Article:

Dhimish, Mahmoud, Holmes, Violeta, Mather, Peter et al. (2018) Preliminary assessment of the solar resource in the United Kingdom. Clean Energy. pp. 112-125.

https://doi.org/10.1093/ce/zky017

Clean Energy, 2018, Vol. 2, No. 2, 112–125

doi: 10.1093/ce/zky017
Advance Access Publication Date: 7 September 2018
Homepage: https://academic.oup.com/ce

Research Article

Preliminary assessment of the solar resource in the United Kingdom

Mahmoud Dhimish*, Violeta Holmes, Peter Mather and Martin Sibley

Laboratory of Photovoltaics, School of Computing and Engineering, University of Huddersfield, United Kingdom

*Corresponding author. E-mail: mahmoud.dhimish@gmail.com

Abstract

Solar radiation resources data are the foundation of knowledge for programs of large-scale deployment of solar energy technologies. This article summarizes the analysis of a new weather stations network in the United Kingdom. The analysis used three years (January 2015–December 2017) of data from 27 weather stations distributed across the country. The data comprises global horizontal irradiance (GHI), diffuse horizontal irradiance, direct normal irradiance and the ambient temperature. Network design, implementation and data quality assurance are described to document the network extent and quality. From all observed datasets, we found that Plymouth (located in southwest England) has the dominant GHI and ambient temperature among all other 26 locations. The least GHI is observed for Aberdeen (located in northeast Scotland) estimated at 77.3 kWh/m^2. The least average ambient temperature is equal to 9.1°C; the data were detected by the weather station located in the capital of Scotland (Edinburgh). Although continued measurements are needed to understand the interannual resource variability, the current study should have significant applications for preliminary technology selection, power plant modeling and resource forecasting.

Key words: solar resources; GHI; ambient temperature; United Kingdom

The United Kingdom estimates the country will need enormous energy assets in the coming decades for electricity generation, desalination and process heat to meet the needs of a rapidly growing population and economy [1]. To use petroleum for higher value purposes and export, the UK is planning a sustainable energy mix that includes renewable energy based on local resources. With an expected large solar resource, solar energy has long been considered promising in the United Kingdom [2].

The Department of Energy & Climate Change is leading renewable energy resource monitoring and mapping across the country [3]. As of February 2018 reports, the total installed capacity of solar photovoltaic in the UK reached 12 713 MW across 942 247 installations [4].

Whether globally, regionally or locally in the UK, successful solar technology development and power project applications rely, in part, on understanding the available solar resource and its spatial, temporal and spectral characteristics. For project deployment, characterization of the solar resource drives technology selection and project design, and assists in identifying the leading source of uncertainty in power project output estimates with implications for financing terms and returns on investments [5]. Thus, accurate measurements of the solar resource, along with environmental parameters such as ambient air temperature and dust levels, are critical to project arrangement. Furthermore, best practices in solar resource measurement are well established, such as those documented by the US Department of Energy's National Renewable Energy Laboratory (NREL) [6].

Various studies have already investigated solar resources in various regions across the world [7–12]. For instance, Zell et al. [7] assessed solar radiation resources in Saudi Arabia. Their valuation was based on datasets

Received 11 April, 2018; **Accepted** 16 July, 2018

collected from 30 stations distributed across Saudi Arabia. The methodology was based on analysis of the global horizontal irradiance (GHI), diffuse horizontal irradiance (DHI), direct normal irradiance (DNI) and related meteorological parameters such as wind speed and daily average temperature.

Nematollahi and Kim [8] published a feasibility study of solar energy in South Korea. The solar assessment was based on the maximum, minimum and average values of yearly horizontal radiation collected from 24 stations over a five-year period. Monthly and annual clearness indices for these stations were also calculated.

Rosma et al. [9] studied the development of an automatic solar station to measure the potential of solar energy resource in the unique tropical region of Pekanbaru, Indonesia. Abyad et al. [10] presented a unique model to estimate solar direct normal irradiance by evaluating and comparing various datasets from different regions such as Boulder, Colorado, USA.

Other advanced solar radiation forecasting is presented in the literature. Most recently, in 2018, Sun et al. [11] presented a decomposition-clustering-ensemble (DCE) learning approach for such forecasting. The authors verified the performance of the proposed DCE learning approach for solar radiation datasets in Beijing, China. The results of their solar radiation forecasting showed that the DCE learning approach produces a smaller mean absolute percentage error (MAPE) rate of 2.83%.

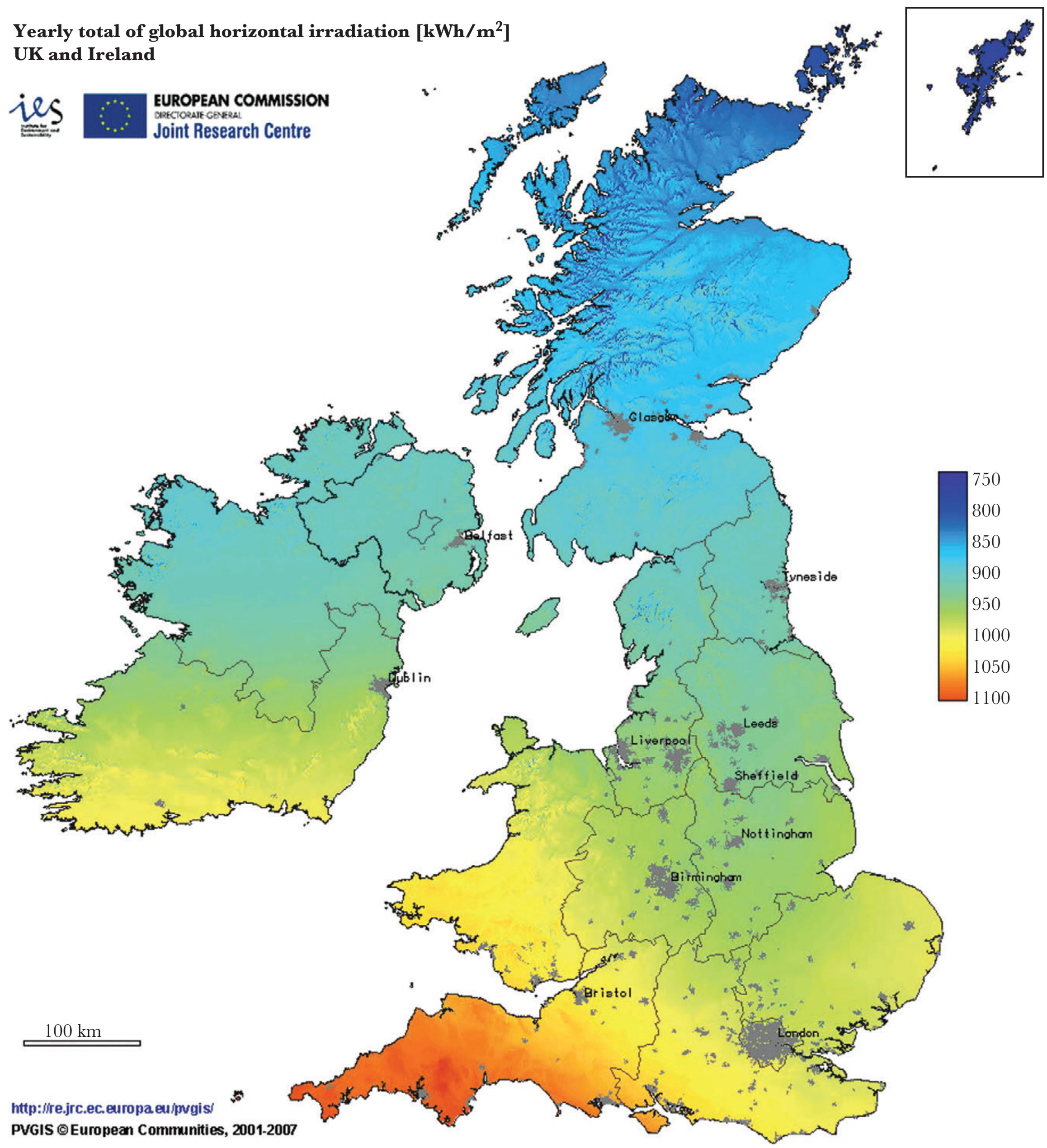

Fig. 1 Yearly total GHI in the UK (map taken from the European Commission Joint Research Center [16])

Another interesting solar forecasting model was proposed by Rohani et al. [12], based on a Gaussian process regression with k-fold across the validation process. The biggest advantage of the proposed technique is that it can be used with small-size data. The model has been tested in Mashhad, Iran, and the MAPE is equal to 1.97%.

