Micro-hydro power in the UK: the role of communities in an emerging energy resource

Bracken, L.J., Bulkeley, H.A. and Maynard C.M.

Department of Geography, Durham University, Durham, DH1 3TE

Abstract

Research around micro-hydro power is focused on technical aspects with limited understanding of the social organisation and environmental implications. We examine the ways in which micro-hydro is engaged by people and organisations as a means of contributing to the UK's policy ambition for renewable energy. We bring to the fore the way in which expertise is used and contested. A web based review of micro-hydro schemes in the UK was undertaken and a detailed evaluation of two schemes in the North of England was conducted to determine how expertise and contestation figures in community schemes. Results demonstrate a rapid expansion of micro-hydro in the UK. Ownership/control is highly 'community based'. Until now research around micro-hydro has been dominated by technical approaches with schemes defined in terms of hardware. We propose a third dimension to Walker and Cass's (2007) classification of renewable energy developments: the environmental dimension. We suggest this dimension of micro-hydro is critical, both in terms of the extent to which resources can be realised but also the ways in which it might attract controversy, in particular around how expertise is used and valued.

1. Introduction

The UK has committed to an ambitious target of generating 15% of its energy from renewables by 2020 (Ward and Inderwildi 2013). Responding to this target has proven far from straightforward, with significant contestation arising over which might be the most appropriate renewable energy resources to deploy where, as well as concern over the ways in which the benefits and costs of such a transition are being distributed (Walker, 2012; Ward and Inderwildi 2013). In the midst of this contested debate, one key dimension of the drive towards renewable energy targets has been the increasing interest in 'community' level developments. Often regarded as a means through which to address public concerns about the impact of renewable energy and as a way of recouping benefits to particular places, community-based renewable energy projects have been championed by a range of government and commercial interests over the past decade (Walker et al., 2007; Haggett, 2009; Walker and Devine-Wright, 2009). Such initiatives, and the research that has accompanied them, have tended to focus on wind, wood, and solar energy. In this paper, we turn to a seemingly neglected resource – hydro power – and examine the ways in which 'micro hydro' is being engaged by governments, private companies and communities as a means of contributing to the UK's policy ambition for renewable energy. In so doing, we provide the first UK survey of the development of micro-hydro schemes and provide new insights into their social and environmental dimensions.

Engaging with the social and environmental dimensions of micro-hydro is particularly important, we suggest, because previously published research on micro-hydro power generation has focused on technological advances in energy production to exploit hydro-power effectively and efficiently (e.g. Singh 2004) and how to assess potential sites where schemes may be located (e.g. Larentis et al., 2010; Cyr et al., 2011; Punys et al., 2011). Yet whilst the potential of micro-hydro has been noted (Paish, 2002; Roberts 2008), there has been little consideration of the challenges and consequences of developing this energy resource. Micro-hydro is often portrayed as a relatively benign technology, particularly in relation to on-shore wind, which has received significant levels of political and academic attention given the controversies which have accompanied the development of different projects. Moving beyond the technical assessment that has dominated studies of micro-hydro to date, to consider in addition its social organisation and environmental implications, we find that the development of micro-hydro resources is highly complex and controversial.

The purpose of this paper is to explore the role of the community in developing micro-hydro schemes in the UK. Through case-studies of two projects in the North of England, we then examine the ways in which issues around community led schemes have unfolded, and their implications for future research in this field. In particular we focus on the role of expertise and how this is contested in community initiatives around micro-hydro. In section 2 we evaluate the environmental and social dimensions of micro-hydro as an energy resource. Section 3 outlines the approach taken in this study and introduces the case studies: micro-hydro schemes at Settle and at Ruswarp, both in the North of England. Section 4 presents an assessment of the development of micro-hydro in the UK focusing on the range and number of schemes in the UK. The findings of the assessment of the two case studies are then presented in section 5. In this section we draw out themes around the software, hardware and environmental concerns of developing micro-hydro in the UK. We conclude by highlighting key themes emerging from the analysis and outline implications for future research.

