Renewable Energy Scenarios: Exploring Technology, Acceptance and Climate - Options at the Community- Scale

A. M. Gormally[a*], J. D. Whyatt[a], R. J. Timmis[b] & C. G. Pooley[a]

[a] Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ

[b] Environment Agency, c/o Lancaster Environment Centre, University, Lancaster, LA1 4YQ

* Corresponding author: a.gormally@lancaster.ac.uk

Abstract:

Community-based renewable energy could play a key role in the transition to a low carbon society. This paper argues that given the right environmental and societal conditions, communities in the UK could source a high percentage of their electricity supply from a mixture of localised renewable electricity technologies. Here we use exploratory scenarios to assess demand and renewable electricity supply-side options at the community-scale for a location in Cumbria, UK. Three scenarios are presented, using narratives of how local demand and renewable electricity supply could be constructed under either existing or modified environmental and societal conditions. The three scenarios explored were 'Current State of Play', 'Low Carbon Adjusted Society' and 'Reluctant Scenario'.

Keywords: Energy scenarios, energy & environment, community-based renewable electricity, climate.

1. Introduction

Approaches that will increase the supply of renewable energy and reduce demand are needed in response to the UK's goal of reducing carbon emissions by 2050 (Climate Change

Act, 2008) and in response to the European Union's (EU) renewable energy target of 20% by 2020 (DECC, 2009). The UK has a lower target of 15% renewable energy by 2020, however is making slow progress having achieved 7% in 2014 (DUKES, 2015, Renewable Energy Strategy, 2009). Furthermore, the UK aims to generate 30-40% of its electricity from renewable sources but to date has only achieved ~18% (DUKES, 2015). Significant changes will need to be made in the UK's approach to energy if these targets are to be met.

Although a centralised large-scale approach to energy currently dominates, there is emerging interest in distributed small-scale renewable energy, particularly where communities are involved in the ownership or management of local developments. Interest has been fuelled by the perceived benefits that locally-led developments can play in increasing local acceptance of renewable technologies and in altering energy behaviours by providing real-time information to inform energy use decisions (Heiskanen et al., 2010, CSE, 2007, Warren and McFadyen, 2010). The concept of generating and using locally-owned energy is gaining popularity with residents in the UK, with the number of energy schemes labelled as 'community-based' rising to over 1000 in 2012 (Hargreaves et al., 2012). This is partly due to concerns over increasing fuel prices, with consumers wanting to become more independent from large energy providers and having more control over where their energy comes from (Butler et al., 2012, Watson et al., 2008, Gormally et al., 2013). The UK coalition government declared support for community-based activities, releasing it's first 'Community Energy Strategy' recognising the 'advantages that community-based action offers energy and climate change policy' (DECC, 2014, p.3)

Given the perceived relevance community energy could have in promoting low carbon technologies and reducing local demand, this paper examines the technical, societal and environmental aspects of local schemes by exploring the potential contributions of renewable supply and demand-side options for a case study community, using a set of exploratory scenarios. This paper argues that given the right societal and environmental conditions, communities in the UK could become significant producers of electricity. As shown on The Isle of Eigg (Yadoo et al., 2011), it is possible for a small community to generate almost all electricity needs through community-based renewables when this is the only option available. Supply-side options used on Eigg involve combining a mix of renewable resources which have different seasonal and weather dependencies. By combining a mix of hydro-power, wind-power and solar photovoltaics (PV), together with 24 hour battery storage and back-up diesel generators, they have managed to overcome some of the issues associated with the variability of renewable generation. This is coupled with demand-side measures including a household cap of 5KW (all households are provided with OWL energy meters) and by asking residents to voluntarily reduce demand in times of low renewable electricity generation. Here we consider whether this concept of balancing supply and demand locally through utilising local renewable resources translates to on-grid rural communities on the UK mainland.

This paper presents the final phase of an interdisciplinary, mixed methods research project that has examined community-based renewable energy in Cumbria, UK. The first phase combined quantitative methods (spatial analysis and calculated energy outputs) with secondary data in order to assess annual renewable resource potential at the regional scale and identify areas with sufficient local resources to support a portfolio of renewable energy technologies (Gormally et al., 2012). The second phase involved using quantitative and qualitative methods to assess residents' attitudes to renewable energy, in three Cumbrian communities. Themes included attitudes towards localised ownership of renewable energy, involvement in local energy schemes and preference towards different renewable technologies (Gormally et al., 2013). The communities were chosen using the results of the spatial analysis conducted in the initial phase, which identified them as having high resource potential for a portfolio of renewable technologies. Subsequently, one of the three communities was chosen as the focus for developing community-level energy scenarios in this final phase of the overall study.

In this paper we use one type of energy scenario to explore possible ‘renewable futures’ for our chosen case study community. Scenarios are a means of exploring alternative futures and Kowalski et al., (2009) describe three main types that are often used - forecasting scenarios (those which are a continuation of the past), normative scenarios (those which aim for milestones and assume a certain future can be created) and exploratory scenarios (those which explore a possible space for the future but do not aim to predict it). Here we use exploratory scenarios to examine electricity demand and supply at the community scale. Therefore, we do not aim to predict the future for this community, we simple aim to explore plausible and potential futures based on different assumptions of technologies, acceptance and climate.

The scenario options described in this paper are modified by both local demand and renewable supply-side conditions. Reviewing renewable supply-side options involves exploring the existing potential (current meteorological conditions) and future potential (possible future meteorological conditions) by exploring the effects of climate and extreme weather events. The impact of extreme weather events is important in terms of ensuring security of supply, especially as extreme events in the UK are predicted to become more severe and more frequent in the coming decades (Meehl, 2007, Fowler and Ekström, 2009). Indeed, this has raised interest among the energy-related research community with studies addressing the energy outputs and economic impact of such changes on hydro-power and wind-power (Harrison and Whittington, 2002, Greene et al., 2010). The UK has seen a shift in some meteorological conditions, for example, rainfall patterns are found to be changing with winter rainfall events becoming more intense and more frequent in upland areas such as Cumbria (Ferranti et al., 2009, Malby et al., 2007, Burt and Ferranti, 2012, Osborn et al., 2000). This could have implications for renewable technologies in the future (for instance, energy outputs from hydro-power). It is important to note that the aim of this paper is not to model future climate for this community. That is beyond the scope of this research and outside of the remit of the 'exploratory' scenario approach taken here. To help explore possible impacts of climate or changing weather patterns on renewable supply-side options, we take a simplified approach by using 'extremes' identified in the local 30-year meteorological record (for more details see section 2.1.2).

Supply-side options are additionally modified by societal acceptance which is used to define both the renewable technology options used and the scale of the chosen technology. Demand-side options use current estimates of local residential electricity demand and future estimates which explore both reduced (high awareness) and increased (low awareness) levels of residential demand. For an example of all pathway options used to construct the scenarios described in this paper, see Figure 1.

