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Exploratory evaluation of solar radiation and ambient temperature in twenty locations distributed in United Kingdom

Mahmoud Dhimish* and Peter Mather

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

Abstract

Solar radiation and ambient temperature is a foundation resource programs of large-scale deployment of solar energy technologies. This paper summarizes the analysis of a weather station network in United Kingdom. Whistle 3 years (January 2015 – December 2017) of data from twenty weather stations distributed across the country. The data comprises of Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), Direct Normal Irradiance (DNI), ambient temperature, wind speed, and the humidity. Network design, implementation, and data quality assurance are described, in order to document the network extent and quality. From all observed datasets, it was found that Plymouth (located in southwest England) has the dominant GHI, and ambient temperature among all other 19 locations. The least GHI is observed for Aberdeen (located in northeast Scotland) estimated at 77.3 kWh/m^2. However, the least average ambient temperature is equal to 9.1 ºC, this data was detected from the weather station located in the capital of Scotland (Edinburgh). Although continued measurements are needed to understand the interannual resource variability, the current study provides significant guidance for preliminary technology selection, power plant modeling, and resource forecasting.

Keywords: Solar resources; GHI; Ambient Temperature; United Kingdom.

1. Introduction

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

The Department of Energy & Climate Change (DECC) in the United Kingdom is leading the renewable energy resource monitoring and mapping across the country [3], hence to support the large increases to the country solar generation capacity, moving toward a sustainable energy generation. As of February 2018 report, the total installed capacity of solar photovoltaic in the UK reached 12,713 MW across 942,247 installations [4].

Whether regionally or on a local level, successful solar technology development and power project applications rely, in part, upon understanding the available solar characteristics such as spatial, temporal, and spectral. For project deployment, characterization of the solar resource drives technology, design, and characterizes 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. Best practices in solar resource measurement are well-established such as those documented by the National Renewable Energy Laboratory (NREL) [6].

Studies have previously investigated the weather conditions in various regions across the world. For example, the assessment of solar radiation resources in Saudi Arabia is presented by Z. Erica et al [7]. Where the assessment is based on the datasets collected from 30 distributed stations. The presented methodology is based on the 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.

A feasibility study of solar energy in South Korea is presented by O. Nematollahi and K. C. Kim [8], where the solar assessment is based on the maximum, minimum, and the average values of yearly horizontal radiation collected from twenty-four weather stations for a period of five years. Monthly and annual clearness indices of the solar irradiance have also been considered.

An alternative study, R. Iswadi *et al.* [9], presented the development of an automatic solar station to measure the potential of solar energy resource in the unique tropical region like Pekanbaru, Indonesia. While, A. Emad *et al.* [10] offered a unique model to estimate solar direct normal irradiance. The evaluation process was possible by comparing various dataset from different regions across the united states.

Additional advanced solar radiation forecasting is widely presented in research literature, however, most recently, in 2018, authors in [11] presented a decomposition-clustering-ensemble (DCE) learning approach for solar radiation forecasting. The performance of the proposed DCE learning approach for a solar radiation dataset in Beijing, China. It was found that the maximum accuracy in estimating the solar radiation one-day-ahead is 88.24%. Another interesting solar forecasting is proposed by R. Abbas et al [12], which is based on a Gaussian process regression with k-fold across validation process. The biggest advantage of the proposed technique that it can be used with small data size; the model has been tested in Mashhad, Iran, where its maximum accuracy is equal to 99%.

In the UK, there is a lack of assessment for installed weather stations, and solar radiation methods. Some primarily work established by [13-15], but still, the solar irradiance and temperature assessment are based on small scale studied datasets, yet more, the assessment is based on a historical data set over short period of time (one year as a maximum). Additionally, the analysis of the weather is usually based on the solar irradiance data presented in Fig. 1.

In order to overcome this significant knowledge gap, found in the literature, we have established a data analysis tool to examine the behavior of various weather stations installed in different UK based locations. This paper summarizes the analysis of three years of data (January 2015 – December 2017) for a network of twenty weather stations distributed across the country. The data comprises the Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), Direct Normal Irradiance (DNI), and the ambient temperature. Network design, implementation, and data quality assurance are described to document the network extent and quality. This is being the main contribution of this work. In addition, the current study should have significant applications for preliminary technology selection, power plant modeling, and resource forecasting, not only in the UK, but internationally.

