Management and Operation of Qatar's Solar Radiation Monitoring Network

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Abstract

Solar resource assessment in Qatar by the Qatar Environment and Energy Research Institute (QEERI) started in late 2012 with the deployment of a complete monitoring station in Doha to measure direct, global, diffuse and longwave (infrared) irradiances. In May 2019, another monitoring station was installed at the site of Qatar's first solar PV plant, and in collaboration with the Qatar Meteorological Department (QMD) a network of 13 high-precision monitoring stations was fully deployed later that year. Thus, QEERI's 15 stations across the country measure direct, global and diffuse radiations with one-minute resolution at all sites, in addition to the meteorological parameters measured by QMD, and some extra measurements (ultraviolet and infrared radiation) at two of the sites. This paper presents a description of the solar stations deployed in Qatar, with the related operation and management processes, covering from data collection to transmission and quality assurance, with an initial overview of the collected data.

Keywords: solar radiation, monitoring network, irradiance measurements, data quality

1. Introduction

At a latitude between 24 and 26 degrees north in the Middle East, Qatar is located in the Sun Belt region of the world, which promises a favourable potential for solar energy production; however, being a desert country with frequent sandstorm events, the local atmospheric conditions have important effects on the quality of available solar resources. Qatar has defined goals for the inclusion of renewable energy sources in its 2030 National Vision, primarily solar energy, with photovoltaic (PV) being the main technology, and Qatar's first large-scale PV plant is already operating since October 2022. Therefore, detailed studies of the solar resources are fundamental in order to not only properly assess Qatar's solar potential, but to support the deployment of solar power technologies both at large and small (including residential) scales.

QEERI, the Qatar Environment and Energy Research Institute, deployed its first complete high-precision solar radiation monitoring station in Education City, Doha, in November 2012 (Perez-Astudillo and Bachour, 2014), while a large network of stations across the country was being designed and developed, and QMD, the Qatar Meteorology Department, had been measuring global horizontal radiation (G) for some years already at several stations across Qatar (Bachour and Perez-Astudillo, 2014a and 2014b). In May 2019, QEERI installed a monitoring station at Al Kharsaah, the site where Qatar's first solar PV plant would be built (construction started near the end of 2020), and in the second half of 2019 QEERI deployed a network of 13 additional stations sharing several sites with QMD. In line with QEERI's vision of supporting the development of clean, renewable energy in Qatar, this network provides critical data for solar energy projects, both small- and large-scale, with some of the initial data already having been used for the planning development of the Al Kharsaah plant, with more projects currently in development.

The following sections describe the distribution of the monitoring stations and an overview of the managing process, from maintenance to data collection, retrieval and quality checking for monitoring the operation, and finally some initial views of data collected from the first years of operation.

2. Stations

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Figure 1 illustrates the locations of the 15 stations (see also Table 1). The top right-side graph in the figure presents the distances between all possible pairs of stations, while the bottom right-side graph shows the distances to the nearest neighbour. The longest distances are in the north-south direction, given the country's geography; note also that Qatar's geography is mostly flat, and the station elevations range between sea level and around 50 m above sea level. This dense monitoring network provides an excellent spatial coverage of the country, with a compact distribution of gap distances (bottom right of Fig.1) between 10 and 35 km.