2. Micro-Hydro as an Energy Resource: conceptualising the technical, environmental and social dimensions

Micro-hydro is a well-established technology that has been implemented for rural electrification throughout the world (Nouni et al., 2009; North 2010). As Walker and Cass (2007: 459) argue, however, micro-hydro technologies should be viewed “not simply as a series of engineered artefacts performing energy conversions, but as configurations of the social and technical which have emerged contingently in particular contexts and which mirror wider social, economic and technical relations and processes.” To this end, Walker and Cass (2007: 459) characterise the “meshing of the technological and the social within evolving infrastructures of renewable energy provision” as a matter of the “‘hardware’ of engineered artefacts as being utilised within and through the co-dependent and co-evolving ‘software’ of its social organisation.” Operating at different scales and sites, and comprising of multiple relations between technical ‘hardware’ and forms of social organisation ‘software’ micro-hydro can be readily characterised in these terms. This framework provides a starting point for considering how, why and with what implications micro-hydro is being developed as an energy resource. However, such an approach neglects the important *environmental* dimension of micro-hydro (and other renewable energy socio-technical systems). Rather than consider renewable energy resources only in sociotechnical terms, attending to their important environmental dimensions we suggest that there is a need to regard them as simultaneously sociotechnical and socioecological systems (Monstadt 2009). Below, we consider the hardware, software, and environmental issues of micro-hydro.

2.1 Technological Hardware: physical capacities and system design

The definition of micro-hydro varies between countries to include systems with a capacity of a few megawatts up to approximately 100 kW capacity (Table 1). The limit tends to be set to 100 kW because this is considered to be the maximum size for most stand-alone hydro systems not connected to the grid, and suitable for "run-of-the-river" installations. The term ‘Pico-hydro’ is also used as a term to denote size of scheme, with a maximum power output of 5 kW (Haidar et al., 2012).

Country	Micro (kW)	Mini (kW)	Small (MW)	Source
UK			< 5	Paish 2002
United States	< 100	100 - 1000	1 - 30	Moreire and Poole (1993)
China	-	< 500	0.5 - 25	Moreire and Poole (1993)
USSR	< 100	-	0.1 - 30	Moreire and Poole (1993)
France	5 - 5000	-	-	Moreire and Poole (1993)
India	< 100	101 - 1000	1 -15	Moreire and Poole (1993)
Brazil	< 100	100 - 1000	1 - 30	Moreire and Poole (1993)
Norway *	< 100	100 - 1000	1 - 10	Moreire and Poole (1993)

Table 1: different definitions used for hydro power

By examining the hydraulic head and river flow at existing in-channel structures in rivers 13 000 sites have been deemed practical and technically feasible for the development of micro-hydro power in Scotland and 26 000 potential sites have been identified in England and Wales (EA 2010). Construction details of a micro-hydro plant are site-specific, but the common elements of all micro-hydroelectric schemes include: a supply of water to provide a minimal flow of water to be available year-round; a settling pond to remove sediment from the flow so as not to damage the turbine; an intake structure to screen out floating debris and fish; a pipe or canal to route water to the turbine; a controlling valve to regulate the flow and the speed of the turbine; a turbine to convert the flow and pressure of the water to mechanical energy; and finally a tailrace to transfer the water emerging from the turbine to the natural watercourse (Khennas and Barnett 2000; Paish, 2002). Existing research has explored ideal conditions for micro-hydro development and how to maximise investment returns (Punys et al., 2011; Catalao et al., 2012).

