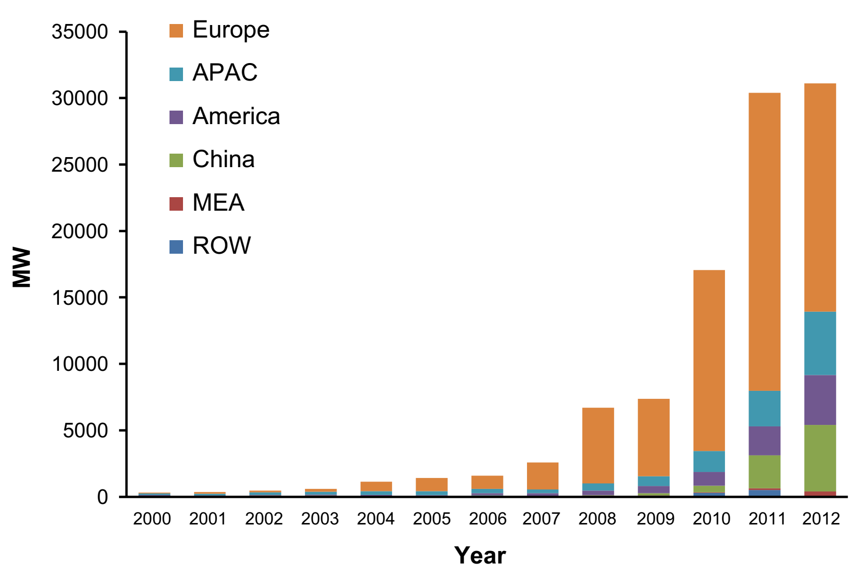

Fig. 10. Evolution of global PV annual installations in 2000–2012 (MW) [52].

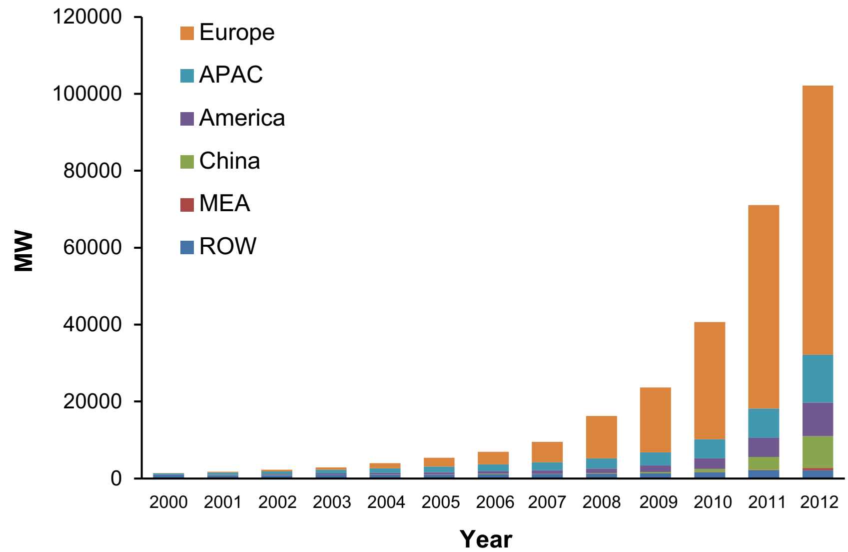

Fig. 11. Evolution of global PV cumulative installed capacity in 2000–2012 (MW) [52]. ROW: Rest of the World. MEA: Middle East and Africa. APAC: Asia Pacific.