The UK still lacks assessments for existing weather stations and solar radiation methods. Previous work [13–15] has evaluated the solar resources across the country, but the solar irradiance and temperature assessment is based on small-scale studied datasets. Moreover, the assessment is based on a historical dataset over a short period of time (one year as a maximum). Additionally, the analysis of the solar radiation is usually taken from the solar irradiance data presented in Fig. 1.

To overcome this knowledge gap, we have established a data analysis tool to examine the behavior of various weather stations installed in different locations across the UK. This article summarizes our analysis of a new weather station network, using three years (January 2015–December 2017) of data from 27 weather stations distributed across the country. The data comprises the GHI, DHI, DNI and the ambient temperature. Network design, implementation and data quality assurance are described to document the network extent and quality.

Additionally, the current study should have significant applications for preliminary technology selection, power plant modeling and resource forecasting, not only in the UK but also internationally.

1 Data gathering and analysis methods

The data used in this article is based on three years of solar resource measurements (GHI, DHI and DNI) and the average ambient temperature. The atmospheric data were collected from a subset of weather stations distributed across the UK. Because this is a modern network of weather stations, this section briefly describes the network instrumentation and design, along with the data collection process.

1.1 Weather station network and instrumentation

Multiple needs for accurate ground-based measurements of solar radiation and atmospheric parameters shaped the basis for the network architecture, to achieve the following objectives:

- Support the development of analysis tools for evaluating and predicting solar resource levels and technology presentation characteristics
- Support instant prospecting by potential solar resource power project designers
- Support atmospheric studies into unique climate characteristics of the UK

Table 1 Details on weather stations used in various locations

Site location	Site number	Site name	Latitude	Longitude	Elevation
England	1	Plymouth	50.371	−4.143	17
	2	Exeter	50.726	−3.527	49
	3	Bristol	51.454	−2.597	15
	4	Oxford	51.752	−1.258	70
	5	London	51.507	−0.128	19
	6	Cambridge	52.203	0.125	20
	7	Norwich	52.629	1.292	26
	8	Nottingham	52.953	−1.149	45
	9	Liverpool	53.405	−2.981	41
	10	Manchester	53.479	−2.244	55
	11	Huddersfield	53.647	−1.782	93
	12	Hull	53.744	−0.339	9
	13	York	53.959	−1.082	21
	14	Sunderland	54.906	−1.375	28
	15	Whitehaven	54.547	−3.589	9
Wales	16	Cardiff	51.482	−3.179	17
	17	Aberystwyth	52.414	−4.082	6
Scotland	18	Glasgow	55.857	−4.244	29
	19	Edinburgh	55.950	−3.191	72
	20	Aberdeen	57.148	−2.093	53
Ireland	21	Cork	51.898	−8.471	9
	22	Carlow	52.841	−6.926	55
	23	Dublin	53.350	−6.260	13
	24	Galway	53.274	−9.049	14
	25	Athlone	53.425	−7.941	40
	26	Sligo	54.272	−8.475	17
	27	Belfast	54.597	−5.930	15

Solar radiation can be transmitted, absorbed or scattered by an intervening medium in fluctuating amount depending on the wavelength over the approximate range of 300–3000 nm. The interactions of the Earth's atmosphere with inward solar radiation result in three fundamental components of interest to solar energy conversion technologies [17]; these components can be illustrated as follows:

(1) *Direct normal irradiance (DNI):* the direct radiation available from a 5° field of view across the solar disk on a surface oriented normal to the sun's position in the sky. Measurements of DNI are made with a pyrheliometer mounted in a solar tracker. This solar component is of particular interest to concentrating solar technologies such as for PV systems [18] and solar power [19].
(2) *Diffuse horizontal irradiance (DHI):* the scattered solar radiation from the sky dome except from the solar disk (i.e. not including DNI) on a horizontal surface. Measurements of DHI are made with a shaded pyranometer [20]. Levels of DHI are generally lower under clear sky conditions than under cloudy sky conditions. DHI data are helpful for assessing the plane-of-array (POA) irradiance [21, 22], and daylighting architectural design applications.
(3) *Global horizontal irradiance (GHI):* total hemispheric or geometric sum of the DNI and DHI components available on a horizontal surface. GHI measurements are made with an unshaded pyranometer. GHI data represent the amount of solar radiation incident on horizontal flat-plate solar collectors, and can be used to estimate the solar radiation on tilted flat-plate collectors [23, 24].

A total of 27 weather stations are in operation in the studied areas. The stations and their locations are listed in Table 1. In this work, we examined 15 weather stations in England, 2 weather stations in Wales, 3 weather stations in Scotland and 7 weather stations in Ireland. Fig. 2 shows the overall distribution of all the weather stations.

Each weather station comprises various sensors that measure the following environmental parameters:

i. Wind speed, range: 2–150 mph
ii. Wind direction
iii. Temperature, range: −40 to 65°C

Fig. 2 Distribution of weather stations across the UK (map retrieved from Google Maps [25])

iv. Relative humidity, range: 0–100%
v. Rainfall in millimetres or inches
vi. Solar irradiance (DNI, DHI and GHI), range: 0–2000 W/m^2

The weather stations are wirelessly connected to a monitoring unit called Vantage Pro2, which is accessible using an IP address from the Huddersfield site. The connection network is shown in Fig. 3(a). As can be seen, three main substations gather the data from different locations: Dublin, Oxford and Edinburgh. All data are gathered at the Huddersfield site, in which the data collection and the analysis process begins. This procedure is presented in Fig. 3(b).

Proper operation and maintenance of the weather stations used, along with documentation of these practises, is critical for constructing reliable weather measurements. We followed a procedure such that cleaning and maintenance are carried out twice weekly for the observed stations as per best practices developed by the U.S. Department of Energy's National Renewable Energy Laboratory [17]. Major tasks during cleaning and maintenance included cleaning all sensors and checking the wireless connections. Instrument calibration is planned to be conducted every three years as per manufacturer recommendations [26]; the instruments will be sent to the manufacturers to perform the calibration.