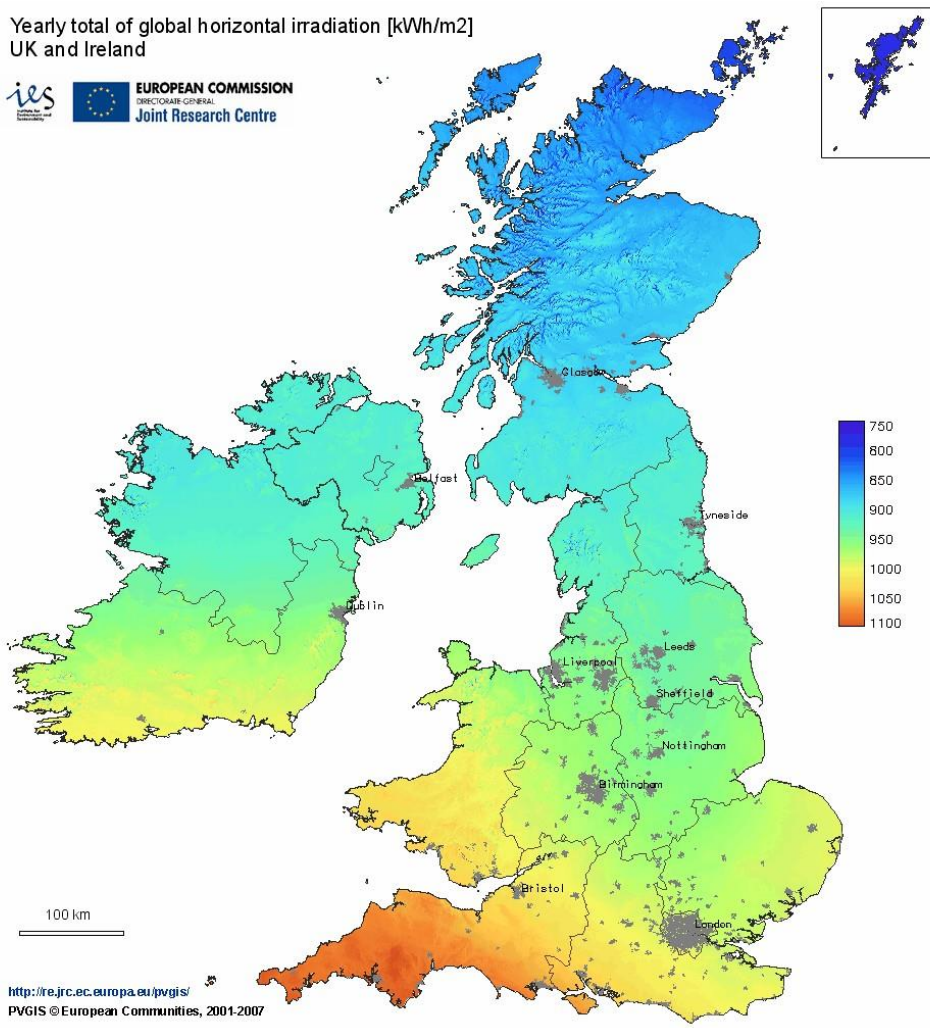


Fig. 1. Yearly total GHI in the United Kingdom – the map is taken from the European Commission Joint Research Center [16]

2. Data Gathering and Analysis Methods

The data used in this paper is based on three years of solar resource measurements (Global Horizontal Irradiance [GHI], Diffuse Horizontal Irradiance [DHI], and Direct Normal Irradiance [DNI]) and the average ambient temperature. The atmospheric data is collected by a subset of the weather stations distributed across the UK, this section briefly describes the network instrumentation and design, along with the data collection process.

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

- Support the growth 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

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 up to 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:

- <u>Direct normal irradiance (DNI):</u> the direct radiation available from a 5º 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 Concentrating Photovoltaic (CPV) systems [18] and Concentrating Solar Power (CSP) [19].

- <u>Diffuse horizontal irradiance (DHI):</u> the scattered solar radiation from the sky 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], and daylighting architectural design applications.

- <u>Global horizontal irradiance (GHI):</u> 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 [22].

A total of twenty weather stations are in operation in the studied areas. The list of the stations and their locations are listed in Table 1. In this work, the locations have been studied in different parts of the United Kingdom, we have examined 15 weather stations in England, 2 weather stations in Wales, and 3 weather stations in Scotland. The overall distribution of the weather stations is shown in Fig. 2.

Table 1 Details on weather stations used in various locations

Site Location	Site Number	Site Name	Latitude	Longitude	Elevation
	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
England	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
	18	Glasgow	55.857	-4.244	29
Scotland	19	Edinburgh	55.950	-3.191	72
	20	Aberdeen	57.148	-2.093	53

Fig. 2. Distribution of weather stations in the studied locations

Each weather station comprises various sensors which measures the following environmental parameters:

- Wind speed, range: 2 to 150 mile per hour (mph)
- Wind direction
- Temperature, range: -40 ºC to 65 ºC
- Relative humidity, range: 0% to 100%
- Rainfall in mm or inches
- Solar irradiance (DNI, DHI, and GHI), range: 0 W/m^2 to 2000 W/m^2

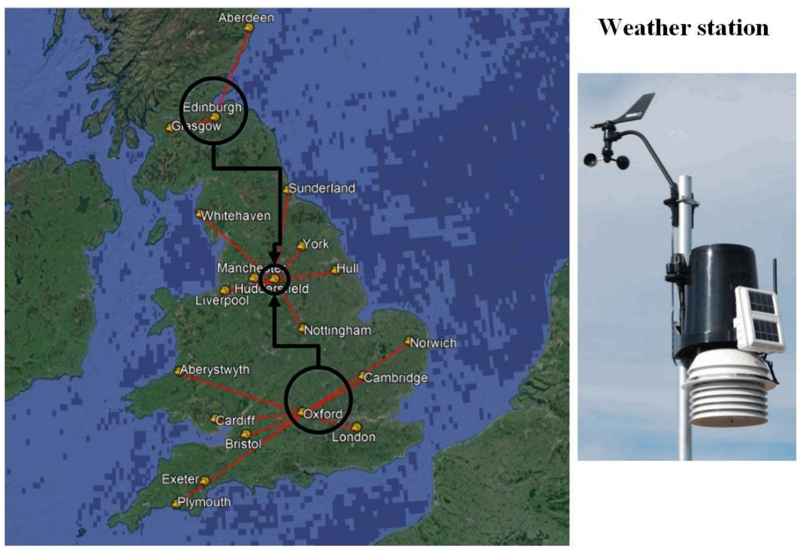
These weather stations are wirelessly connected to a monitoring unit called Vantage Pro2 which is accessible using an IP address from the Huddersfield site. The connection network is shown in Fig. 3(a). As can be noticed, there are two main sub-stations located in Oxford and Edinburgh which gather the data from different locations. All data is gathered at the Huddersfield site, where the analysis process is preformed, as presented in Fig. 3(b).

In fact, a proper operation and maintenance of the used weather stations, along with documentation of these practices, is critical for constructing reliable weather measurements. We have 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 [23] and [24]; the instruments will be sent to the manufacturers to perform the calibration.

Moreover, additional data may be relevant to forecast the effectiveness of solar energy exploitation such as wind velocity (which may affect temperature and efficiency of PV modules and also that of solar thermal panels), humidity or water vapor pressure (which may affect the spectrum of solar and, consequently, the efficiency of PV panels based on different technologies). These factors (Wind velocity and Humidity) are covered in this article, particularly in section 3.3.