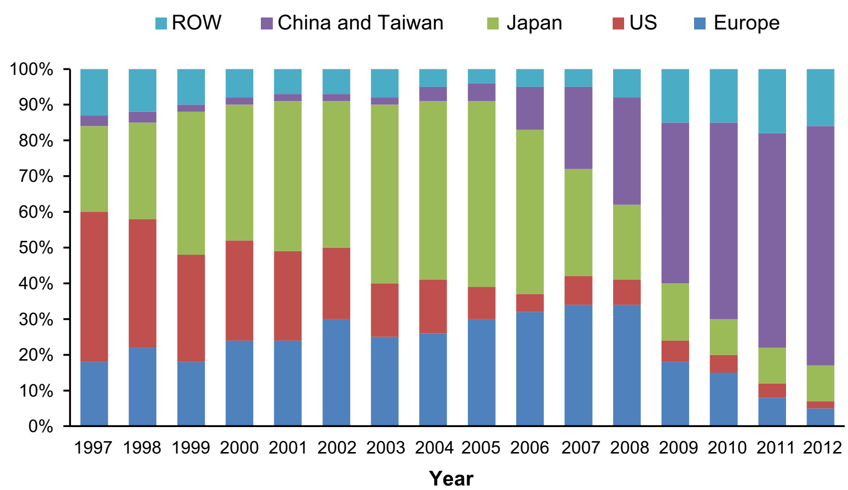

Fig. 12. PV cells/modules production by region in 1997–2012 (percentage of total MWp produced).

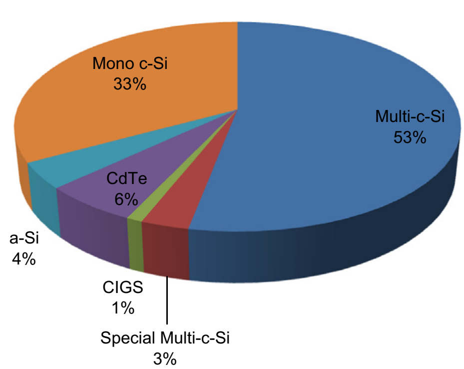

Fig. 13. Production share of PV technologies [55].

7. The photovoltaic electricity industry and its future

The PV industry is a rapidly developing industry. The development began in 1954 when American Bell Laboratories developed the first silicon solar cell. World PV industry analysts have shown that significant growth has occurred over the last couple of years [59]. Worldwide total PV installations represented 1.8 GW in 2000 and 71.1 GW in 2011 with a growth rate of 44%. Up to 2012, global cumulative PV installations have reached about 106 GW [52]. At present, public research programs for renewable energy systems is a hot issue in the energy sector. Renewable energy and energy efficiency sectors have reported that worldwide, new investments for renewable energy have reached US$263 billion and research and development (R&D) departments have spent nearly US$25.8 billion. New investments for solar PV systems have increased by about 44%, at around US$128 billion. Solar energy systems have experienced continual growth. For the future growth of PV, the Photovoltaic Industry Associations, like Greenpeace, the European Renewable Energy Council (EREC), and the International Energy Agency (IEA), have taken different supportive steps and present different future plans (see Table 4) [60].

Mainly Japan, Germany, the UK, China, Spain, and Italy have produced electricity with PV based power [61]. In 2012, European capacity for PV electricity production was 17.2 GW; and in 2011, it was 22.4 GW. Europe has the largest share of the PV market with 55%. Other countries have the following estimated capacities: Germany 7.6 GW, China 5 GW, Italy 3.4 GW, USA 3.3 GW, and Japan 2 GW. PV systems are a primary source for producing electricity in Europe. It is expected that annual PV electricity production will be 48 GW by 2017 [62]. The PV industry and market have fostered a comparative advantage for PV electricity production over other conventional electricity production systems, because of its impact on the environment, efficiency improvements, and reduced costs of PV modules, among others [59]. Today, the PV industry is the fastest growing industry worldwide. Up to 2012, the global cumulative PV installations have reached about 102 GWp and represents possible production of 110 TWh/year of electricity [52]. The amount of electricity meets the demand of more than 20 million households worldwide and covers only 0.5% of global electricity demand [63].

We can summarize this section stating that the PV market and related industries appear to be entering a period of acceleration. PV module costs have decreased and knowledge of these technologies and its advantages have become well-known. Therefore, the future of PV industries is positive.