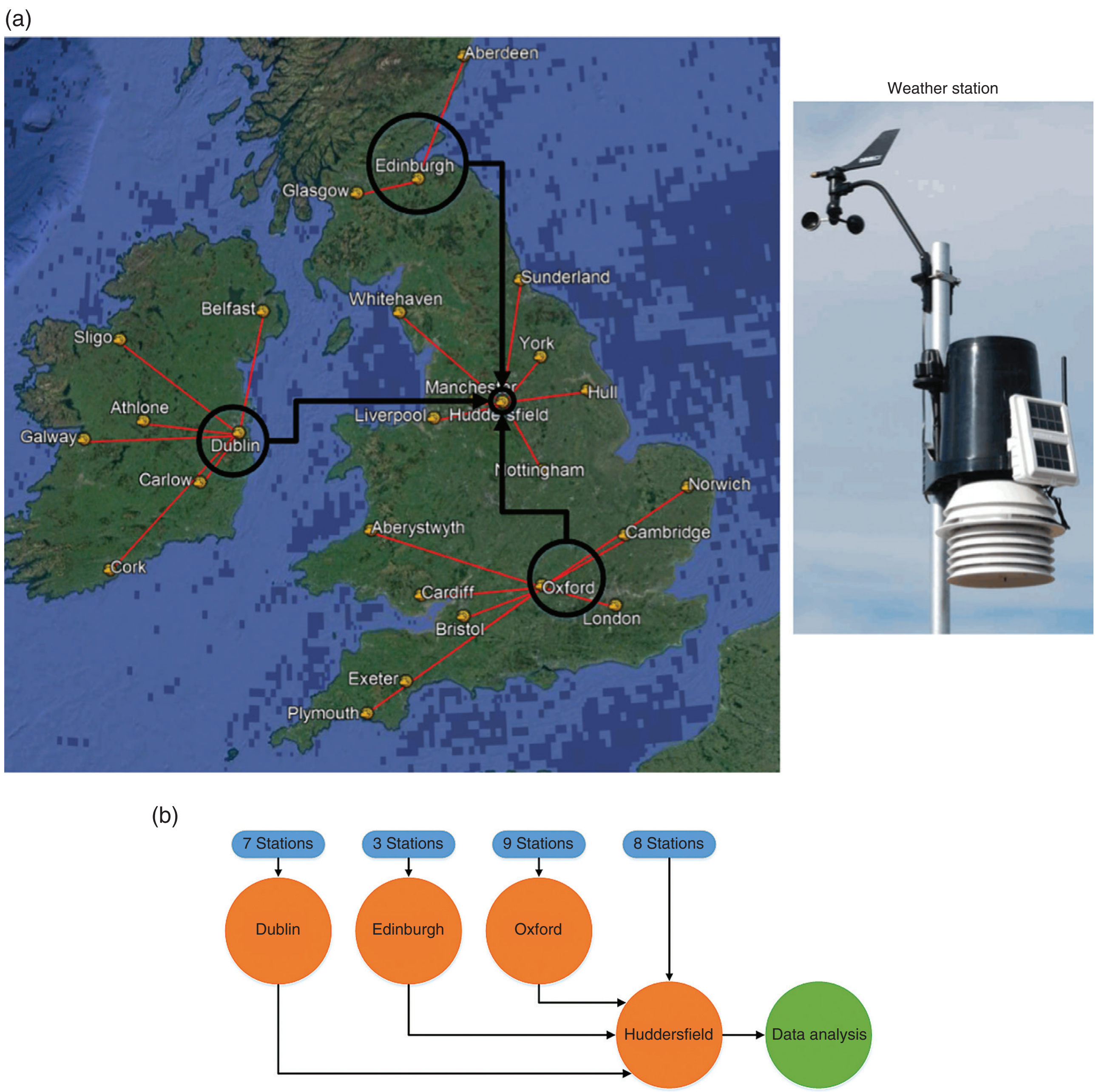

Fig. 3 (a) Connection network from all observed weather stations; (b) weather station allocation, where Huddersfield site processes the analysis of all the measured data

No calibration was required during the three years of this study.

The data gathered at the Huddersfield site were analysed to determine trends and patterns by station and region. The yearly average solar radiation (in kWh/m²) was calculated for GHI, DNI and DHI to assess the overall magnitude of the solar resource at each site and within each region, and to identify resource variability and temporal patterns.

Furthermore, the average ambient temperature data across all studied location were also examined, and the pattern of the temperature variations (increase or decrease) has been planned. The data measurements for all weather stations were analysed, logged and compared over the period from January 2015 to the end of December 2017.

2 Results and discussion

The analysis includes assessment of the monthly solar irradiation data from all studied weather stations as well as the ambient temperature measurements.

2.1 Solar irradiation and ambient temperature in England

In this section, the weather stations placed in various locations in England are compared. As stated in Section 1, the data were captured over a period of three years (2015–17). The yearly average GHI, DNI, DHI and ambient temperature are reported in Tables 2–4; Table 2 summarizes the measurements in 2015, Table 3 corresponds to data captured in 2016, and Table 4 summarizes the measurements in 2017.

It is noticeable from Tables 2–4 that the maximum observed GHI was at Plymouth, whereas London ranked second. The minimum irradiance level over the studied period was observed for Huddersfield with an average of 84.6 kWh/m² yearly. The second minimum GHI was observed by the weather station located in Sunderland, where the average GHI over the studied period was 85.6 kWh/m².

The highest average ambient temperature between 2015 and 2017 among all studied locations in England was obtained at Plymouth (average temperature 12.2°C). The second highest average temperature was found in Liverpool, ~11.7°C. However, Sunderland had the lowest average temperature between 2015 and 2017, with an average ambient temperature of 9.1°C.

In northern regions of England, the yearly GHI is relatively low compared to southern regions. For example, York,

Table 2 Summary of the average solar irradiance and ambient temperature in England, 2015

Location	Year 2015			
	Average GHI (kWh/m²)	Average DNI (kWh/m²)	Average DHI (kWh/m²)	Average temp. (°C)
Plymouth	106	114	46	12.5
Exeter	96	87	52	12
Bristol	95	88	49	12
Oxford	92	83	51	10.9
London	98	94	50	11.6
Cambridge	91	84	51	11.4
Norwich	92	88	50	11.4
Nottingham	88	79	50	10.5
Liverpool	95	94	47	11.2
Manchester	85	73	51	10.8
Huddersfield	83	75	48	10.4
Hull	92	93	49	10.5
York	85	78	49	10.2
Sunderland	83	83	46	9.6
Whitehaven	93	94	44	11.2

Table 3 Summary of the average solar irradiance and ambient temperature in England, 2016

Location	Year 2016			
	Average GHI (kWh/m²)	Average DNI (kWh/m²)	Average DHI (kWh/m²)	Average temp. (°C)
Plymouth	102	106	47	12
Exeter	95	87	52	11.5
Bristol	93	88	49	11.5
Oxford	89	80	51	10.4
London	97	93	49	11.1
Cambridge	90	83	50	10.8
Norwich	93	88	50	10.8
Nottingham	90	82	51	10
Liverpool	96	97	48	10.5
Manchester	87	77	50	10.2
Huddersfield	87	80	49	9.8
Hull	95	99	49	10
York	88	84	50	9.7
Sunderland	88	94	46	8.9
Whitehaven	96	98	45	10.4

Table 4 Summary of the average solar irradiance and ambient temperature in England, 2017

Location	Year 2017			
	Average GHI (kWh/m²)	Average DNI (kWh/m²)	Average DHI (kWh/m²)	Average temp. (°C)
Plymouth	101	100	50	12.1
Exeter	95	85	53	11.6
Bristol	91	81	51	11.6
Oxford	89	78	52	10.3
London	95	88	51	10.9
Cambridge	90	82	51	10.7
Norwich	92	85	50	10.8
Nottingham	88	79	50	10
Liverpool	96	97	48	10.6
Manchester	86	76	50	10.3
Huddersfield	84	74	49	9.9
Hull	94	94	49	10
York	87	81	50	9.7
Sunderland	86	86	46	9
Whitehaven	94	94	46	10.8

Manchester, Huddersfield and Sunderland had a yearly average GHI <90 kWh/m². However, if we select southern locations such as Plymouth, Exeter and London, the yearly average GHI was >95 kWh/m². The map in Fig. 4(a) illustrates the geographical distribution of the yearly average GHI in all locations studied in England.

