Climate change impacts on renewable energy - is it all hot air?

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Abstract

The harnessing of renewable energy sources is vital to constraining the extent of climate change. However, the very fact that such sources are driven by the climate may leave them exposed as climate changes over the coming decades. The impacts will manifest themselves through changes in resource, altered operational capability and impacts on economic performance. With the electricity industry increasingly market-based it is the latter impact that will be of most concern to would-be investors. This paper reviews the current level of understanding of climate change and the potential implications for a range of renewable energy sources including hydropower, wind and wave.

1 Introduction

Global energy demand is expected to increase threefold over the twenty-first century [1]. Consequently, greenhouse gas concentrations look set to rise significantly with the prospect of up to 5.8°C greater global mean temperatures by 2100 [2]. The impacts of such changes will be significant and far-reaching and have prompted unprecedented international co-operation to control the rise in greenhouse gas concentrations. These targets, and, in future, even more challenging targets, will require the energy sector to reduce fossil-fuel use, use more renewable energy and practice greater energy efficiency.

While just over 20% of global demand is currently met by renewables (mostly hydropower) they could, potentially, meet up to 70% of demand by the end of the century [1]. Indeed, rising electricity demand, the likelihood of continuing increases in fossil-fuel prices as well as emissions trading all appear to favour renewables. However, there are several impediments to this. Firstly, the high capital costs of many renewables means that economic performance often appears inferior to conventional fossil-fuelled schemes, an issue that is particularly important in the deregulated industry. Secondly, the forecast changes in climate will directly affect the exploitation of renewable energy; this aspect is explored further here.

2 Climate Sensitivity of Renewables

In addition to the well known temperature projections, climate models suggest changes in a wide range of climate variables including precipitation, humidity, wind speed and cloudiness. With renewable technologies inherently reliant on the climate, changes will result in [3]:

1. changes in the quantity and timing of the renewable resource,
2. changes in operational performance and energy production, and
3. impacts on the 'willingness to develop' resources.

The changes in the resource will include shifts in the mean potential as well as altered variance. A further aspect is that, in many cases, climate change would appear to further enhance seasonal differences. Overall, the extent of changes will be dependent on the relationship between the resource potential and the driving climate variable(s); where power laws are involved, the changes in energy potential are likely to be disproportionately great. Figure 1 shows a stylised probability distribution of a renewable resource under current and an assumed future climate in which both the mean and the variance of the resource have increased. In this example the distributions are assumed to be Gaussian although for many renewables (e.g. wind speed) this is clearly not the case.

Renewable energy installations are generally designed or installed to suit prevailing climate conditions. They tend to be able to extract energy from a defined band within the overall range of conditions with the maximum level dictated by the rating of the power take-off equipment (generator) or the avoidance of damage. The minimum level may be dictated by control issues or the ability of the resource to overcome friction. Figure 1 shows an assumed operational range and the proportion of the distribution that falls within it. In this example the change in climate serves to decrease the probability of the resource falling within these bounds and increasing the likelihood of falling outside (as indicated by the hatched and greyed areas for current and future climates, respectively). The impact on overall energy capture will depend very much on the resource and, in particular, on power law relationships which for an example such as this might be expected to increase.

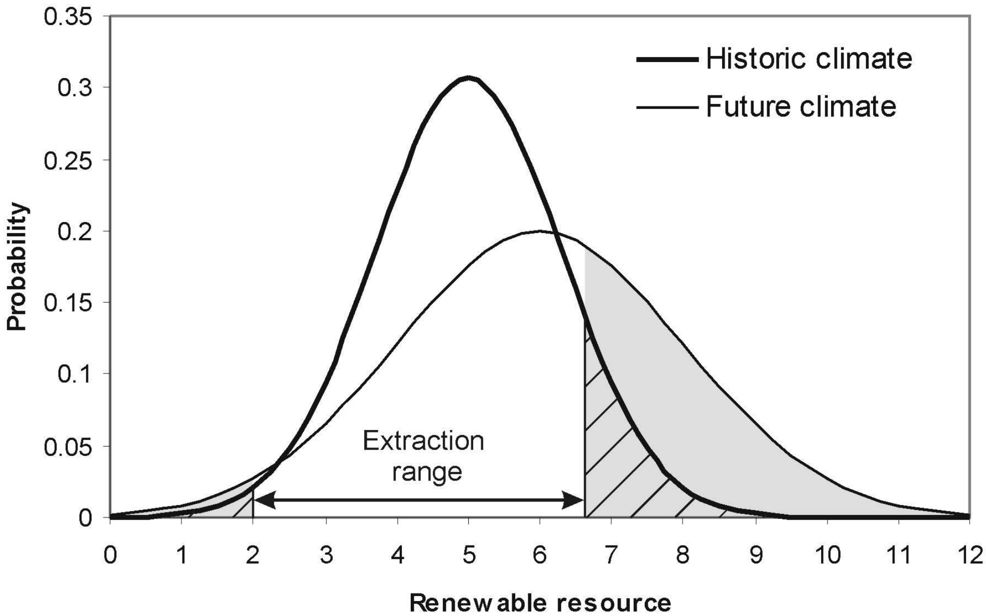

Figure 1: Renewable resource and extraction capability under historic and future climate