2. Methodology & Results

The following methodology was used to develop exploratory energy scenarios for one community in Cumbria, UK. We firstly describe the case study community followed by the methods and data used to determine local levels of electricity demand and renewable energy supply. Three exploratory scenarios are then constructed. These are 'Current State of Play', 'Low Carbon Adjusted Society' and 'Reluctant Society'. All three scenarios represent different narratives of how local demand and renewable energy supply could be constructed under either existing or modified environmental and societal conditions. Each scenario considers the demand and supply balance on temporal scales ranging from annual to monthly and daily. To contextualise the results, each scenario considers whether the community could generate sufficient renewable electricity to satisfy three different levels of local demand. Firstly, greater than 30% of the community's electricity needs; secondly 90-100% of the community's electricity needs and thirdly, in excess (>100%) of the community's electricity needs. The 30% contribution was chosen in line with the UK's overall target of >30% renewable electricity by the year 2020 (Renewable Energy Strategy, 2009), the 90-100% contribution was chosen due to its suggested feasibility given the evidence from The Isle of Eigg (Yadoo et al., 2011), and the >100% contribution was chosen to establish whether given the right conditions of environmental, societal and technology mix, the community could become a net exporter of electricity to the grid.

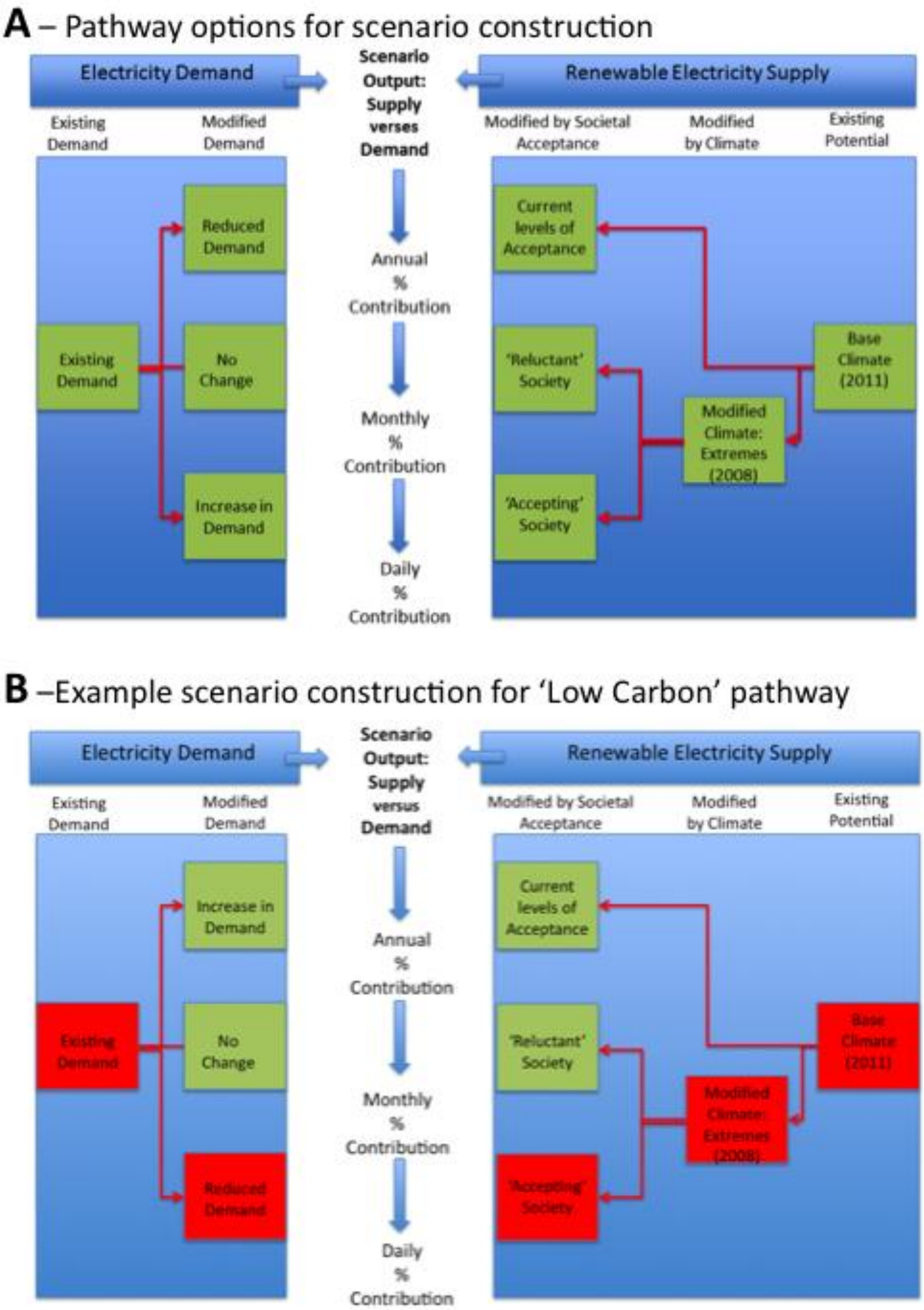


Figure 1. (A) Shows the different pathway options for scenario construction through considering modifications of demand (ie. existing demand and increase or decrease in demand), which then aligns with the chosen scenario options for renewable supply electricity supply (ie. Impact of climate and societal acceptance). The scenario output considers the contribution of the renewable electricity mix to annual, monthly and daily

demand patterns. Figure 1 (B) provides an example pathway for the scenario 'Low Carbon Society' option, with reduced demand, 'accepting' society and modified climate (increased rainfall).

2.1 Case Study Community

The village of Sedgwick (Figure 2) was chosen as the case study community to develop the energy scenarios and explore possible 'renewable futures' at the community level. It is located in the South Lakeland District of Cumbria in the North-west of England and is situated between the boundaries of the Lake District National Park and the Yorkshire Dales National Park. It has a population of 378 inhabitants (source: 2001 census; key statistics) and achieved a high response rate (61%) to the household questionnaire survey on community energy carried out in an earlier phase of this research (Gormally et al., 2013). Results of this survey indicated a high level of support for locally-led initiatives. The regional scale mapping of resource potential carried out in Gormally et al., (2012) also suggests that this community and its immediate surroundings could potentially support a number of renewable electricity developments. For example, hydro-power, wind-power, solar PV and land for bioenergy crops, specifically Miscanthus or Short Rotation Coppice (SRC).

