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- Bowersox, Donald J., Closs, David J., (1996), "Logistical Management." Tata McGraw, Hill, New Delhi.
- Hunker, H.L. and A.J. Wright (1963), "Factors of Industrial Location in Ohio" Ohio State University, Nigeria.

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# PHOTOVOLTAIC SYSTEMS: A PROBABLE ALTERNATIVE TO CONVENTIONAL ENERGY SOURCES

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## ABSTRACT

*Three centuries ago, we used nothing but renewables, with a fully sustainable energy system consisting of wind power, hydro power and bio-fuels. Now we are trying to return to the past, with the addition of a few new sources such as solar and geothermal. In the interim our population has increased and economic activities by several orders of magnitude. There is a literature, and there are some notable contributions, but nothing remotely in keeping with the emphasis on renewables in policy circles. Renewable energy is enjoying great but probably short-lived if not taken seriously while put in use. The first discussion of renewables in economics was in the post 1973 oil shock era, when we rediscovered Hotelling's work on resource depletion and refined it in various ways. We invented the phrase "backstop technology," a technology that would eventually replace exhaustible resources with an energy source continuing forever. No one modeled the backstop explicitly, but it was clearly not a fossil fuel that we had in mind: it could have been nuclear fusion, or solar or wind energy. The need for renewables, in the sense of energy from non-exhaustible sources having no environmental footprint, was recognized. Presently, despite its poor environmental credentials, fossil fuel remains a crucial contributor to energy supply in many countries. The world will be running out of fossil fuel within a few decades due to high demand & consumption. The problems with energy supply and use are related not only to global warming but also to environmental concerns such as air pollution, acid precipitation, ozone depletion, forest destruction, ect. It is argued that oil will run out in 53 years, natural gas in 54, and coal in 110 years. The exhaustion of conventional resources and its effect on climate requires an urgent call for the substitute power resources to convene up the current power requirement. Renewable energy is an endless, unsoiled and prospective energy source among all other non-conventional energy options. More concentration is being done on focal point for the development of renewable energy sources globally. Thereby, energy generated from clean, efficient and environmentally-friendly sources has become one of the major challenges for engineers and scientists. Among them, the photovoltaic (PV) generation system has received great attention in research because it appears to be one of the possible solutions to the environmental problems. In this paper, the thrust has been given to study the economic and technical viability of photovoltaic systems as one of the alternative to depleting conventional energy sources.*

## KEYWORDS

Photovoltaic systems, Backstop resources, Hotelling's work, Central and distributed generation, Conventional and non-conventional energy sources, Solar revolution.

## ABBREVIATIONS

| | | |
|---|---|---|
| GHG | : | Green House Gases. |
| Gt | : | Giga Tonnes. |
| CO2 | : | Carbon Di Oxide. |
| GW | : | Giga Watts. |
| TWh/Y | : | Terra Watt hours per year. |
| PV | : | Photovoltaic. |
| CCS | : | Carbon capture and storage. |
| E_Storage | : | Energy storage. |
| PWh/Y | : | Photovoltaic Watt hours per year. |
| WtE | : | Waste to Energy. |
| CAGR | : | Compound Annual Growth Rate. |
| NIMBY | : | Not in my back yard. |
| RE | : | Renewable Energy, |
| VRE | : | Variable Renewable Energy. |
| PV System | : | Photovoltaic System. |
| CSP | : | Concentrating solar power |
| MPPT | : | Maximum power point tracking. |
| Wp | : | Watt peak. |
| SMR | : | Small Modular Reactors |
| TES | : | Thermal energy storage |
| SRA | : | Solar Resource Assessment |

## NOMENCLATURE

| | | |
|---|---|---|
| pt | : | is price in period t, |
| po | : | is price in initial period, |
| r | : | is rate of interest |

## 1. INTRODUCTION

The efficient use of scarce natural resources, both renewable and non-renewable sources, has long been a concern of natural resource economics (Shogren 2000). Adam Smith explored on the natural progress of opulence and suggested that for a country to achieve an optimum economic progress, it had to allocate capital to land, fisheries and mines (Barnett and Morse 1963). Ricardo explored on the significance of land quality on economic rent. Robert Malthus raised concern about the dangers of population growth, asserting that the increasing population was likely to preclude the endless progress towards a utopian society (Barnett and Morse 1963). Jevons raised concern about the consequences of coal depletion on population growth (Shogren 2000). A feature shared by all these economists is their treatment of natural resources as a free factor of production. That is, they all treat natural resources as provided freely by nature. But towards the beginning of the 21st century, a shift in mindset occurred as economists began treating natural resources as something more distinct than just a free factor of production (Shogren 2000). Theorists such as Hotelling and Gray particularly pointed out to the additional inter temporal cost of extracting natural resources (Shogren 2000). According to Hotelling's rule, the price of an exhaustible resource must grow at a rate equal to the rate of interest, both along an efficient extraction path and in competitive resource industry equilibrium [1]. It is symbolized as

$$p_t = p_o e^{rt} \quad [1]$$

(Where, $p_t$ is price in period t, $p_o$ is price in initial period, r is rate of interest)

This shows that the competitive resource owner would deplete at socially optimal rate. Therefore, the conservationist's plea for public interventions cannot be based on any inherent tendency for competition to exploit a resource too rapidly assuming no divergence between the social and private discount rates.

The past 15 years have seen unprecedented change in the consumption of energy resources. Unexpected high growth in the renewable market, in terms of investment, new capacity and high growth rates in developing countries have changed the landscape for the energy sector. We have seen the growth of unconventional resources and improvements in technology evolution for all forms of energy resources. This has contributed to falling prices and the increased decoupling of economic growth and GHG emissions. Around 2000 Gt $CO_2$ gas emitted since 1750 out of which half of it just in past 40 years and this leads to temperature rise by (+ 0.85$^0$C) since 1850. To stabilize climate change at today's level by 2100, cumulative $CO_2$ emissions must not exceed 1000 Gt $CO_2$ between now and 2100. However, currently emission rates are increasing by ~30 Gt $CO_2$/yr. and current carbon-burning infrastructure alone can approach 1000Gt $CO_2$ in next 40 years.

