Solar Energy Education and Skill Development for Enhancing Quality of Life in Developing Countries

Namrata Sengar[1], Christopher Sansom[2], Douglas Halliday[3] and Deepak Gadhia[4]

[1] University of Kota, Kota (India)

[2] Cranfield Universiy, Cranfield (UK)

[3] Durham University, Durham (UK)

[4] MSA Renewtech, Vadodara (India)

Abstract

Worldwide, around more than one billion people are without access to electricity and around three billion people use solid biomass for cooking, water heating and heating their homes. Majority of the developing countries of the world receive more than 5 kWh/m^2 of global solar irradiation per day, which can be utilized for a variety of applications such as providing electricity, cooking, drying, water heating, space heating etc. Use of solar energy can provide pathways for social and economic development of communities without triggering climate change but it requires consistent growth and efforts in providing solar energy education and skill development. The paper discusses the inclusion of solar energy education at school level and in higher education, the solar awareness programs and establishing a skilled chain for installation, repair and maintenance of solar systems at regional/community level. It also discusses some of the initiatives being taken in India.

Keywords: Solar education, solar awareness, skill development, socio-economic development, employment.

1. Introduction

Energy is linked to almost every aspect of life in one form or another. According to the report of World Energy Council worldwide more than one billion people are without access to electricity (WEC 2016). Around 3 billion people use solid biomass for cooking, water heating and heating their homes and over 4 million people die prematurely from illness attributable to the household air pollution from cooking with solid fuels as per World Health Organization (WHO 2016). For sustainable development of communities in developing countries it is essential that clean, safe and affordable energy is made available. In order to provide clean lighting source and clean fuel for cooking to billions of people in this world, apart from technical and financial support, awareness and knowledge dissemination is important. The implementation of policies and schemes can only be successful if people are willing to accept the technology. Majority of the developing countries of the world receive more than 5 kWh/m^2 of global solar irradiation per day, which can be utilized for a variety of applications such as providing electricity, cooking, drying, water heating, space heating etc. Use of solar energy can provide pathways for social and economic development of communities without triggering climate change but it requires consistent growth and efforts in providing solar energy education and skill development. Solar energy education at school levels can help in enhancing the awareness and increasing the acceptability of solar systems into the society for various applications. Inclusion of solar energy education in technical courses in higher education may provide the deeper understanding of solar technologies, enhance the research and development and produce innovations for use of solar energy to solve local problems. Further, there is need for awareness programs for communities and development of chain of local persons who can install, repair and maintain solar systems. These measures may help to a large extent in improving the quality of life of many communities through solar lighting, solar cookers, dryers, distillation stills etc. and at the same time provide employment opportunities to many. According to a study by Karakul (2016) during last two-three decades there has been rise in unemployment as the links between education system and economic system has been loosened. The links between education system and economic system may be strengthened by educating according to the needs of the economy. Though solar and wind energy accounted for only 4% of power generation in 2014, but it is estimated by

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2060 it will account for 20% to 39% of power generation as per World Energy Council (2016). According to Ciriminna et. al. (2016) with the prospective rise of solar economy it becomes important to think on solar energy education. They have discussed about a multi-disciplinary graduate course on solar energy.

With the above aspects in mind, the present paper discusses the course structures for inclusion at school level and in higher education, the solar awareness programs and establishing a skilled chain for installation, repair and maintenance of solar systems at regional/community level. The basis has been taken as the educational system in India, it may be replicated in other developing countries as well.

2. Solar energy for improving lives

Worldwide many communities are still struggling for basic facilities from which clean and affordable energy supply is one. According to World Bank (2015), more than one billion people are living without electricity and another one billion face the problem of unreliable and inadequate supply of electricity. Mainly kerosene lamps are used for lighting lamps which provides dim light and is polluting. Around three billion people use polluting fuels like wood, charcoal, coal, dung and kerosene for cooking and heating applications. It is estimated that around four million deaths take place each year due to indoor and outdoor air pollution caused by use of polluting fuels. Most of this population lives in rural areas of developing countries of sub-Saharan Africa, Pacific region, south and east Asia and are poor. Energy availability is closely linked with social and economic development. Absence or inadequate availability of clean energy affects health care, availability of clean water, education, information, communications, environment, agricultural or industrial growth and productivity. Most of the time of women and children is spent is picking wood and carrying water. It deprives them of quality time for studying, recreation, leisure and following creative interests. It hinders their productivity and economic growth also. Access to affordable, clean and adequate energy is essential to reduce poverty, promote welfare and meet the goals of climate change mitigation.