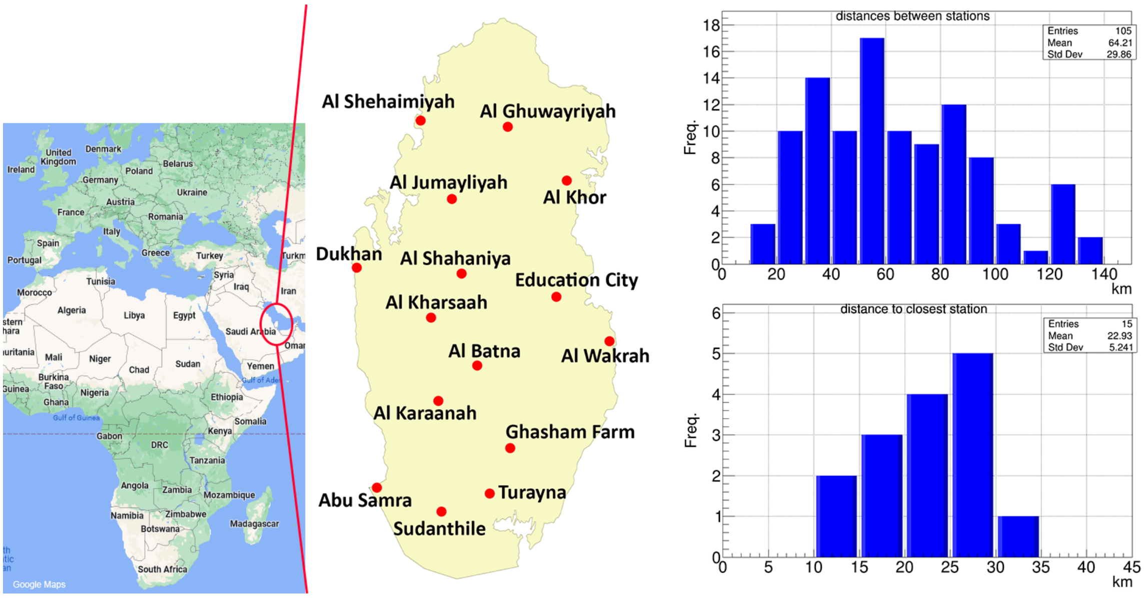

Figure 1: Locations of QEERI's solar radiation monitoring stations in Qatar, and the distributions of distances between them, and of distance to the nearest neighbouring station.

Tab. 1: Locations of the 15 solar radiations monitoring stations.

Site	Lat (deg. N)	Lon (deg. E)	Site	Lat (deg. N)	Lon (deg. E)
Abu Samra	24.75	50.82	Al Shahaniya	25.39	51.11
Al Batna	25.10	51.17	Al Shehaimiyah	25.86	50.96
Al Ghasham	24.85	51.27	Al Wakrah	25.19	51.62
Al Ghuwayriyah	25.84	51.27	Dukhan	25.41	50.76
Al Jumayliyah	25.61	51.08	Education City	25.32	51.42
Al Karaanah	25.01	51.04	Sudanthile	24.63	51.06
Al Kharsaah	25.22	51.00	Turayna	24.74	51.21
Al Khor	25.66	51.46			

At all 15 stations, the three so-called components of broadband solar radiation are measured, namely beam or direct normal (Gb), global horizontal (G) and diffuse horizontal (Gd) irradiances. All stations use ISO 9060:2018 Class A (https://www.iso.org/standard/67464.html) thermopile sensors (two pyranometers and one pyrheliometer) for each component, mounted on a sun tracker with sun sensor and shading ball or disk, and all are powered by solar panels with battery storage, except for the Education City station, which is located at the rooftop of QEERI's building.

Solar radiation measurements are sampled at 1 Hz and saved as one-minute averages in W/m^2 by their on-site data loggers. The stations were deployed, and are managed, in three groups, hereby called “Education City”, “Al Kharsaah”, and “network of 13”. The process of data retrieval is automated for each of these groups as follows:

- Education City (red in Figure 2). The station is on the rooftop of the QEERI building in Doha, and the data logger is connected via a serial cable to a laboratory workstation, with automated data download every 30 minutes.
- Al Kharsaah (green in Figure 2). The logger uses a GSM modem and SIM card to connect to the internet, and a workstation in QEERI’s premises pulls the data every 30 minutes.
- Network of 13 (blue in Figure 2). The loggers also use a GSM modem and SIM card to connect to the internet. In an initial configuration, the loggers sent the data as email attachments to an email account, from which the data were pulled to a local server in QEERI, and then inserted into a database. Recently this has been changed to using a cloud server between loggers and local server, replacing the email method. As Ammonit data loggers are used in this network, the AmmonitOR cloud service (https://www.ammonit.com/en/products/online-services/product-details/ammonit-online-report-ammonitor/) is used, which allows for an easy user-friendly logger configuration, and provides an API for automated data downloads.