As per World Energy Outlook 2014, in spite of maximum use of non-renewables, about 1.3 billion people did not have access to electricity in 2012, about 2.7 billion people use traditional biomass for cooking and other heating energy needs, and 1.7 billion people are likely to be electrified by 2030. Still 1 billion people will remain without access to electricity.

Considering above facts, there is a necessity for an energy transformation from fossil power generation to renewable energies in the first place. Enormous increase in use of fossil fuels leads to continuous increase in $CO_2$ emissions and concentrations in the global atmosphere climate change will lead to an increase in global average temperature until the end of the century of approximately [4 - 5$^o$C]. The costs of natural catastrophes thereby driven and intensified exceed the costs of such an energy transformation by a multitude. Instead of moaning about victims and persons affected, efforts are to be made to generate potential for energy transformation to generate income and wealth for many.

Therefore, the time has come for altogether energy transformation to a renewable energy system which offers more chances and prosperity than business as usual.

**OBJECTIVES OF THE STUDY**

1. To study World Energy Resources & Consumption.
2. To study backstop technology as a new technology producing a close substitute to an exhaustible resource.
3. To study IEA's PV Roadmap Projections.
4. To study main objectives of this Task to achieve the goal of IEA/SHC Task36 "Solar Resource Knowledge Management" to provide the solar energy.
5. To study the Pathway to 100% Renewable Energy Requirement.
6. To study a PV system design.

## 2. WORLD ENERGY RESOURCES AND CONSUMPTION

Most countries have achieved a more diversified energy mix with a growth in community ownerships and an evolution of micro grids. To better understand these unprecedented changes the 2016 World energy resources report highlights the key trends and identifies the implications for the energy sector.

### 2.1. Oil

Oil remained the world's leading fuel, accounting for 32.9% of global energy consumption. Crude oil prices recorded the largest percentage decline since 1986 (73%). Roughly 63% of oil consumption comes from the transport sector. Oil substitution is not yet imminent and is not expected to reach more than 5% for the next five years. Unconventional oil recovery accounts for 30% of the global recoverable oil reserves and oil shale resources contains at least three times as much oil as conventional crude oil reserves, which are projected at around 1.2 trillion barrels.

### 2.2. Natural gas

Natural gas is the second largest energy source in power generation, representing 22% of generated power globally and the only fossil fuel whose share of primary energy consumption is projected to grow.

### 2.3. Coal

Coal production declined with 0.6% in 2014 and with a further 2.8% in 2015, the first decline in global coal production growth since the 1990s. Coal still provides around 40% of the world's electricity. However, climate change mitigation demands, transition to cleaner energy forms and increased competition from other resources are presenting challenges for the sector. Asia presents the biggest market for coal and currently accounts for 66% of global coal consumption.

### 2.4. Nuclear

Global Uranium production increased by 40% between 2004 and 2013, mainly because of increased production by Kazakhstan, the world's leading producer. As of December 2015, 65 nuclear reactors were under construction with a total capacity of 64 GW. Two-thirds (40) of the units under construction are located in four countries: China, India, Russia and South Korea. Currently there are more than 45 Small Modular Reactors (SMR) designs under development and four reactors under construction.

### 2.5. Hydropower

Hydropower is the leading renewable source for electricity generation globally, supplying 71% of all renewable electricity at the end of 2015. Undeveloped potential is approximately 10000 TWh/y worldwide. The global hydropower capacity increased by more than 30% between 2007 and 2015 accounting to a total of 1 209 GW in 2015, of which 145 GW is pumped storage.

### 2.6. Solar

Global installed capacity for solar-powered electricity has seen an exponential growth, reaching around 227 GWe at the end of 2015, producing 1% of all electricity used globally. The total capacity for solar heating and cooling in operation in 2015 is estimated at 435 GWth. As solar PV module prices have declined around 80% since 2007 (from ~ 4$/W in 2007 to ~ 1.8$/W in 2015), the cost associated with balancing the system represents the next great challenge for the Solar PV industry.

### 2.7. Wind

Global wind power generation capacity reached 432 GW in 2015, around 7% of total global power generation capacity (420 GW onshore, 12 GW offshore). A record of 63 GW was added in 2015 and total investment in the global wind sector was US 109$ billion in 2015.

### 2.8. Others

#### 2.8.1. CCS

CCS is an essential element of any low carbon energy future, but policy is the main issue, not technology. The world's first large-scale application of $CO_2$ capture technology in the power sector commenced operation in October 2014 at the Boundary Dam power station in Saskatchewan, Canada. There are 22 large-scale CCS projects currently in operation or under construction around the world, with the capacity to capture up to 40 million tonnes of $CO_2$ per year (Mtpa).

#### 2.8.2. Geothermal

Geothermal global output is estimated to be 75 TWh for heat and 75 TWh for power, but is concentrated on geologic plate boundaries.

#### 2.8.3. Bio-energy

Bio-energy (including traditional biomass) is the largest renewable energy source with 14% out of 18% renewables in the energy mix and supplies 10% of global energy supply

#### 2.8.4. E-storage

E-storage has been characterized by rapid change, driven by reduced costs (especially batteries) and increased industry requirement to manage system volatility. As of end 2015, the global installed storage capacity was 146 GW (including pumped hydro storage), consisting of 944 projects. There are already around 25 000 residential-scale units in Germany alone. Bottom-up projections suggest a global storage market of 1.4 GW/y by 2020 (excluding pumped hydro storage), with strong growth in electro-mechanical technologies in particular.

**2.8.5. Marine energy**

Around, 0.5 GW of commercial marine energy generation capacity is in operation and another 1.7 GW under construction, with 99% of this accounted for by tidal range. The total theoretical wave energy potential is said to be 32 PWh/y, but is heterogeneous and geographically distributed, technology costs for marine energy are still very high, hindering deployment.