Changes in production levels will undoubtedly impact on the revenue earned, particularly when changes coincide with high price periods (e.g. winter in the UK). Despite low variable costs, adverse changes in revenue pose a potential risk to the ability of the renewable installation to service its relatively high capital debt. Support mechanisms such as the UK Renewables Obligation, that aim to make renewables more competitive by augmenting the revenue stream will tend to make the overall economics relatively more sensitive to changes in production. Changes in the revenue earning potential of schemes will clearly impact on investors' willingness to develop renewables as opposed to fossil-fuelled plant. Indeed the additional resource uncertainty that stems from potential climate change might appear to increase the potential risk for investors.

3 Brief Review of Impacts

Many renewable resources are potentially vulnerable to changes in climate and Moreno and Skea [3] provide a good overview of these. The extent and sophistication of analysis has tended to reflect the relative maturity of renewable technologies and their regional or system-wide importance. There is also a bias towards studies in developed counties, presumably as a result of greater availability of funding for such studies and data availability. Here hydropower, wind and wave power are briefly examined.

With large hydropower schemes of major importance in many electricity systems (e.g. Norway, Pacific Northwest), research on hydro impacts has tended to dominate the field. Hydropower appears to be relatively vulnerable because it is sensitive to the quantity, timing, and spatial pattern of precipitation as well as the influence of temperature on evaporation and the accumulation and melting of snow [4]. In particular and, despite production being a relatively linear function of river flow, projected changes in flow tend to be relatively greater than the driving change in precipitation [5]. While most studies have concentrated on the hydrological changes, a significant number have dealt with energy production changes and few – with exceptions, e.g., [6]-[7] – having considered the consequences for economic performance. Very limited consideration has been given to the implications for small-scale hydro [8].

With the growing importance of wind power, there have been an increasing number of studies looking at changes in wind speed and the impact on energy production [9]-[11]. Once again there is a relative dearth of information regarding economic performance [12]. A key outcome is that while there are clearly significant increases in energy capture with raised wind speeds, these are capped by the need for current generations of turbines to furl in high winds; this is clearly of interest given the projections of increasingly stormy weather in the UK and elsewhere.

Wave energy is now very much back on the agenda and with prototype devices on test in the UK and elsewhere, consideration [12] is being given to the potential impact of changes in the wave regime on production and the economics of converters. With waves being the product of local and distant wind activity and, with wave power proportional to the fifth power of wind speed, changes in wind speed will produce relatively large changes in available wave energy. The rich wave climate off Western Europe is heavily dependent on storm activity in the North Atlantic and there is evidence that storm intensity has been increasing in recent decades [13]; this is backed up by trends in mean and extreme wave heights [14], [15].

From the studies that consider economic implications – including those carried out by the authors [12], [16] – it appears that the economics of these three technologies are sensitive to changes in mean climate. In each case, the sensitivity of project returns to alterations in mean climate is comparable to, or in excess of, that associated with key project variables such as capital cost or discount rate. Given such sensitivity, further in-depth study of the financial risks posed by changing climate is clearly warranted.

4 Climate Change and Uncertainty

One of the key difficulties in exploring the climate change impacts on renewables is that one climate model may suggest negative impacts whilst others suggest positive changes. This creates uncertainty and may be attributed to [17]:

- future emissions uncertainty,
- climate modelling uncertainty,
- natural climate variations,
- renewable resource modelling uncertainty.

Future greenhouse gas emissions will depend on a wide range of socio-economic factors, not least the fuel mix of the electricity sector, itself dependent on these factors. In saying that, the difference in warming suggested under a wide range of emissions scenarios is relatively small up to 2040 as a result of the long effective greenhouse gas lifetimes, the inertia of the climate system and with much of the warming built-in due to current and recent emissions. The divergence in the latter half of the century is, however, strongly dependent on future emissions [17].

The largest uncertainties arise from the structure and processes within climate models and these give rise to the divergence in projections between different models [18]. In addition to representing aspects of the climate system (e.g. clouds) in different ways, the spatial refinement of models remains coarse. This is particularly important for precipitation projections and, accordingly, there is disagreement between models over the magnitude and direction of change. On the other hand, there is some degree of agreement over the magnitude of warming expected. The need for data at smaller spatial scales means that downscaling techniques tend to introduce additional uncertainties into the projections. While new techniques [19] are allowing the uncertainty in the Hadley model to be estimated, there remains a need to quantify the uncertainty across different climate models.

The third source of uncertainty in the projections of future climate is the natural climate variability which acts over annual and decadal scales. At a given point in time, these variations may either augment or detract from the changes resulting from anthropogenic climate change. Although this variability cannot currently be predicted, the range of uncertainty can be quantified by varying initial climate conditions [18].

The final source of uncertainty is introduced by the need for additional models to translate climate variables into estimates of renewable potential, e.g. the use of catchment or wind-wave models. However, in most cases this can be limited by the use of high quality models.