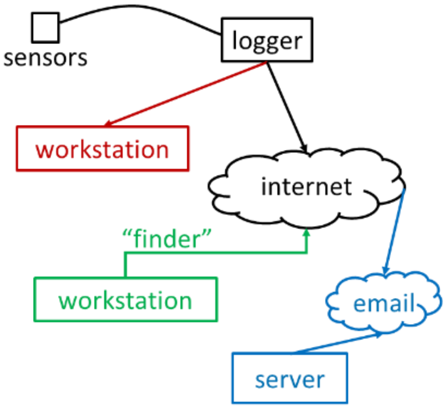

Figure 2: Representation of the data retrieval methods used.

Thus, in the 14 remote (outside Education City) stations, the data logger’s connection to the internet is currently done via Qatar’s mobile telephone providers. This means that data retrieval relies on the availability of the mobile service connection at the scheduled transmission times. Given that most stations are not located inside or next to cities or villages, and in spite of the good mobile coverage across Qatar, the loggers often lose connection and are unable to transmit data with the scheduled frequency. In their current setup, the loggers in the network of 13 stations can display the current strength of the mobile signal as a percentage from 0 to 100%, so a record has been kept of these values since 2020, sampled at each maintenance visit, i.e. twice per week (maintenance is described in the next section). Figure 3 shows the signal strengths observed at each visit and their averages per year for the 13 sites for 2020 and 2021, and from January to May 2022. As a whole, the all-site, all-time average is 69%, with the highest averages in Al Karaanah (100%) and Abu Samra (96%), and the lowest values in Al Shehaimiya (51%), Al Batna (53%) and Al Shahaniya (55%). Note, however, that these values are on-site samples taken by the maintenance team twice a week at best, and high values here do not necessarily imply that good connections are available all the time; due to the ‘manual’ and sporadic nature of the signal observations (which were not coincident with the time of scheduled data transmission) and to high variability of the signal strength (the value frequently had large oscillations during the few seconds in which the technicians made the observations), total uptime was not recorded, and a lower limit on the signal strength needed for successful transmission was not determined (except, naturally, that a signal of 0% results in no connection). Nevertheless, these values provided a general view of the communications conditions and highlighted a need for improvement; indeed, one possible cause of signal losses is that the modems used are 3G-capable only, and Qatar’s operators have moved to 4G and recently to 5G, so 3G coverage is less reliable.