**2.8.6. Waste-to-energy**

Despite Waste-to-Energy (WtE) occupying less than 6% of the total waste management market, the global WtE market was valued at approximately US 25$ billion in 2015 and is expected to reach US 36$ billion by 2020, growing at CAGR of around 7.5% between 2015 and 2020.

## 3. WORLD ENERGY CONSUMPTION

The energy landscape has changed with most countries achieving a more diversified energy mix as well as a growth in community ownerships and an evolution of micro grids.

A new World Energy Congress launched 2016 Resources Report, at the 23rd World Energy Congress on 12th October reveals that the unexpectedly high growth in the renewable energies market, in terms of investment, new capacity and high growth rates in developing countries, is a key factor in this notable shift. It has contributed to falling prices and the increased decoupling of economic growth and greenhouse gas (GHG) emissions.

**FIGURE 1: WORLD ENERGY CONSUMPTION**

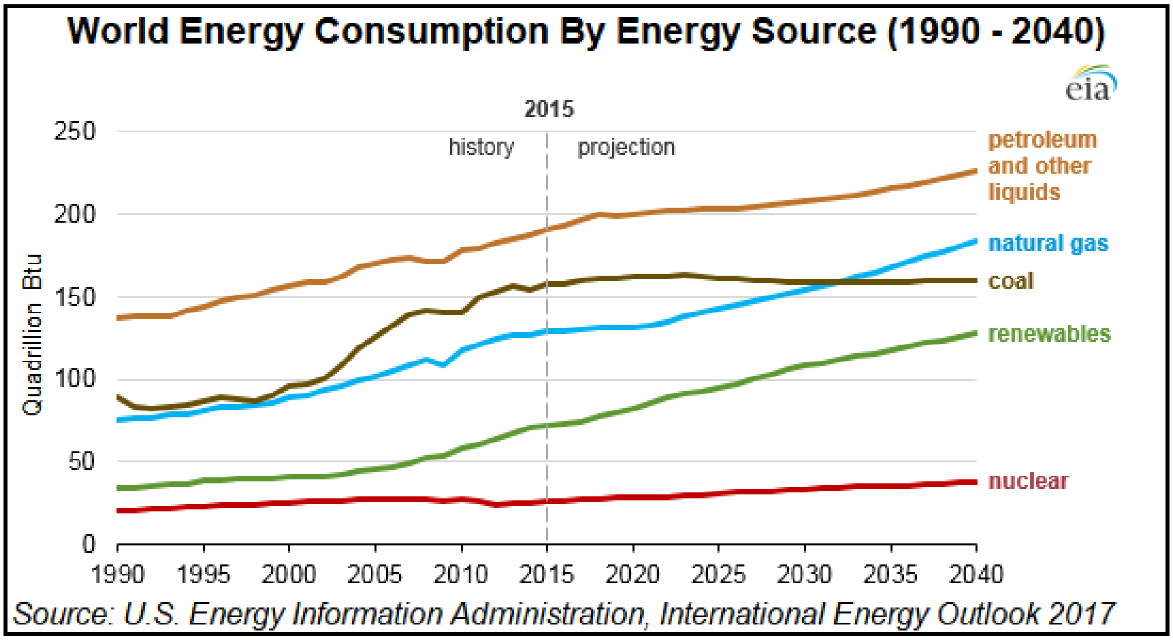



**FIGURE 2: COMPARATIVE PRIMARY ENERGY CONSUMPTION [2]**


There is already significant transition in the sector; however, some energy resources have challenges.

Despite some notable progress, the rate of improvements towards cleaner energy is far slower than required, to meet emissions targets. Public acceptance remains a challenge, regardless of the energy source, with an increased 'Not in my back yard' (NIMBY) attitude to the development of energy sources. Increased commodity and energy price uncertainty that results in higher risk and larger investments with long lead times are less appealing. Without diversification and review of business models, national and international oil and gas companies could struggle over the medium to long term. Incentive-assisted renewable energy companies have created a boom in certain countries and regions. However, as incentives are decreased, some companies might not be viable anymore. Rare earth elements, metals used in especially renewable energies, create new dependencies in the value chain and could represent possible future barriers to growth. Change is at its slowest at the moment, but our research identifies that technologies will change a lot quicker and the regulatory system is not keeping up, which may also become a barrier. Liberalized markets could reach their limit, as the lowest cost generation in the short term can be perceived to provide the highest value. There is a significant need to balance other aspects of the Energy Trilemma such as environmental considerations, including increased resilience and security of supply. This is particularly important for long-term planning in short-term power operations, with the lack and lag of new, expanded, upgraded and smart infrastructure offering the potential to hinder new energy developments. Heat generation and cooling technologies are lagging behind in terms of innovation. Increased use of natural gas combined with decreased use of coal will see energy associated carbon dioxide emissions from natural gas surpass those from coal. Failure to timely plan for replacement of decommissioned base-load power plants might pose a risk to energy reliability in some countries. All of this creates a highly dynamic context for the energy sector.

## 4. BACKSTOP RESOURCES

The work of Harold Hotelling in 1931 is considered by many to be the single most important contribution to the understanding of the economics of exhaustible resources ever made. There can be no doubt that at a theoretical level that this is so and it provided the seed for huge numbers of research efforts made during the period 1972 to the early 1990s, nearly two decades when the growing scarcity of natural resources was of concern to many. In terms of a contribution to mining operations the theory describes exactly how a mineral resource should be depleted, provided we can make some strong assumptions. The experience of extracting mineral resources in the mining industry is, however, significantly different to the proposed theory. Perhaps the single most important contribution made by Hotelling in guiding the schedule of extraction is that the discounted rent derived from the sale of the minerals, should be the same in every period. In order to achieve this end, the single greatest hurdle is that the rate of depletion should decline over the life of the mine, beginning at a maximum and ending at a minimum just before the mine closes.