The annual average ambient temperature detected by the weather stations in England is geographically mapped

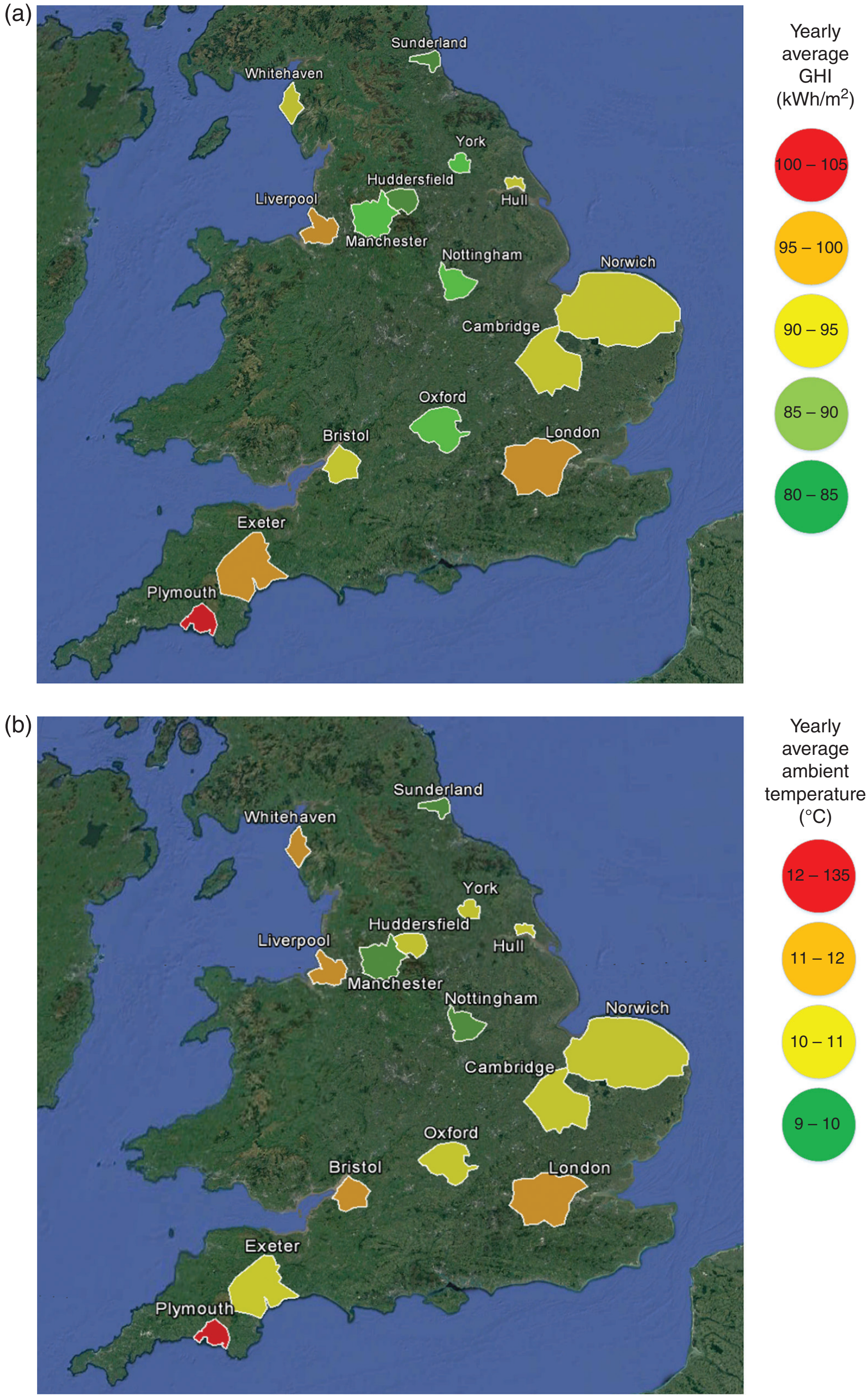

Fig. 4 (a) Distribution of yearly average GHI for the studied locations in England; (b) yearly average ambient temperature in 15 different locations in England

and presented in Fig. 4(b). It is evident that Plymouth has the maximum yearly average temperature compared to all other locations. In fact, the distribution of the temperature varies in different areas of England; for example, Sunderland has a yearly average temperature of 9.1°C whereas Whitehaven is ~11.2°C. The cities are 144 km apart.

In conclusion, this section demonstrated the variations of the GHI, DNI and DHI in all observed locations. The analysis is based on the GHI data because this parameter is usually used to study the impact of sun irradiance on solar panels and solar thermal systems, and it is calculated using the addition of the DNI and DHI with respect to the incident radiation angle. The yearly average temperature in England also was presented, where a geographical map representation was drawn to explain the variation of the temperature.

As described earlier, northern and southern England have variations of the yearly average GHI. It is evident from Fig. 4(a) that southern locations have higher GHI compared to northern locations. To explain the variations of GHI in both northern and southern sites, a histogram including a normal distribution plot is plotted in Fig. 5(a).

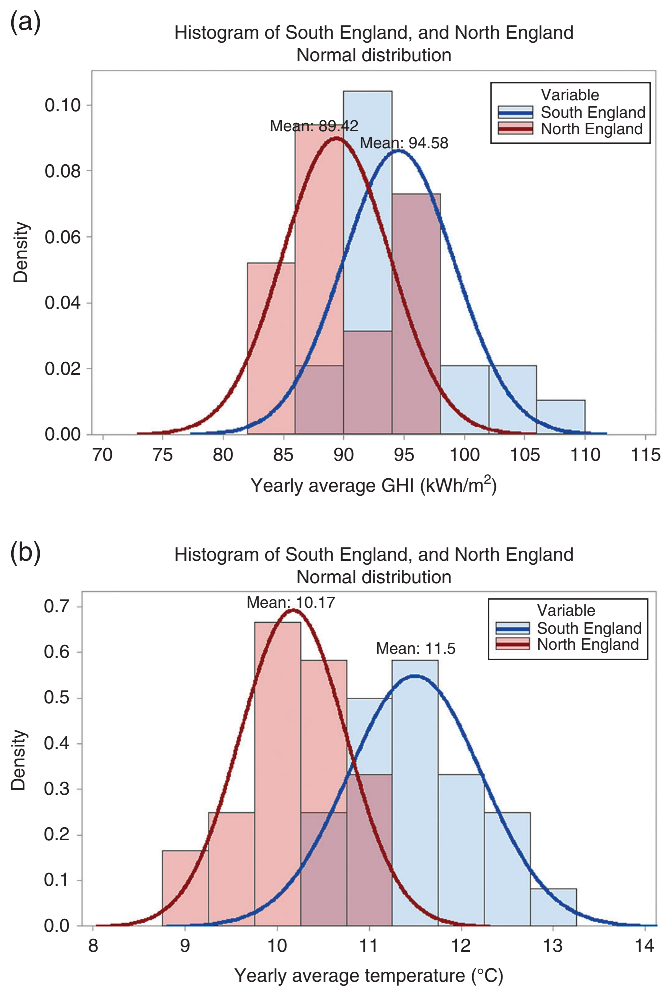

Fig. 5 Southern and northern England histogram and normal distribution plot: (a) yearly average GHI; (b) yearly average temperature

Table 5 Summary of the average solar irradiance and ambient temperature in Wales, 2015–17

Year	Location	Average GHI (kWh/m^2)	Average DNI (kWh/m^2)	Average DHI (kWh/m^2)	Average temp. (°C)
2015	Cardiff	102	102	48	12
	Aberystwyth	85	69	49	12
2016	Cardiff	101	101	48	11.5
	Aberystwyth	86	75	48	11.5
2017	Cardiff	98	94	51	11.4
	Aberystwyth	81	63	49	11.6

Northern sites have lower yearly average GHI, with a mean of 89.42 kWh/m². However, in southern sites the mean of all gathered samples for the yearly average GHI is 94.58 kWh/m².