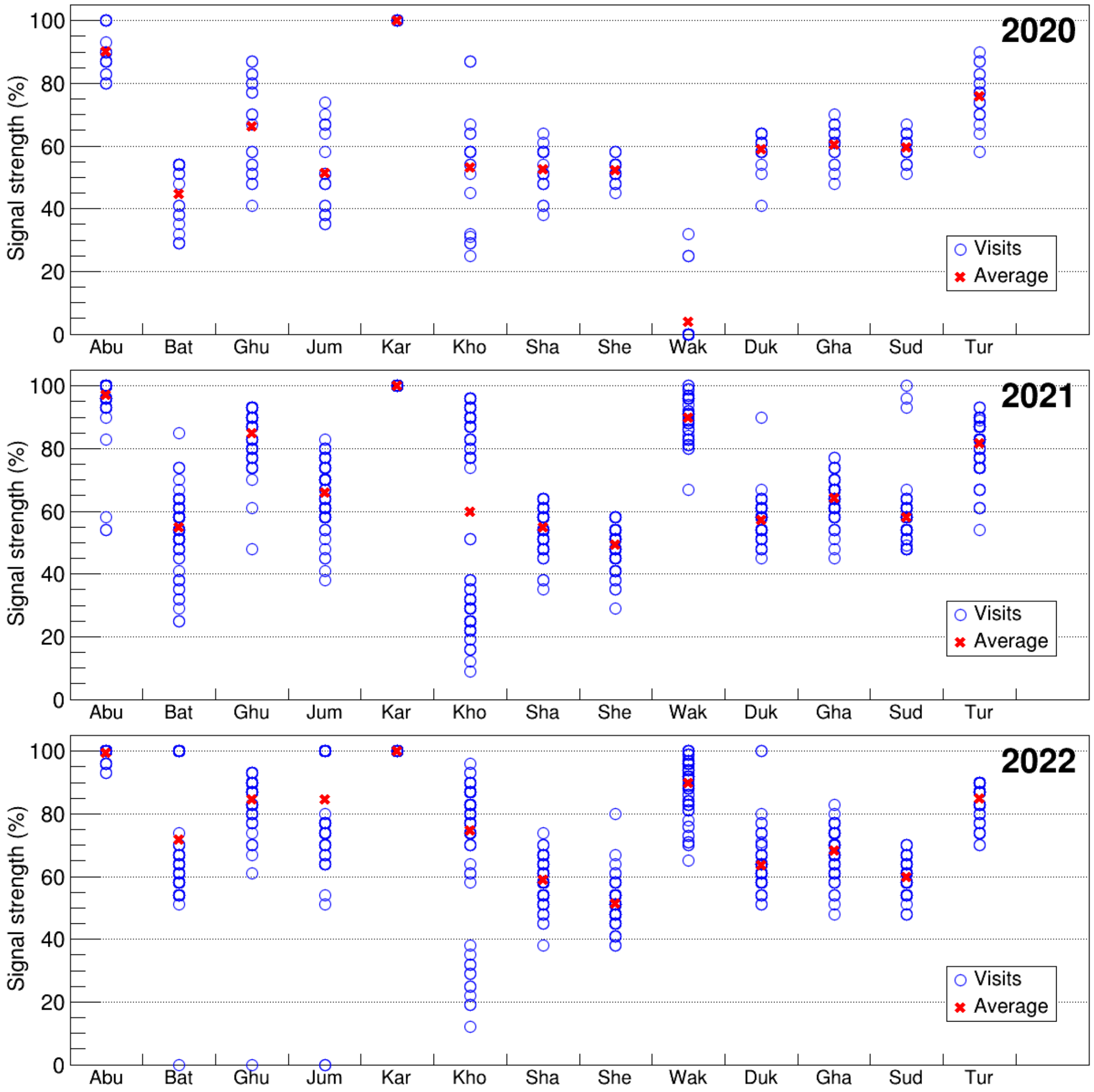

Figure 3: Mobile connection strength observed at each visit (blue circles) and their annual averages (red cross) at the 13 sites, Jan/2020 to May/2022.

3. Operations, data

3.1. Maintenance

A high-precision station, like the ones used here, requires itself close monitoring and frequent preventive maintenance in order to reduce risks and durations of malfunctions and low-quality measurements. Considering distances and nearby locations between the different stations, the schedule of the maintenance for the stations was designed in a way to cover all the 15 sites in three days, resulting in two site visits per week for all sites. Given the desert environment for these stations, the most important activities are the cleaning of sensor domes, windows, bodies (including tracker, cabinets and PV panels, etc.), but also include checks on alignment, levelling, shading and general site conditions.

In the period from 1/Jan/2020 to 31/May/2022, on average the stations were visited for maintenance once every 3.6 days. This average, however, excludes the values from two sites, namely Education City and Abu Samra, during 2020, when due to Covid-19 lock-downs access to these sites was restricted for some periods. Figure 4 shows the annual averages of days between visits for the 15 sites.

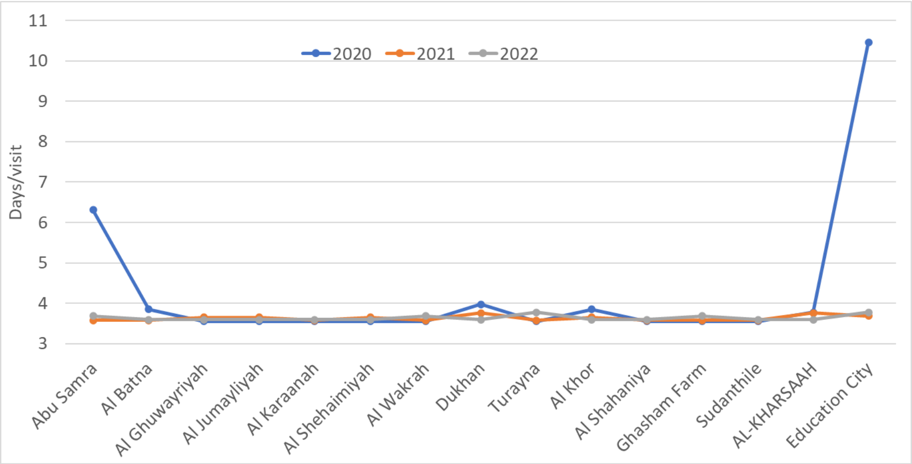

Figure 4: Annual averages of number of days between maintenance visits for all sites, Jan/2020 to May/2022.