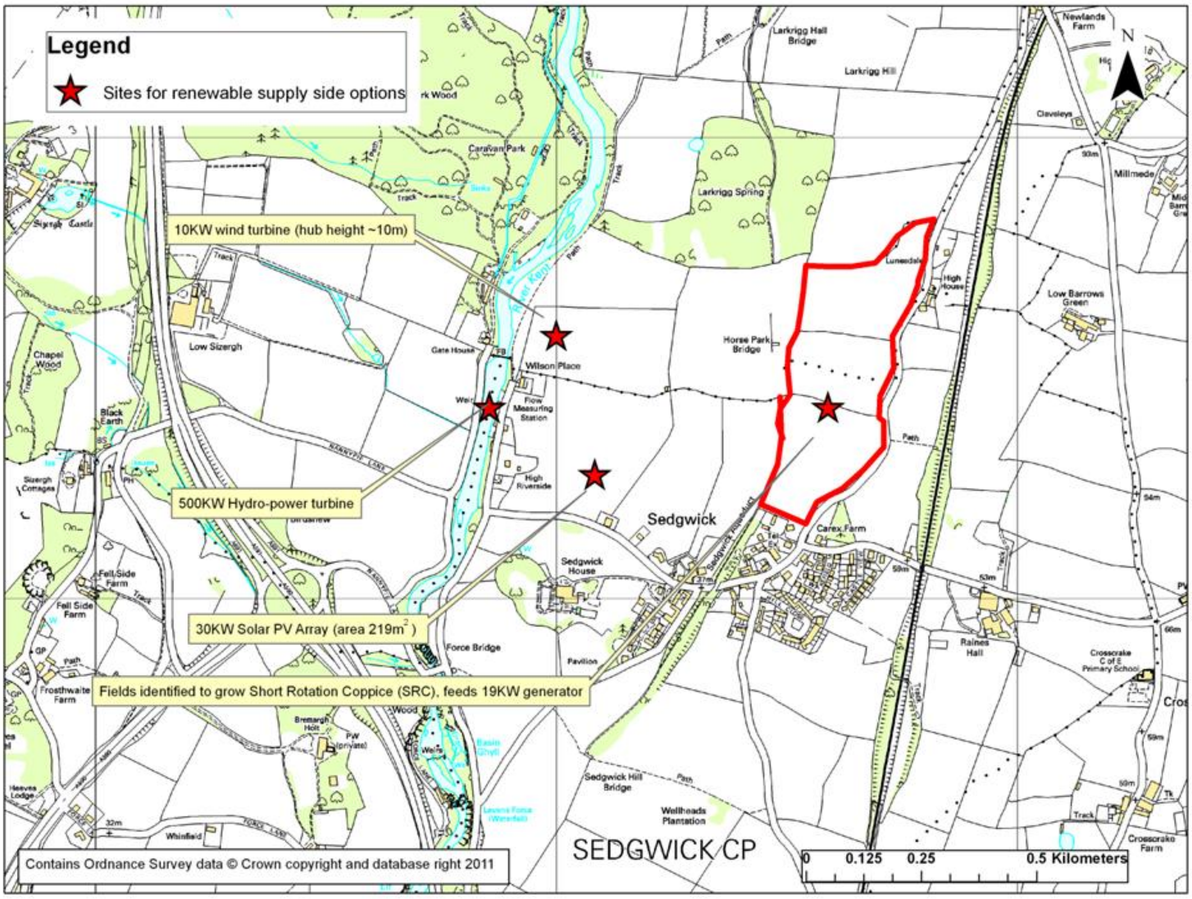


Figure 2. The village of Sedgwick in Cumbria showing proposed locations of renewable supply-side technologies including, wind-power, solar PV array, hydro-power and land identified for bioenergy (SRC) crops.

2.1.1 Electricity Demand

Existing levels of local electricity demand were derived on an annual basis. This was achieved using domestic electricity consumption data taken from the Digest of UK Energy Statistics produced by the Department for Energy and Climate Change (DUKES, 2010) available at Lower Level Super Output Area (LLSOA). LLSOA consist of approximately four Output Areas which are used to define the UK Census. LLSOA's take into account population size (mean population 1500), mutual proximity and social homogeneity (ONS, 2011). This electricity data has been used due to its availability over LLSOA scales, however it is acknowledged that it doesn't provide information on other factors that could contribute to electricity consumption such as building type, income, occupation and weather dependencies (for examples of studies considering these aspects see Azevedo et al., 2015 and Azevedo et al., 2016).

These data revealed that the community had an annual domestic electricity consumption of 4725 KWh per household. To determine the mean annual electricity consumption for the community, this value was multiplied by the number of households in the village (204 households) taken from the 2001 UK census of population (most recent available at the time of the research). Although this approach leads to an estimate of community electricity consumption rather than demand, it gives an indication of how much renewable capacity would be need to be developed to match generation with demand on an annual basis.

Existing levels of community electricity consumption were also derived on a monthly and daily (including hourly) basis. Seasonal adjustments (eg. For months DJF, MAM, JJA, SON) were then applied based on seasonal patterns of UK household electricity use (Sustainability First, 2012). Daily profiles were based on UK household electricity consumption data taken from the Energy Saving Trust (2012) which were compared to the localised outputs from above and adjustments (including daily and seasonal) were made accordingly. These figures were then multiplied by the number of households in the case study community.

Having derived current levels of household demand (consumption) two future modifications were considered; one in which local demand was reduced through high levels of energy awareness, and one in which local demand was increased through lack of energy awareness. These demand-side modifications are based on scenarios used by DECC (2012). Modifications resulting in reduced levels of local demand were based on 'policy on' pathways resulting in high levels of residential abatement. This results in a reduction of residential electricity consumption of ~42%, which was then applied to existing levels of local electricity demand, described above. Modifications resulting in increased levels of local demand were based on the 'policy off' pathway (also called business as usual) used by DECC (2012), which implies no significant policies have been implemented to reduce carbon and energy usage. This results in an increase of ~16% of residential electricity consumption. This modification was then applied to existing levels of local electricity demand, described above.

2.1.2 Renewable Energy Supply

The village of Sedgwick has already been identified as having significant resource potential to develop run-of-river hydro-power, wind-power, bioenergy (SRC or Miscanthus) and solar PV (Gormally et al., 2012). Therefore these four technologies were considered as renewable energy supply-side options. To determine energy outputs from supply-side options, base environmental data were used from the year 2011, for example, river flow, wind speed and solar radiation data. Renewable energy supply-side options were also modified by meteorological extremes (referred to in this article as climate). In this study we focus on extremes of river flow (data taken from the flow gauge on the River Kent at Sedgwick), a decision justified by evidence showing notable changes in rainfall in Cumbria and an increased frequency of extreme events (Ferranti et al., 2009, Burt and Ferranti, 2012). The inter-annual variability of wind speed was also examined using data taken from a weather station at Hazelrigg, Lancaster, located 28 km south of Sedgwick. These data were obtained from the British Atmospheric Data Centre (MIDAS, 2013), and adopted for reasons including length of record (> 30 record)[1] reliability of readings and similar

[1] A climate period in meteorological terms is based on a 30 year time period (see UK Met Office for more details http://www.metoffice.gov.uk/climate)

landscape to the village of Sedgwick. For further particulars relating to environmental data, see Table 1.

On examining both the river flow and wind-speed records it became apparent that wind speed varied little on an annual basis (annual mean wind-speed 5.05m s^{-1} from 1977-2009, SD: 0.39m s^{-1}), however, river flow showed much greater inter-annual variability (annual mean flow 9.24m^3 s^{-1} from 1969-2010, SD: 1.65m^3 s^{-1}). Therefore, for scenario options that considered a modified climate, environmental data for the year 2008 were used, as this was the year in which the flow deviated most significantly from the long-term (30 year) annual and monthly means. Wind-speed data for 2008 was also used for a modified climate, to keep meteorological and hydrological parameters consistent and to avoid unnecessary 'mixing and matching' of data. In contrast, modelled solar radiation data was adopted (as used for base climate) since there was no difference when modelling radiation between years. No change was made to bioenergy yields as it was felt this was beyond the scope of this paper.

Point locations for run-of-river hydro-power were pre-determined from the Environment Agency's (2010) mapping study and therefore restricted to certain locations. The site selected for use in this study was located by the monitoring station on the River Kent at Sedgwick. This site had a potential generating capacity of between 100-500KW (Environment Agency, 2010). Due to the predicted increases in rainfall (and subsequently, river flow), the upper capacity of 500KW was used for the generator size. In order to find locations for wind turbines the DTI's 1km wind-speed data base was used to assess variations in annual wind speed across the study area. 15 min wind-speed data from Hazelrigg, either for the base climate (2011) or modified climate (2008), were then used for the chosen location for the wind turbine to calculate energy outputs. All scenarios used small-scale (10KW) wind turbines and therefore no vertical interpolation of wind-speed was necessary. Wind-speed data were recorded at 10m above ground level (agl) and the suggested hub-height of a 10KW wind turbine is approximately 10m.