According to Fig. 5(b), southern England has higher yearly average temperatures compared to northern England. As shown by the histogram and the normal distribution plot, the mean of the temperature for all locations in southern England is 11.5°C, but drops by 1.33°C for the northern sites.

2.2 Solar irradiation and ambient temperature in Wales

We examined, two weather stations in Wales: at Cardiff and at Aberystwyth. The distance between the weather stations is 92.4 km. We compared data from both weather stations over a period of three years.

A summary for the yearly average solar irradiance and ambient temperature is reported in Table 5. As can be seen, Cardiff has a higher yearly average solar irradiance. However, the temperature variations are comparatively identical.

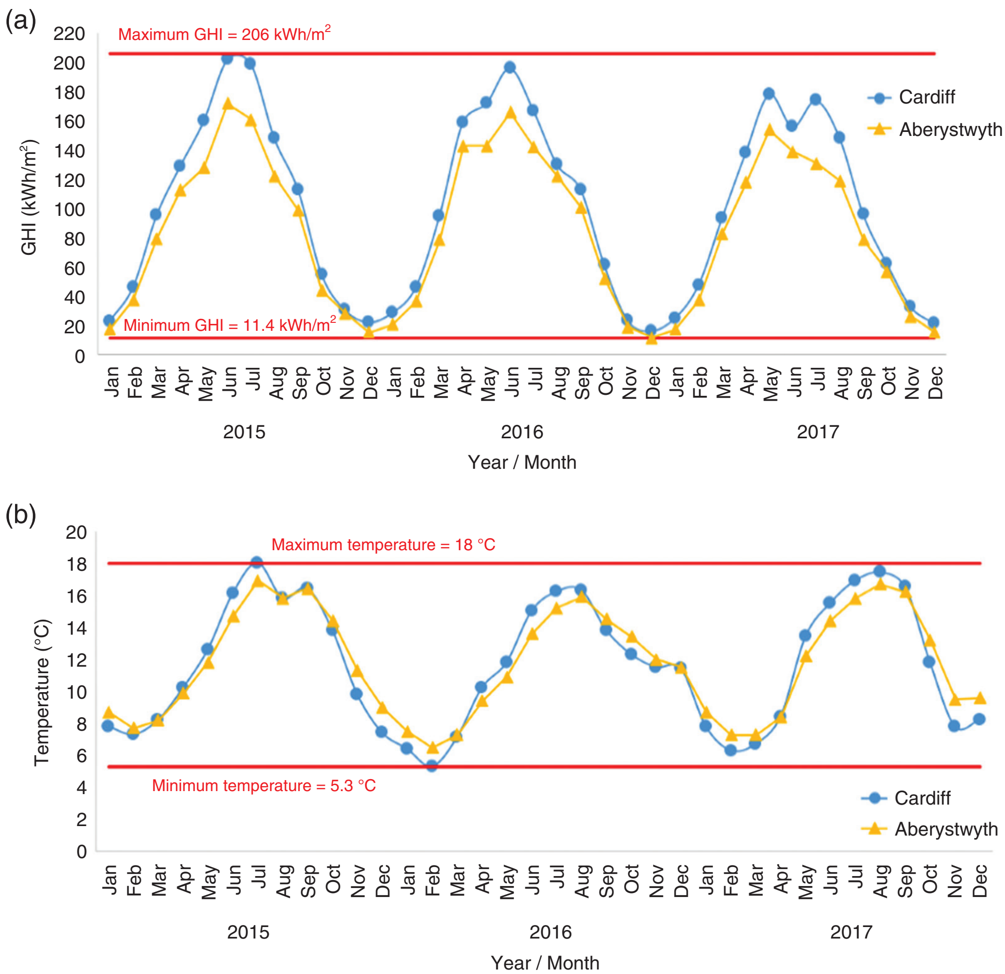

Fig. 6 (a) Monthly average GHI for both examined locations in Wales; (b) monthly average ambient temperature for examined locations in Wales

Table 6 Summary of the average solar irradiance and ambient temperature in Scotland, 2015–17

Year	Location	Average GHI (kWh/m²)	Average DNI (kWh/m²)	Average DHI (kWh/m²)	Average temp. (°C)
2015	Glasgow	79	67	48	10.1
	Edinburgh	84	94	48	9.6
	Aberdeen	79	84	44	9.7
2016	Glasgow	83	75	49	9.2
	Edinburgh	89	94	48	8.7
	Aberdeen	82	84	45	9
2017	Glasgow	82	73	49	9.6
	Edinburgh	85	82	48	9
	Aberdeen	71	78	46	9

For a more detailed explanation, we examined the monthly data of both weather stations. Fig. 6(a) shows the monthly average GHI for both stations. The maximum GHI, obtained for Cardiff in June 2015, was 206 kWh/m^2. In addition, the minimum GHI was 11.4 kWh/m^2, detected in Aberystwyth in December 2016.

As shown in Fig. 6(b), both locations have approximately the same average ambient temperature over the considered period. The maximum and minimum perceived levels for the average monthly ambient temperature were 18°C and 5.3°C, respectively; both levels were detected in Cardiff in July 2015 and February 2016.

In fact, Cardiff ranked second in terms of yearly average GHI compared to all other observed sites considered here (including England, Wales, Scotland, and Ireland); the site that had the maximum yearly average GHI, Plymouth, was discussed in the previous section. This data will briefly be discussed in Section 3.

2.3 Solar irradiation and ambient temperature in Scotland

In Scotland, we examined data from three weather stations: Edinburgh (capital of Scotland), Glasgow and Aberdeen. The distance between the weather stations in Glasgow and Edinburgh is ~70.4 km; the distance is much longer between the weather stations fitted in Edinburgh and Aberdeen: ~154.7 km.