Some of the most frequent corrections made by the technicians during these visits include the levelling of pyranometers. Also, at some sites the loggers occasionally report that the modem is unavailable, or that the signal strength is 0%; in these cases, a reboot of the modem generally corrects the issue with the signal strength restored to the usual value at the site. Other issues observed have been faster corrosion on cabinets at the coastal sites and, in a few pyranometers, an expansion and then disappearance of the bubble level, possibly due to an imperfect sealing of the bubble compartment and loss of liquid due to evaporation.

3.2. Data Monitoring

From here on, the rest of this work relates only to the data collected by the network of 13 stations, which, as explained in section 2, is managed as a group, and provides the largest amount of solar resource data. Data collected from the network of 13 stations is monitored in real time using a data display system based on the open-source web application Grafana (https://grafana.com), through which the measured data points are shown on maps, tables, or on graphs spanning a given time interval. This display system is designed for real-time monitoring of the general operation and of the data collection.

To complement this display system, a reporting tool was developed in-house that automatically runs every morning to analyse the data (from each of the 13 sites separately) of the previous day, doing quality checks and generating a report in PDF format and mailed to the person in charge. These reports (to be described in a separate paper) consist of one page per site showing different key details like the number of collected minutes and some results of the quality checks, with graphs that help identify some common problems. The quality checks done in this automatic tool include: maximum physically possible limits, consistency between Gb, G and Gd (i.e. $G = Gb*\cos(SunZenithAngle) + Gd$) and ratio Gd/G as per the BSRN recommendations, and two custom checks on the clearness index Kt and diffuse fraction Kd:

$Kt = G / ETh$ (eq. 1)

$Kd = Gd / G$ (eq. 2)

where ETh is the (calculated) top-of-the-atmosphere solar radiation projected on a horizontal surface at the corresponding time. The quality tests are described and discussed in (Perez-Astudillo et al., 2018) and correspond to numbers 3-5, 7-10, 14 and 15 in Table 1 of that work.

3.3. Spatial coverage and variations

As discussed in section 2, QEERI's dense network of stations provides a thorough spatial coverage of the country. For an assessment of the spatial variation of solar resources in Qatar, the difference in measured irradiances can be studied between all possible pairs of stations as a function of distance, as depicted in Figure 5, which shows the relative values (in %) of the mean bias difference (rMBD), mean absolute difference (rMAD) and root-mean-squared difference (rRMSD) as function of distance between each pair of stations, obtained from the 1-minute measurements of Gb (left side), G (centre) and Gd (right side). As the order of stations in each pair was basically random, the sign of MBD does not provide meaningful information. The increase of differences with distance is clear on MAD and RMSD, especially for the direct and diffuse irradiances, being more sensitive than the global irradiance to local atmospheric variations (clouds and aerosols). This shows that in spite of Qatar's small size and flat geography, solar resources do indeed have measurable variations across the country, mainly due to varying aerosol loads in the atmosphere between coastal and inland locations.