Solar irradiance was modelled using a GIS from a 50m digital terrain model (DTM)). Potential sites for the PV array were located by identifying areas of high solar irradiance within fields currently not used for agriculture (eg. non-arable land). Fields were selected by eye due to the small size of the study area, using Ordnance Survey (OS) Mastermap data (1:2500 scale) and the Centre for Ecology and Hydrology (CEH) Land Cover Map (2007). The Land Cover Map (LCM) is derived from satellite images and describes land cover for the UK, for instance urban areas, water bodies, natural and managed vegetated surfaces (CEH, 2011).

For bioenergy, we assume that the community will source its own feedstock, and therefore, only consider land close to or within the community boundary. The bioenergy methodology first identified non-arable land (ie. areas of grassland but not semi-improved grassland which are important for ecological reasons) using LCM (2007). The slope of the terrain was then calculated from OS 1:10,000 scale Landform Profile data and areas with gradients $<$ 12% were considered as being most practical for growing crops such as SRC due to harvesting constraints ie. suitable for harvesting machinery to work (Tenerelli and Carver, 2012). Areas of land that satisfied the land use and slope criteria and which fell in close proximity to a road (essential for coppicing machinery access) were selected (Defra, 2004). The total area of land available was then calculated and the number of available hectares determined. A yield potential of 12 odt (oven dried tonnes) ha^{-1} yr^{-1} was used to calculate potential annual electricity output as per the methodology in Gormally et al., (2012). Yield outputs were taken from Defra’s (2007) study on Opportunities and Optimum Sitings for Energy Crops. A total of three fields covering approximately 13 hectares were selected, giving a potential annual electricity output of 148.2 MWh yr^{-1}. This would be suitable feedstock for a 19KW generator.

Renewable energy supply-side options were also modified by societal acceptance. This constrained both the technology choice and scale of technologies. Information gathered on what the community would be willing to accept was taken from questionnaires and interviews with residents (for more detailed information on outputs from this research see Gormally et al., (2013)). The modification by societal acceptance will be detailed for each scenario in section 3: 'Scenario Selections and Results'.

Resource	Renewable Technology	Dataset	Source	Data Type	Time Period	Time Resolution
River flow	Hydro-power	Gauging Data (m^3 s^{-1})	Environment Agency	Observed	1969-2012	15min
Windspeed	Wind-power	10m windspeed data (m s^{-1})	BADC	Observed	1977-2012	10min
Solar radiation	Solar PV	Solar irradiance (wh m^{-2})	Derived from terrain model	Modelled	2011	60min
Land/crops	Bioenergy	Defra energy crop yield study	Defra	Modelled	-	-
		Land Cover Map 2007	CEH	Observed	-	-

Table 1. Source and resolution of environmental data.

3. Scenario Selections and Results

Three exploratory scenarios were produced which narrate different possibilities of how the case study community could balance local demand with different renewable energy supply-side options. These considered pathways modified by societal and environmental conditions. For all scenarios, demand and renewable supply contributions are shown annually and monthly (not all the results can be shown here, however, highest and lowest monthly contributions per scenario are highlighted in Table 2). Additionally, portfolio contributions were broken down into daily profiles. This was achieved specifically for a given winter week and summer week, to highlight seasonal weather dependencies. A single day from each week was chosen to show daily and hourly profiles, an example of which is shown for the 'Low Carbon Adjusted Society' scenario. Although this only provides an example, and there will inevitably be variability both between daily profiles and between different weeks, it demonstrates how demand could be compared to renewable supply options at finer temporal scales. The following will describe the scenario options and results. Figures 3 to 5 show annual, winter day and summer day profiles.

3.1 Current State of Play

This scenario assumed existing levels of local electricity demand and existing levels of renewable resource potential (base climate, 2011). Resource potential is then modified by societal acceptance, using results of local preferences to renewable technologies and scales. Details of the societal acceptance results can be found in Gormally et al., (2013). In this scenario we assume the portfolio of hydro-power (500KW), solar PV array (30KW) and small-scale wind (10KW). These options were chosen to provide a balance between providing some level of seasonally inter-changeable renewable generation (ie. as achieved on The Isle of Eigg) and residents' preference for specific renewable technologies. For instance, wind farms and bioenergy schemes appeared to hold least favour with residents in terms of perceived visual impacts, efficiency (wind farms) and land use issues (bioenergy). Consequently, only small-scale wind was included in this scenario and bioenergy was excluded.

Overall this mix contributed 11% annually to the community's electricity needs (Figure 3A). The highest monthly generation is achieved in December (at 14.9%). Although demand for electricity is high in winter and the contribution from the PV array is negligible, demand is offset by the high levels of electricity generation from the hydro-power turbine and wind turbine. The lowest monthly generation is in March (at 7.5%) due to low performance from all renewable sources.

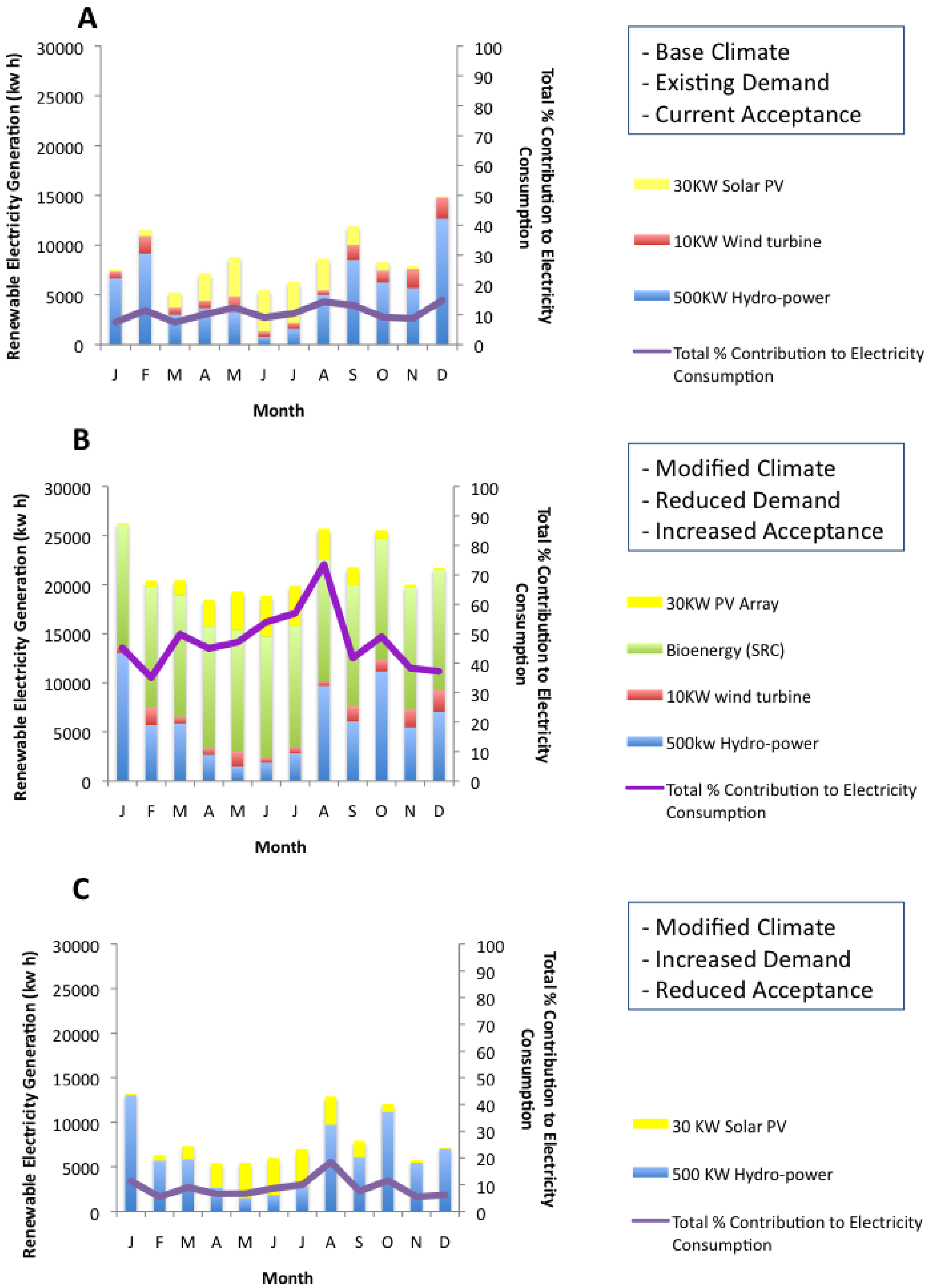
This scenario was also explored for a typical winters day and summers day. On the winters day, the generation from the chosen renewable mix generates double the community’s needs. Generation is dominated by hydro-power as a result of high winter river flows. However, the same mix only contributes to 27% of the community’s electricity needs on a typical summers day. Although the solar PV array is now making a significant contribution, low river flow and limited wind-power leave the community with a 73% electricity deficit. Demand and supply-side pathways including an overview of annual, monthly and winter/summer day examples, are illustrated in Table 2.