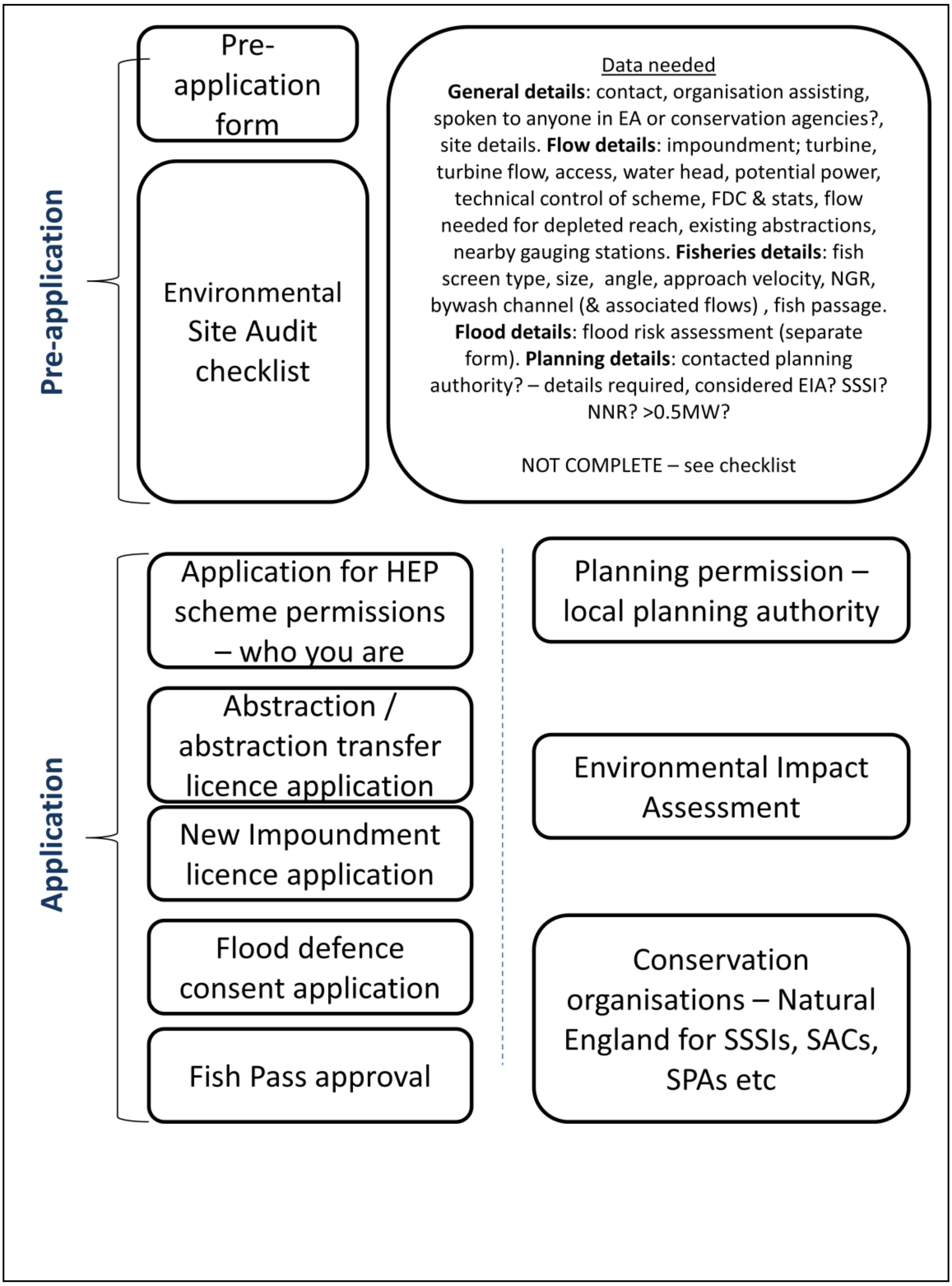
Most schemes in the UK are designed as 'run-of-the-river' systems. This means they do not require a dam or storage facility to be constructed, but simply divert water from the stream or river (with relevant permission), channel it in to a valley and 'drop' it in to a turbine via a pipeline. There are two main types of design; low-head schemes where in-stream structures are used and high-head schemes where water is diverted using pressurised pipes over longer distances to take advantage of changes in elevation. The variety of different micro-hydro installations that can be found in the UK is explained by characteristics of the local water resource, the availability of local structures/construction materials, and the technical capacity of installers (Catalao et al., 2012; Susanto and Stamp, 2012). Such analyses start to demonstrate the inherent geographical variation of micro-hydro, and point to the ways in which its success and failure are not simply technically determined but also relate to the social and environmental context in which it is deployed.