The data at Huddersfield site were analysed to determine trends and patterns by station and region. The average yearly total solar radiation (in kWh/m^2) was calculated for GHI, DNI, and DHI, to assess the overall magnitude of the solar resource at each site and within each region. The values of maximum and minimum yearly total solar radiation (GHI, DNI, and DHI), along with the average total GHI and DNI, were analyzed to identify resource variability and temporal patterns. In addition, the average ambient temperature, wind speed and humidity among all studied locations were also examined.

In this article, the data measurements for all weather stations were analysed, logged, and compared over the period from January 2015 to the end of December 2017 (3 years).



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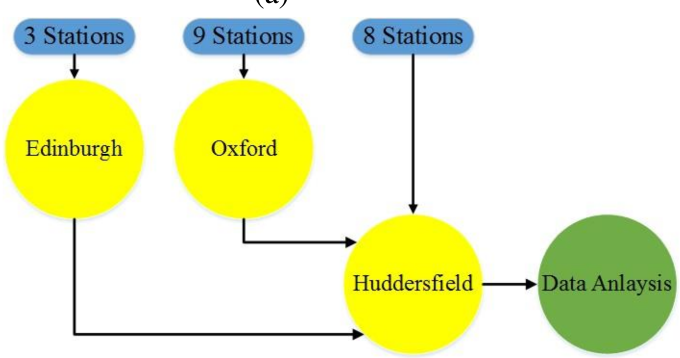


(b)

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

3. 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.

1.1Solar Irradiation and Ambient Temperature in England and Wales

In this section, the weather stations placed in various locations in England will be compared. As stated earlier in section 2, the data is captured over a period of three years (2015 to 2017). The yearly average GHI, DNI, DHI, and ambient temperature is reported in Tables 2 to 4; Table 2 summaries the measurements in 2015, Table 3 corresponds to data captured in 2016, and finally Table 4 summaries the measurement in 2017.

Since the GHI is the addition of DNI and the DHI with respect to the incident angle (θ) of the irradiance, we will analyse and compare the investigated locations based on the GHI, and average ambient temperature. The GHI is calculated using (1).

$$\text{Global Horizontal (GHI)} = \text{Direct Normal (DNI)} \times \cos(\theta) + \text{Diffuse Horizontal (DHI)} \quad (1)$$

It is noticeable from Tables 2 to 4, that the maximum observed GHI is at Plymouth city, whereas London is ranked the second, where the GHI of 98 KWh/m^2. The minimum irradiance level over the studied period (3 years) is observed for Huddersfield town with an average of 84.6 kWh/m^2 yearly. The second minimum GHI is observed for the weather station mounted in Sunderland city, where the average GHI over the studied period is equal to 85.6 kWh/m^2.

On the other hand, the highest average ambient temperature between 2015 and 2017 among all studied locations in England is obtained at Plymouth (average ambient temperature 12.2 ºC). The second highest average ambient temperature is found in Liverpool city, with an approximate of 11.7 ºC. However, Sunderland had the lowest average ambient temperature between 2015 and 2017, which is equal to 9.1 ºC.

In northern regions of England, the yearly GHI is relatively low, compared to southern regions. For example, York, Manchester, Huddersfield, and Sunderland have a yearly average GHI below 90 kWh/m^2. However, if we select southern locations such as Plymouth, Exeter, and London, the yearly average GHI is above 95 kWh/m^2. The map in Fig. 4(a) illustrates the geographical distribution of the yearly average GHI in all studied locations in England.

The annual average ambient temperature detected by the weather stations in England is geographically mapped and presented in Fig. 4(b). It is evident that Plymouth has the maximum yearly average temperature competed to all other locations. In fact, the distribution of the temperature varies in different areas of England, for example, Sunderland city has an average yearly temperature of 9.1 ºC, whereas Whitehaven is around 11.2 ºC. Both cities are 144 km apart.

Out of all examined locations in England, Plymouth had the highest yearly average GHI, whereas Huddersfield had the lowest level. The maximum GHI is detected by Plymouth weather station in June 2015 at 204 kWh/m^2, the minimum GHI is observed in Huddersfield at 14.9 kWh/m^2, December 2016. With reference to the ambient temperature, Plymouth city had the highest levels, however, Sunderland had the lowest among all observed locations. The maximum and minimum monthly temperature is 17.2 ºC and 3.1 ºC, respectively.

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

Location	Average GHI (kWh/m^2)	Average DNI (kWh/m^2)	Average DHI (kWh/m^2)	Average Temp. (ºC)
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	Average GHI (kWh/m^2)	Average DNI (kWh/m^2)	Average DHI (kWh/m^2)	Average Temp. (ºC)
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