At the industry level this means that the last ton of ore is being hoisted just as the price of the commodity reaches either a point where it is replaced by the next most inferior ore-body, or the choke price, or the commodity is replaced by a backstop technology. At the individual mine level it means that the rate of depletion has moved steadily down the marginal cost curve, from a point where marginal costs equal marginal revenue, to a point where marginal costs equal average costs. At this point the mine should be totally depleted. If not it may continue to operate but it will generate no rent, only normal profit, and can just survive. It is essential that we explore the economics of exhaustible resources, particularly because it promises so much, but does not deliver much in the way of valuable application in mining. In addition, the simple volume of research demands that we examine the theory and try to understand what it is about the work that has made it so appealing. The continuing search for Hotelling's scarcity rents has a quality about it something akin to the fox-hunt: one is not sure which way it could go next. By and large the average mine operator is not even aware that Hotelling-type scarcity rents exist, far less spend time identifying and scheduling his output according to them (Tilton, 2003).

A backstop technology [3] is defined as a new technology producing a close substitute to an exhaustible resource by using relatively abundant production inputs and rendering the reserves of the exhaustible resource obsolete when the average cost of production of the close substitute falls below the spot price of the exhaustible resource.

Backstop resources theory states that as a heavily used limited resource becomes expensive, alternative resources will become cheap by comparison, therefore making the alternatives economically viable options. In the long term, the theory implies faith that technological progress will allow backstop resources to be essentially unlimited, and that need will cause the development of new technologies to become cost effective. This idea is supported by economist Robert Solow who claimed that four-fifths of US economic growth could be attributed to technological development (the other fifth being accounted for by expansion of labor and capital).

Backstop Resource is a sustainable natural resource that is used in place of, and as a substitute for, finite, exhaustible natural resources that have been exhausted. A sustainable resource is one in which the amount used today cannot reduce the amount available tomorrow. An example is solar energy.

## 5. IEA's PV ROADMAP PROJECTIONS

### 5.1 Project (Task) objectives

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was and is two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The goal of IEA/SHC Task 36 [4] "solar resource knowledge management" is to provide the solar energy industry, the electricity sector, governments, and renewable energy organizations and institutions with the most suitable and accurate information of the solar radiation resources at the earth's surface in easily-accessible formats and understandable quality metrics. The scope of solar resource assessment information includes historic data sets and currently derived data products using satellite imagery and other means.

There are three main objectives of this Task to achieve this goal:

1. To provide further standardization and benchmarking of international solar resource data sets to insure worldwide inter-comparability and acceptance,
2. To provide improved data reliability, availability and accessibility in formats that address specific user needs, and
3. To develop methods that improve the quality and the spatial and temporal coverage, with customized solar resource products, including reliable solar radiation forecasts.

Achieving these objectives would reduce the cost of planning and deploying solar energy systems, improve efficiency of solar energy systems through more accurate and complete solar resource information, and increase the value of the solar energy produced by solar systems. As per IEA, by 2050, with appropriate support, CSP could provide 11.3% of global electricity (Figure 3). The country wise share of solar of total electricity generation will be 16% (Figure 4).

**FIGURE 3: UTILITY WISE SHARE OF TOTAL ELECTRICITY SUPPLY BY 2050.**

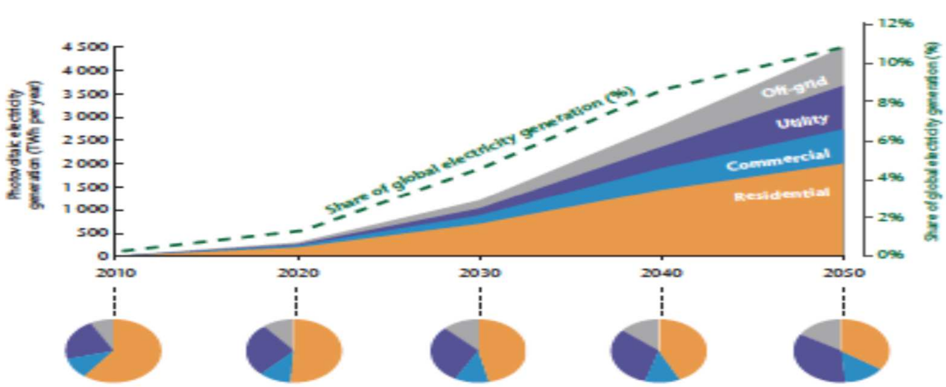
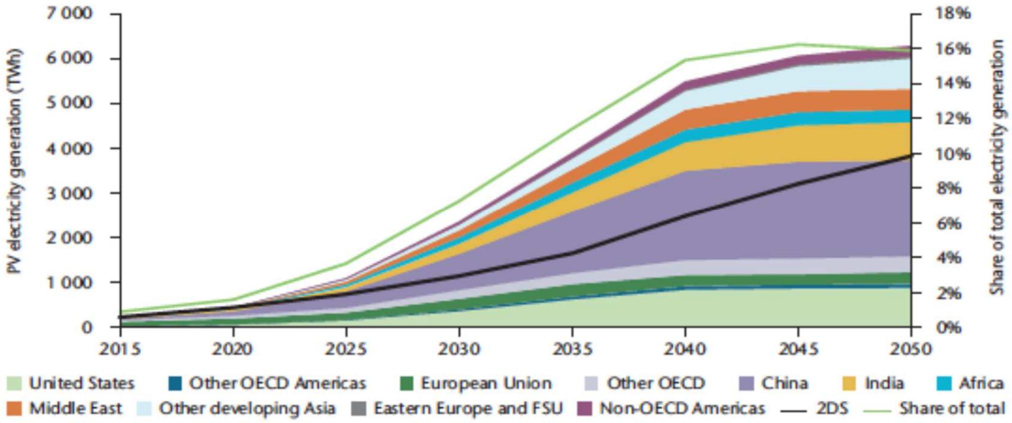


FIGURE 4: ~16% OF TOTAL ELECTRICITY SUPPLY BY 2050[5]