2.2 Multiple softwares: expertise and community engagement in the system of provision

Rather than being simply a technological artefact, the development of micro-hydro has enabled different forms of social organisation and engagement than in the conventional provision of energy through large scale forms of energy production. In this sense, the development of micro-hydro involves establishing new systems of provision, dependent on new forms of interaction between the providers and users of energy in which intermediaries emerge and new patterns of co-production can come to the fore (Van Vliet et al., 2005; Walker and Cass 2007). Within these systems of provision, Walker and Cass (2007: 460) suggest that "what makes up the software of social organisation is a combination of different interacting arrangements and relations between actors and institutions" including "function and service … ownership and return … management and operation … infrastructure and networking" in terms of the way in which the electricity generated is fed into grids or used to supply different communities. In theory, any renewable energy resource can be developed at multiple scales and is shaped by each of these dimensions of social organisation. Micro-hydro schemes might therefore be intended to deliver different kinds of energy service, be designed to deliver different rates of financial and or social returns, managed/owned by cooperatives, partnerships, users and privately owned utilities, and intended to either directly supply communities or be fed into national grids (Walker and Cass 2007).

Central to the ways in which these different forms of social organisation play out in practice, we suggest, are issues of expertise, on the one hand, and community engagement, on the other. The constitution of micro-hydro as a potential resource and the design of specific schemes are critically dependent on expertise. Figure 1 presents the Environment Agency's (EA) outline of the application process, detailing the nature of information needed and the multiple organisations involved in securing permission for development. In Scotland the process of gaining permission is still complex, involving negotiation with the Scottish Environmental Protection Agency (SEPA) for an abstraction licence and the local authority for planning permission. Across this process, multiple forms of expertise are invoked. Underpinning such a

Figure 1 The EA application process for securing permission to develop a micro-hydro scheme in England and Wales. Source EA website.



process is the assumption that expertise is held in particular individuals or institutions, and that it is value free. However, as social science research has demonstrated, the nature of evidence, ideas, arguments and framing all matter in the way in which expertise is determined and used in the process of environmental governance (Jasanoff 2003; Owens, 2010; Bracken and Oughton, 2013). As such, expertise is not self-evident but rather determined by both 'what' is going to count as relevant knowledge and subsequently 'who' then possesses such knowledge to inform policy debates within the public arena (Gieryn, 1999; Jasanoff, 2003, Eden et al., 2006).

Such processes are highly contested creating what have become known as knowledge controversies; events "in which the knowledge claims and technologies of environmental science, and the regulatory and policy practices of government agencies that they inform, become subject to public interrogation and dispute" (Whatmore, 2009; p588). Micro-hydro schemes frequently draw upon multiple forms of expertise, both from local and expert communities, and may also emphasise existing local tensions over particular sites and resources. The importance of expertise in the social organisation or 'software' of micro-hydro schemes is therefore not only a means through which dissent and controversy is reduced, but can also prove a source through which it is ignited.

Alongside questions of expertise, therefore, the ways and means through which communities are engaged with micro-hydro projects is also critical in shaping their social organisation. Over the past decade, there has been a growing emphasis on communities as a site for the generation and ownership of renewable energy projects particularly in rural areas (Walker et al., 2007; Walker and Devine-Wright 2008; Haggett, 2009; North 2010). Recent government policy, including the Low Carbon Transition Plan, the 2009 Low Carbon Communities Challenge in England, Wales and Northern Ireland and the 2008 Climate Challenge Fund in Scotland, have continued to focus on 'community', and associated micro-generation energy technologies, as a site within and through which a transition to a low carbon economy may be forged. Intuitively, such initiatives provide for greater consideration of issues of community engagement and social justice. Community scale energy projects provide for public participation in their design, ownership or management, while on the other they may offer more secure or cost-effective forms of energy generation, as well as other forms of social benefit (Walker and Devine-Wright, 2008; Haggett, 2009). While these issues have been debated at length in relation to wind energy, to date little analysis has been undertaken to examine the extent to which micro-hydro schemes are realising these forms of benefit or fostering new forms of community engagement.