8. Environmental analysis

Traditional fossil fuel based power generation systems have created serious environmental problems (i.e. climate change, air pollution, acid rain, and global warming, among others) which are harmful to human life. PV energy is clean, silent, abundant, sustainable, and renewable as well as inherently safer than any other traditional electricity generation systems. Renewable energy systems can solve many environmental problems that were created by traditional fossil fuels [68,69].

8.1. Emissions reduction

PV systems are defined as zero emissions or emissions-free energy systems. In fact, PV systems have a negligible effect on greenhouse gas emissions [64]. During PV system operations, there are zero releases of CO_2, NO_X, and SO_2 gases and it does not contribute to global warming. PV systems save 0.53 kg CO_2 emission for every kWh of electricity produced [65]. Table 5 shows average emission rates [66]. There are two sets of emission rates in use as follows: (i) EPA from eGRID 2000 database; and (ii) calculated by ECONorwest using the most accurate eGRID data available [67].

Table 6 shows that the use of PV systems can reduce 69–100 million tons of CO_2, 68,000–99,000 t of NO_X, and 126,000–184,000 t of SO_2 by 2030.

Table 4
Evolution of the photovoltaic power generation capacities up to 2040.

Year	2010 (GW)	2015 (GW)	2020 (GW)	2030 (GW)	2035 (GW)
TOTAL INSTALLATIONS	70				
Greenpeace[a] (reference scenario)		88	124	234	290
Greenpeace[a] (evolution scenario)		234	674	1764	2420
IEA present policy[b]		60	161	268	314
IEA new policy		112	184	385	499
IEA 450 ppm Scenario[b]		70	220	625	901
IEA PV system Roadmap[c]		76	210	872	1330

8.2. Health benefits

Many serious diseases will be reduced due to reductions of NO_X and SO_2. Heart attacks will be reduced by 490–720 by 2030. Different types of Asthma will be reduced by 320–470 annually by 2030. Table 7 shows the health impact caused by emission reductions.

We can summarize from this section that PV based energy provides substantial environmental benefits when compared to others sources of energy. The use of this technology has a positive environmental impact (i.e. CO_2 emissions are reduced, they generate no noise, and have positive health benefits, among others).

9. Renewable energy policy

Most countries have implemented a variety of policies and have provided financial support to increase the use of renewable energy in power generation systems. Most countries have used Feed-in-Tariff and quota systems as their policies. A bidding system for renewable energy development activities is often used. Incentives and subsidies are helpful and increase the usage of renewable energy systems. Net metering systems have been introduced for small-scale renewable energy systems [68]. All aforementioned

Table 5
The average emission rates (ibs/mwh).

Source	Natural gas			Coal		
	CO_2	NO_X	SO_2	CO_2	NO_X	SO_2
EPA, eGRID 2000	1135	170	0.10	2249	6.00	13.00
ECONorthwest, eGRID 2006	1169	0.69	0.02	2164	3.50	10.30

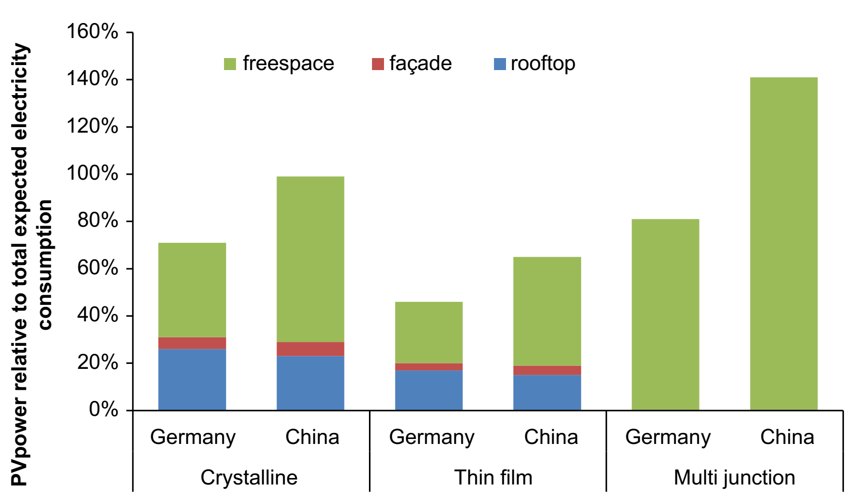

Fig. 14. PV technical importance in China and Germany in 2020 on different technology preferences [56].