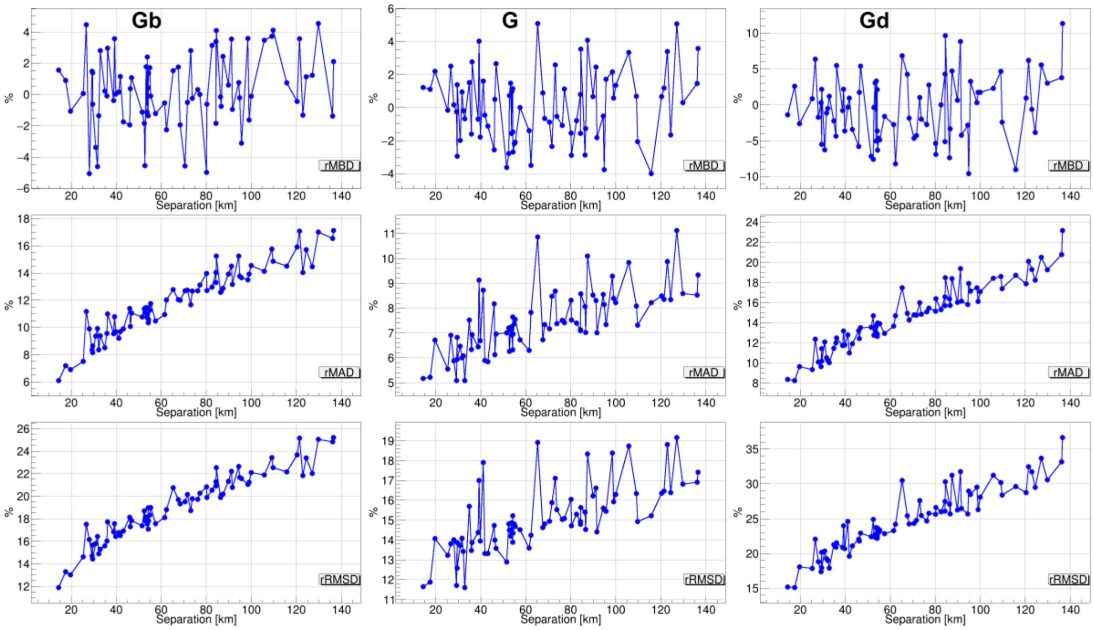

Figure 5: Relative differences (mean bias difference, mean absolute difference, root mean square difference) in measured Gb (left), G (centre) and Gd (right) at 1-min level, between all pairs of stations as function of distance, for the network of 13, Jan/2020 to May/2022.

As another indicator of spatial variability, the anomalies of daily irradiation in daily kWh/m^2 among sites are shown in Figure 6, for all days from 1/Jan/2020 to 31/May/2022. The anomalies here are calculated as the difference between the daily irradiation value from each station on a given day and the average of the daily values from all stations on that day. The empty bins correspond to days when a daily value could not be obtained for a given station due to a large number of missing data, where missing means either not collected or quality-rejected. As per the procedure established for these stations, a minimum of 85% of the daytime (from sunrise to sunset) 1-minute entries must pass the quality checks in order to allow for the calculation of a daily average; otherwise, the daily average is reported as missing. For sub-daily periods (e.g. 5-min, 10-min, 15-min, hourly), the criterion is that at least 50% of the minutes within that period must pass the quality checks. Therefore, a missing daily value does not necessarily mean that sub-daily averages are also missing. On the other hand, monthly and annual averages are obtained from the daily averages.

Overall, the largest variations are seen in direct irradiation, with not only the highest maximum and minimum, +3.10 and -3.15 kWh/m^2, respectively, but also more frequent larger anomalies throughout. For global irradiation, the maximum and minimum anomalies were +1.85 and -2.66 kWh/m^2, and for diffuse irradiation the values were +1.39 and -1.56 kWh/m^2. For context, the full-station, full-period average, maximum, and minimum of daily Gb were 5.70, 9.56, and 0.06 kWh/m^2 per day, respectively; for G, these values were 6.11, 8.58 and 1.27.

