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Power Generation Potential and Cost of a Roof Top Solar PV System in Kathmandu, Nepal

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Abstract

The paper presents a comparative study of the 3 most used solar PV module technologies in Nepal, which are Si-mono-crystalline, Si-poly-crystalline and Si-amorphous. The aim of the paper is to present and discuss the recorded Global Solar Radiation, received in the Kathmandu valley by three different, Si-mono-crystalline, Si-poly-crystalline and Si-amorphous calibrated solar cell pyranometers and to propose the best-suited solar PV module technology for roof top solar PV systems inside the Kathmandu valley. Data recorded over the course of seven months, thus covering most of the seasonal meteorological conditions determining Kathmandu valley's global solar radiation reception are presented. The results indicate that the Si-amorphous pyranometer captured 1.56% more global solar radiation than the Si-mono-crystalline and 18.4% more than Si-poly-crystalline pyranometer over the course of seven months. Among the three pyranometer technologies the maximum and minimum cell temperature was measured by the Si-mono-crystalline pyranometer. Following the technical data and discussion, an economical analysis, using the versatile software tool PVSYST V5.01is used to calculate the life cycle costs of a 1kW roof top solar PV RAPS system, with battery storage, and a 1kW roof top solar PV grid connected system with no energy storage facility, through simulations, using average recorded global solar radiation data for the KTM valley and investigated market values for each solar PV module and peripheral equipment costs.

Keywords: Solar PV module, Global solar radiation, Pyranometers, Unit cost, Life cycle, RAPS system, Grid connected

1. INTRODUCTION

It is well known that access to improved energy services is one of the key factors for sustainable development. The more urbanized areas around the globe, and till recent years as well in Kathmandu Nepal, have taken it for granted that they have access to electricity around the clock, without really considering what and when they plug in their equipment. But the recent 20 hours/day load-shedding during the dry season (e.g. in February 2009) and 1-2 hour load-shedding during the rainy season has forced us to learn the hard way the actual value of having readily access to electricity. It's not that Nepal has not the needed natural and renewable resources. In contrary, Nepal is blessed with one of the most abundant renewable water resource to generate electricity. The average annual discharge of the over 6000 rivers with about 225 billion cubic meters, flowing from the high altitude Nepal Himalayas down to India, losing an average height of around 4000 meters within a north-south distance of just 100-200 km, create an economical feasible power generation potential of around 42000 MW[2].

Apart the huge potential of hydropower, Nepal has localized wind resources, geothermal resources, biomass and receives abundant solar power, equally distributed all over the country. Undoubtedly, hydro power plants are the most applicable, long-term source to fulfill Nepal's growing load demand, be it as RAPS systems, medium or large scale power plants. But there are some particular issues with the building and maintaining of medium and large scale hydro power plants which are important, especially within such a fragile and unique ecosystem and environment as in Nepal, and thus have to be taken in due time into consideration. Some of these issues are:
The utilization of hydropower is very site specific and thus needs detailed feasibility studies, including studies of the impact to the local communities' social, cultural and economic context, alongside detailed EIAs (Environmental Impact Assessment) studies of the unique, fragile and often still pristine environment.
In most cases the needed energy services are geographically different from where the hydro resources are, demanding long, expensive to build and maintain access roads and transmissions lines.

Hydro power plants are long-term projects and take years to be built. This has to be considered throughout the planning and execution. Thus, long-term, realistic energy planning is needed at the government level, as no sudden energy gap can be met with medium and large scale hydro power plants.
Hydro power plants, especially built in remote, high altitude areas, pose significant changes to the aquatic system of a river and its surrounding ecosystem. Nepal's different climatic zones, with each zone's own unique and pristine flora and fauna, are sustained and kept alive by the streams. Thus, any significant changes to the flow and landscape pose unpredictable

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long-term stresses and changes to the river's downstream ecosystem.

The building of hydropower plants is very cost intensive. This is in particular the case for Nepal, with its rouged and remote areas, geological instable rocks and mountain layers[1]. Thus not just the buildings of the power plant, but as well the transmission and maintenance costs are immense.
Nepal's fragile and unique environment present new and very challenging engineering problems, which can mostly not be tackled with standard engineering solutions.

In the context of Nepal, with its remote areas and steep valleys, hydro power plants with storage dams would most of the time demand considerable resettlements of the local, indigenous people groups. It is well known that this poses always unforeseen social and cultural problems.