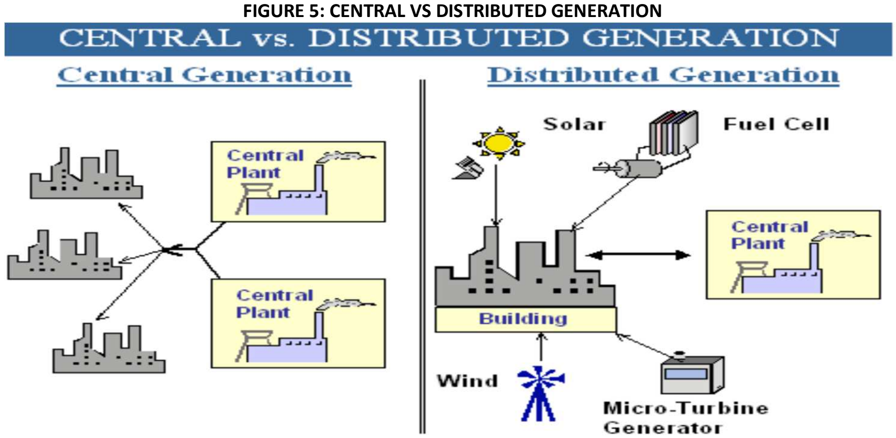



**5.2 Pathway to 100% RE requires**

1. A transformation of our energy systems
2. Shift from residential to large-scale PV over time
3. Increased system flexibility
4. More reliance on distributed generation, smart grids, micro grids
5. Lower energy intensity per capita
6. Ability to incorporate high penetrations of Variable Renewable Energy (VRE)

The electricity generated by centralized generation is distributed through the electric power grid to multiple end-users. Centralized generation facilities include fossil-fuel-fired power plants, nuclear power plants, hydroelectric dams, wind farms, and more. Distributed generation (also known as distributed energy) refers to power generation at the point of consumption. Generating power on-site, rather than centrally, eliminates the cost, complexity, interdependencies, and inefficiencies associated with transmission and distribution.

FIGURE 5: CENTRAL VS DISTRIBUTED GENERATION

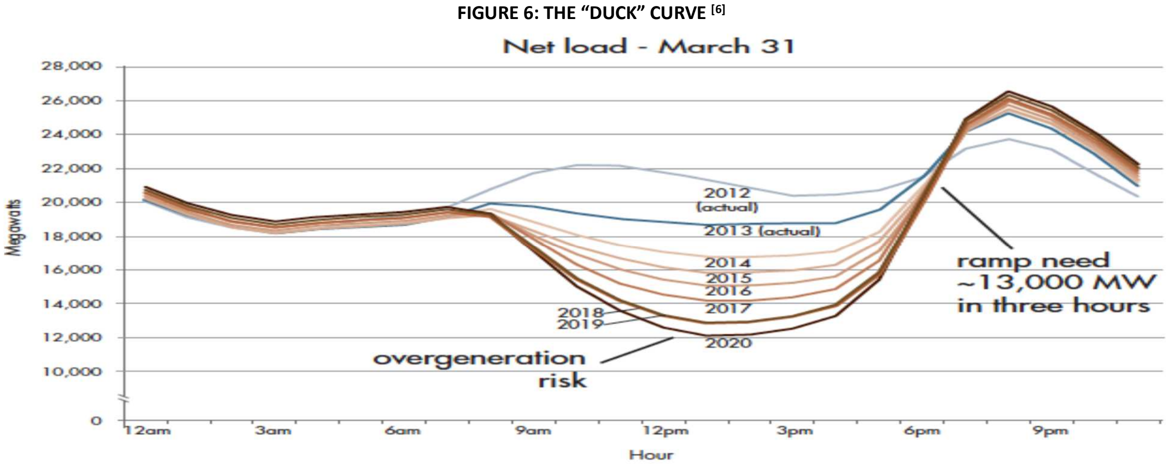



**5.3 Managing increasing solar penetration**

Now research focuses on a novel management strategy of thermal energy storage (TES) system, by increasing solar photovoltaic (PV) penetration. By charging the TES while the PV panels are producing power, and monitoring the maximum charging rate of the TES, it enables to increase the amount of solar PV used, and decrease the overall carbon footprint. Using this new management method, it can be able to increase the current PV generation.

In commercial-scale electricity generation, the duck curve is a graph of power production over the course of a day that shows the timing imbalance between peak demand and renewable energy production. In many energy markets the peak demand occurs after sunset, when solar power is no longer available.

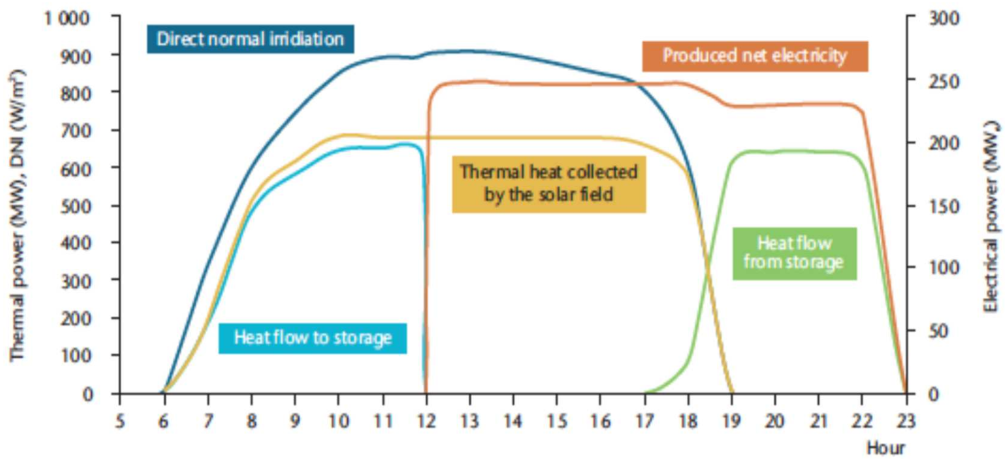
FIGURE 6: THE "DUCK" CURVE [6]



### 5.4 Energy storage can shift time of use of RE

Energy storage, can shift time of use of solar technologies such as CSP Source. Figure. 7 shows hourly consumption and solar generation for the household during an average day (which assumes 12 hours of sunshine and a capacity factor of 19%). When the sun isn't shining the household gets all its power from the grid, but for about 7 hours it gets all its power from solar array. And over this period the array generates a healthy surplus that gets fed back to the grid, sending the electricity meter into reverse and causing it to wind rapidly backwards:

FIGURE 7: ENERGY STORAGE CAN SHIFT TIME OF USE OF RE [8]




Thermal storage uncouples electricity generation from solar energy collection

### 5.5 Solar resource assessment and forecasting

Solar Resource Assessment (SRA) refers to the analysis of a prospective solar energy production site with the end goal being an accurate estimate of that facility's annual energy production.