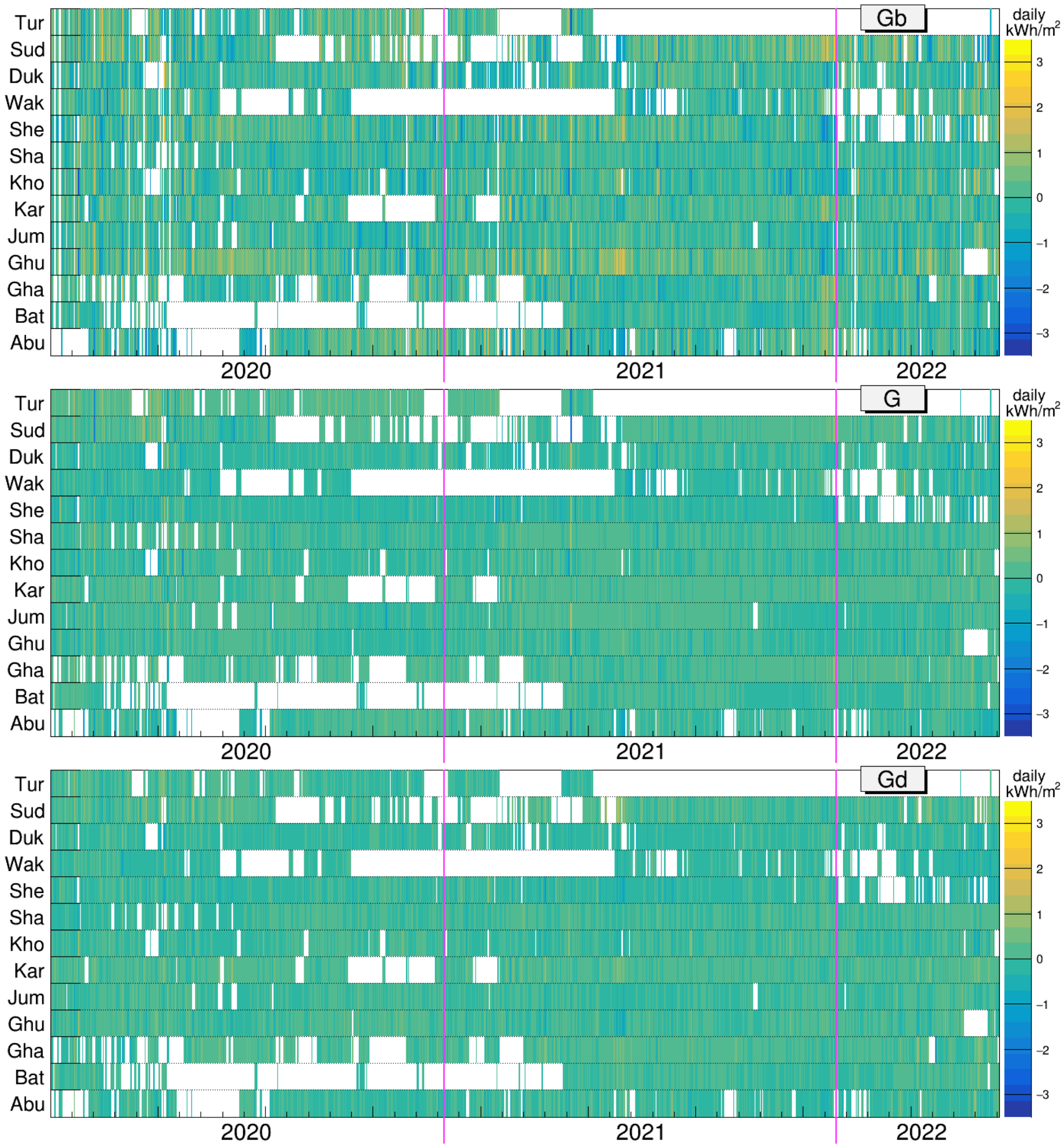

Figure 6: Daily irradiation anomalies, Jan/2020 to May/2022.

3.4. Longer-term view

To gain a better insight on the solar climate, it is important to look at data of as many years as possible; ideally at least one solar cycle. With the first 2.5 years of operation of the network of 13 stations, an initial view can be obtained. Figure 7 shows the monthly averages of the daily direct and global irradiations (values are daily kWh/m^2 during the month), as well as the monthly averages of daily clearness index Kt and diffuse fraction Kd (Kt and Kd are calculated first for each day from the daily values of G, Gd and ETh, and then averaged through the month).

Figure 8 shows the full-period (Jan/2020 to May/2022) averages of Kt and Kd. It can be seen that although Qatar has a relatively high clearness index (all-around average of 0.66), denoting usually low cloudiness, Kd is also high (all-around average of 0.38), denoting high levels of light diffusion that are unfavourable for concentrating solar technologies, for example.