The building and operating of large scale hydro power plants in remote areas in Nepal poses great challenges in regard to the protection and maintaining of the wildlife. Access roads, often changing the local landscape significantly, raise significant environmental as well as social issues. They are not taken as serious as they should be due to the lack of needed policies (such as environmental protection, proper EIA, re-forestation and minimal laborer policies), sound planning and engineering, alongside the needed infrastructures.

While hydro power is and will continue to be Nepal's main energy generation resource, the utilization and conversion of the abundant, at the place of the needed energy, available solar energy through solar photovoltaic arrays, poses often underestimated good opportunities. Solar PV power plants can be installed in almost any specific site, thus generate power wherever required. With today's available different solar PV technologies it is suitable for most of the geographical and climatic locations. The building of a solar power plant can take place within a time frame of weeks or months rather than years, and thus a potential forthcoming short term energy demand growth can be taken into consideration.

Due to the solar PV technology's nature there is a clear boundary to each solar PV project, making it save for the local communities and environment, with no impact beyond its geographical project location. Thus solar PV arrays or power plants pose no grave danger to the ecosystem up- or down-stream.

Being a "motionless" technology, once built and in operation, a solar PV system demands only minimal operational and maintenance effort, which can be easily carried out by locally trained people. Being locally built, operated and maintained, with the power locally consumed, solar PV systems are also often owned by the local community. That creates a strong ownership, an important social parameter for a long-term sustainable project.

No applied technology has only positive points, thus also solar PV systems do have their shortcomings and inherent limitations which need to be known and taken into consideration for any project. The main shortcomings and limitations are:
Solar energy is an intermittent energy resource, thus demanding some kind of energy storage (usually lead acid batteries) if power is needed during the no-sunshine periods.

Solar energy, compared to the non-renewable, fossil energy resources, is a low energy density resource, with a maximum of around 1,000 watt/m^2 incoming global solar radiation at a good, sunny day. This inherently demands much bigger plant sizes for bigger power demands.

Presently, the solar PV technology is still an expensive technology, considering the conversion, or the kWh unit life cycle cost.

For most of the present available solar PV technologies, excessively high ambient temperatures and high air pollution affects the power production.
The present power shortage in Nepal under which, in particular the more urbanized areas suffer is not a short term problem. Rather it is a long-term problem we have become the victims of, due to wrong and inadequate decisions taken by the government 10-15 years ago regarding the urgent needed expansion and building of new hydro power plants. Further, the narrow focus, to concentrate all effort on the exploitation of a single energy resource, is also inadequate and needs to be revised, so that all local available renewable energy resources can be tapped in, to enhance and improve the access to electricity. `

In order to work towards this change, this paper addresses the important issue of understanding the different power and energy production possibilities of the three major, in Nepal available, solar PV

[1] Nepal is "sandwiched" between two major tectonic plates, the Eurasian Plate to the north and the Indian Plate to the south. Three major thrust faults from East to the West have been identified within Nepal's short North-South distance of 100-200 km. The Tectonic Plates, being in constant motion towards each other, cause an under thrusting of the Indian lithosphere beneath the higher elevated Himalayas and Tibet lithosphere, the Eurasian Plate. It is estimated that up to half of the continuing convergence between India and Eurasia is absorbed by under thrusting of the Indian lithosphere, beneath the Himalayas and Tibet, at a rate of an estimated 50mm per year towards the North. Antoine (2004) states that vertical displacement rates, expressed with reference to the Gangetic plain, indicate current uplift of the high Himalayas at 6mm per year. Three of the big Nepalese earthquakes (in 1905, 1934 and 1950, with magnitudes around 8 on the Richter Scale), were caused by a sudden under thrusting of the Indian Plate beneath the Eurasian Plate and the resulting, abrupt release of, gigantic amounts of energy. Most of the earthquakes occur where some of the biggest urban and rural settlements are located. Thus Nepal, and most of its population, is under a permanent threat and fear of earthquakes, which are therefore also of permanent danger to medium and big scale hydro power plants.

technologies, which are Si-mono-crystalline, Si-poly-crystalline and Si-amorphous.