Here solar energy can play an important role as solar energy can directly or indirectly meet most of the energy needs for electric power, heating, cooling, cooking, drying, desalination, transportation etc. Further, it is interesting to observe that most of the developing countries facing the problem of energy access lie in high solar radiation receiving areas of the world. According to Renewables global status report (2016) many countries have started programs for installing off grid and on grid solar PV home lighting systems. Countries such as Kenya, Uganda and Tanzania in Africa; China, India, Bangladesh and Nepal in Asia; Brazil and Guyana in Latin America are seeing rapid expansion of small-scale renewable systems. Solar PV systems with battery storage or grid integration can provide clean and reliable supply of electric power to most of the countries. Further, solar thermal applications can be used for cooking, drying, heating, water treatment, distillation etc. Major global energy use for heat is fossil fuel-based, so solar energy has a huge potential to be used for providing heat. With deployment of solar technologies deep to the rural communities in developing countries, the pace of socio-economic growth can be increased.

3. Solar education

Among many challenges in penetration of solar technologies is reluctance and hesitation of the people. This requires more involvement of people at local level in designing, installation, operation and maintenance of the solar systems. Involving local communities will result in better support, developing region based solutions and sustainability of the projects. Here role of solar education becomes very important. The penetration of solar systems will be smooth and very fast if the new generation as student gains knowledge about the principle, working and maintenance of the systems. Solar education in itself involves application of various scientific and technological principles which will make studies more practical and interesting.

3.1 School level

At school level some theory and experiments on solar energy may be included in the science/physics laboratory, after the student has learnt basics of heat transfer and electricity. The instruments and equipment to be used in the experiments need not be expensive and of very high accuracy. These should be meant to provide students with the fundamental knowledge and inculcate an interest in use of solar energy. The theory and experiments may include

- Observing photovoltaic effect through small solar panel
- Types of solar cells
- Study of I-V characteristics of solar panel
- Estimation of maximum power point and fill factor
- Charging of battery by solar panel
- Effect of shading on power of PV panel
- Effect of tilt on power of PV panel
- Study of PV power during different times of a day
- Differentiating between flat plate and concentrating solar collectors
- Study of box type solar cooker
- Study of parabolic solar cooker
- Study of solar distillation still
- Study of solar dryer,
- Study of Fresnel lens, etc.

The solar PV based experiments involve basic principles of electricity and the learning outcome will be greater understanding of these principles. These experiments mainly require a small size solar panel, a multimeter or voltmeter and ammeter, a resistance box and connecting wires. The students will learn the use of voltmeter and ammeter, understand about dc electricity provided by solar panel, plot I-V characteristics, concepts of short circuit current and open circuit voltage, maximum power point and fill factor. Study of variations of PV power with shading, tilt and time of day will help the students understand the effect of varying solar radiation on the panel.

Fig. 1: A simple experiment to study characteristics of solar cell

The solar thermal experiments give insight to the students about green house effect of glass, transmission, reflectance and absorbance of different materials. The students can learn about beam, diffuse and global solar radiation, optical and thermal properties of materials in a simple manner through solar collectors. A simple hot box solar cooker involves explanation of optical property and heat trap property of glass, black absorber coating on a good thermal conducting material and reduction of heat losses through thermal insulating material. Like this, numerous experiments can be designed according to age group of the students for explaining them various principles. The experiments are generally very simple and safe, and cost of the experiments mainly lies between $20-70. Teachers and students may be motivated to design the systems and study them. Most of the systems may be made from inexpensive materials. Some of the entrepreneurs may also come up with suitable low cost experimental kits for the schools so that the students learn the fundamentals of science in a more effective way through experiments on solar systems.

Fig.2: Fresnel lens experimental set up

Fig. 3: Solar lantern with solar panel

Fig.4: Demonstration of cooking through parabolic solar cooker to village school students

Fig. 5: Demonstration of solar hot box cooker in village school

3.2 Higher Education

Inclusion of solar energy education in scientific/technical courses in higher education may provide the deeper understanding of solar technologies, enhance the research and development and produce innovations for use of solar energy to solve local/regional problems.