#### 5.5.1 Four focus areas:

1. Grid integration of VRE
2. Improved data collection and assimilation
3. Solar forecasting
4. Solar model improvements

Task deliverables: best practices in data collection, site adaptation, and forecasting

#### 5.5.2 Summary points

1. RE will become a major energy source (and ultimately the only energy source) in this century
2. Energy intensity at individual and community level must decrease
3. Our method of delivering energy services is going through a transformation, and even a revolution
4. Strategies to address variable renewable energy supply must include resource forecasting and energy storage
5. With proper grid management, RE can supply both base and peak load energy

### 5.6 Design and cost analysis of 1 kW photovoltaic system [9]

The exhaustion of conventional resources and its effect on climate requires an urgent call for the substitute power resources to convene up the current power requirement. Solar energy is an endless, unsoiled and prospective energy source among all other nonconventional energy options. As more concentration is being done on focal point for the development of renewable energy capital globally. To ascertain their viability, it is necessary to do the economic and technical assessments of these resources. Here it is studied the designing aspects and assessments of solar PV system based on field and actual performance. The study is based on design of solar PV system of 1.0 kW off-grid photovoltaic energy system. Both monthly and weekly costs of energy produced by the 1 kW PV system have been calculated. In addition, the solar PV 1 kW system can give internal rate of return of about 1.714% on investment. Based on assumptions used in this study, solar 1 kW PV system of Rs. 0.9724/kWh is estimated for a project with profitable life of 25 years with no other financial support. This translates to Rs. 80000 payment over the livelier cost of energy of 1 kWh generated by the system. However, if the financial support is more than 50% of the initial investment cost, no further payment fee is necessary to support this type of system. Basically this system has been designed for small home located at the place of availability of grid power is rare. 1 kW PV solar system is also very useful in rural areas of India. India as a subcontinent receives great amounts of solar radiation annually.

There are different types of modules depending on power ratings. Every module has a number of solar cells. Solar cells are fabricated by means of semiconductors such as silicon. Photovoltaic cells generate electricity in clean and reliable manner which is the prime concern for today's environment. Variation in temperature affects the efficiency of solar module greatly (Parlak, 2014). Due to these variations this technology faces enormous challenges in its power quality performance (Patra et al., 2015). Integration of renewable energy is also a tedious process (Pinto and Panda, 2014). Solar photovoltaic standalone systems have better power quality as compared to grid integrated systems. In standalone systems batteries connected with MPPT charge controller tolerates all fluctuations of temperature and radiation associated with environment.

MPPT or Maximum Power Point Tracking is algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called 'maximum power point' (or peak power voltage).

Here, 1 kW PV system is designed for small home mainly for rustic areas. This is small roof top system and its performance based on cost analysis has evaluated using PV system software (Mermoud, 2012). PV system software uses the information of solar radiation to calculate generated power, used power and unused power. Then the economical costing of the system is performed on the generated data. Mainly the study includes the data for one year and the information about the solar radiation is generated by the software itself based on the latitude and longitudinal information of the site. Then for the specified load it gives different values about the generation of solar energy. The second section gives a brief introduction about the designing of PV system, followed by simulation results in the third section. Then the final section concludes the finding of the paper.

#### 5.6.1 PV system design

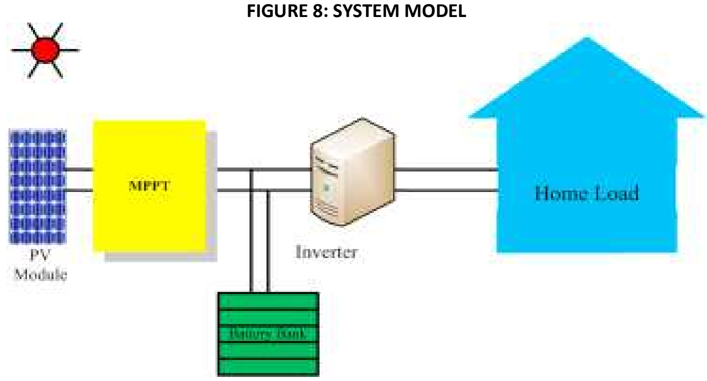
Designing of PV system mainly consists of PV modules, large numbers of PV modules are connected in parallel and series combination called PV array. The size of PV array depends on power rating of the system. 1 kW solar system is designed by using 200 W Moserbaer (MBPV CAAP BC 200Wp) PV Si-Poly modules. The maximum voltage and current rating by each module is 27.6 V and 7.26 A respectively at ideal conditions.

All six PV modules are connected in parallel so maximum voltage is 27.6 V and maximum current is 43.6 A. MPPT is also extremely crucial part of this system so selection of MPPT is also really significant. In this system Generic Universal MPPT controller is used which has maximum input current range is [30–45 A] at 14 A output constant current. List of all components are shown in Table 1 and complete system is shown in Table 1.