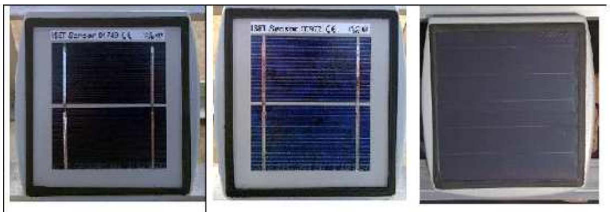
In order to find out the best solar PV module technology with regard to the highest annual energy generation for the Kathmandu valley's meteorological conditions over the year, RIDS-Nepal and the Kathmandu University have started the long-term research project, measuring of the received global solar radiation on each of the three main solar PV technologies. In the main RIDS-Nepal offices in Imadol, Kathmandu, three different types of Pyranometers, one Si-mono-crystalline, one Si-poly-crystalline and one Si-amorphous have been installed in November 2008. Under the same ambient conditions these three different calibrated solar PV cell pyranometers will measure the actual captured global solar radiation, thus providing first hand field data and results to identify the most efficient and highest energy producing solar PV technology for the Kathmandu valley's context.

2. METHODOLOGY

2.1 Research Station

The geographical location of the RIDS-Nepal office at Kathmandu (the research station) is:

Latitude: 27°40'04.70" North
Longitude: 85°20'31.55" East
Altitude: 1,350 meters above sea level



ISET Si-mono-crystalline Solar Radiation Sensor: Model Serial No.: 01749 Calibration Value: 92.8mV (1,000W/m², @ 25°C) Temp. Coefficient I_{sc} = +(0.060 ±0.015) %/°C, >25°C	ISET Si-poly-crystalline Solar Radiation Sensor: Model Serial No.: A0043 Calibration Value: 108.2mV (1,000W/m², @ 25°C) Temp. Coefficient I_{sc} = +0.008 %/°C, >25°C	ISET Si-amorphous Solar Radiation Sensor: Model Serial No.: 00972 Calibration Value: 106.5mV (1,000W/m², @ 25°C) Temp. Coefficient I_{sc} = +0.045%/°C, >25°C

Figure 1. The three different pyranometer used to intercept the global solar radiation.

Three pyranometers, a Si-mono-crystalline, Si-poly-crystalline, and Si-amorphous are installed on the roof of the research station, each accompanied by a thermocouple (PT1000) sensor. The calibrated pyranometers measure the global solar radiation and the thermocouple sensors measure the cell temperature.

These solar radiation sensors contain PT1000 temperature sensors. The PT1000 is a temperature sensor which has 1,000Ω resistance at 0°C and increases by 3.85Ω per 1°C rise >0°C

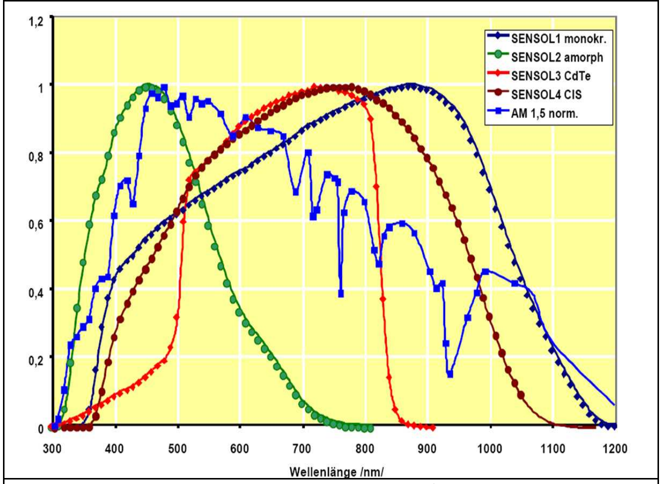


Figure 2: Wave length spectrum sensibility of the ISET pyranometer used in the global solar irradiation measurements. Dark Blue: SENSOL1 Si-mono-crystalline and Si-poly-crystalline; Green: Si-amorphous; Marine Blue: Light wave spectrum of light with an Air Mass of 1.5, or light going through the atmospheric air mass and reaching our ground equaling at about an angle of 46°). The visible wave spectrum is between 380 – 780 nm.

2.2 Data Taker DT80 (Data logger) [3]

The data Taker DT80 is a smart data logger, which provides an extensive array of features that allow it to be used for a wide variety of applications. The DT80 is a robust; stand alone, low power data logger with an inbuilt memory for long-term data storage, a USB support to download data in a remote station without access to a PC or the Internet, 18-bit resolution, extensive communications capabilities and a display. The DT80's Dual Channel concept allows up to 10 isolated or 15 common referenced analog inputs to be used in many combinations.