At the level of higher education many institutes in India offer B.Tech. and M. Tech. courses in renewable energy and recently some have started courses with specialization in solar energy. As solar energy is an extensive field covering materials, power generation, thermal applications, building design, modeling, simulation etc. it is required that a full- fledged master's course specialized in solar energy is run. In India M.Tech. is a two years course of four semesters, which includes a research project of around six months to twelve months. The course on solar energy consists of theory, experiments, seminars and project work mainly on

- Solar radiation –Physics of the Sun, solar constant, spectral distribution and variation of extraterrestrial radiation, air mass, beam, diffuse and global solar radiation, irradiance, solar insolation. Solar radiation on the earth surface - spectral energy distribution of solar radiation. Depletion of solar radiation - Absorption, scattering, atmospheric attenuation. Measurement through pyranometer, pyrheliometer, albedometer. Solar radiation geometry - Earth-Sun angles – Solar angles. Sunrise, sunset, solar day length, tilt factors, solar radiation on horizontal and tilted surfaces. Angles for tracking surfaces. Average and clear sky radiation, beam and diffuse components of hourly, daily and monthly radiation, radiation on sloped surfaces- isotropic and anisotropic sky, radiation augmentation, beam radiation on moving surfaces, effects of receiving surface orientation, utilizability.
- Fundamentals of materials- Electronic and atomic structures, atomic bonding in solids, structure of metals and ceramics, density computations, polycrystalline and amorphous materials. Polymeric structures, thermosetting and thermoplastic polymers, copolymers, polymer crystallinity, semiconductors, imperfections in solids. Diffusion mechanisms, factors affecting diffusion, diffusion in ionic and polymeric materials, phase diagrams, solubility limit, phase, microstructure, phase equilibria. Mechanical properties, concepts of stress and strain, Hooke’s law, tension, compression and shear. Stress-strain diagram and thermal stresses, elasticity, effect of temperature, fracture and failure. Electrical, optical, thermal and magnetic properties of materials.
- Fundamentals of power generation- Power scenario-world and India, thermodynamic cycles, their importance and use, Carnot, Rankine cycle, modified Rankine cycle, Brayton cycle, Stirling cycle , Binary cycles, Combined cycles, reheat, regeneration and supercritical. Load duration curves, location of power plants, types of power plants- Steam, hydroelectric, diesel, gas, nuclear, biomass, solar and wind, relative advantages and disadvantages of different modes of power production, energy conversion and losses, power plant economics.
- Heat and mass transfer- One dimensional energy equations and boundary conditions – Three dimensional conduction equations - Extended surfaces – Critical thickness of insulations – Overall heat transfer coefficient. Convection-Momentum and energy equations, turbulent boundary layer heat transfer –Mixing length concepts, turbulent model – K - ε model. Analogy between heat and momentum transfer – Reynolds, Colburn and Von Karman. High speed flows. Radiation - Gases and vapour. Solar radiation – Sky radiations, solar radiation through fenestrations – Estimations. Phase change heat transfer, heat exchanger. Finite difference formulation of steady and transient conduction problems. Application of heat transfer in solar thermal system and its components.
- Energy audit and management- Role of energy conservation and energy efficiency. Energy Conservation Act- 2001, Electricity Act, Bureau of Energy Efficiency, energy and exergy analysis. Energy management and audit-need, objectives, types, methodology and phases, instruments used and report preparation. Material and energy balance, energy action planning, financial management, project management. Electrical system- losses, demand side management, factors affecting energy efficiency and minimizing losses in compressed air system, motors, fans and blowers, pumps and pumping systems, lighting system. Fuels and combustion, efficient utilization and energy saving opportunities. Thermal systems, cogeneration, heat exchangers, waste heat recovery, energy performance assessment of buildings and commercial establishments, financial analysis.
- Solar collectors- Radiation transmission through glazing, optical properties of cover systems, transmittance transmittance-absorptance product and its angular dependence, spectral dependence of transmittance. Flat Plate Collectors- components, basic energy balance equations, temperature distribution, collector overall heat loss coefficient, collector efficiency factor, collector heat removal factor, flow factor, critical radiation level, collector tilt and orientation, mean fluid and plate temperatures, effective transmittance- absorptance product, effect of dust and shading, heat capacity effects, liquid heaters, air heaters, measurements of collector performance, collector characterization and tests, practical considerations. Concentrating collector configurations, concentration ratio, thermal and optical performance of concentrating collectors, cylindrical absorber arrays, optical characteristics of non-imaging collectors, orientation, absorbed energy and performance of CPC collectors, linear imaging concentrators, ray trace method, incidence angle modifier, energy balance, paraboloidal concentrators, central receiver collectors, practical considerations.