	S1 -CURRENT STATE OF PLAY					
	> 30%	> 90%	> 100%	Average score (% contribution to local electricity needs)	High	Low
Annual	x	x	x	11%		
Monthly	x	x	x	11%	14.9 (Dec)	7.5% (March)
Winter day	yes	yes	yes	>100%	>100% (23:00 hrs)	>100% (08:00 hrs)
Summer day	x	x	x	27%	50.3% (03:00 hrs)	10.9% (20:00 hrs)
	S2 - LOW CARBON ADJUSTED SOCIETY					
	> 30%	> 90%	> 100%	Average score (% contribution to local electricity needs)	High	Low
Annual	yes	x	x	46%		
Monthly	yes	x	x	46%	73.6% (Aug)	35% (Feb)
Winter day*	yes	yes	yes	>100%	>100% (04:00 hrs)	>100% (19:00 hrs)
Summer day*	yes	yes	yes	>100%	>100% (04:00 hrs)	97% (18:00 hrs)
* Excludes bioenergy on hourly basis						
	S3 - RELUCTANT SOCIETY					
	> 30%	> 90%	> 100%	Average score (% contribution to local electricity needs)	High	Low
Annual	x	x	x	8%		
Monthly	x	x	x	8%	18.5% (Aug)	5.4% (Feb)
Winter day	yes	yes	yes	>100%	>100% (05:00 hrs)	>100% (18:00 hrs)
Summer day	yes	x	x	66%	>100% (04:00 hrs)	43.4% (18:00 hrs)

Table 2. Contribution to local electricity needs from the different renewable portfolio options for scenarios 1, 2 and 3.

3.2 Low Carbon Adjusted Society

This scenario considers the community's electricity supply and demand under favourable modifications. It assumes lower levels of demand and considers renewable energy supply under a modified climate (meteorological data from 'extreme' year 2008). The supply side is also modified by societal acceptance in that most renewable energy technologies are assumed to have become both economically and culturally acceptable. Therefore, bioenergy is additionally included in the renewable supply-side mix. Short rotation coppice (SRC) rather than Miscanthus is used because SRC had a higher yield potential across the



329

330 Figure 3. Annual plots for scenario A (Current State of Play), B (Low Carbon Adjusted) and C (Reluctant Society), showing renewable electricity generation under modified conditions of climate, demand and acceptance.

333

case study area (Defra, 2007). The portfolio of renewable energy technologies was subsequently hydro-power (500KW), solar PV array (30KW), small-scale wind (10KW) and SRC bioenergy (19KW CHP generator, assuming feedstock sourced from within the community).

On an annual basis this scenario contributed 46% to the community's annual electricity needs (Figure 3B). Other than the consistent monthly contribution from bioenergy, supply was once again dominated by hydro-power, however wind-power and solar PV also make a significant contribution. This is also complemented by the lower levels of predicted electricity consumption in this scenario.

August saw the highest levels of renewable electricity generation which accounted for 73.6% of local electricity needs. February was the month which contributed the least to local electricity needs (35%). This scenario saw the winter and summer day profiles greatly exceed local electricity needs. For the winters day, supply was heavily dominated by hydro-power (Figure 4B). For the summers day it was a combination of higher summer river flows, the complementary mix of wind-power and solar PV and the lower levels of estimated electricity consumption (Figure 5B). It should be noted that although bioenergy was included in the renewables mix for this scenario (as seen on the annual contribution figures) it was excluded from the daily profiles. This is because it was difficult to determine how much feedstock would be used on an hourly basis. Considering the very high levels of renewable generation for the more 'immediate' renewable technologies such as wind, solar and hydro-power, it was felt that bioenergy would not be used on these days.

3.3 Reluctant Society

This scenario considers the community's renewable energy supply and demand under less favourable conditions. This scenario increases local demand and assumes a modified climate, under which societal acceptance to renewable energy technologies is considered low. The portfolio of renewable energy technologies chosen was subsequently hydro-power (500KW) and a solar PV array (30KW). Hydro-power was chosen because this was by some margin the most favourable renewable technology during the questionnaire and interview stage of phase 2 (Gormally et al., 2013). It was assumed that even in a scenario with societal reluctance towards incorporating renewable technologies, small to medium sized hydro-power would be considered acceptable. Solar PV was included in order to provide some level of seasonal mix and was considered to be the other most likely technology to be accepted under a reluctant future given its perception as a well developed technology in light of the growing numbers of households adopting solar PV occurring the in the UK (Cherrington et al., 2013).

Annually this mix contributed 8% to the community's electricity needs (Figure 3C). August saw the highest contribution (18.5%) and February the lowest (5.4%). This was again a balance between the output from the hydro-power and solar PV and the high estimated levels of local electricity consumption. The winters day profile saw an excess of renewable generation of more than 3 times local needs, dominated by the high winter flows and generation from the hydro-power (Figure 4C). The summer day profile saw a contribution of 66% to local needs (Figure 5C).