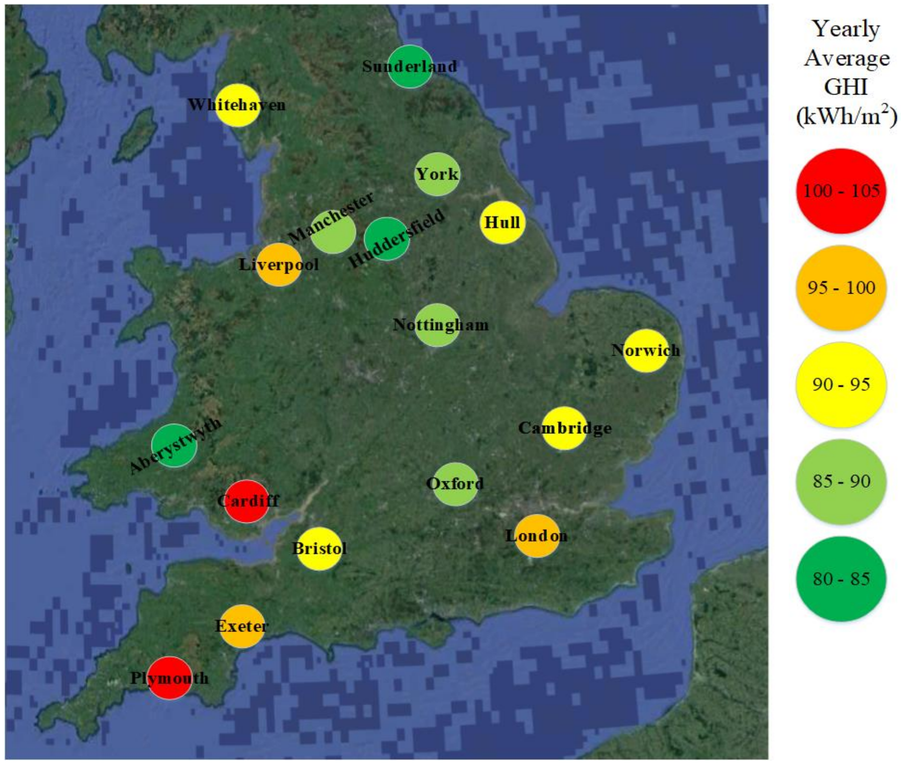
Location	Average GHI (kWh/m^2)	Average DNI (kWh/m^2)	Average DHI (kWh/m^2)	Average Temp. (ºC)
Plymouth	101	100	50	12.1
Exeter	95	85	53	11.6
Bristol	91	81	51	11.6
Oxford	89	78	52	10.3
London	95	88	51	10.9
Cambridge	90	82	51	10.7
Norwich	92	85	50	10.8
Nottingham	88	79	50	10
Liverpool	96	97	48	10.6
Manchester	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

In Wales, two weather stations have been installed, the first is located in Cardiff and the second at Aberystwyth. The distance between the weather stations is 92.4 km. A summary for the yearly average solar irradiance and ambient temperature are reported in Table 5. As can be noticed, Cardiff has a much higher yearly average solar irradiance over the last three years. In addition, the variations of the temperature are comparatively identical.

In fact, Cardiff ranked the second in terms of the yearly average GHI compared to all other observed sites considered in this work (including England, Wales, and Scotland locations), the first site which has the maximum yearly average GHI has been already discussed in the previous section, Plymouth. The assessment for all observed locations will summarized briefly later on in section 4.

Table 5 Summary of the average solar irradiance and ambient temperature in Wales

Year	Location	Average GHI (kWh/m^2)	Average DNI (kWh/m^2)	Average DHI (kWh/m^2)	Average Temp. (ºC)
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



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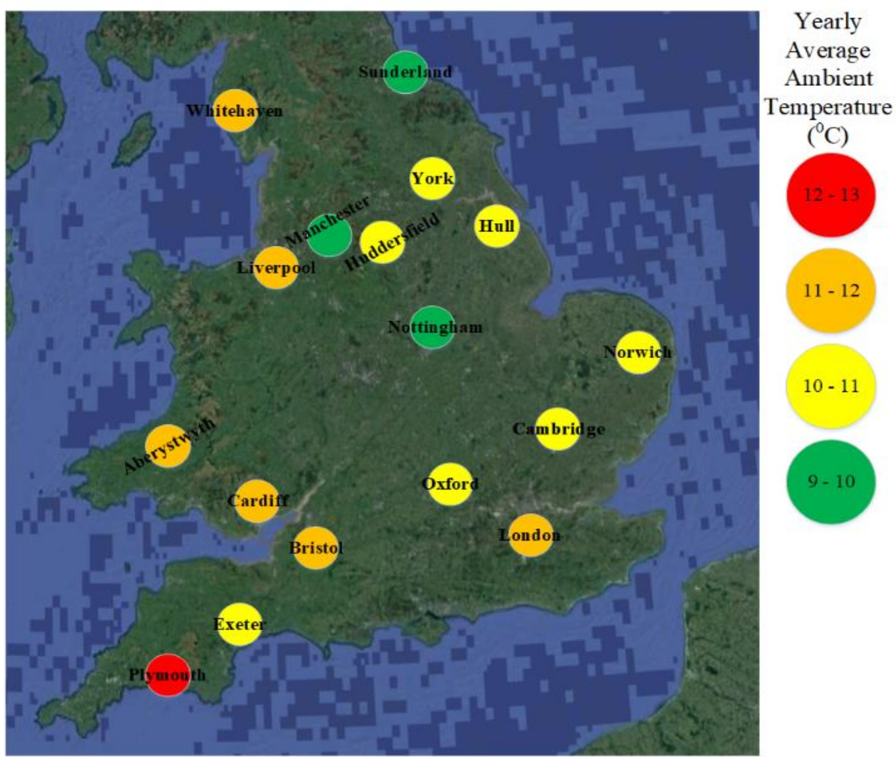


(b)

Fig. 4. (a) Distribution of yearly average GHI for the studied locations in England and Wales, (b) Yearly average ambient temperature in 15 different locations in England and 2 locations in Wales

1.2 Solar Irradiation and Ambient Temperature in Scotland

In Scotland (north of the United Kingdom), three weather stations data have been inspected. The first is located in Edinburgh (capital of Scotland), whereas the second and third are sited in Glasgow, and Aberdeen. The distance between the weather stations between Glasgow and Edinburgh is around 70.4 km. However, the distance is much longer between both weather stations fitted in Edinburgh and Aberdeen; 154.7 km. The distance from each weather station is labeled in Fig. 5(b).