- Solar photovoltaics- Semiconductors, charge carriers, carrier concentration, drift, diffusion, light absorption, recombination of carriers, solar cell design for high fill factor, properties of efficient solar cells, lifetime and surface recombination effects, efficiency and band gap, spectral response, parasitic resistance effects, temperature effects, efficiency limits for photovoltaic conversion. Crystalline silicon solar cell- manufacturing process, multicrystalline solar cells, photovoltaic modules, thin film silicon solar cells, high efficiency III-IV multijunction solar cells, amorphous silicon, $Cu(InGa)Se_2$ solar cells, Cadium Telluride solar cells and modules. Dye-sensitized solar cells, introduction, fabrication, new developments, approach to commercialization. measurement and characterization of solar cells and modules, rating PV performance.
- Solar thermal applications- Active and passive systems, auxiliary energy, natural and forced circulation systems, integral collector storage systems, testing and rating of water heaters, solar cookers-types, design components, factors affecting performance, Indian and international testing procedures. Solar process loads, energy storage, sensible, latent and chemical energy storage systems, solar dryers- types, direct gain, indirect gain, design components, application areas, solar distillation- design fundamentals, efficiency and practical considerations. Solar cooling: Fundamentals of refrigeration and air conditioning, solar absorption cooling, combined solar heating and cooling, solar industrial process heat. Solar thermal power plants: low, medium and high temperature power generation systems, thermal conversion systems, solar chimney power plant, central receiver power plant.
- Energy efficient buildings- Thermal comfort, factors affecting thermal comfort, comfort parameters, Climatic conditions, climate zones, heat flow calculations in buildings. Building heating and cooling- active methods, solar heating systems- liquid and air systems. solar energy- heat pump systems, phase change and seasonal storage systems, solar and off-peak storage systems, solar air-conditioning. Passive and hybrid methods for heating and cooling, insulation, shading, sunspace, storage walls and roofs, ventilation, evaporative and nocturnal cooling, earth–air tunnel, solar chimney, active collection-passive storage hybrid systems, heat distribution in passive buildings, Energy conservation building code. Building integrated photovoltaic systems.
- Solar power generation- Photovoltaic systems: Configuration and applications, grid –independent for small devices, PV systems for remote consumers of medium and large size, decentralized grid-connected PV systems, central grid connected PV systems. Components of PV systems-battery storage, charge controller and inverters. Design methodology for SPV system, system sizing. Installation, troubleshooting and safety, Economic analysis.
- Modeling and simulation- system, experiment, model, simulation - definition, importance, application areas, advantages, disadvantages and difficulties, types of models. Steps of modeling process-problem analysis, model formulation, model abstraction, defining variables, solving, execution, verifying, analysis of results. Verification and validation, Solar energy modeling techniques-, Brief introduction to the software used for simulation in solar energy field, comparative review of software for solar photovoltaics, solar thermal systems and buildings. Use of software such as TRNSYS, PVSYST, PVSOL, SAM, SOLTRACE, HOMER, Meteonorm etc.

The seminars focus on advancements in solar technologies, research and development, policy changes and their impact on industry and society. During project work student has to opt for a problem related to research depending on technical, industrial or society requirement.

At master’s level students need to learn the principles and technologies with more depth and accuracy. More practical trainings, hands-on workshops and industrial collaborations improve the quality of the course and learning by the students. In order to improve the engineering education Royal Academy of Engineering,UK and FICCI, India have started Higher Education Partnership Project. This scheme involves partnership between Indian and UK universities and industry. In this scheme University of Kota has been awarded a project entitled “Enhancing teaching and research and development in Solar Energy Materials and Technologies through Capacity Building and Collaborative Research Projects” for its M.Tech. (Solar Energy) course. During this project instead of taking one major research problem, it was decided to carry out several minor research projects with involvement of students. This helped the students in gaining the skills. Solar based systems have been designed and developed through use of mainly locally available materials. The systems have been tested on-field for their performance and their economic analysis has been done. The systems have been developed after analysing the requirement of the lower and middle income households and cottage industries of developing countries like India, which face the problem of availability of fuel in adequate amount and pollution due to solid fuel use. The system designed and tested are- solar cookers, solar distillation stills, solar dryer, solar PV cooler, solar PV induction cooker and solar water heater. The research projects aim at providing a solution to some regional/community level problem through use of solar energy. This promotes innovation, entrepreneurship and spin-out companies.