One exception is the study by Watkin et al. (2012) of the conflict around small-scale hydro power generation in Hampshire (UK) which found stakeholder bias towards favouring economic appraisal over intangible social and environmental benefits (Watkin et al., 2012). These findings raise the possibility that the social organisation of micro-hydro may work to exclude communities and to reduce their potential for realising social justice, and that this dimension of micro-hydro resource development merits particular attention.

2.3 Bringing in the socio-environmental dimension: fluvial processes and river habitats

Many researchers have suggested that micro hydro is one of the most environmentally benign energy conversion options available because it does not interfere significantly with river flows (Fraenkel et al., 1991; Mishra et al., 2011). Yet environmental managers in the UK see micro-hydro power as a massive contemporary issue (Cussens, Natural England, pers. Com) due to how the application of technology may transform rivers and their ecosystems by fragmenting channels and altering river flows (Renofalt et al., 2010). There are three key aspects of the socio-environmental issues raised by micro-hydro. Firstly, the potential to increase flood risk. Installations of micro-hydro power sites in effect add a barrier into the river system. This alters the conveyance of water through the river system. The 2007 IPPC report assumes that precipitation will increase in intensity in the UK under different emission scenarios, potentially increasing localised flooding (Lane et al., 2007). Installing a barrier has the potential to increase this flood risk. Secondly, the effect of schemes on the transfer of sediment. Research has suggested that local aggradation of weir structures over a 2-year period can have a considerable effect on the cross-sectional area of a channel and therefore the capacity of conveyance of both water and sediment; this has the potential to outweigh the impact of climate change caused by increased precipitation over 50 years (Lane et al., 2007). Thus local effects on some UK rivers can be more important than regional climate change. Micro-hydro weirs have the potential to increase this trapping of sediment by acting as a barrier and blocking natural sediment moving through system.

Thirdly, the impact on biodiversity; both wildlife and habitats. This is the most widely researched aspect of micro-hydro. By modifying the water, sediment transfer and flow velocity in river channels the range of species and habitats is likely to be altered (Renofalt et al., 2010). There is currently little understanding of these impacts, although there is evidence of high profile dispute around the impact of schemes; notably around fish and the impact on fish passage between anglers and scheme designers. Most research continues to suggest that there is negligible impact of small-hydro power schemes, but some work is starting to question the impact on wildlife and habitats. Castro-Santos et al., (2006) found that 10% of fish passes in Portugal were not suitably designed for effective fish pass and even where fish passes were effective, populations upstream and downstream of constructions developed different sizes structures. Abundant small scale barriers may therefore fragment freshwater habitats (Larinier, 2008; Lucas et al., 2009). Studies of algal communities suggest changes do take place in habitats downstream of structures and that it may take up to three years before the effect can be identified (Wu et al., 2009). Since freshwater habitats are one of the world's most threatened ecosystems (Renofalt et al., 2010) it is important to understand the impacts of micro-hydro power on habitats and biodiversity.

From this review of the debate, it is clear that micro-hydro cannot simply be conceived in technological terms, but is rather bound up with new forms of social organisation and environmental processes that have potentially profound implications in terms of environmental impacts, and the development of micro-hydro as an energy resource. In the rest of this paper, we examine how these three dimensions have shaped the emergence of micro-hydro in the UK, first through documenting the rise of micro-hydro and its technical and social characteristics and second through examining the ways in which socio-technical and socio-ecological processes played out in the development of two cases in the North of England.

3 Research methods

To explore the role of communities in the development of micro-hydro in the UK we undertook a two phase research project. First, we conducted a web-based survey of the emerging policy context for micro-hydro projects in the UK. This involved an assessment of the policy process in England, Wales, Northern Ireland and Scotland, and an assessment of the key characteristics of emerging micro-hydro projects.