The three different ISET solar radiation pyranometers are connected to the Data Taker DT80 via 20 pairs connecting cable (each wire of Ø0.4mm). Figure 3 shows the schematic diagram of the experimental setup.

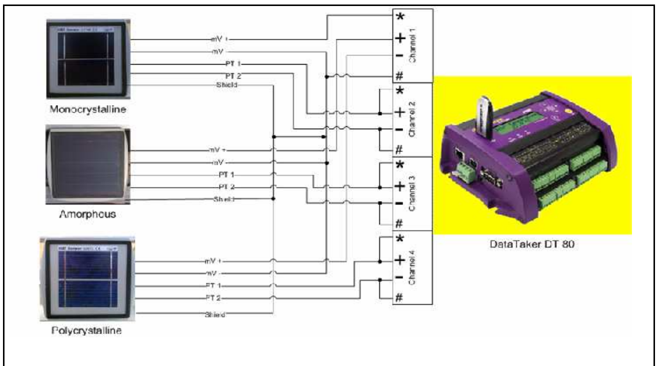


Figure 3: Experimental set up of measuring and recording each Pyranometers' data

Three different pyranometers are connected to the data taker DT80 as shown in Figure 3 so as to record the global solar radiation by three different pyranometers. Along with this, we connect the thermal sensors PT1000 in order to record the cell temperature of each pyranometer which is indicated by PT1 and PT2 as shown in above Figure 3 in each pyranometer.

2.3 Solar Path Diagram

The Solar path diagram indicates the position of the sun relative to the position of the pyranometers. In Figure 4 the annual solar path diagram, in rectangular coordinates for the RIDS-Nepal office research site in Imadol, Kathmandu is provided.

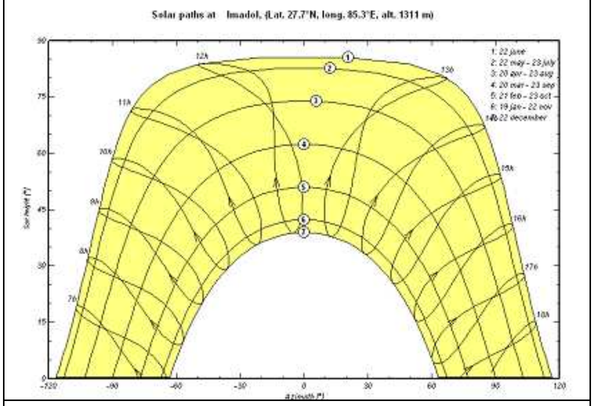


Figure 4. Solar path diagram of the research station (RIDS-Nepal office) in Rectangular coordinates

2.4 Results

Since November 2008 the three different pyranometers are installed and record data. Though some initial technical and software problems prevented us thus far to have a full year's data, in the following some of the available months' data and graphs for the global solar radiation intercepted by the three different pyranometers are presented. In order to cover the main seasonal variations, graphs for three different months, April, June and September 2009, representative for three of the four different seasons in the Kathmandu valley, are presented. Each month's average global solar radiation is calculated and is presented along with the graph of the respective month.

Further, the average of the total global solar radiation for the seven months data is calculated and presented as graphs. Averaged pyranometer temperatures for each pyranometer technology, along with their maximum and minimum values are presented in a table.

Analyzing the average global solar radiation intercepted, and the working temperatures of each of the three different pyranometers, results in the recommendation of the best solar photovoltaic module technology for the Kathmandu valley in regard to generating the maximum energy over the course of the year under the same meteorological conditions.

The average values recorded by three different pyranometer for the month of April are:

Si-mono-crystalline records 5.297kWh/m^2 per day
Si-poly-crystalline records 4.692kWh/m^2 per day
Si-amorphous records 5.209kWh/m^2 per day

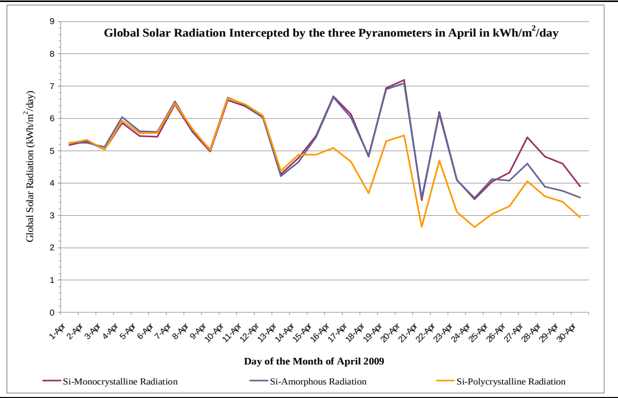


Figure 5: Global solar radiation, measured with the three different pyranometers, for April 2009