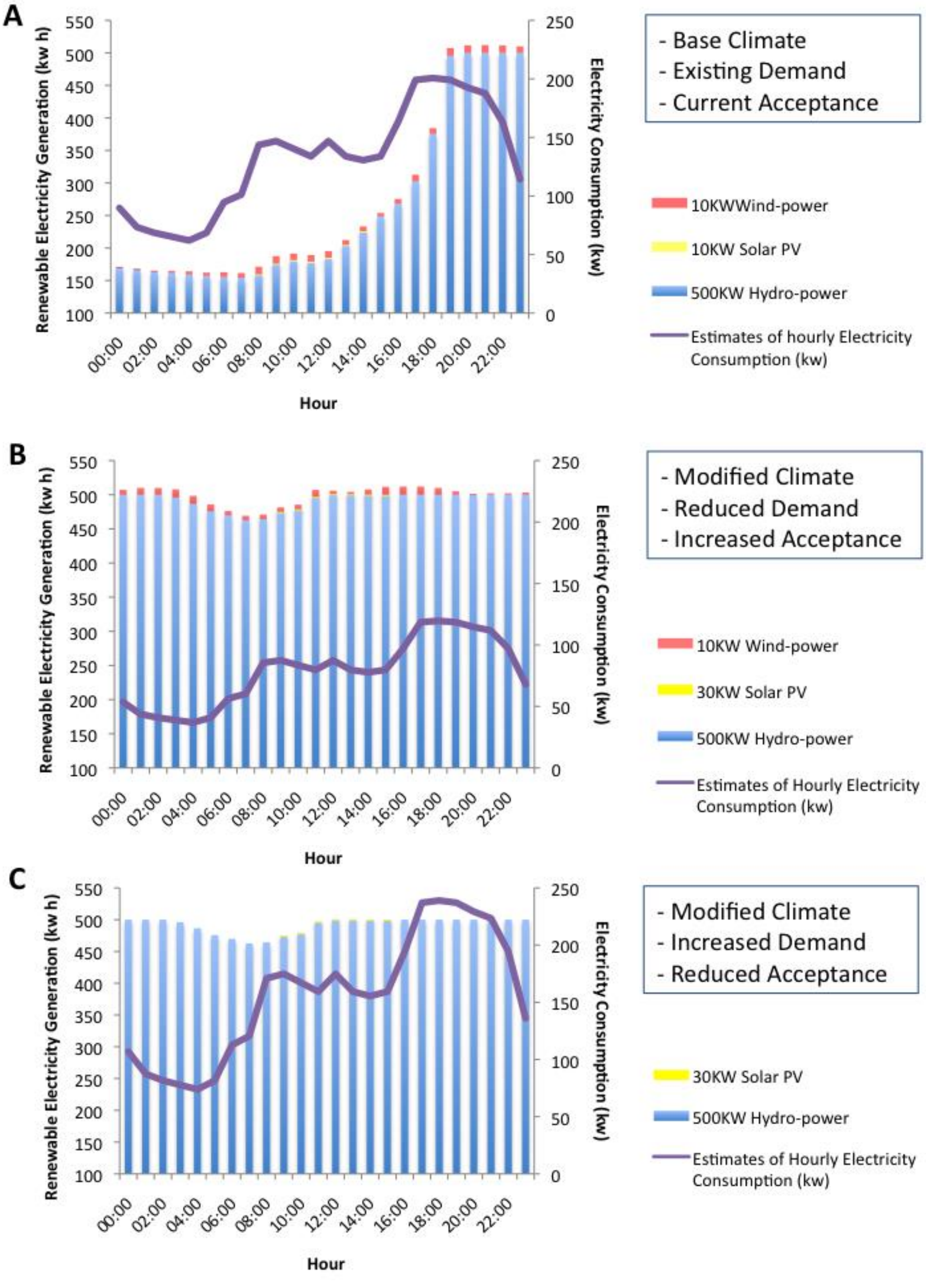
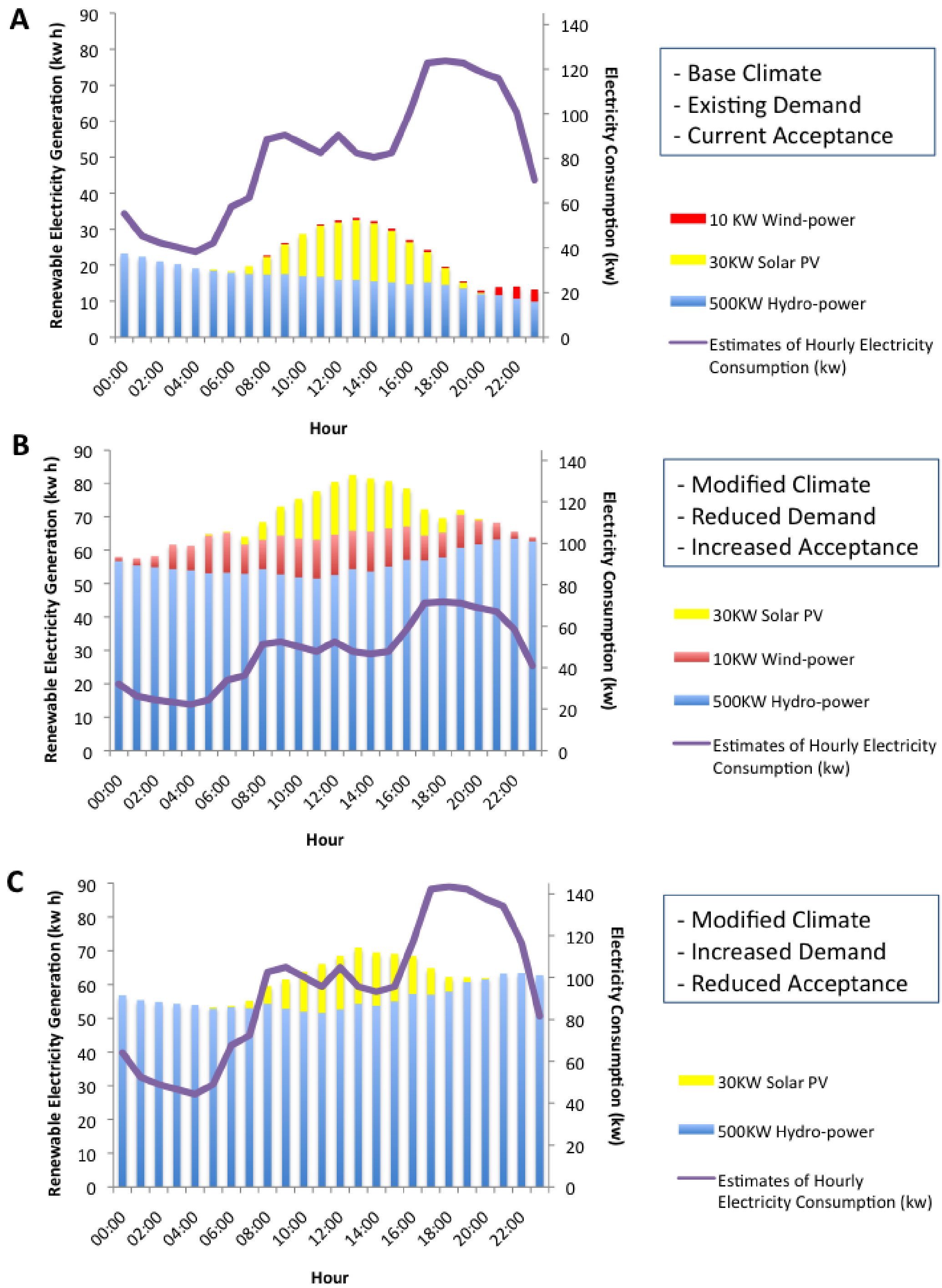


Figure 4. Winter day plots showing hourly renewable electricity generation compared to consumption for scenarios A (Current State of Play), B (Low Carbon Society) and C (Reluctant Society).