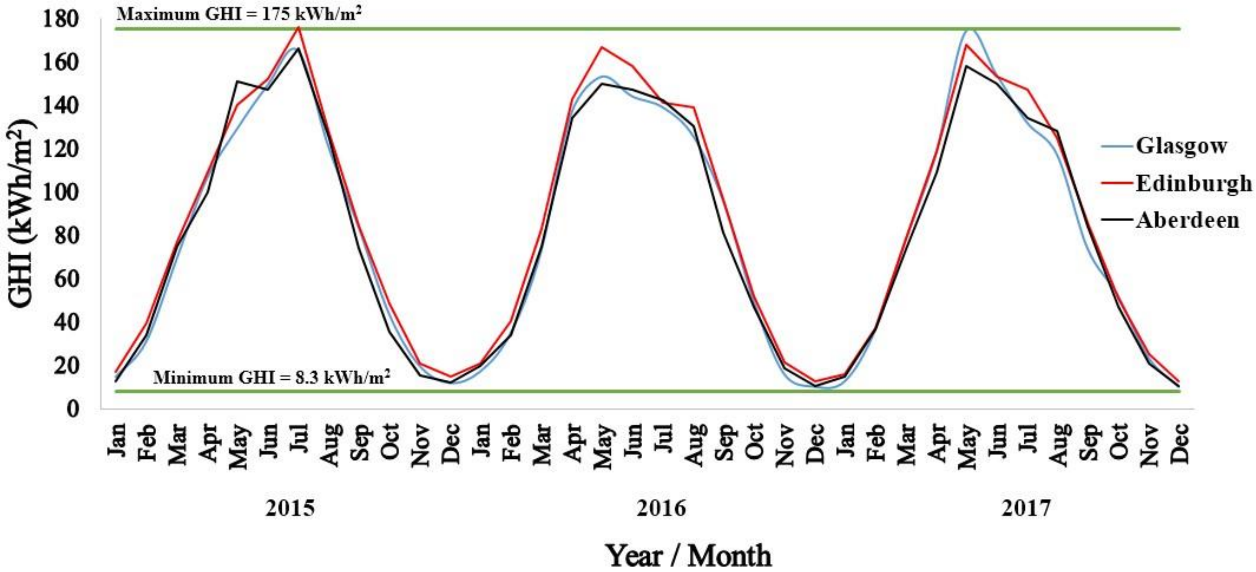
Table 6 summaries the solar irradiance and ambient temperature in the observed locations between 2015 and 2017. It is evident that Edinburgh has the highest yearly average GHI, whereas the second is Glasgow. For more data remarks, Fig. 5(a) presents the average monthly GHI detected by the weather stations. From the observed data measurements, it was found that over the considered study period, Edinburgh and Glasgow reaches the maximum GHI at 175 (kWh/m^2), this data is presented in Fig. 5(a). Edinburgh weather station detected this data in July 2015, however, the weather station in Glasgow detected this measurement last year in May 2017.

Table 6 Summary of the average solar irradiance and ambient temperature in Scotland from 2015 to 2017

Year	Location	Average GHI (kWh/m^2)	Average DNI (kWh/m^2)	Average DHI (kWh/m^2)	Average Temp. (ºC)
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

Approximately all locations have identical average ambient temperature over the considered period. Fig. 7(b) illustrates the yearly average ambient temperature observed by the weather stations, which can be classified as follows (maximum to minimum):

- Glasgow: 9.6 ºC
- Aberdeen: 9.2 ºC
- Edinburgh: 9.1 ºC



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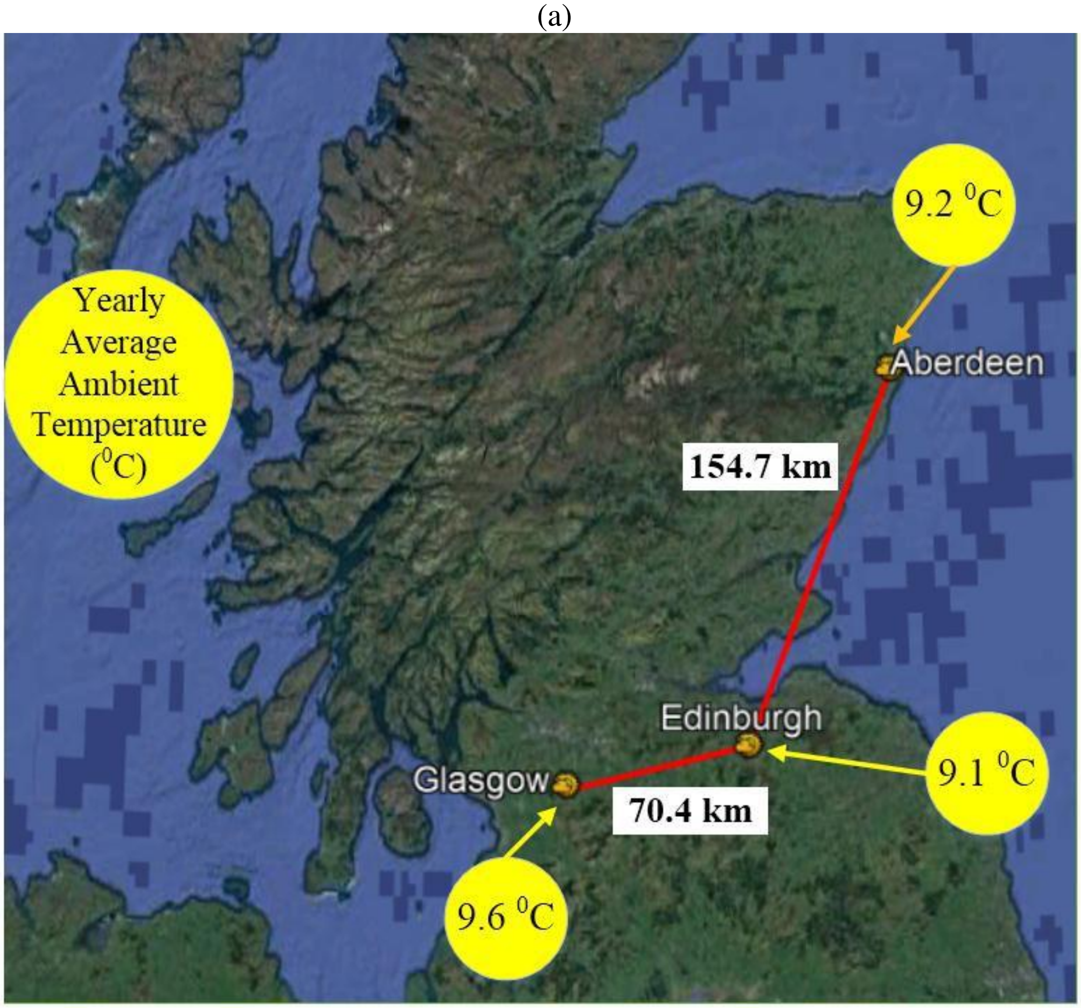