The global solar radiation intercepted during April 2009 by the Si-amorphous and Si-mono-crystalline pyranometer is greater than that intercepted by the Si-poly-crystalline pyranometer. Thus we can conclude that energy production level of Si-amorphous and Si-mono-crystalline Photo Voltaic (PV) panels will be measurable higher than that of Si-poly-crystalline panels under the same meteorological and environmental conditions during the more clear sky spring season in the Kathmandu valley.

There is no considerable difference in average temperature recorded by the pyranometers. Thus, there is a negligible loss difference in the energy generated caused by increased temperature among the three different solar PV panel technologies tested under the same meteorological and environmental conditions.

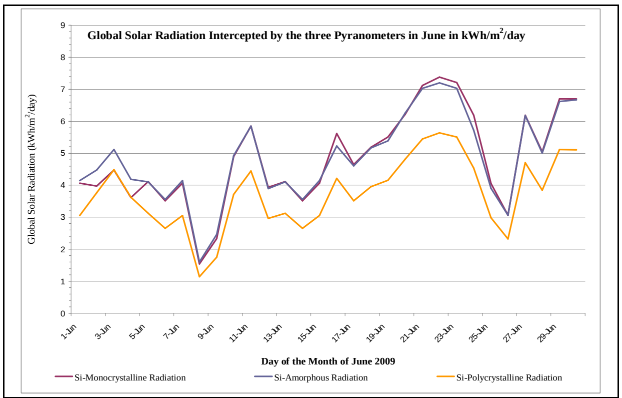


Figure 6: Global solar radiation, measured with the three different pyranometers, for June 2009

The average values recorded by the three different pyranometers for the month of June are:

Si-mono-crystalline records 4.827kWh/m^2 per day
Si-poly-crystalline records 3.747kWh/m^2 per day
Si-amorphous records 4.840kWh/m^2 per day

The global solar radiation intercepted during June 2009 by the Si-amorphous and Si-mono-crystalline pyranometer is again greater than that intercepted by the Si-poly-crystalline pyranometer. Thus we can conclude that energy production level of Si-amorphous and Si-mono-crystalline PV panels will be again measurable higher than that of the Si-poly-crystalline panels under the same meteorological and environmental conditions during the more clouded sky late spring and early rainy season in the Kathmandu valley.

There is no considerable difference in average temperature recorded by the pyranometers. Thus, there is a negligible loss difference in the energy generated caused by increased temperature among the three different solar PV panel technologies tested under the same meteorological and environmental conditions.

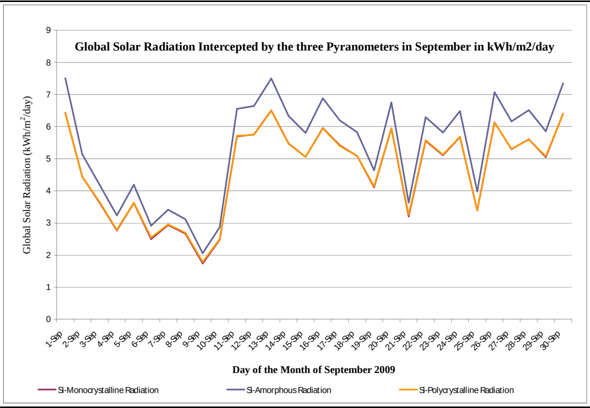


Figure 7: Global solar radiation, measured with the three different pyranometers, for September 2009

The average values recorded by three different pyranometer for the month of July are:

Si-mono-crystalline records 5.432kWh/m^2 per day
Si-poly-crystalline records 4.458kWh/m^2 per day
Si-amorphous records 5.575kWh/m^2 per day

The global solar radiation intercepted during September 2009 by the Si-amorphous and Si-mono-crystalline pyranometer is again greater than that intercepted by the Si-poly-crystalline pyranometer. Thus we can conclude that energy production level for the Si-amorphous and Si-mono-crystalline PV panels will be measurable higher than that of the Si-poly-crystalline panels under the same meteorological and environmental conditions during the late monsoon and early autumn, more clear sky, conditions.