382

383 Figure 5. Summer day plots showing hourly renewable electricity generation compared to
384 consumption for scenarios A (Current State of Play), B (Low Carbon Society) and C
385 (Reluctant Society).

386

4. Discussion & Conclusions

This paper set out to describe and explore the final phase of an interdisciplinary mixed-methods research project that has examined community-based renewable energy in Cumbria, UK. This final phase has produced exploratory energy scenarios for a specific community, Sedgwick in the South Lakeland area of Cumbria, which was identified as having significant resources to support a range of renewable technologies at the community-scale and was also found to have a high level of interest in the concept of local energy by residents (Gormally et al., 2012, Gormally et al., 2013). The exploratory scenarios considered how local demand could be matched with a portfolio of seasonal and weather dependent renewable supply-side options under existing conditions and modified futures. The results are contextualised by comparing results firstly to the UK's renewable electricity target (30-40% renewable electricity), then to the success on The Isle of Eigg (> 90% renewable electricity), and finally in relation to export of excess electricity to the national grid (> 100%).

In our regional-scale assessment of renewable resources we concluded that there were sufficient supply-side resources to provide a surplus of electricity to this community on an annual basis (based on existing levels of demand) (Gormally et al., 2012). Here, we find that when community preferences to renewable technologies and scales of development are incorporated at local scales, and when demand and supply are considered at different temporal scales, it is much harder to not only achieve a target of 90% or greater renewable electricity supply but also to achieve the national target of 30-40%, at the community-scale. Under the 'Current State of Play' scenario which considers existing levels of demand and incorporates local preferences to supply-side options, the downscaling of wind-power and the exclusion of bioenergy has a significant impact on the ability of the community to match demand with supply. It is only during the winters day profile that supply exceeds demand and this is dominated by the significant level of river flow influencing hydro-power production. This is seen again in the Reluctant Society scenario, which excludes bioenergy and wind-power altogether but does consider the effects of a modified climate in terms of extreme river flows and a slight increase in local demand. The only positive effect from this scenario in terms of matching supply and demand is the increase in summer river flow influencing outputs from hydro-power in both winter and summer day profiles. The Low Carbon Adjusted Society scenario offers a more successful option by reducing levels of local demand, using a modified climate with extremes of river flow and incorporating bioenergy (SRC) into supply options. Under this scenario the community could source approximately half their electricity needs from the accepted portfolio of technologies, and become exporters to the grid on days of high generation, given the reduction in local demand.

At the beginning of this paper we set out to argue that under the right societal and environmental conditions, some on-grid communities in the UK could generate a significant proportion of their electricity needs by incorporating a portfolio of local renewable energy resources. The outcomes from previous work on annual resources in this area (Gormally et al., 2012), and the results from the scenarios reported here, would suggest that there is the *potential* for local resources to meet local demand. However, *realising* this potential in a way that is acceptable to the community is likely to be problematic. Of course, these scenarios only offer specific narratives of events determined by community attitudes and predictions of future climatic events. These narratives have imposed limitations on the scale of certain technologies eg. wind turbines, and have focussed on certain meteorological effects eg. river flow effecting hydro-power potential. Alternative scenario narratives could be developed, for instance, by increasing the size and/or scale of the generators or by incorporating the effects of changes in other meteorological resources and their effects on renewable electricity generation. Equally, other scenarios of local demand could be used, for instance, demand patterns influenced by climate modifications.

However, what these scenarios do suggest is that unless on-grid communities have the pragmatic response to energy supply that off-grid communities have, they are currently unlikely to successfully integrate these types of renewable portfolios in a way which successfully matches demand with supply. Other measures would need to be incorporated, such as localised storage and/or some form of demand response measure. This currently poses difficulties for on-grid solutions with large-scale electricity storage expensive, and storage at the distributed level unconventionally aligned with existing infrastructures (Jardine and Ault, 2008, Grunewald et al., 2012). Local-level initiatives also offer up interesting questions surrounding management and regulation. Developments of this kind (variable output to the grid) and of this scale will also have implications for grid operators when trying to balance electricity flows around the national grid and in balancing supply with demand on a national scale (Wilson et al., 2010). Understanding the potential role that these types of on-grid community-based developments might have in the future is not only important when trying to envisage changes in future energy behaviours, but additionally when trying to connect these with the role of new energy infrastructures and the impact this will have nationally (and internationally) in configuring our future energy supply. Although on-grid community-based initiatives are on the increase in the UK as evidence by the new implementation of the Community Energy Strategy (DECC, 2014, Hargreaves, 2012), without the right co-ordination of economic, societal and environmental conditions, on-grid communities are unlikely to have enough incentive to become independent from the national grid. However, the concept of self-dependent electricity generating communities is interesting given the increased interest in locally owned energy and the social reasoning behind that impetus, for example, disenchantment with current energy suppliers.

The approach described in this paper helps shed some light on the role of on-grid community-based renewable energy for a specific case study community in Cumbria, UK. It offers a way of assessing the contribution of renewable supply-side options to local electricity demand under different societal and environmental conditions and on a range of temporal scales. The methodology could also be adapted to incorporate the effects of climate extremes on local demand patterns in addition to supply. Future work could involve assessing the impact of localised energy storage and greater levels of demand-side management in balancing demand and supply at the local-level. Understanding these areas in greater detail would provide a better picture of the role on-grid community-based renewable energy could have in the UK and provide an evidence base on which to make future policy decisions in this area.

Cumbria holds many of the attributes associated with aspects of community energy that have been specifically addressed in this paper and previous work in this area, for example, diverse resources, range of community scales and evidence of climatic changes. (Gormally, et al., 2012 and Gormally et al., 2013). Other regions hold similar challenges in terms of understanding the role of community energy, but will hold different solutions. Other regions might have different resources to utilise, be experiencing regionally specific changes in climate and contain communities which hold different concepts of place. These differences would offer alternative options for communities to become 'energy independent' through utilising renewable portfolios. Future research could test out this hypothesis by replicating the methodological approach for alternative regions, both upland and lowland. This would provide a greater evidence base to help understand and inform the future role of community energy in the UK and its potential to become a significant part of any future energy system. It could also be used to highlight relevant support that would need to be put in place if community-based renewables were chosen to be supported further in the future.

5. Acknowledgements

This research was funded as part of an interdisciplinary Ph.D. studentship from the UK Energy Research Centre and was supported by the UK Research Councils under the Natural Environment Research Council award NE/G007748/1. The authors would like to acknowledge the Environment Agency for the provision of hydro-power data, the British Atmospheric Data Centre (BADC) for weather data and those residents in Cumbria who generously gave up their time to participate in this study.

6. References

Azevedo, J.A., Chapman, L. and Muller, C.L., 2015. Critique and suggested modifications of the degree days methodology to enable long-term electricity consumption assessments: a case study in Birmingham, UK. Meteorological Applications, 22(4), pp.789-796.

Azevedo, Juliana Antunes, Lee Chapman, and Catherine L. Muller. "Urban heat and residential electricity consumption: A preliminary study." Applied Geography 70 (2016): 59-67.

Burt, T. P. & Ferranti, E. J. S. (2012) Changing patterns of heavy rainfall in upland areas: a case study from northern England. International Journal of Climatology, 32518-532.

