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The UK solar energy resource and the impact of climate change

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ABSTRACT

Solar energy use in the UK is increasing dramatically, providing both heat energy and generation of electricity. This trend is expected to continue due to solar technologies becoming cheaper and more readily available along with low carbon government legislation such as the Renewable Heat Incentive (RHI) and Feed in Tariffs (FiTs) supporting solar energy deployment. However, the effects of climate change on the solar resource remain largely unstudied. Climate change affects cloud cover characteristics and consequently directly affects the performance of solar energy technologies.

This paper investigates the UK solar irradiation resource for both the present and future climates.

The present solar irradiation level was assessed through the conversion of 30 years of observed historical monthly average sunshine duration data. The method and results are validated by comparing the converted solar irradiation levels to actual solar irradiance measurements at weather stations with significant historical records of solar irradiance data.

The impact of climate change is investigated across different regions of the UK by using the UKCP09 probabilistic climate change projections.

We find that the current average UK annual solar resource is 101.2 Wm^{-2}, ranging from 128.4 Wm^{-2} in the south of England to 71.8 Wm^{-2} in the northwest of Scotland. It seems likely that climate change will increase the average resource in the south of the UK, while marginally decreasing it in the Northwest. The overall effect is a mean increase of the UK solar resource, however it will have greater seasonal variability and discrepancies between geographical regions will be reinforced.

1. Introduction

The UK has a target to meet 15% of its energy consumption from renewable sources by 2020 [1]. In order to achieve this, the generation capacity from renewable sources is increasing rapidly. Currently wind is the dominant renewable energy source in the UK, however the solar resource is huge and solar energy use in the UK is increasing (at the end of 2012 totalling 1.8 GW of PV capacity with 925 MW installed in 2012 [2]). Solar PV is commonly deployed in commercial and domestic buildings, and it offers the most appropriate source of distributed renewable energy generation in urban areas, due to the ease of incorporating solar PV into building materials. Small scale solar PV generation also qualifies for the FITs scheme, a government incentive to increase energy production from renewable energy. Solar PV converts global solar irradiance into electricity via the photo-generation of charge carriers in a semi-conducting material such as silicon.

It is ironic that much of the motivation to use renewable sources of energy generation comes from the desire to mitigate climate change, and climate change directly affects renewable energy resources. In the case of solar energy, cloud cover is the most important property of the climate to consider. Human activity causing an increase in atmospheric particles (aerosols) can in turn increase cloud cover by providing greater numbers of cloud condensation nuclei. Global solar irradiance levels depend on the cloud cover characteristics, and therefore will change due to climate change.

When considering solar energy as a sustainable energy solution it is therefore important not only to quantify the present solar resource but to try and anticipate how the solar resource will change along with any climate change in the future.

The UK Climate projections UKCP09 [8] have been designed to show how the future climate may differ (from the current climate) due to the past and current levels of greenhouse gas emissions. The projections offer 3 different future climate scenarios corresponding to Low, Medium and High greenhouse gas emissions, with the output for each scenario being a normal distribution of the change in the desired variable. In this manner probability levels can be

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associated with a certain change (here we use 10%, 50% and 90% probability levels). The climate projection variables include the change in downward surface shortwave radiation flux (Wm^{-2}).

There has been some previous work to try and gauge the effects of climate change on solar energy. Ref. [3] examines global changes in PV and concentrated solar power outputs, using two climate change models (HadGEM1 and HadCM3) and a single emissions scenario. They conclude that CSP is more sensitive to climate change than PV and overall solar power from 2010 to 2080 will increase a few percent in Europe and China, stay similar in Algeria and Australia and decrease by a few percent in USA and Saudi Arabia. Ref. [6] investigates the uncertainty in long term solar resource datasets is the U.S., highlighting the seasonal components in the solar resource, aiming to provide a better understanding of the solar resource for particular applications. Ref. [9] uses a regional climate change model and suggests that seasonal-mean daily global irradiance in the US may decrease by up to 20% by the end of the 2040's. Recent work by Ref. [24] reviews the adaptability to climate change of California's electricity sector as a whole. Similar work has been done relating to wind energy, e.g. [12] reviews the mechanisms by which wind energy can interact with climate change, focussing on Northern Europe, and conclude that in the near term (up to 2050's) climate change will have little effect compared to natural variability. Ref. [13] characterises the UK wind resource by examining recent trends in wind speed measurements, but does not discuss climate change. There is relatively little available literature relating to the UK solar resource and the impact of climate change on this resource. In this work we characterise the UK solar resource providing a detailed assessment. Then combining this with the UKCP09 outputs, we examine the effect of climate change to give estimates of the future UK solar resource, in order to inform PV manufacturers, developers and policy makers alike.

