Paper 4 and 7 plots –Nepal Streetlights

1. Issues with streetlight data –
   1. Obtaining data from the Victron server and SD card – Data from the streetlight system is transmitted to an online Victron portal and can be downloaded as .csv files. This data has gaps owing to occasional failure in internet connectivity. Data in these instances is stored locally in an SD card. While the information available from the SD card and portal is the same, the format in which data is stored differs. For instance, while the power variables (Battery power, Solar charger battery power, etc) are calculated and, perhaps slightly manipulated/pre-processed, and stored in server file, these values are unavailable in the SD card data. Instead, the battery current and voltage values are recorded that can be used to calculate power (minus the pre-processing that may be done by the system leading to difference in accuracy of the two variables). Moreover, data in SD card and server files is stored in different time zones and must be corrected before it can be merged. Furthermore, the files differ in the number of header rows – while the header in server files spans across 3 rows, the header in SD card files spans across 2 rows and must be adjusted accordingly.
   2. Change in ID associated with the same component – In certain instances, the ID associated with components of the streetlight changes upon restarting the system. For instance, battery monitor data for a given streetlight is stored with ID 258 and 260 in differing parts of the file. As such, the columns with the same variable need to be fetched and merged/overlapped to get complete data. In case of SL6, a system error also caused the same variable with the same ID to be stored in different columns. This is because the variable name was appended with a value owing to system fault, thus, creating several different columns. These had to be identified and merged into one.
   3. Errors in values of Load current – Load current value is used to calculate the light load. The lights are programmed to turn on at 6PM and turn off at 6AM. However, it has been observed that the lights do not strictly come on and off at the above times and there is slight variation in the timings across streetlights as well as months of study. Nonetheless, the lights are on roughly between 6PM-6AM that can be verified using light state value. This implies, that the load current value must be >0 for this period. However, the load current value is found to be 0 for some instances during the night or wee hours in the morning. Moreover, the load current value varies from the pre-defined values for the three states – bright, dim and off. The light is found to be dim on a number of instances with the value of load current varying between 1-3A. Lastly, the values of light load vary greatly as the light changes state changes between charge, discharge and idle. These issues, in turn, affects the battery power value leading to issues with system and socket load calculations.
   4. Errors in values of charge and discharge energy – These values were found to be erroneous and have instead been calculated using Solar Charger Battery Power values.
   5. Errors in PV-DC coupled values post Dec – The PV DC-coupled values are used to calculate the system and socket load. While the same information can be obtained using Solar Charger Battery Power value, the PV DC-coupled values are found to have greater accuracy (perhaps due to pre-processing done by the system). However, these values are erroneous post Dec 2019 and cannot be used for analysis. In these instances, we have resorted to using Solar Charger Battery Power to calculate the system and socket load. Moreover, battery power values are found to have some errors owing to lag in data recorded, especially, when the lights go on or off.
   6. Fluctuations in data after changing the frequency of data collection from 10 mins to 1 min on Dec 18th – given the nature (noisy) of electrical/energy data, the data is found to have lots of the above issues post 18th Dec where the frequency of recording data was reduced from 10 mins to 1 min. The noise in data must be removed through pre-processing prior to performing any analysis.
2. Data pre-processing – Following steps were taken to clean and pre-process the data
   1. Stitching data from SD card and server - stitched all data together from server and SD card files keeping in mind the issues mentioned above. The timestamps were corrected, same variable merged into 1 column, power calculated using voltage and current, and cleaned the data to remove any duplicated instances.
   2. Removed missing or NA values
   3. Calculated system and socket load using both PV DC-coupled and Solar charger battery watts values – while both PV DC coupled power and solar charger battery power contain the same data, we have used the values of PV DC-coupled battery power where possible to calculate the system and socket load owing to higher accuracy. For all other instances, we have used the solar charger battery power.
   4. Removed instances where the system and socket load – this is caused by the errors in load current.
   5. Removed outliers in system and socket data per hour using the 67-95-99 rule – owing to the errors in light load and battery power, we obtained a lot of outliers that interfered with the mean load value for each hour. To remove these values we used the 67-95-99 rule and removed all values beyond 95% limit.
   6. Removed Nov and Dec data for SL6 – The Nov and Dec data for SL6 had a number of outliers leading to erroneous hourly values and was therefore removed from analysis.
   7. Calculating variables – the formulas used are:
      1. Charged energy = ifelse(System Battery power<0, 0, System Battery power)
      2. Discharged energy = ifelse(System Battery power>0, 0, System Battery power)
      3. Light load = ifelse(Solar charged Battery Power<0, Solar Charger Battery Power, 0)
      4. System and socket load
         1. Solar charger Battery power – System battery power **OR**
         2. System PV DC-coupled power – System battery power (when PV DC-coupled values can be used)
      5. Capture loss = Potential PV power – Actual PV power
      6. Total load = abs(Light load) + System and socket load
      7. System loss = Actual PV power – Total load
   8. Calculating hourly data – Once the above values were calculated, we analysed the data for each SL to reduce it to hourly means per variable.
3. Yield – Yield is calculated using the hourly data as the % of total number of hours per day for which the data is available i.e. the number of hours for which data is available as a percentage of 24 hours (which the expected value) per day per streetlight. Yield has been calculated for raw data to show the quality of data obtained from the server as well as SD card as well as for pre-processed data to show the quality of data available for further analysis.
   1. Yield for raw data i.e. prior to the above pre-processing