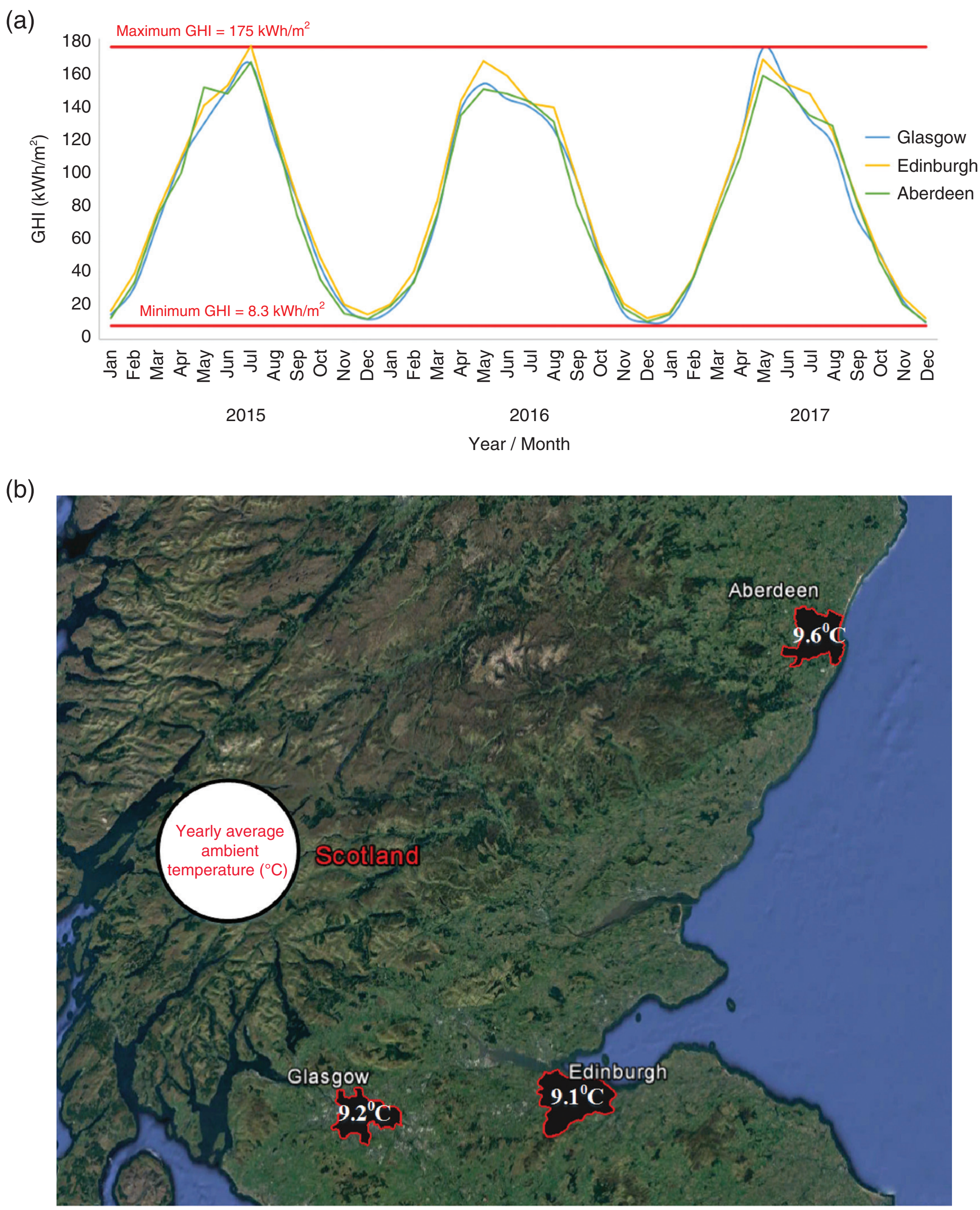

Fig. 7 (a) Monthly average GHI for three examined locations in Scotland; (b) yearly average ambient temperature for the examined locations in Scotland

Table 6 summarizes the solar irradiance and ambient temperature in the observed locations between 2015 and 2017. It is evident that Edinburgh has the highest yearly average GHI; Glasgow is second. Fig. 7(a) presents the average monthly GHI detected by all three weather stations. From the observed measurements, we found that over the considered study period, Edinburgh and Glasgow reached a maximum GHI at 175 (kWh/m^2). Edinburgh weather station detected this data in July 2015 and the weather station in Glasgow detected this measurement in May 2017.

All the Scottish locations had approximately identical average ambient temperatures over the considered period. Fig. 7(b) illustrates the yearly average ambient temperature observed by the weather stations, which can be ranked as follows (maximum to minimum): Aberdeen: 9.6°C, Glasgow: 9.2°C, Edinburgh: 9.1°C.

2.4 Solar irradiation and ambient temperature in Ireland

In this section, we compare the weather stations sited in various locations in Ireland. The yearly average GHI, DNI, DHI, and ambient temperature are illustrated in Table 7 for the period 2015–17.

From the results, Dublin had the maximum overall yearly average GHI at ~91.7 kWh/m^2. The second maximum GHI was detected by the Cork weather station, 91.3 kWh/m^2. The minimum GHI was observed in Athlone at 84.6 kWh/m^2. The distribution of the yearly average GHI at all locations with is geographically mapped and analysed in Fig. 8(a).

Fig. 8(b) shows the yearly average ambient temperature detected by all installed weather stations. Cork city had the extreme ambient temperature across all examined locations, with an annual temperature equaling 11.1°C. The lowest annual temperature, 9.7°C, was detected in Athlone.

3 Evaluating the observed GHI and temperature datasets

To draw a relevant assessment for the results discussed earlier in Section 2, all studied locations were compared and analysed based on the yearly average GHI and ambient temperature. For data comparison to be valid, the weather stations must have similar exposure and be carefully set up. The set-up criteria used in the newly developed weather network are similar to the weather stations placed across the country by the UK government, specifically, under evaluation and control by the Met Office [27], the UK's national weather service.

Fig. 9(a) presents a histogram and normal distribution plot for GHI in all observed locations. We found that the yearly average GHI (kWh/m^2) is equal to (from maximum to minimum):

- South England: 95
- Wales: 92
- North England: 89
- Ireland: 87
- Scotland: 82

Southern England has the highest GHI whereas the lowest is in Scotland. Remarkably, these findings are consistent with the histogram and normal distribution plot shown in Fig. 9(b), which displays the data taken from the UK's historical monthly GHI for meteorological stations [27]. The

Table 7 Summary of the average solar irradiance and ambient temperature in Ireland, 2015–17

Year	Location	Average GHI (kWh/m^2)	Average DNI (kWh/m^2)	Average DHI (kWh/m^2)	Average temp. (°C)
2015	Cork	93	86	52	11.2
	Carlow	85	72	52	10.7
	Dublin	91	88	49	10.9
	Galway	84	75	49	11
	Athlone	84	73	51	10
	Sligo	84	76	50	10.3
	Belfast	84	72	50	10.8
2016	Cork	93	86	52	11.2
	Carlow	86	72	52	10.2
	Dublin	94	96	49	10.4
	Galway	87	81	49	10.4
	Athlone	87	78	51	9.5
	Sligo	88	83	49	9.6
	Belfast	88	78	51	10.1
2017	Cork	88	77	52	10.9
	Carlow	83	70	52	10.5
	Dublin	90	85	50	10.6
	Galway	85	76	49	10.8
	Athlone	83	72	51	9.7
	Sligo	86	81	50	10
	Belfast	85	73	51	10.5