2. Method

2.1. Baseline resource assessment

A UK solar resource assessment of the present climate would ideally be performed using solar irradiance historical measurements. However, there are very few weather stations that have sufficiently long historical solar irradiance observation data to be of use for evaluation over a 30 year time period.

Solar irradiance is measured using Pyranometers or Pyrheliometers. Pyranometers measure horizontal solar irradiance (global solar irradiance) while pyrheliometers measure direct normal solar irradiance. The former are more commonly deployed in the UK, and are more relevant to solar PV as it utilises both diffuse and direct solar irradiance. Solar irradiance can also be indirectly calculated from sunshine duration observation measurements. Sunshine duration is more commonly measured at weather stations; the measurement device is a Campbell Stokes Sunshine Recorder which has been in use since the late nineteenth century. Hence there is a long historical time series of available data at many UK locations.

The Met Office has developed UK gridded observed sunshine duration data sets which are based on observations from an average of 290 weather station locations across the UK [10,11]. This data has been used to develop annual monthly average 5 km × 5 km gridded data sets of daily sunshine duration over the UK. The gridded data sets cover in excess of 30 years and were used as the main source of observed sunshine duration. Here, the sunshine duration data was converted to solar radiation using a method described by Ref. [14] and then averaged over a 30 year baseline period (1961–1990). Verification of the conversion method was achieved by comparing the converted data with actual observed solar irradiation data from several locations across the UK (weather stations which have pyranometers).

The baseline resource is essentially an estimation of the UK solar resource for the current climate. It is averaged over a 30 year period to remove inter-annual variability. The baseline period of 1961–1990 has been chosen to match the baseline period used by UKCP09.

Satellite inferred solar irradiance data for Europe is also available (e.g. Ref. [19]) and provides a very useful resource for the analysis of large regions, especially where ground based measurements are sparse. However for this study there were a number of reasons why it was not used. In order to best project outputs from the UKCP09 model on to a baseline solar resource, the baseline was generated using observations from the same time period as used by the UKCP09 model (1961–1990) for which satellite data was unavailable. Satellite inferred data is also less accurate than ground based measurements when met stations are close together (especially so during winter months due to difficulty in the satellite models of distinguishing frost, low-cloud, fog and snow etc) and it also has a lower spatial resolution than the gridded met office data. Significant discussion about how well satellite inferred data fits with observed ground measurements can be found in Ref. [23].

An accurate UK solar energy baseline resource map was created by converting a 30 year time series of monthly average daily sunshine duration observation data sets to solar irradiance.

2.2. Observation data

The ‘UKCP09: Gridded observation data sets’ were created primarily to assist with research into climate change and adaptation. They include sunshine duration data for the UK with a resolution of 5 km × 5 km for the 1961–1990 baseline time period. The raw data has been subjected to regression and interpolation to generate regular values from the irregular station network, and the dataset output also accounts for other attributes such as location, altitude, terrain, coastal influence, and land use [10,11].

The UK 5 km gridded sunshine duration data was converted to global irradiance using a method introduced by Ref. [14]. This is based on the widely used Angstrom–Prescott equation which describes a relationship between the relative sunshine duration and solar irradiance on the surface of the earth. (See Ref. [7] for a historical appraisal of the evolution of the Angstrom–Prescott equation). There have been several studies that have tested Suehrcke's sunshine duration to radiation relationship with favourable results. Ref. [4] tests the Suehrcke relationship, concluding that it is of ‘prime interest’ due to ‘its simplicity and the elegance of its derivation’ and that it is adequate but no more accurate than the Angstrom-Prescott method at estimating monthly average values. Ref. [18] found Suehrcke's relationship to give slightly better accuracy than the Angstrom–Prescott method.

The advantage that the Suehrcke method has over the Angstrom–Prescott method is that it does not rely on two empirically derived, location specific constants. Instead, the Suehrcke method requires only an estimate of the monthly average daily clear sky clearness index. Ref. [14]. states the value as being ‘typically between 0.65 and 0.75’. The next section briefly outlines the Suehrcke conversion method.

2.3. Suehrcke conversion method

Monthly average daily sunshine duration data was converted to solar irradiance using Suehrcke's derived equation relating the sunshine fraction to monthly average of daily horizontal extraterrestrial solar radiation [14]. The process of relating sunshine hours to solar irradiance on a horizontal plane requires the