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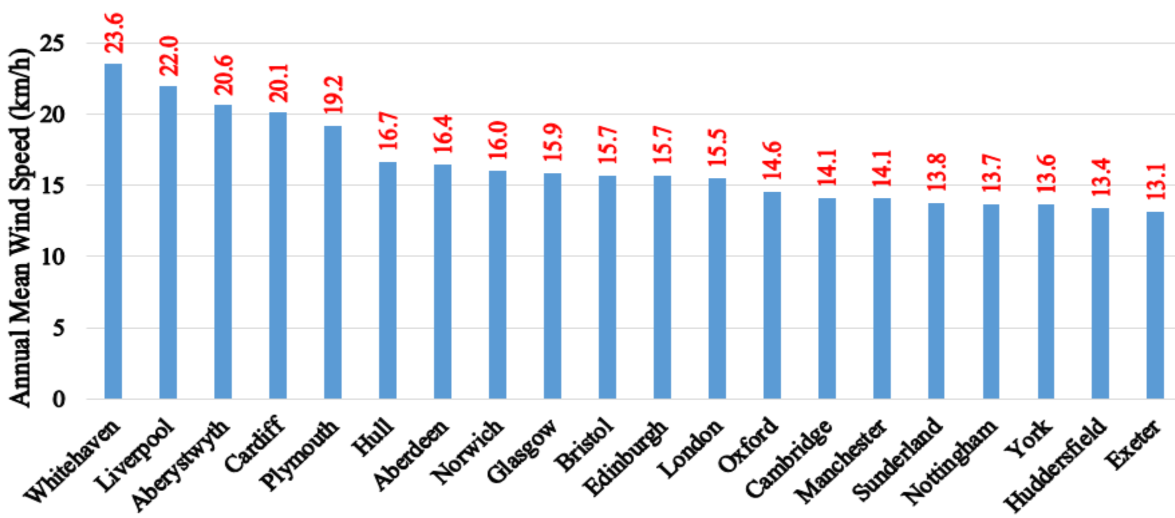
Fig. 5. (a) Monthly average GHI for three examined locations in Scotland, (b) Yearly average ambient temperature for the examined locations in Scotland

1.3 Wind Speed and Humidity

The wind speed and humidity in all studied locations are summarized in Fig. 6. The annual mean of the wind and humidity are taken over a period of three years: 2015 to 2017, where the wind speed is in km/h, while the humidity is presented in percentile.

As presented in Fig. 6(a), costal locations such as Whitehaven, Liverpool, Aberystwyth, and Plymouth had the highest annual mean wind speed ranging from 23.6 km/h to 19.2 km/h. Locations sited in middle of the UK such as Manchester, Nottingham, Huddersfield, and York had always an annual mean wind speed below 14.5 km/h.

Fig. 6(b) presents that the annual mean humidity in almost all locations are ranging from 85% to 80%. The highest annual mean humidity is detected in Glasgow at 84.5%, while the lowest is observed in Whitehaven and Sunderland at 77%.



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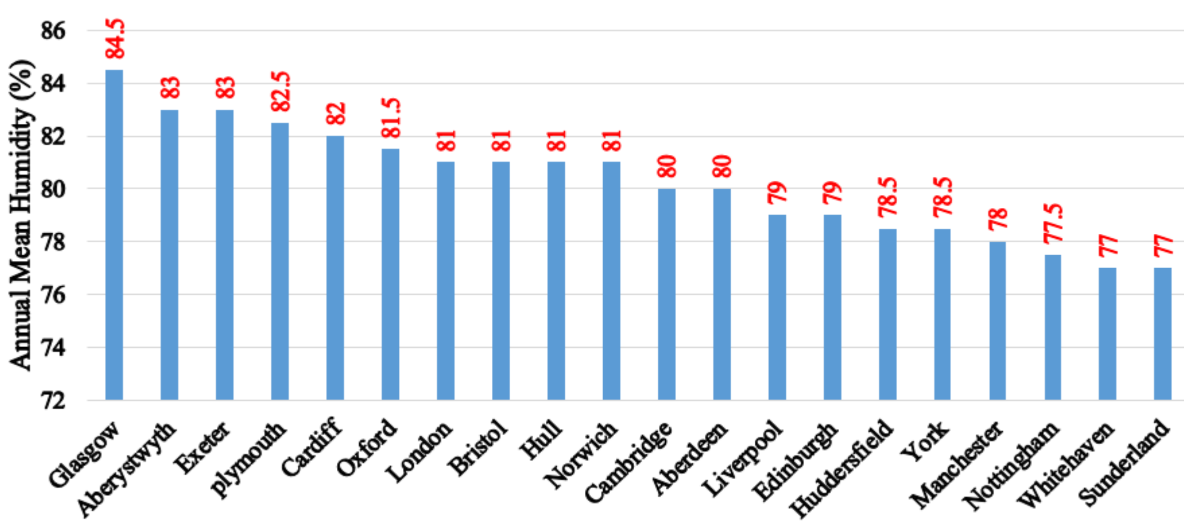


(b)

Fig. 6. (a) Annual mean wind speed (km/h) (b) Annual mean humidity (%)

4. Overall Assessment for Solar Irradiance and Ambient Temperature: compared with data observed by the European Commission Joint Research Center (JRC)

In order to draw a relevant assessment for the entire presented results, all studied locations have been compared, and analysed based on the average GHI and ambient temperature. The results are illustrated in Fig. 7.