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Fig. 1a: Yield for raw data for all SL

* 1. Yield for pre-processed data

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Fig. 1b: Yield for pre-processed data for all SL

1. Hourly system and socket load – As mentioned above, the system and socket load is calculated as the difference between System PV-DC coupled power and System Battery power. The PV-DC coupled value however is faulty around mid December for most streetlights (except SL2 for which change occurred in March). The load where PV-DC is unavailable is calculated as the difference between Solar Charger Battery Power and System Battery power. While the values of PV-DC coupled power and Solar Charger Battery Power should be same, PV-DC is more accurate and is used for the quarters where applicable.

Given the poor yield of SL5 and issues with SL7 (the system was damaged in Sep and could not be repaired since), the data for these streetlights is not used for further analysis. The hourly system and socket load for the remaining streetlights is shown below as box plots for all months of study.

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Fig. 2a: System and socket load at Nepal SL1

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Fig 2b: System and socket load at SL2

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Fig. 2c: System and socket load at SL3

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Fig. 2d: System and socket load at SL4

Fig. 2e: System and socket load at Nepal SL5. Only data for Jul and Aug is available

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Fig. 2e: System and socket load at SL6. Note that a few outliers are not shown in this plot that were as high as 40-50W.

Outliers in the box plots often occur when the battery charging state changes (discharging, charging and idle). The system load follows the actual PV power curve, meaning that very small loads at the socket can be difficult to detect. Using the box plots to determine when the sockets are being more commonly used is therefore also difficult. Daily load variations are plotted to shown if there have been any increases in socket consumption since installation.

1. Daily system and socket load – this has been computed for full data days i.e. where hourly values are available for all 24 hours in a day or 100% yield for the day, since commissioning of lights on 1st July. As mentioned earlier, the system and socket load at SL6 is removed for Nov and Dec months. As seen from the plots, the load is constant throughout.

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Fig. 3a: Daily system and socket load at Nepal SL since commissioning on full data days. For SL6, data from Nov and Dec has been removed.

A close up of a map

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Fig. 3b: Daily daytime (7:00 to 16:59) system and socket load at Nepal SL since commissioning on full data days during daytime. For SL6, data from Nov and Dec has been removed.

1. Daily averages for electrical energy values – the below plots show the daily average values for capture loss, socket and system load, light load (absolute value) and system loss. The daily averages are calculated using the full data days in a month. The typical day value for each month is calculated using mean daily value.

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Fig. 4a: Daily average system and socket load, light load, system loss and capture loss at Nepal SL1 for each month since commissioning.

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Fig. 4b: Daily average system and socket load, light load, system loss and capture loss at Nepal SL2 for each month since commissioning.

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Fig. 4c: Daily average system and socket load, light load, system loss and capture loss at Nepal SL3 for each month since commissioning.

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Fig. 4d: Daily average system and socket load, light load, system loss and capture loss at Nepal SL4 for each month since commissioning.

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Fig. 4e: Daily average system and socket load, light load, system loss and capture loss at Nepal SL6 for each month since commissioning.

1. Key performance indictors include production factor, PF, (actual PV yield/potential PV power), performance ratio, PR, (total consumption/potential PV power) and total system efficiency, ηtotal, (total consumption/irradiance on PV array). The total load consumption is a combination of the light, socket and system consumption. Each streetlight is shown along with an average of all streetlights.

Socket consumption was low and relatively constant at all streetlights from July to March. Socket consumption did not have a positive impact on the utilisation and performance of the streetlights in terms of the performance ratio. Changes in the monthly production factor and performance ratio were due to the seasonal variability of the potential PV power. A lower solar availability in the rainy season (July – Sep) meant that a higher proportion of the potential PV power was being used during these months, resulting in a PR and PF of 40-50%. The streetlights were expected to have a PF > 80% during this period, but issues with the LED light driver meant that the lights were dimming too much and too frequently.

The total load does not include the solar charger losses and battery charge/discharge losses (these are referred to as system losses). However, the system and socket load does include small electrical losses and losses at the inverter; the light load also includes some electrical losses and losses due to LED driver inefficiencies. The energy flow diagram for the smart streetlights below shows were these different losses occur in the system.