Butler, C., Parkhill, K. & Pidgeon, N. (2012) UKERC Briefing Note: Transforming the UK Energy System: Public Values, Attitudes and Acceptability. Interim findings. <http://psych.cf.ac.uk/home2/butler/Briefing%20Note%20I%20Transforming%20the%20UK%20Energy%20System[4].pdf> Accessed:03/06/2013

CEH (2011) Centre for Ecology & Hydrology: Land Cover Mapping. <http://www.ceh.ac.uk/landcovermapping.html#LCM2007> Accessed:17/07/2013

Cherrington, R., Goodship, V., Longfield, A. & Kirwan, K. (2013) The feed-in tariff in the UK: A case study focus on domestic photovoltaic systems. Renewable Energy, 50(0), 421-426.

Climate Change Act (2008) The Climate Change Act. HM Goverment. <http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf> Accessed:04/06/2013

CSE (2007) Report by the Centre for Sustainable Energy (CSE) and Community Development Xchange (CDX) for; Defra: 'Mobilising individual behavioural change through community intitiatives: Lessons for Climate Change'. <http://www.cse.org.uk/pdf/pub1073.pdf> Accessed:12/12/2011

DECC (2009) The UK Renewable Energy Strategy. IN Department of Energy and Climate Change (Ed.). HM Government.

DECC (2012) Capturing the full electricity efficiency potential of the UK. <https://www.gov.uk/government/publications/capturing-the-full-electricity-efficiency-potential-of-the-uk--2> Accessed:25/06/2013

Defra (2004) Best Practice Guidelines For Applicants to Defra's Energy Crops Scheme: Growing Short Rotation Coppice. <http://www.naturalengland.org.uk/Images/short-rotation-coppice_tcm6-4262.pdf> Accessed:25/06/2013

Defra (2007) Opportunities and optimum sitings for energy crops <http://archive.defra.gov.uk/foodfarm/growing/crops/industrial/energy/opportunities/nw.htm> Accessed:12/12/2011

DUKES (2010) Digest of UK Energy Statistics, LLSOA Electricity and Gas:2009 (experimental). <http://www.decc.gov.uk/en/content/cms/statistics/publications/dukes/dukes.aspx> Accessed:20/03/2012

DUKES (2015) Digest of UK Energy Statistics. < https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/450302/DUKES_2015.pdf > Accessed:11/02/2016

Energy Savings Trust (2012) Powering the Nation: Household electrcity-using habits revealed. <http://www.energysavingtrust.org.uk/Publications2/Corporate/Research-and-insights/Powering-the-nation-household-electricity-using-habits-revealed> Accessed:24/06/2013

Environment Agency (2010) Opportunity and environmental sensitivity mapping for hydropower in England and Wales.

Ferranti, E. J. S., Whyatt, J. D. & Timmis, R. J. (2009) Development and application of topographic descriptors for conditional analysis of rainfall. Atmospheric Science Letters*,* 10(3)**,** 177-184.

Fowler, H. J. & Ekström, M. (2009) Multi-model ensemble estimates of climate change impacts on UK seasonal precipitation extremes. International Journal of Climatology*,* 29(3)**,** 385-416.

Gormally, A. M., Pooley, C. G., Whyatt, J. D. & Timmis, R. J. (2013) "They made gunpowder...yes down by the river there, that's your energy source": attitudes towards community renewable energy in Cumbria. Local Environment*,* 1-18.

Gormally, A. M., Whyatt, J. D., Timmis, R. J. & Pooley, C. G. (2012) A regional-scale assessment of local renewable energy resources in Cumbria, UK. Energy Policy*,* 50(0)**,** 283-293.

Greene, S., Morrissey, M. & Johnson, S. E. (2010) Wind Climatology, Climate Change, and Wind Energy. Geography Compass*,* 4(11)**,** 1592-1605.

Grunewald, P. H., Cockerill, T. T., Contestabile, M. & Pearson, P. J. G. (2012) The socio-technical transition of distributed electricity storage into future networks-System value and stakeholder views. Energy Policy*,* 50449-457.

Hargreaves, T., Hielscher, S., Seyfang, G. & Smith, A. (2012) Exploring the Role of Intermediaries in UK Community Energy: Grassroots Innovation and Niche Development'.Science, Society & Sustainability (3S) Working Paper 2012-12. <http://www.3s.uea.ac.uk/publications/exploring-role-intermediaries-uk-community-energy-grassroots-innovations-and-niche-deve> Accessed:04/06/2013

Harrison, G. P. & Whittington, H. W. (2002) Susceptibility of the Batoka Gorge hydroelectric scheme to climate change. Journal of Hydrology*,* 264(1-4)**,** 230-241.

Heiskanen, E., Johnson, M., Robinson, S., Vadovics, E. & Saastamoinen, M. (2010) Low-carbon communities as a context for individual behavioural change. Energy Policy, 38(12), 7586-7595.

Jardine, C. N. & Ault, G. W. (2008) Scenarios for examination of highly distributed power systems. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 222(7), 643-655.

Kowalski, K., Stagl, S., Madlener, R. & Omann, I. (2009) Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. European Journal of Operational Research, 197(3), 1063-1074.

Malby, A. R., Whyatt, J. A., Timmis, R. J., Wilby, R. L. & Orr, H. G. (2007) Long-term variations in orographic rainfall: analysis and implications for upland catchments. Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, 52(2), 276-291.

Meehl, G. A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao., (2007) Global Climate Projections. IN Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, Miller, H.L., & (Eds.) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press,

MIDAS (2013) MIDAS Land Surface Stations data (1853-current). British Atmospheric Data Centre, 2006. <http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_ukmo-midas> Accessed:25/06/2013

ONS (2011) Information Note: Super Output Areas (SOAs). Office for National Statistics.

Osborn, T. J., Hulme, M., Jones, P. D. & Basnett, T. A. (2000) Observed trends in the daily intensity of United Kingdom precipitation. International Journal of Climatology, 20(4), 347-364.

Renewable Energy Strategy (2009) The UK Renewable Energy Strategy. Crown Copyright. <http://www.official-documents.gov.uk/document/cm76/7686/7686.pdf> Accessed:04/06/2013

Sustainability First (2012) GB Electricity Demand - 2010 and 2025: Initial Brattle Electricity Demand-Side Model - Scope for Demand Reduction and Flexiable Response. <http://www.sustainabilityfirst.org.uk/gbelec.html> Accessed:18/07/2013

Tenerelli, P. & Carver, S. (2012) Multi-criteria, multi-objective and uncertainty analysis for agro-energy spatial modelling. Applied Geography, 32(2), 724-736.

Warren, C. R. & McFadyen, M. (2010) Does community ownership affect public attitudes to wind energy? A case study from south-west Scotland. Land Use Policy, 27(2), 204-213.

Watson, J., Sauter, R., Bahaj, B., James, P., Myers, L. & Wing, R. (2008) Domestic micro-generation: Economic, regulatory and policy issues for the UK. Energy Policy, 36(8), 3095-3106.

Wilson, I. A. G., McGregor, P. G. & Hall, P. J. (2010) Energy storage in the UK electrical network: Estimation of the scale and review of technology options. Energy Policy, 38(8), 4099-4106.

Yadoo, A., Gormally, A. & Cruickshank, H. (2011) Low-carbon off-grid electrification for rural areas in the United Kingdom: Lessons from the developing world. Energy Policy, 39(10), 6400-6407.