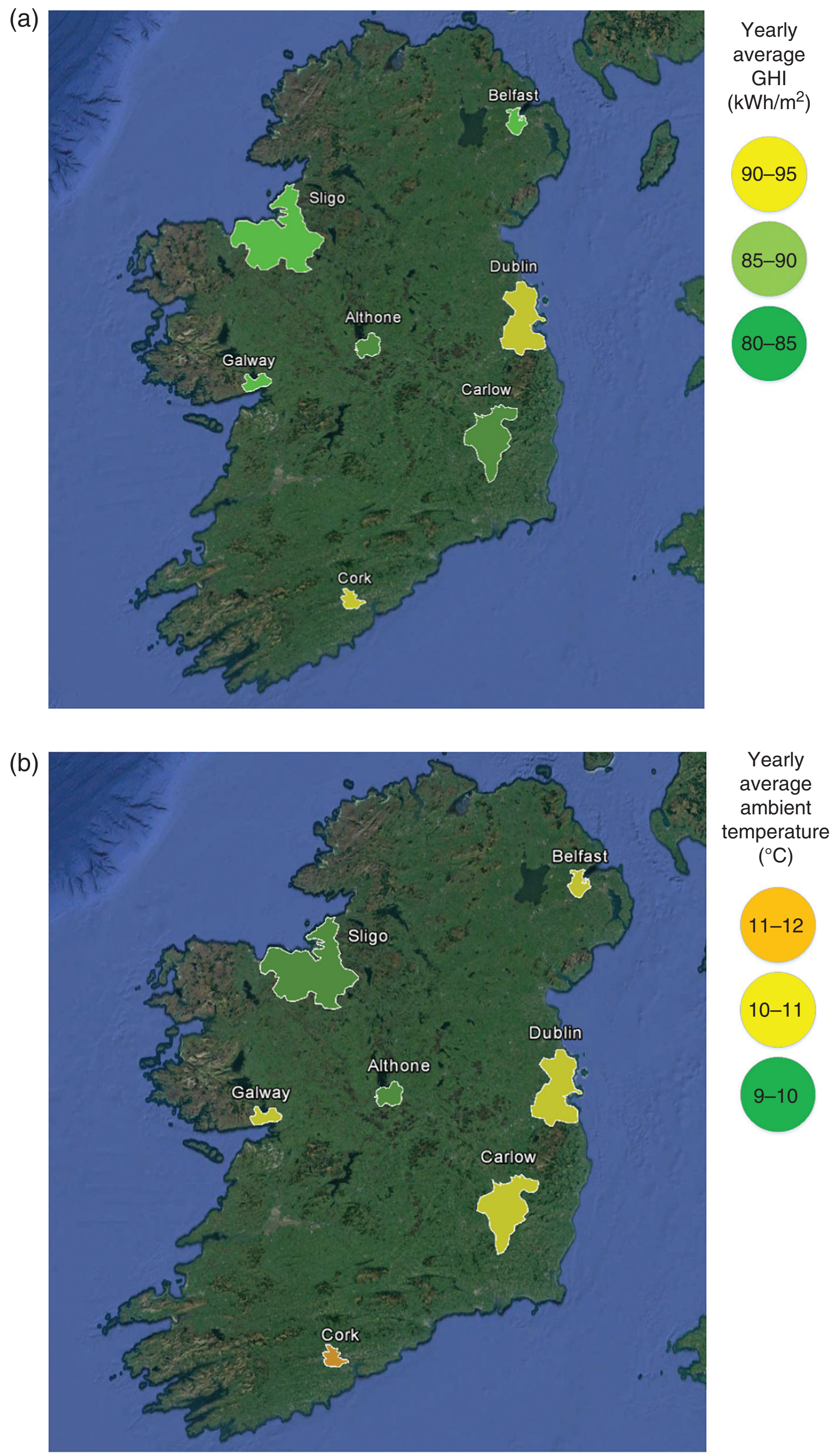

Fig. 8 (a) Distribution of yearly average GHI for the studied locations in Ireland; (b) yearly average ambient temperature in seven different locations in Ireland

maximum difference between the observed data taken from the weather station network discussed in this article and the data taken from the Met Office is less than ±3 kWh/m^2.

As to the yearly average temperature, Fig. 9(c) shows the distribution of temperature based on the analysed data previously discussed in Section 2; Fig. 9(d) shows the results obtained using the data taken from the Met Office

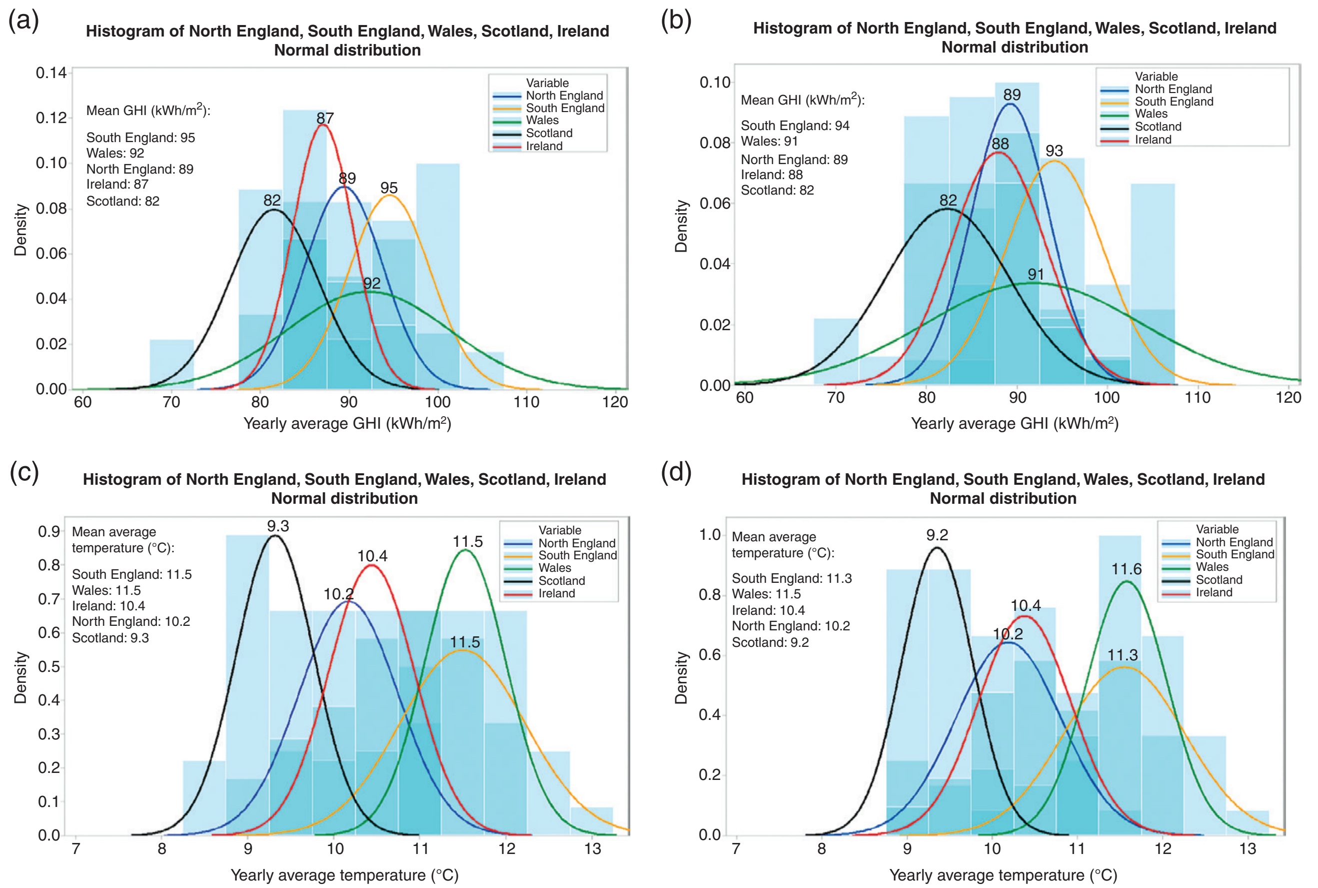

Fig. 9 Histogram and normal distribution plots for yearly average GHI and temperature in all studied locations across the UK: (a) GHI plot using observed data from this article; (b) GHI plot using data taken from the UK Met Office [27]; (c) temperature plot using observed data from this article; (d) temperature plot using data taken from the UK Met Office

[27]. The differences between the observed data from both resources are as follows:

- South England: 0.1°C
- Wales: 0.2°C
- Scotland: 0.1°C
- Data for both Ireland and North England are identical

Comparable to the results obtained for the GHI, the yearly average temperature observed in the new weather station network discussed in this article matches the results observed by the Met Office.