Table 6
Emission reductions for replaced fuel (kilotons/year).

Probability	Total PV capacity	Natural Gas			Coal			Total		
	Capacity(GW)	CO_2	NO_X	SO_2	CO_2	NO_X	SO_2	CO_2	NO_X	SO_2
2015 Minimum	5	3122	1.84	0.04	1927	3.11	9.17	5049	4.96	9.21
2015 maximum	10	7026	4.14	0.09	4336	7.01	20.63	11,362	11.15	20.72
2030 Minimum	70	42,938	25.34	0.55	26,495	42.85	126.11	69,434	68.19	126.66
2030 maximum	100	62,456	36.86	0.80	38,539	62.33	183.43	100,995	99.19	184.23

Table 7
Human health benefit for lesser emissions.

Scenario	2015 (Minimum)	2015 (Maximum)	2030 (Minimum)	2030 (Maximum)
Total PV installation(GW)	5	10	70	100
Cases reduced				
Death	22	50	300	440
Chronic Bronchitis	16	35	205	301
Heart stock	40	82	495	720
Respiratory problem				
Asthma (0–64)	3	4	25	37
Pneumonia (65+)	7	16	100	150
Total	10	20	125	187
Cardiovascular problem				
All cardiovascular	9	21	125	181
Visit to Emergency Room for Asthma	25	50	325	470
Acute Bronchitis	35	78	479	697
Lower–higher Respiratory symptoms	716	1612	9849	14,326
Loss of working days	2540	5708	34,895	50,750
Less Restricted Activity Days	17,440	39,240	239,792	348,788

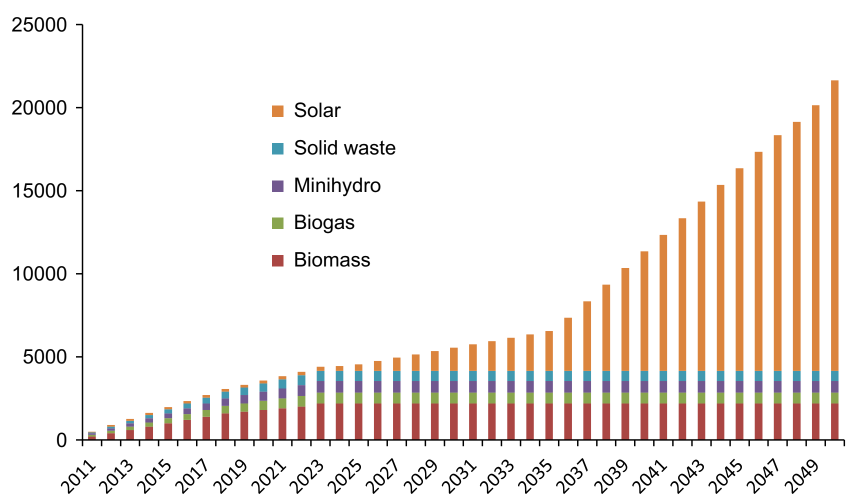

Fig. 15. Solar energy target up to 2050 in Malaysia [70].

policies are divided as follows: (i) market incentives; and (ii) technological and R&D incentives.