There is no considerable difference in average temperature recorded by the pyranometers. Thus, there is a negligible loss difference in the energy generated caused by increased temperature among the three different solar PV panel technologies tested under the same meteorological and environmental conditions.

In all three months presented, the intercepted global solar radiation values show very little differences between the Si-amorphous and the Si-mono-crystalline pyranometers, but clear lower values for the Si-poly-crystalline pyranometer. That results in measureable higher energy produced by the Si-amorphous and the Si-mono-crystalline PV panels compared to the Si-poly-crystalline pyranometer under the same meteorological and environmental conditions, during all three different seasons present in the Kathmandu valley.

The following graph (Figure 8) shows the averaged hourly daily global solar radiation values intercepted by the three different pyranometers in W/m^2 over the course of seven months thus covering three of the four seasons prevailing in the Kathmandu valley. Additionally, the pyranometers averaged hourly daily cell temperatures are as well presented.

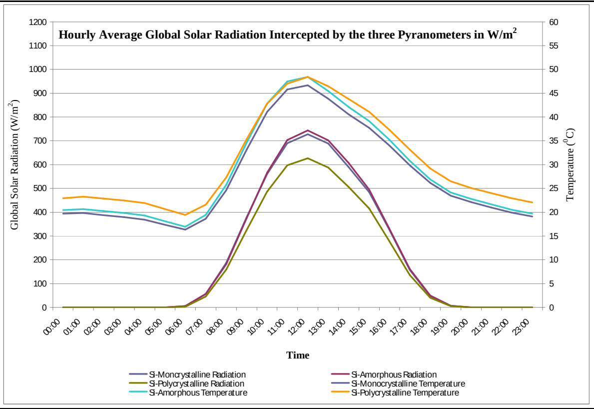


Figure 8: Hourly averaged global solar radiation and cell temperature of 3 different pyranometers

The above graphs show that the average global solar radiation captured by the Si-amorphous pyranometer is 4.987kWh/m^2 per day. This is +1.57% higher than the Si-mono-crystalline pyranometer (4.910kWh/m^2 per day) and +18.4% higher than the Si-poly-crystalline pyranometers (4.212kWh/m^2 per day) recorded.

Thus, we know that among the three different pyranometers analyzed under the same meteorological conditions, the Si-amorphous pyranometer recorded the highest average global solar radiation values. But not significant different are the values recorded by the Si-mono-crystalline pyranometer. But, the values recorded for the Si-poly-crystalline pyranometer are considerably lower in comparison to the other two pyranometers. In contrast, the averaged temperature graphs for each of the pyranometers' cell do not show considerable differences. However, the Si-amorphous and the Si-poly-crystalline measured values are both slightly higher than the Si-mono-crystalline pyranometer cell. Comparing the minimum cell temperature attained by the pyranometers, we find that the Si-mono-crystalline pyranometer attained the lowest temperature value whereas the Si-poly-crystalline and the Si-amorphous attained the highest minimum cell temperature values of 48.4°C (Table 1).

Table 1 presents a summary of the main data recorded.

Pyranometer type	Hourly average global solar radiation (kWh/m²/day)	Minimum cell temperature (°C)	Maximum cell temperature (°C)
Si-mono-crystalline	4.910	16.3	46.6
Si-poly-crystalline	4.212	19.5	48.4
Si-amorphous	4.987	17.0	48.4

The PT1000 temperature sensors measure the pyranometer cell temperature of each pyranometer under the same meteorological conditions. Thus, they are directly comparable with each other. The resulting data show that there is no considerable difference in temperature attained by three different pyranometers. The minimum cell temperature is attained by the Si-mono-crystalline pyranometer whereas the maximum cell temperature is attained by both the Si-amorphous and Si-poly-crystalline pyranometers.

The data reveals that there is no significant difference in the different pyranometers' cell temperatures causing significant, measurable differences in generated energy due to increase losses caused by high temperatures under the same meteorological and environmental conditions.

All three different pyranometers recorded the global solar radiation over the course of seven months under the same environmental and meteorological conditions. Thus they can be directly compared with each other. The resulting data show that there are measurable differences between the various solar PV technologies used under the same conditions. The data shows that it is important, especially for small solar PV systems for rural and remote places, to choose the most efficient solar PV technology for a defined context. Thus, based on the recorded data for the Kathmandu valley, the Si-amorphous PV module would generate the highest overall annual energy yield, closely followed by the Si-mono-crystalline, though with a still clear higher annual yield predicted energy yield than the Si-poly-crystalline PV module.