Fig. 6: Developed small size solar water heater for cottage textile industry of Kota

Fig.7: Solar dryer developed by students

Fig. 8: Design development and study of solar distillation stills with different absorber coatings

Fig. 9 Developed large size solar cooker/solar hot case

Fig. 10: Design, development and study of solar PV air cooler

Fig. 11: Developed solar PV induction cooker

4. Solar awareness and skill development

The Government of India has set a target of renewable energy capacity of 175 GW by 2022. 100 GW of this is planned through solar energy, 60 GW through wind energy, 10 GW through small hydro power, and 5 GW through biomass-based power projects. Out of the 100 GW target for solar, 40 GW is expected to be achieved through decentralized rooftop projects, 40 GW through utility-scale solar plants and 20 GW through ultra-mega solar parks. For achieving this target it is necessary to address the availability of skilled manpower and capacity building.

In 2015Government of India announced the National Policy for Skill Development and Entrepreneurship. It envisages a major role of private sector as shared responsibility for skill development in the country. The Ministry of Skill Development and Entrepreneurship has been creating Skill Councils in various domains. The initial funding for the Sector Skill Council is by the government through National Skill Development Corporation (NSDC) with 10% contribution from the industry. It becomes a self-sustainable body over a period of 3-5 years. Skill Council for Green Jobs (SCGJ) has been created in 2015, promoted by the Ministry of New and Renewable Energy (MNRE) and Confederation of Indian Industry (CII). In a report by SCGJ the skill gap is assessed as around 0.4 million for solar engineering, procurement and construction, 0.2 million for solar operation and maintenance, 36 thousand for solar off-grid and 16 thousand for solar thermal applications. SCGJ is offering various courses related to solar PV installations such as solar PV installer (Suryamitra), solar PV installer (Electrical), solar PV installer (Civil), solar PV rooftop entrepreneur, solar proposal evaluation specialist and rooftop solar grid engineer etc. for reducing the skill gap (SCGJ reports, 2016)

Apart from government initiatives, many not for profit organizations are also working for solar awareness and skill development such as Barefoot College. Barefoot college is exemplary as it involves women from rural areas, train them in solar technologies and empower them. They have trained more than 750 engineers in more than 1300 villages worldwide and have provided light 0.5 million people with light. Some companies are using their corporate social responsibility fund to disseminate solar systems which is also promoting solar awareness. Academic institutions and departments of science and technology hold workshops, exhibitions and competitions for spreading the knowledge.

5. Challenges and suggestions

Solar education and skill development are important for sustaining the deployment of solar systems deep into the regions waiting for access to clean energy. The various schemes and projects die out if proper measures are not taken. It is important the training should focus on both the technical aspects as well as engaging community, explaining and managing finances, knowledge of policies and project implementation. There can be several challenges in the way of solar education and skill development, overcoming those require following steps

- Understanding local needs
- Engaging communities and women
- Maintenance of quality of training programs
- Development of specialized solar courses
- Research and development as per local problems
- Involving industries as partner with academic institutions to enhance skills
- More hands-on training
- Monitoring and assessing the skills
- Support for entrepreneurship
- Reducing bureaucracy and corruption in implementation of skill development schemes
- Motivating rural communities to be self-reliant
- Sustained effort by government, academic institutes, industries and society.

Terrapon-Pfaff (2014), Dóci (2015) and Bossink (2017) have stressed on continuous evaluation and learning to develop sustainable prototypes as per need and engagement of the community and following chain of up scaling and making it commercial with industry. So, solar education and skill development will be a continuous process involving evaluation and improvements.

6. Conclusions

Solar energy holds the potential to improve the quality of life of people in developing countries. Solar energy education and skill development are important for promoting the solar energy technologies to the communities without access to clean energy in developing countries. Solar energy education can easily form a part of school curriculum with simple theory explaining scientific principles involved and simple low cost experiments for practical understanding. In higher education, advanced and in-depth study of solar energy will help students get equipped with designing, improving and innovating new solar systems as per the need of local communities. Skill development initiatives can form a part of government's action plan, and industries and academic institutes can play a significant role in it. With these measures, it will be important to monitor, evaluate and assess the quality and need of programs. Further, involvement of local communities is essential for sustainability of the projects.

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