Fig. 7(a) presents a geographical map for the yearly average GHI for all studied locations during the considered period (January 2015 – December 2017). As can be noticed, Plymouth (located in southwest England) has the dominant GHI with annual estimate of 103 kWh/m^2. The least GHI is observed for Aberdeen (located in northeast Scotland), the data collected from the weather station sited in Aberdeen shows that the average annual GHI is equal to 77.3 kWh/m^2.

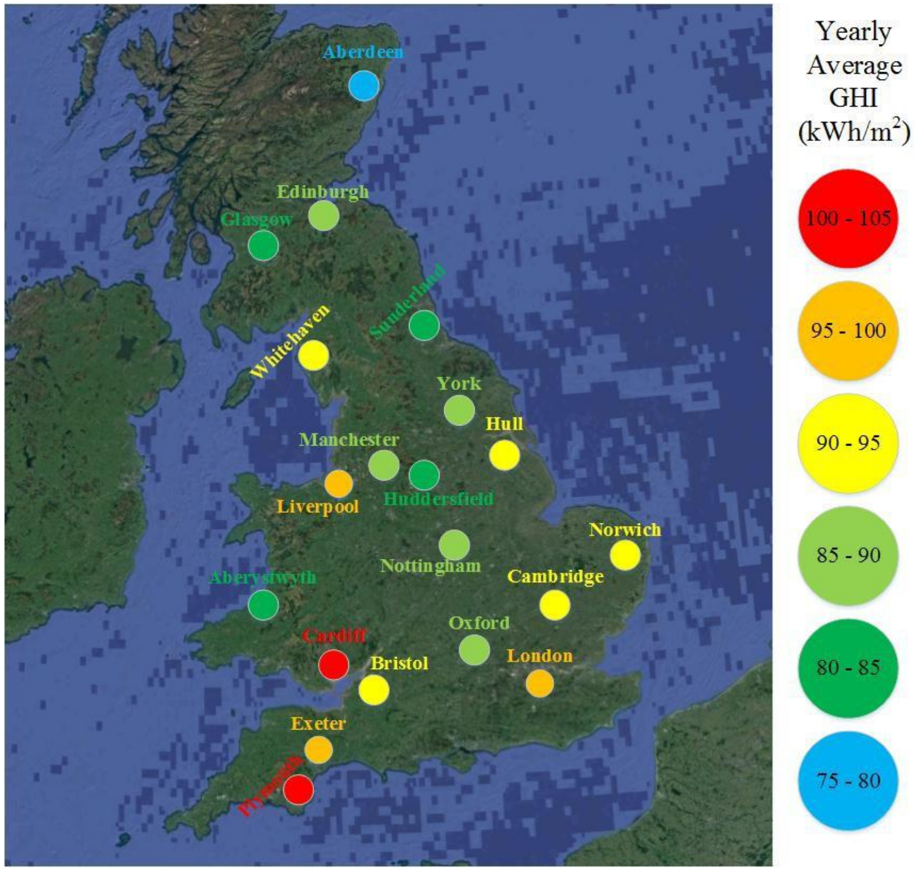
On average, it is evident that the middle region of England, containing Oxford, Nottingham, Huddersfield, and Manchester, relatively have low yearly GHI. On the other hand, London, northeast London, and southwest England have high irradiance profile, this is summarized in Fig. 7(a) by the yearly average GHI in the following locations:

- Plymouth: 103 kWh/m^2
- London: 99.8 kWh/m^2
- Exeter: 95.3 kWh/m^2
- Bristol: 93 kWh/m^2
- Norwich: 92.4 kWh/m^2
- Cambridge: 90.5 kWh/m^2

The yearly average ambient temperature in all 20 locations is summarized in Fig. 7(b). The least average ambient temperature is detected by the weather station in Scotland (Edinburgh), where the annual average ambient temperature is 9.1 ℃. However, the highest ambient temperature profile is detected in Plymouth, where the annual temperature is equal to 12.2 ℃. The second highest annual ambient temperature is observed in London at 11.7 ℃.

The middle and east locations of England had an annual ambient temperature always below 11 ℃. Whereas the west regions of England have an annual ambient temperature between 11 – 12 ℃. Six locations had relatively low ambient temperature among the three years of the study, the annual ambient temperature for these locations are summarized as follows:

- Edinburgh: 9.1 ℃
- Sunderland: 9.2 ℃
- Aberdeen: 9.2 ℃
- Glasgow: 9.6 ℃
- Manchester: 9.8 ℃
- Nottingham: 9.9 ℃



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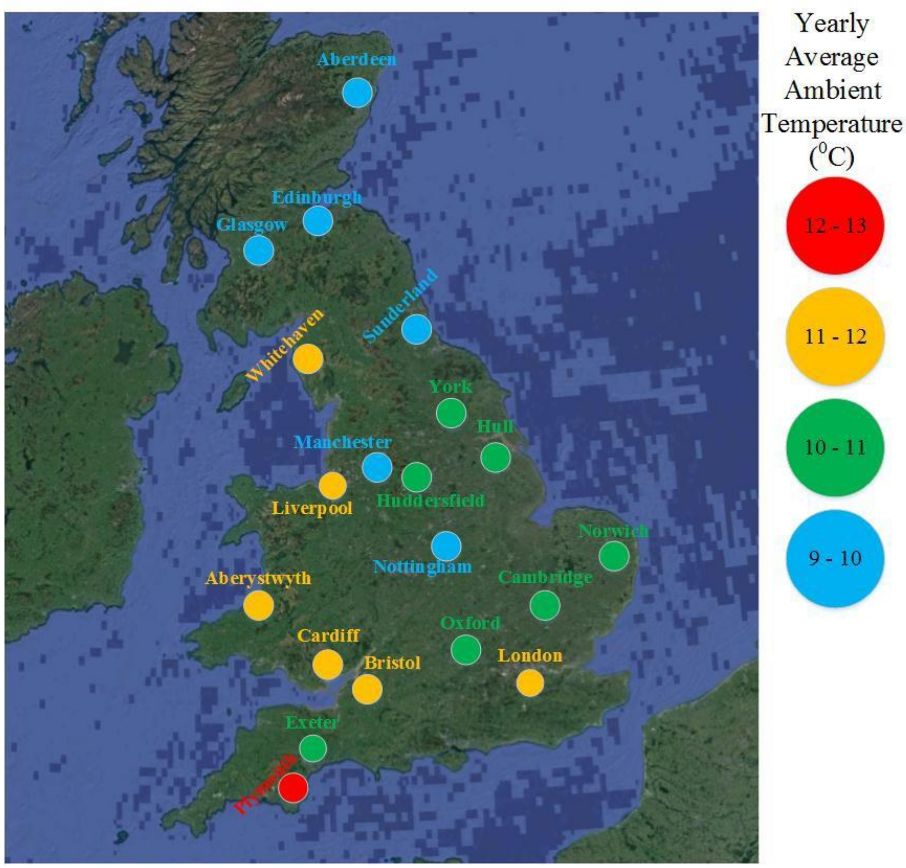