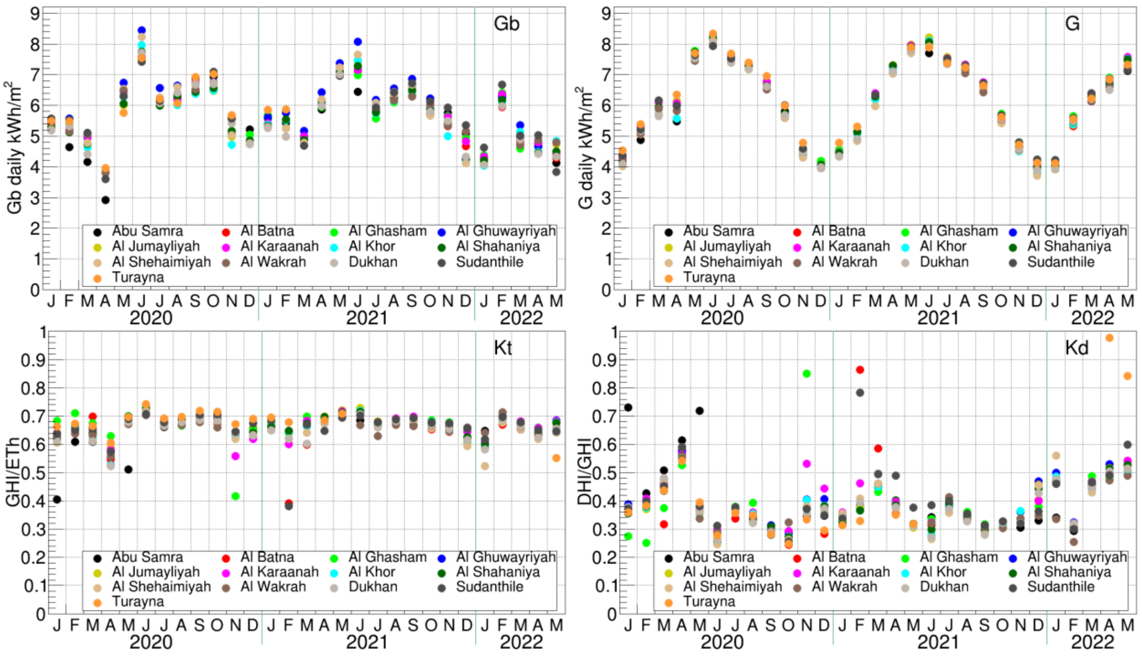

Figure 7: Monthly averages of Gb, G, Kt and Kd, Jan/2020 to May/2022, for each site.

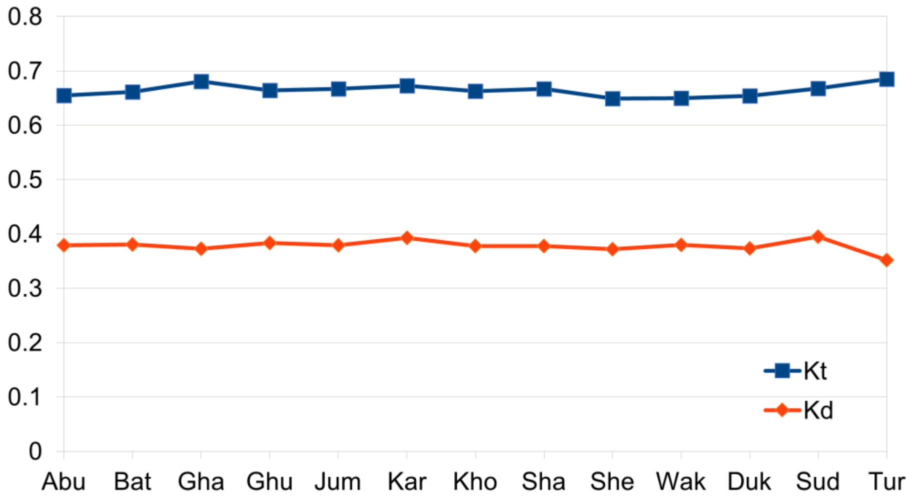

Figure 8: Full-period (Jan/2020 to May/2022) averages of Kt and Kd for each site.

4. Conclusions

QEERI currently operates 15 solar monitoring stations across Qatar, measuring direct, global and diffuse irradiances with high-precision pyranometers and pyrheliometers mounted on sun trackers. The generated one-minute data support the country's goals of sustainable and renewable energy production, with Qatar's first large-scale solar PV plant soon to start operations. This work provides a description of the continuous activities needed for maintaining and monitoring the operation of the stations, data retrieval and initial assessment of the quality of the generated data, with a first look at some results from the data collected during the first 2.5 years of country-wide monitoring. Although Qatar has a small size and mostly flat terrain, variations in solar resources, although not large, are observable. The stations provide a thorough coverage of the country, but the harsh weather conditions and difficult off-road access to some of the sites create challenges that have to be addressed or mitigated.

5. Acknowledgments

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6. References

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