(i) **Market incentives**: market incentives increase the awareness for people as the resulting market rapidly expands. Market incentives provide the following advantages [69]:
- Feed-in-Tariffs: for fixed pricing Feed-in-Tariff is a good system. It is also provides financial support for the consumer.
- Investment subsidies: investment subsidies are a great chance for the consumer. Many people are interested for building integrated PV systems at home. However, most people are not able to build these systems due to the large initial investment required, so an investment subsidy offers them a chance to become involved.
- Loans: different loans for projects help people who are interested in the installation of a PV system at home.
- Tradable Green Certificates: many certificates are given to homeowners who implement PV systems to allow them to save money as well.

(ii) **Technological and R&D incentives:** the technological and R&D incentives provide better opportunities for researchers to increase efficiency, lifetime and develop new systems that will increase their usage and reliability [69].

9.1. Renewable energy policy in Malaysia

Renewable energy policies are important for the proper utilization of different resources as well as to secure and sustain power generation [70]. The Sustainable Energy Development Authority (SEDA) of Malaysia has taken on many strategies to increase the use of solar energy and make it one of the main sources of its energy supply by 2050. The objectives of these policies are as follows: to increase the share of renewable energy for power generation; to develop renewable energy based power industry in the country; to reduce the costs of the renewable energy resource based products; to protect the environment; and to enhance awareness of the role of renewable energy in the National economy [71]. SEDA has a goal to generate 6% (985 MW) and 73% (21.4 GW) by 2015 and 2050, respectively (see Fig. 15) [70].

SEDA provides a quota for the users who install solar home systems in every six-month period. In 2013, about 4000 homes have installed solar home systems. According to the FiT rate, Tenaga Nasional Berhad (TNB) compensates the installation costs of solar energy systems. FiT rates are activated for 21 years from the commencement date (Table 8) [72]. The local PV module manufacturers receive a sale tax exemption for imported solar PV modules with a sales tax of 10% [71].

9.2. Renewable energy policy in the other countries

European countries have taken different steps and utilized different policies to develop renewable energy systems that increase the share of renewable energy, to reduce CO_2, and reduce dependency on fossil fuels [69]. Japan targets to develop R&D, provide incentives for installation, and to install easily with lower investment costs [73]. In Germany, the policies are divided as follows: 1000 PV roof programs from 1990 to 1995 with 100,000 PV roof program soft loans introduced in 1999 and it was followed by the Renewable Energy Source Act (premium tariffs) that was started on 1 April 2000 [74]. In France, total PV production capacity was 1054 MW in 2010. By providing the FiT, tax reductions, and subsidies, the total PV production was 2500 MW in 2011. By implementing these policies, PV production capacity increased more than double in one year. For R&D, annual subsidies are given by the International Energy Agency [75]. China's Renewable Energy law of 2005 was made to activate FiT and to increase and develop the renewable energy resources [76]. In 2009, China rolled out two national solar subsidies programs: the Building Integrated Photovoltaics (BIPV) subsidy program and the Golden Sun program. The BIPV subsidy program offered upfront RMB20/W for BIPV systems and RMB15/W for rooftop

Table 8
Amended schedule for solar PV effective from 15th March 2014.

Description	Revised Fit rate for 2014 (RM/kWh)	Revised degression rate (%)
(a) Basic Fit rates having capacity of:		
Individual:		
i. Up to and including 4KW	1.0184	10
ii. Above 4 KW and including 12 KW	0.9936	10
Non-individual:		
i. up to and including 4 KW	1.0184	10
ii. above 4 KW and up to and including 2 4 KW	0.9936	10
iii.above2 4 KW and up to and including 72 KW	0.8496	10
iv. above 72 KW and up to and including 1 MW	0.8208	10
v. above 1 MW and up to and including 10 MW	0.684	10
vi. above 10 MW and up to and including 30 MW	0.612	10
(b) Bonus Fit rates having the following criteria (one or more)		
i. use as installation in building or building structures	+0.2153	10
ii. use as building materials	+0.207	10
iii. use of locally manufactured or assembled solar PV modules	+0.05	0
iv. use of locally manufactured or assembled solar PV inverters	+0.05	0