Secondly, we collated as much information as possible about micro-hydro developments and schemes in the UK using a survey of material and information published on the web. Information published on the web provides a constant source of information that is readily available and can be used effectively to underpin academic research (e.g. Battistini et al., 2013). Key words related to micro-hydro were used systematically to mine as much information as possible on micro-hydro schemes in the UK. Identification took place of standalone developments, but also noted schemes included on professional and/or organisational sites (e.g. h2hope consultants, Micro-hydro Society). Information was interrogated to determine the location, river discharge, head, cost, power generated, funding, whether the scheme was developed by an individual, community or business, and the date of development. Data was stored in an excel database for analysis. In total 106 schemes were included in our analysis. However, as the survey is biased to those published on the web it is hard to be certain about the proportion of schemes captured in the UK. We found that schemes developed by many different organisations were present, from individuals, to communities to more formal organisations such as consultants, the EA and Local Councils. Once again we do not know the proportion of schemes of each type promoted on the Web. However, this is the only method available to start to interrogate the number and type of schemes in the UK and we felt that the advantages of this method outweighed the uncertainties.

Thirdly, we conducted an in-depth examination of two micro-hydro projects in the North of England; a scheme at Settle on the River Ribble, Yorkshire Dales and one at Ruswarp on the River Esk, North Yorkshire. These two schemes were selected since they were community led. One was already constructed and working, the second was in the process of being built. Hence the ways in which expertise had been brought to bear on the development and the ways in which knowledge had been contested within the community were at different stages and results would reflect a wide range of schemes and experiences.

The Settle scheme, Settle Hydro, has developed a reputation as a pioneering scheme and first produced electricity in November 2009 (http://www.settlehydro.org.uk/). The scheme was developed as an Industrial and Provident Society for the Benefit of the Community (a legal entity for a trading business or voluntary organization) who would own the Settle Weir Hydro Electric Scheme (Figure 2). The scheme uses a 50kW Archimedean screw at Settle Weir near Bridge End Mill. The screw was installed close to the original waterwheel and uses part of the existing millrace. The Scheme generates approx 165,000 kWh (units) of electricity per year – enough for around 50 average houses, over an expected lifetime of 40 years, which is sold to the grid. The total cost of the scheme was £415,000. Around £135,000 was raised through a share offer; the remaining costs were covered by grants from Yorkshire Forward, Future Energy Yorkshire, and a loan. At the end of each financial year there is a division of profits between the shareholders and the community, should the company be in a financial position to issue dividends.

Figure 2: The Settle scheme. Source Settle Hydro.

The Ruswarp Scheme, located on the River Esk at Ruswarp Weir, is currently in the process of being built (Figure 3). The developers, Esk Energy, have installed a 50kW Archimedes Screw turbine on the south side of the River Esk adjacent to an existing fish pass. The turbine will generate 50kW of electricity, which will be sold via the local electricity network. Any profits made by the scheme will be invested in energy projects in the North York Moors. As with the Settle scheme, Esk Energy is an Industrial Provident Society. Grants have been obtained from the local council and NGOs for the development of this site as a flagship demonstration project which will hopefully lead to further development of hydro power at other sites in the North York Moors. A loan has also been secured with the balance of funds coming from a Community Share Issue which took place in summer 2011. Planning permission has been approved for the development and the details of the development have been finalized with the EA for the Abstraction License. Building of the scheme started in May 2012 and is currently underway.