Beside the need to know which solar PV technology promises the highest energy yield for a defined context, the economical analysis, defining the unit (kWh) cost of the solar PV module generated over its life cycle, is another important key factor to consider before the final decision for a defined solar PV technology can be made for a known context. The following chapter, with various cost analysis, considering all necessary parameters to simulate the life cycle costs for solar PV system with Si-mono-crystalline PV modules, will provide some indicative answers.

3. ECONOMICAL ANALYSIS [4]

The economical life cycle analysis is carried out with the software PVSYST V5.01 for a 1kW solar PV stand alone system, with a battery bank and a grid-connected PV system with no battery bank back-up. The simulation is performed only with the Si-mono-crystalline solar PV technology.

The payback period of the PV system is one of the very important factors; thus the definition and policies for the feed-in tariff are of crucial significance. As of today, Nepal does not have yet any government approved and defined values for the feed-in tariff for the energy produced from solar PV grid-connected power plant.

We analyzed a stand alone system with three different daily user loads. They are:

- Case 1 : 3.2 kWh per day (system with least loss of load),
- Case 2 : 4 kWh per day (optimized system) and
- Case 3 : 5 kWh per day (most economical system),

All the systems have the same initial investment of NRs. 6'75'740 and running cost of NRs. 18'059 per year with 3 days of autonomy.

Case 1

A load of 5 kWh per day is the upper limit for a 1 kW system, and thus results in the lowest energy cost of NRs. 45.8 per kWh. The unused energy (considered as loss) of the system's total energy produced (1399 kWh per year) is only 0.4 %, or 7.1 kWh per year. As this system is designed for a minimum unit cost it has a high, average loss of load (LoL) fraction of 26.3% over the year, with maximum LoL values of 50% during the rainy season. This will be for many cases unacceptable. On a positive note, this system has a high annual performance ratio (PR) factor of 69% as almost all the energy generated is consumed.

Case 2

For a user's load of 3.2 kWh per day, the unit energy cost is NRs. 54.6 per kWh. This is due to the higher fraction of unused energy of 21.4%, or 404 kWh per year. But this system has a much lower average LoL factor of 4.7%, providing the user 95.3% of time reliable energy throughout the year, including 80.7% availability during the worst season. This high availability comes of course at a cost, which means that the average PR value of 57.9 % is significant lower.

Case 3

For a user's load of 4.0 kWh per day, the unit energy cost is NRs. 47.2 per unit. The unused energy loss for this system is 6.9%, or 130 kWh per year. The averaged LoL factor is 11.5%, with up to 34.5% for the worst season during the summer months of the monsoon. That means that on an average this system provides 88.4% of time throughout the year the demanded loads. The PR value of 67.0% makes this system an optimized system among the 3 systems simulated.

Besides the above results, the analysis also show that the losses in regard to non-maximum power point (MPP) energy generating conditions increase slightly with respect to the higher user loads. However, the unit cost of energy varies with the defined users' daily needs thus creating the different performance ratio, the energy losses, as well as the different life time expectancies (and thus costs) of the battery bank.

With regard to the 1kW grid-connected solar PV system, the simulations brought forth the following results. Considering the different types of losses occurring during the energy generation, the 1kW grid-connected plant produces around 1,487kWh per year. The total initial investment for the 1kW grid-connected system is NRs. 6'01'160; resulting in NRs. 27.3 per kWh. Assuming a feed-in tariff (FIT) of NRs. 30 per kWh (nearly equal to the cost of energy production), the pay back period for the system is 13.47 years.

If the FIT is NRs. 50 per kWh, the pay back period for the system will be 8.08 years. However, in the absence of a defined FIT and thus a feed-in unit energy cost paid equal to the 2009 cost charged by NEA of NRs. 10 per kWh, the payback period is very long, 41.42 years and thus unrealistic. This shows clearly how important it is that a long-term government approved and promoted FIT exists under which independent solar PV system owners can generate energy and feed it into the grid.

From the two main different analyses for a RAPS and a grid-connected system we clearly see, that there is a significant difference in unit cost. The energy unit produced by the RAPS system is very high (NRs. 45.8 – 54.6 per kWh) in comparison to the energy unit produced by the grid-connected system with NRs. 27.3 per kWh. It has to be mentioned, that the economical analysis were carried with only 2.5% of interest on loan and without including any subsidies. Hence if subsidies are available and considered, significant differences in the overall lower unit costs can be expected.