TABLE 1: LIST OF ALL COMPONENTS

| Particular | Company | Quantity | Investment (in Rs.) |
|---|---|---|---|
| PV modules | Moserbaer | 5 | 48,000 |
| Batteries | Exide | 2 | 25,000 |
| MPPT controller | Generic | 1 | 2000 |
| Inverter | Microtech | 1 | 5000 |
| Total | | | 80,000 |

FIGURE 8: SYSTEM MODEL




**5.6.2 Simulation results**

The performance of 1 kW PV system has evaluated using PVsyst software. The initial cost of the considered system is approximately Rs. 80,000. This investment includes the cost of PV module, MPPT controller, batteries and inverter mainly for home use. Information for the load and the daily consumption of energy is given in Table 2. The load specified for the dedicated system needed 8109 Wh energy per day.

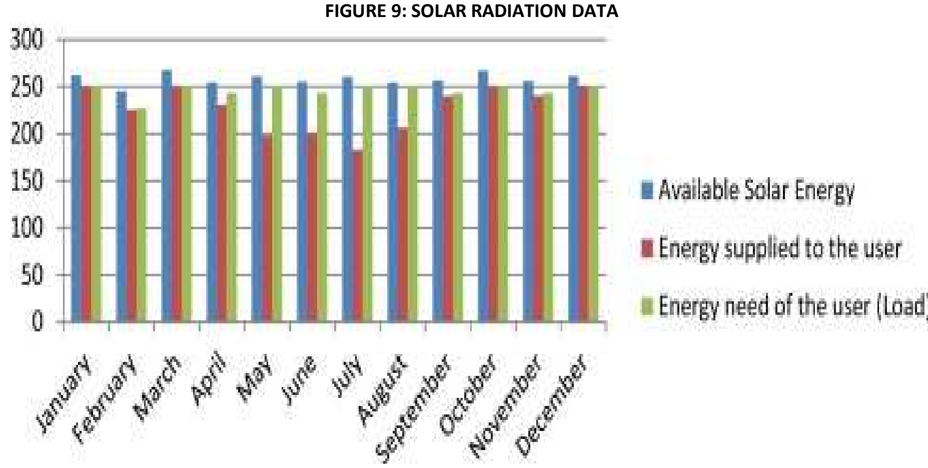
TABLE 2: LOAD AND CONSUMPTION

| Load | Quantity | Power consumption | Uses | Energy |
|---|---|---|---|---|
| Lamp (LED/Fluorescent) | 5 | 15 W | 11 h/day | 825 Wh/day |
| TV/PC | 2 | 80 W | 6 h/day | 960 Wh/day |
| Domestic appliances | 5 | 60 W | 15 h/day | 4500 Wh/day |
| Other uses | 5 | 60 W | 6 h/day | 1800 Wh/day |
| **Total** | | | | **8109 Wh/day** |

Monthly energy production by the PV system is calculated using PV system software. According to simulated data maximum global irradiation were found in the month of May (222.1 kWh/m$^2$) but effective global irradiation is low (199.3 kWh/m2) due to temperature effect on PV modules. In the month of March, the horizontal global irradiation is low but available solar energy is maximum (267.6 kWh) as compared to other month. Annual solar energy produced by the system is 3101.2 kWh while the energy supplied to the user is 2933.4 kWh.

167.8 kWh energy has not consumed may be due to the reason that either the load is not available during generation or batteries may reach their storage capacity of charging. This unused energy can be used either by increasing the storage capacities of the batteries or by increasing the consumption during generation time (Figure. 9).

FIGURE 9: SOLAR RADIATION DATA




Here, 1 kW PV system is studied for small homes only for rustic areas sited in India. Performance of the system and cost analysis for the designed system has been evaluated using PV system software. The desired PV system generates 3101.2 kWh/year solar energy, but only 2933.4 kWh/year solar energy is supplied to the user and 167.8 kWh energy unused may be due to battery full condition or low energy demand during generation. The energy produced by the PV system is also calculated month wise. Also the effect of global radiation on the generation of solar energy is depicted. Comparison of energy generated by PV, energy supplied and needed by user is also calculated.

**5.6.3 Design of solar PV system**

A solar PV system design can be done in four steps:

1. Load estimation
2. Estimation of number of PV panels
3. Estimation of battery bank
4. Cost estimation of the system.

Base condition: 2 CFLs (18 watts each), 2 fans (60 watts each) for 6 hours a day.

1. The total connected load to PV panel system

= No. of units × rating of equipment
= 2 × 18 + 2 × 60 = 156 watts

2. Total watt-hours rating of the system

= Total connected load (watts) × operating hours
= 156 × 6 = 936 watt-hours

3. Actual power output of a PV panel

= Peak power rating × operating factor
= 40 × 0.75 = 30 watt

4. The power used at the end use is less (due to lower combined efficiency of the system)

= Actual power output of a panel × combined efficiency
= 30 × 0.81 = 24.3 watts (VA) = 24.3 watts

5. Energy produced by one 40 Wp panel in a day

= Actual power output × 8 hours/day (peak equivalent)
= 24.3 × 8 = 194.4 watts-hour

6. Number of solar panels required to satisfy given estimated daily load

= (Total watt-hour rating (daily load) / (Daily energy produced by a panel)
=936/194.4 = 4.81 = 5 (round figure)

1. Inverter size is to be calculated as:
2. Total connected load to PV panel system = 156 watts
3. Inverter are available with rating of 100, 200, 500 VA, ect.
4. Therefore, the choice of the inverter should be 200 VA.

**5.6.4 Cost estimation of a PV System**

I. Cost of arrays = No. of PV modules × Cost/Module

= 5 × 8000 (for a 40 Wp panel at the rate of 200. Rs/Wp)
= 40000.0 Rs

II. Cost of batteries

= No. of Batteries × Cost/Module
=1 × 7500= Rs.7500

III. Cost of inverter

= No. of inverters × Cost/Inverter
= 1 × 5000 = 1 × 5000
= Rs.5000

IV. Total cost of system = I + II + III

= 40000 + 7500 + 5000
= 52500.0 Rs
[Additional cost of wiring may be taken as 5% of total system cost]

**5.6.5 Assumptions taken for design**

1. Inverter converts DC into AC power with efficiency of about 90%.
2. Battery voltage used for operation = 12 volts
3. The combined efficiency of inverter and battery will be calculated as combined efficiency = inverter efficiency × battery efficiency = 0.9 × 0.9 = 0.81 = 81%
4. Sunlight available in a day = 8 hours/day (equivalent of peak radiation).
5. Operation of lights and fan = 6 hours/day of PV panels.
6. PV panel power rating = 40 Wp (Wp, meaning, watt (peak), gives only peak power output of a PV panel)
7. A factor called "operating factor‟ is used to estimate the actual output from a PV module. The operating factor between 0.60 and 0.90 (implying the output power is 60 to 80% lower than rated output power in normal operating conditions, depending on temperature, dust on module, etc.