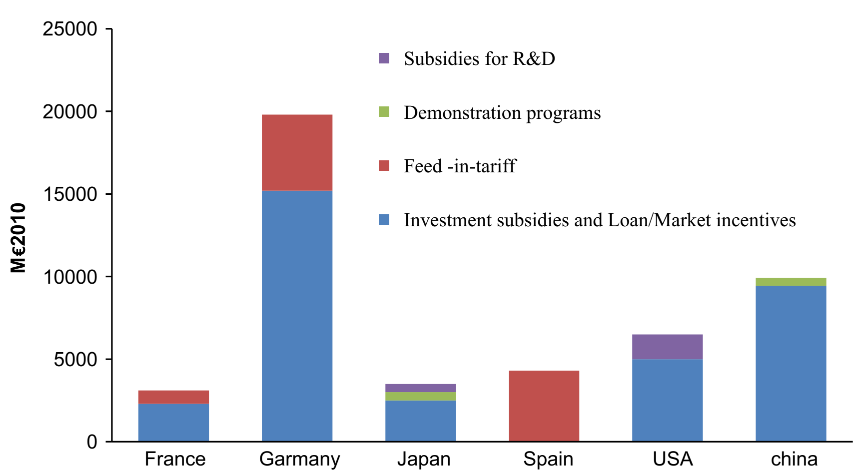

Fig. 16. PV development policies cost in 2010 in Germany, France, Spain, Japan, China and the USA [69,80].

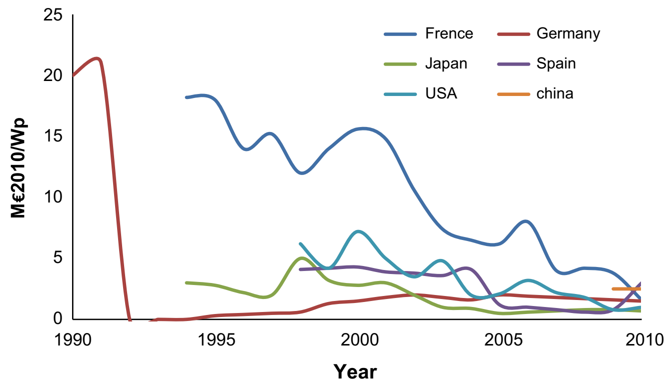

Fig. 17. Yearly PV incentives cost in €/Wp in Germany, France, Spain, Japan, China and the USA from 1990 until 2010 [69,77].

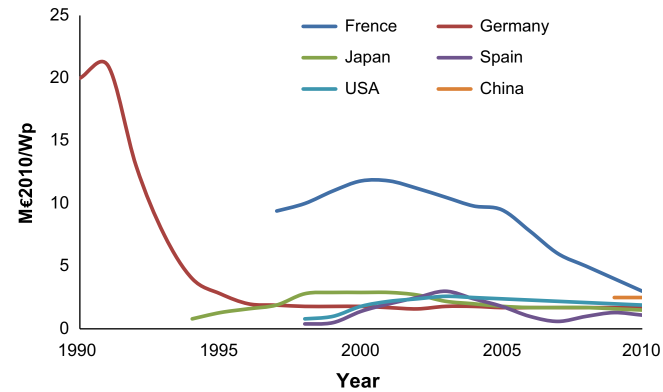

Fig. 18. The PV power generation Wp cost economic help in Germany, France, Spain, Japan, China and the USA from 1990 up to 2010 (discount rate 8%) [69,77].