4. CONCLUSIONS & RECOMMENDATIONS

The paper analyzes the global solar radiation measured with three different pyranometer technologies (including each one's temperature values) at the RIDS-Nepal office in Imadol, Kathmandu. Based in these results, the overall best performing solar PV technology, with regard to the highest annual energy generation, was identified for a roof top PV system installation in the Kathmandu valley. Among the three pyranometers analyzed, the Si-amorphous and the Si-mono-crystalline recorded higher, and within their accuracy range considered to be about equal, intercepted global solar radiation values in comparison to the Si-poly-crystalline pyranometer. Thus for the Kathmandu valley's seasonal and annual meteorological conditions, considering the used equipments' data measuring accuracies, it is reasonable to conclude that Si-mono-crystalline and the Si-amorphous solar PV modules perform both equally good and measurable (within the instrumentations' accuracy range) better than Si-poly-crystalline solar PV modules on an annual energy yield basis.

Therefore, we recommend using either Si-amorphous solar PV modules or Si-mono-crystalline solar PV modules within the Kathmandu valley for both, RAPS systems with a battery bank back-up and for grid-connected systems.

Further, we recommend that Si-amorphous solar PV modules are considered due to there lower purchase cost per rated watt, if the roof top surface is big enough to accommodate the more space needed system, as Si-amorphous solar PV modules are roughly half as efficient in converting the intercepted global solar radiation into direct current electricity compared to Si-mono-crystalline, or Si-poly-crystalline PV modules. If the needed roof top space is not available we recommend that the Si-mono-crystalline PV modules provide the most appropriate solution.

With regard to higher altitude areas and the use of solar PV systems, we recommend that Si-mono-crystalline modules are used as they have on an average about a twice as high negative temperature increased power generation loss coefficient compare to the Si-amorphous PV modules. That means that if the PV modules run in cold areas, below the defined STC conditions of 25°C, the Si-mono-crystalline modules generate proportionally more power than the Si-amorphous PV modules. Further, as the Si-mono-crystalline are today still about twice as efficient compared to the Si-amorphous PV modules, they are smaller and thus lighter and thus easier and less costly to be transported (often by air, and porters, as there are no drivable roads) to the remote mountain regions.

The economical analysis showed that we have various options to provide to an end user. There is the most economic solution in regard to the lowest energy unit cost, able to provide the highest daily average load demand though with strings attached in regard to significant higher and longer times of not being able to meet the expected load demands, especially during the rainy season. Thus this system can be promoted to users who want the maximum daily average load, and do not mind, or can accommodate their load demand, if they have increased and more frequently no power available during the monsoon time.

The second simulation option provides the highest average availability of electricity at any given time of the year. That comes at a significant higher energy unit cost, as the solar PV system needs to be oversized with regard to the daily load demand. But this system is the one to be promoted to users who put great emphasis of readily and sustainable electricity availability throughout the year with a minimum of LoL at any time of the year, and for that they are willing to pay for a noteworthy increased unit cost.

Third, there is the solar PV system which presents the averaged solution of both the above identified and described systems. It provides reasonable and acceptable availability of electricity for the average consumer, willing to have some longer times no access to power during the rainy seasons, but is able for the rest of the year to provide on an average energy to greater/more load demands at lower cost.

These simulations show that the economical analysis provides the users with a great varieties and flexibility for the design and use of a solar PV system. It allows the end user to identify the system needed and thus have the overall most economical conditions for their needs and demands.

The results and analysis of the grid-connected solar PV system clearly shows, that much more intensive investigations and discussions are needed with the government to come up with a long-term FIT policy which enables the users to be motivated to invest into a roof top solar PV system and feeding the generated energy into the grid, in order to provide a realistic solution to the present, and for the next decade ongoing, electricity shortage within the Kathmandu valley.

Some obvious recommendations for policy makers would be the introduction of seasonal tariffs, more flexible policy in order to encourage more independent power producers to feed into the grid, with more strict laws for activities such as misuse, theft or leakage of energy. Above all, to promote the solar PV technology and the use of renewable energy, the government should develop appropriate policies, with realistic long-term subsidies and FIT laws.

This all will help Nepal and its people to have with a rather short time, compared to the building of new big hydro power plants, good solution to the present power shortage. It also inspires the potential new renewable energy producers and helps to raise awareness of Nepal's real richness, its renewable energy resources.

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