**5.7 Noteworthy solar parks**

The following solar parks were at the time they became operational, the largest in the world or their continent, or are notable for the reasons given:

**TABLE 3: NOTEWORTHY SOLAR PARKS**

| Name | Country | Nominal power (MW) | Commissioned | Remarks |
|---|---|---|---|---|
| Lugo San Bernardino County, California | USA | 1 MW | Dec 1982 | First MW plant in World |
| Charanka, Gujarat | India | 221 MW | Apr 2012 | Asia's largest solar park |
| Longyangxia PV/Hydro power project, Gonghe, Qinghai | China | 850 $MW_P$ | Dec 2014 | Phase II of 530 MW added to 320 MW Phase I (2013) makes this the world's largest solar power station |
| Solar Star, Los Angeles County, California | USA | 579 $MW_{AC}$ | Jun 2015 | World's largest solar farm built in **One Phase** |

Note: In China, the name-plate capacity of a photovoltaic power station is rated in MegaWatt-Peak (MWP), which refers to the solar arrays DC power output. However, Canada, Japan, Spain and some parts of the United States often specify using the converted lower nominal power output in MWAC; a measure directly comparable to other forms of power generation.

In recent years, PV technology has improved its electricity generating efficiency, reduced the installation cost per watt as well as its energy payback time (EPBT), and has reached grid parity in at least 19 different markets by 2014. Photovoltaic is increasingly becoming a viable source of mainstream power. However, prices for PV systems show strong regional variations, much more than solar cells and panels, which tend to be global commodities. In 2013, utility-scale system prices in highly penetrated markets such as China and Germany were significantly lower (1.40$/W) than in the United States (3.30$/W). The IEA explains these discrepancies due to differences in "soft costs", which include customer acquisition, permitting, inspection and interconnection, installation labor and financing cost.

## 6. CONCLUSION

The immense global energy flux from the Sun makes it the prime candidate for future sustainable energy production. Both solar thermal energy and solar PV conversion involve technologies that can be deployed on personal through community to regional scales, using both simple and advanced technologies. The solar PV panels that power automatic roadside weather stations and other low-drain communications systems. The panels require low maintenance and usually charge batteries to allow them to remain operational during the night. In poor countries where the energy infrastructure is rudimentary or absent, PV systems hold out great potential. An important use is for daytime pumping of water from wells.

In its 1997 renewable energy plan, the EU set a target of half a million village-scale direct solar systems to be deployed in developing countries and a similar number in European houses by 2010. The United Nations has asked world governments to deploy 4.5 GW of solar PV electricity generating capacity in developing countries by 2012. Both Japanese and German governmental subsidies have boosted both photovoltaic production and deployment, and a similar 'hard-sell' stems from commercial sources in the US. As a result, power capacity of solar PV rose from a global 50 MW in 1995 to over 2 GW in 2002, and is estimated to be growing at a rate of 40% per year. The main hindrance to greater deployment is simply that of cost; at between US 0.2 to 0.5$ per kWh, solar PV electricity was almost ten times as expensive in 2005 as that from the cheapest fossil-fuel source, natural gas. To progress, the technology requires continued reduction in the cost of the solar cells themselves, but the enormous reduction in cost of silicon-based computer hardware since the 1970s is cause for optimism. During a few years, the photovoltaic (PV) market has shown unprecedented growth and wide-spread use of this environmentally friendly and distributed source of power generation. On a global basis, new PV installations approximately varies between 78 GW and 82 GW in 2016 and estimates for 2017 are in the 80–85 GW range. This is a correct power supply for telecommunication relay stations, especially in areas where there is no electricity, is a handicap for operators to expand their clientele.

Solar PV could theoretically supplement grid-power during daylight hours to reduce generating costs and environmental emissions. However, at this scale serious disadvantages emerge. The daily intensity of sunlight varies dramatically because of cloud cover. Moreover, solar power is greater in the summer while the demand for electricity is lower, except in areas with high use of air conditioners. Provided photovoltaic conversion contributes no more than 10-20% of the total amount of electricity in the grid, its integration seems feasible. This is because electricity grid systems are designed to cope with large variations in demand, and they can cope equally well with fluctuations from different forms of supply.

Should future solar PV power rise above 20% of the total electricity supply, then existing grid systems built to be dominated by coal, oil and nuclear generation would have to be modified. This is because conventional power plants are slow to start up and shut down; they are slow response systems. Solar conversion, along with other alternative sources whose power source fluctuates uncontrollably (e.g. wind and waves), is a fast-response system. A distribution grid with solar PV power as a major component would need to be supplemented by controllable fast response systems, principally hydroelectric and gas-turbine generators. Another solution would be short-term electrical storage installations, but they are both costly and inefficient. A means of 'having one's green cake and eating it', however, would be to use electricity from solar PV to generate hydrogen by electrolysis of water. Hydrogen gas is combustible, storable and moveable, and so avoids most of the problems associated with electrical storage. The hydrogen could even be converted back into electricity using fuel cells.

Despite these caveats, the potential of solar PV is enormous. If photovoltaic conversion with 10% efficiency was installed over an area of 500 000 km$^2$ (about 1.3% of the area of tropical deserts) humanity's present energy requirements would be met. That outlook is probably far off. Of the electricity generated from all alternative energy sources in the early 21st century, solar PV contributes only about 0.02%, with solar thermal generation a little more significant at 0.06%.

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