Overall, there is a ‘cascade of uncertainty’ surrounding future resource projections and the production and financial modelling based on them. Given this, what reliance can be placed on the forecasts and should they influence decisions about when, where and what renewable technology to deploy, if at all?

5 Developing Renewables under Climate Uncertainty

Every renewable development is assessed using forecasts that make assumptions about how the future will develop and deals explicitly (or otherwise) with uncertain factors such as interest rates, electricity demand, prices and competing generation technologies. While it is clearly an option to ignore climate change in appraising renewables, it is an interesting point that current project decisions are based on resource records that, to a greater or lesser extent, already include the early effects of climate change. Given this and, the apparent sensitivity of project economics to changing resources, it is not a particularly defensible approach. Climate change must now be included as one of the uncertainties facing developers of renewables but the question, ultimately is how best to incorporate it into decisions regarding renewable developments in a rational, defensible manner using the best available information.

In order to make decisions, uncertainty in forecasts is often addressed by conducting sensitivity analyses wherein the financial outcome of the project is tested by defined changes in individual project variables. Alternatively, scenario analyses provide a more sophisticated approach which tries to place bounds on aspects of the projected factors. Finally, probabilities can be assigned to key project variables and probabilistic forecasts of performance can be generated by Monte Carlo analysis. Application of these techniques to climate impact assessment is complicated not only by the difficulties in simulating future climate but also by the often non-trivial resource modelling. Despite this, examples of each approach do appear in the literature, although they are generally deficient in some manner.

The UK Climate Impacts Programme developed a general methodology for assessing climate risk and formulating adaptation responses [20]. This sets out a process (Figure 2) for exploring potential climate impacts and how best to account for them in investment, operational or policy decisions across a wide variety of sectors [20]. It includes four aspects:

1. Problem structuring to identify the problem and criteria of interest (stages 1 – 2)
2. Problem analysis to assess risk and identify and appraise options (stages 3 – 5)
3. Decision-making (stage 6)
4. Post-decision actions including the implementation and review (stages 7 – 8)

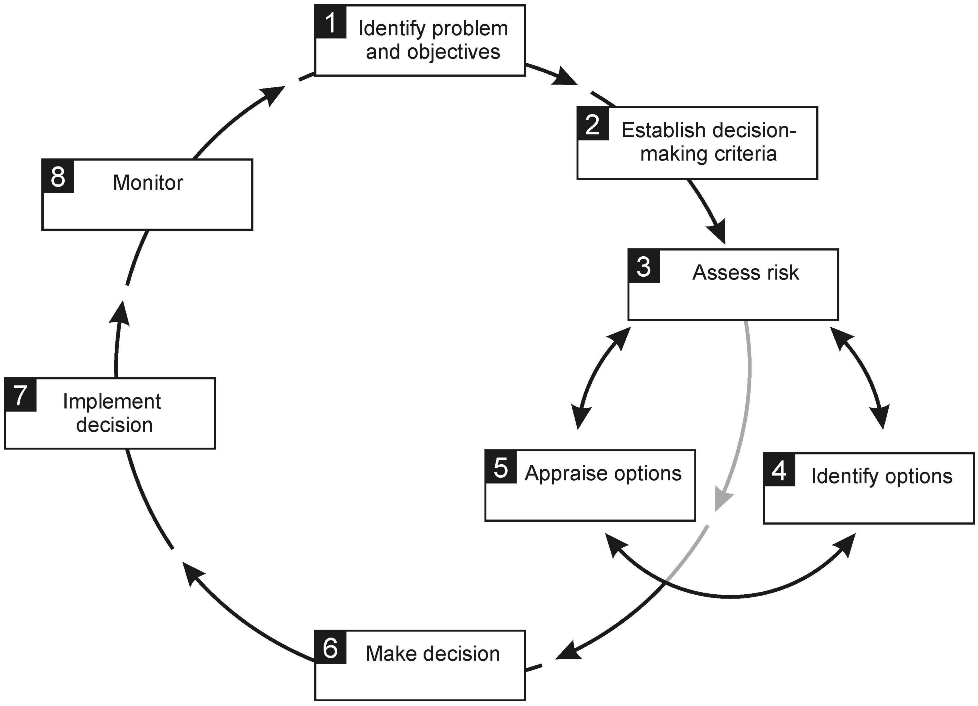

Figure 2: UKCIP Climate change risk-uncertainty-decision-making framework, after [20]

Currently, climate assessment of renewables is very much concentrated towards the earlier stages of this scale, although increasingly sophisticated approaches are being taken in assessing the risk, particularly with hydropower. Despite that there is some way to go in terms of being able to define the risk in a sufficiently robust fashion for it to be incorporated into the investment decision-making process.

6 Conclusion

This paper explores some of the issues relating to the impact of climate change on renewable energy. In particular, it sets out the nature of such impacts in a general sense and with reference to specific technologies. The difficulties faced by appraising renewable projects with the prospect of climate change and the uncertainties inherent within the process are highlighted. Finally, initial thoughts regarding robust methods for incorporating climate change into project decision-making are presented.

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