(b)

Fig. 7. (a) Distribution of yearly average GHI for the studied all locations, (b) Yearly average ambient temperature in all studied locations

A comparison between the obtained results found in this research with data gathered by the European Commission (UC) Photovoltaic Geographical Information System (PVGIS) [25] has been analysed. Only the GHI and ambient temperature is compared, since the PVGIS does not have valid data for the wind speed and humidity across the studied locations.

Table 7 summarizes the results of the GHI and ambient temperature for all studied locations. Remarkably, it was found that the rank (highest to lowest) obtained for both the GHI and ambient temperature in this article are almost identical with those obtained by the PVGIS. Accordingly, this results confirms the applicability and accuracy of (i) sensors integrated in the weather stations, (ii) sampling rate used "1 sample/second", and (iii) the site of the weather station do not need to be modified or changed.

Furthermore, Table 7 confirms that the optimum city with the highest GHI is Plymouth estimated at 102.5 - 103.0 KWh/m^2, whistle Aberdeen located in Scotland had the lowest at 76.6 - 77.3 KWh/m^2. Moreover, Plymouth had the highest ambient temperature around 12.2 - 12.4 ºC, while the lowest with ambient temperature is measured in Edinburgh at 9.1 – 9.2 ºC.

Table 7 Comparison between results obtained in this article with results gathered by the European Commission PVGIS [25] from 2015 to 2017

GHI rank by location (highest to lowest)	Obtained results in this article (KWh/m^2)	Obtained results by the European Commission PVGIS [25] (KWh/m^2)
Plymouth	103.0	102.5
Cardiff	100.3	99.7
London	96.7	96.5
Liverpool	95.7	95.5
Exeter	95.3	95.4
Whitehaven	94.3	95.1
Hull	93.7	93.7
Bristol	93.0	93.2
Norwich	92.3	92.1
Cambridge	90.3	91.2
Oxford	90.0	89.8
Nottingham	88.7	89
York	86.7	86.6
Manchester	86.0	86
Edinburgh	86.0	85.7
Sunderland	85.7	85.5
Huddersfield	84.7	84.4
Aberystwyth	84.0	83.9
Glasgow	81.3	82.1
Aberdeen	77.3	76.6

Ambient temperature rank by location (highest to lowest)	Obtained results in this article (ºC)	Obtained results by the European Commission PVGIS [25] (ºC)
Plymouth	12.2	12.4
London	11.7	12.1
Liverpool	11.7	12
Aberystwyth	11.7	11.8
Cardiff	11.6	11.5
Whitehaven	11.2	11.2
Bristol	11.0	11.1
Hull	11.0	11
Huddersfield	10.8	10.9
Cambridge	10.8	10.9
Exeter	10.5	10.5
Oxford	10.4	10.3
Norwich	10.2	10.1
York	10.2	10.1
Nottingham	10.0	9.9
Manchester	9.9	9.9
Glasgow	9.6	9.5
Aberdeen	9.2	9.4
Sunderland	9.2	9.4
Edinburgh	9.1	9.2

5. Conclusion

This paper presents a detailed assessment for 20 weather stations data installed at different locations in England, Scotland, and Wales. This resource monitoring network has been specifically designed to meet the objective of improving available data and models of solar resources in the United Kingdom 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 paper summarizes the data measurement over three years, specifically January 2015 to the end of December 2017. The data analysis has been carried out at Huddersfield Town site. A detailed assessment for the yearly average global horizontal irradiance (GHI) and ambient temperature are investigated.

It was found that Plymouth (located in southwest England) has the dominant GHI, and ambient temperature among all other 19 locations. The least GHI is observed for Aberdeen (located in northeast Scotland) which is equal to 77.3 kWh/m^2. The least average ambient temperature has been analysed for the capital of Scotland (Edinburgh y), the observed average temperature by the weather station over three years is equal to 9.1 ºC.

Costal locations such as Whitehaven, Liverpool, Aberystwyth, and Plymouth had the highest annual mean wind speed ranging from 23.6 km/h to 19.2 km/h. Locations sited in middle of the UK such as Manchester, Nottingham, Huddersfield, and York had always an annual mean wind speed below 14.5 km/h. On the other hand, the highest annual mean humidity is observed in Glasgow at 84.5%, while the lowest is observed in Whitehaven and Sunderland at 77%.

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

This paper represents only a segment of examination that can be done with the dataset and of other research on solar resources in the United Kingdom. As the next stage, detailed analysis could be done at each station location combined with local knowledge and other environmental datasets, and comparison could be made to other solar resource assessments in the region (probably in Europe). Also, the Clearness Index could be calculated for each station, to further identify seasonal and regional patterns.

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