4 Conclusion

This article presents a detailed assessment for 27 weather stations installed at different locations in England, Scotland, Wales, and Ireland. This resource monitoring network has been specifically designed to improve available data and models of solar resources in the UK to support power project developers, researchers, and policy decision-makers. To that end, the network has used the latest equipment and protocols for operations and maintenance, and tiered the station capabilities as appropriate to achieve spatial coverage and sufficient maintenance in remote locations.

This article summarizes the data measurement over three years, specifically January 2015 to the end of December 2017. The data analysis was carried out at the Huddersfield site. A detailed assessment for the yearly average global horizontal irradiance (GHI) and ambient temperature was investigated and geographically mapped for each site.

We found that Plymouth (located in southwest England) has the dominant GHI and ambient temperature among all 27 locations. The least GHI was observed for Aberdeen (located in northeast Scotland), ~77.3 kWh/m². The least average ambient temperature was determined for the capital of Scotland (Edinburgh); the observed average temperature by the weather station there over three years is 9.1°C.

All observed data measured in England, Scotland, Wales and Ireland were compared to actual measured data taken from the UK Met Office, the UK's national weather service. After comparing both datasets, we found that the maximum difference in the GHI is below ±3 kWh/m², whereas the maximum difference for the yearly temperature is 0.2°C.

The data presented in this work will be valuable for creating and validating solar resource forecasts to support utility-scale plant operation and electric grid integration of solar-based power generation. The geographical maps presented also could be used to analyse the impact of irradiance and ambient temperature in each location, and thus estimate the annual production of renewable energy resources, specifically photovoltaic systems.

Conflict of interest statement. None declared.

References

[1] Drysdale B, Wu J, Jenkins N. Flexible demand in the GB domestic electricity sector in 2030. *Appl Energy* 2015; 139:281–90.

[2] Muhammad-Sukki F, Ramirez-Iniguez R, Munir AB, et al. Revised feed-in tariff for solar photovoltaic in the United Kingdom: a cloudy future ahead? *Energy Policy* 2013; 52:832–8.

[3] Department of Energy & Climate Change, United Kingdom. *Policy Area Climate Change*. 2017. https://www.gov.uk/government/topics/climate-change (16 August 2018, date last accessed).

[4] National Statistics, UK Government. *Monthly Deployment of All Solar Photovoltaic Capacity in the United Kingdom*. 2018. https://www.gov.uk/government/statistics/solar-photovoltaics-deployment (16 August 2018, date last accessed).

[5] Bauner C, Crago CL. Adoption of residential solar power under uncertainty: implications for renewable energy incentives. *Energy Policy* 2015; 86:27–35.

[6] Sengupta M, Habte A, Kurtz S, et al. *Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications*. NREL Report No. TP-5D00-63112. 2015. http://www.nrel.gov/docs/fy15osti/63112.pdf (1 June 2015, date last accessed).

[7] Zell E, Gasim S, Wilcox S, et al. Assessment of solar radiation resources in Saudi Arabia. *Solar Energy* 2015; 119:422–38.

[8] Nematollahi O, Kim KC. A feasibility study of solar energy in South Korea. *Renew Sustain Energy Rev* 2017; 77:566–79.

[9] Rosma IH, Sukma DY, Ali IT, et al. Automatic solar station for ground-based measurement of solar energy resource in Pekanbaru City Indonesia. In: *International Conference on Electrical Engineering and Informatics (ICELTICs)*, Banda Aceh, Indonesia, October 2017. IEEE, 2018, 78–81.

[10] Abyad E, Valdivia CE, Haysom J, et al. Modeled estimates of solar direct normal irradiance in Al-Hanakiyah, Saudi Arabia and Boulder, USA. In: *2016 Electrical Power and Energy Conference (EPEC)*, Ottawa, Ontario, Canada. IEEE, 2016.

[11] Sun S, Wang S, Zhang G, et al. A decomposition-clustering-ensemble learning approach for solar radiation forecasting. *Solar Energy* 2018; 163:189–99.

[12] Rohani A, Taki M, Abdollahpour M. A novel soft computing model (Gaussian process regression with K-fold cross validation) for daily and monthly solar radiation forecasting (Part: I). *Renew Energy* 2018; 115:411–22.

[13] Dhimish M, Holmes V, Mehrdadi B, et al. Multi-layer photovoltaic fault detection algorithm. *High Voltage* 2017; 2:244–52.

[14] Hall RJ, Hanna E. North Atlantic circulation indices: links with summer and winter UK temperature and precipitation and implications for seasonal forecasting. *Int J Climatol* 2018; 38: e660–e677.

[15] Dhimish M, Holmes V, Mehrdadi B, et al. Simultaneous fault detection algorithm for grid-connected photovoltaic plants. *IET Renew Power Gener* 2017; 11:1565–75.

[16] European Commission Joint Research Center. *UK and Ireland Annual Insolation Map*. 2017. http://contemporaryenergy.co.uk/insolation-map/ (16 August 2018, date last accessed).

[17] Stoffel T, Renné D, Myers D, et al. *Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data*. NREL/TP-5500–47465. Golden, CO: National Renewable Energy Laboratory, 2010.

[18] Du B, Hu E, Kolhe M. Performance analysis of water cooled concentrated photovoltaic (CPV) system. *Renew Sustain Energy Rev* 2012; 16:6732–6

[19] Cavallaro F, Zavadskas EK, Streimikiene D. Concentrated solar power (CSP) hybridized systems. Ranking based on an intuitionistic fuzzy multi-criteria algorithm. *J Clean Prod* 2018; 179:407–16.

[20] Eissa Y, Marpu PR, Gherboudj I, et al. Artificial neural network based model for retrieval of the direct normal, diffuse horizontal and global horizontal irradiances using SEVIRI images. *Solar Energy* 2013; 89:1–16.

[21] Copper JK, Sproul AB, Jarnason S. Photovoltaic (PV) performance modelling in the absence of onsite measured plane of array irradiance (POA) and module temperature. *Renew Energy* 2016; 86:760–9.

[22] Dhimish M, Holmes V, Mather P, et al. Novel hot spot mitigation technique to enhance photovoltaic solar panels output power performance. *Sol Energy Mater Sol Cells* 2018; 179:72–9

[23] Zamzamian A, KeyanpourRad M, KianiNeyestani M, et al. An experimental study on the effect of Cu-synthesized/EG nanofluid on the efficiency of flat-plate solar collectors. *Renew Energy* 2014; 71:658–64.

[24] Amri A, Jiang ZT, Pryor T, et al. Developments in the synthesis of flat plate solar selective absorber materials via sol–gel methods: a review. *Renew Sustain Energy Rev* 2014; 36:316–28.

[25] Google Maps. *United Kingdom*. 2018. https://www.google.co.uk/maps/@54.4104063,-2.008357,6.25z (16 August 2018, date last accessed).

[26] Davis United Kingdom. *Davis Weather Station*. 2017. http://www.davisweather.co.uk/ (16 August 2018, date last accessed).

[27] Met Office - Data.gov.uk. *Historical monthly data for meteorological stations*. 2017. https://data.gov.uk/dataset/17ba3bbe-0e98-4a8c-9937-bd1d50fdc3c5/historical-monthly-data-for-meteorological-stations (16 August 2018, date last accessed).