systems. China's Ministry of Housing and Urban–Rural Development announced a stimulus plan for BIPV applications in mid-April of 2009 that offered RMB 20/watt for construction material- and component-based BIPV projects and RMB 15/W for rooftop and wall-based projects. In July 2009, the media reported that 111 rooftop-based or BIPV projects nationwide with a combined capacity of 91 MW had been allocated subsidies of nearly RMB 1.2 billion [77]. The Golden Sun program was started in 2009 with six major golden sunlight projects of 20,000 kW rooftop PV power generation projects; a 50,000 kW on-grid solar power station demonstration project, a solar campus project, a solar thermal water project, a rural solar power project, and a solar energy-powered nightscape lighting project. According to a project-by-project basis, the capital subsidy was about 70% for off-grid (stand-alone) PV projects and about 50% for grid-connected PV projects in 2011. Nevertheless, the capacity of grid-connected projects must be greater than 300 kW. About 300 projects with the capacity of 640 MW were submitted under the Golden Sun program with investments of around RMB 20 billion. The off-grid projects must be equal or greater than 50 kW with a minimum cell efficiency for modules around 16% for mono-crystalline, 14% for poly-crystalline, and 6% for amorphous. In 2010, the subsidy amounts were changed with rates around RMB13/watt ($1.90/W) for grid-connected and RMB17/watt ($2.50/W) for BIPV [78]. Between 2010 and 2012, Beijing planned to spend RMB 1.44 billion to promote the development of solar energy [79]. It has been reported that Chinese solar companies have benefited from low-interest loans offered by the state-owned banks. In March 2010, Yingli Solar announced to build the Panda single-crystal integrated production line with a capacity of 300 MW. Jiao Tong Bank provided Yingli with an RMB 1.5 billion project loan and RMB 250 million special liquidity loans. In April 2010, Reuters reported that Suntech and Trina Solar had signed deals with the government-backed China Development Bank that gave them access to a total of RMB 80 billion ($11.72 billion) [80]. France, Japan, Germany, the UK, Spain, and China have also been provided with investment subsidies and market incentives. Figs. 16 and 17 show FiT and subsidies for R&D. France has given maximum incentives for PV installation and development (Fig. 18).

In Germany, investment subsidies, loan, and market incentives for PV power generation systems were introduced in 1990. Germany was the first and China was the second for maximum expenditures on PV power generation systems.

We can summarize this section as overcoming the negative impacts on the environment caused by fossil fuels, many countries have been forced to change to environmental friendly alternative energy sources. Different countries such as Germany, Japan, China, Malaysia, Spain, France, and the UK have different policies (i.e. FiT, intensive, quotas, tax exemptions, and loans, among others) to encourage PV based power generation.

10. Conclusion

Solar energy is a potential clean renewable energy source and PV has the most potential for solar power systems in homes and for industrial power generation. Solar power generation demand increases worldwide as countries strive to reach goals for emission reduction and renewable power generations. Malaysia has a target of 40% less emissions by 2020. Malaysia's SEDA has developed many strategies to increase the country's usage of solar energy as the primary source of energy by 2050.

The following conclusions can be summarized from this paper as follows:

- At present, thin film solar cell are not commercially viable in the marketplace, but other cell prices are lower and have a lower efficiency level than crystalline silicon solar cells. Multi-junction thin film cells are more attractive because of their higher efficiency and the ability for large production, but commercially this technology is still developing. Free space multi-junction PV technology has been the primary choice for China and Germany.
- The IRR is 6.7%, 7.74%, 11.96%, 15.9%, and 19.70%, the payback time 11.32, 10.32, 7.47, 5.86, and 4.82 years along with selling price (US cent/kWh) 0.277, 0.30, 0.40, 0.50, and 0.60.
- This PV system can save US$ 220,875.00 in fuel costs and US $26,800.00 in power loss reductions yearly.
- Sunny and cloudy days have a great effect on PV power generation systems.
- The PV industry is the fastest growing industry for new investments and solar PV systems have increased by 44% (i.e. about US$128 billion).
- The total global PV installation capacity is capable of producing 110 TWh/year electricity.
- PV power generation will reduce CO_2 emission about 69–100 million tons, NO_X 68–99 thousand tons, and SO_2 126–184 thousand tons by 2030.
- Different countries have different policies for solar energy systems but still need to address appropriate system planning and operations for power systems to supply quality and reliable electric power.

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