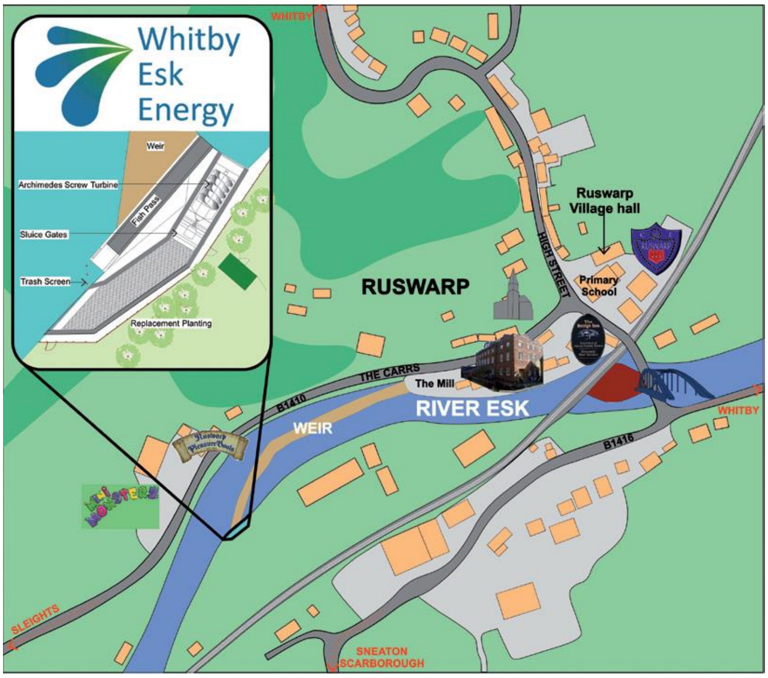


Figure 3: The Ruswarp scheme. Source Esk Energy.

In each case, a combination of methods was used to understand the way in which the micro-hydro schemes had been designed and implemented. We collected empirical data across as wide a spectrum of people as possible including people involved in the development of the micro-hydro schemes, local residents who were not members of the development group, tourists, people who use the river for recreational purposes, local councillors and people whose income is related to the river. Firstly, site visits were made to each scheme to see the locations and schemes and to gauge local opinion where possible. Secondly, semi-structured interviews were conducted with people both involved in the development of the two schemes, but also with others from the local community. Some people spoken to, especially those those in favour of the Settle scheme, declined to comment. Hence representation may be dominated by those with complaints. Yet, inclusion may also reflect the zeal that proponents have about a scheme Thirdly, opinions and thoughts were also received through email communication from people that were willing to share their views but were unavailable for interview. At Settle 10 people were engaged with the study; one person involved in the scheme development, two recreational river users, four people who were local residents and three tourists. At Ruswarp seven people were involved; two people from the development group, one recreational river user, one business owner, one councillor, and two local residents. Below, we first analyse the findings from our review of micro-hydro in the UK before analysing the insights generated from this more detailed and field based study of individual micro-hydro projects.

4 Charting the emergence and characteristics of micro-hydro in the UK

Despite the predominant focus of community-based renewable energy projects on wind, wood and solar, our review found that there were 106 sites in the UK where micro-hydro power had been developed, or were in the process of being established. This figure is likely to underestimate the total number of schemes in the UK since information on many schemes is not publically available. There were three very old schemes that had been initiated in 1880, 1922 and 1956, but all had been modernised recently. Despite this long history of interest in micro-hydro, we found that there has been an exponential increase in schemes initiated since 1990 (Figure 4), with a dramatic increase in uptake since 2005. These projects tend to be clustered throughout the UK with centres of focus in Yorkshire, the South West, Wales and Scotland. This may relate to the presence of particular kinds of hydrological resources and distinct 'networks of practice', where people have the necessary experience and knowledge of regulation to support and champion micro-hydro schemes.

Projects that have been established in the UK are mostly sites for small scale production (less than 100 000 KWh/yr), but there are a number producing substantially more power (up to 500 000 KWh/yr) and one major producer (25 M KWh/yr) (Figure 5). The cost of developing these schemes varied dramatically from under £100k, up to £1.5 M (Figure 5). Importantly, there does not appear to be a relationship between cost and power output. This is due to the range of designs that can be used to underpin the development of schemes, and is affected by whether existing infrastructure (e.g. weirs, mill races) can be used to host the scheme thereby reducing the overall construction costs. Costs are also increased substantially if a fish pass needs to be constructed. Perhaps more than other community-based renewables resources, therefore, the costs of micro-hydro, and hence the economy of any project development, tend to be very dependent on local conditions.

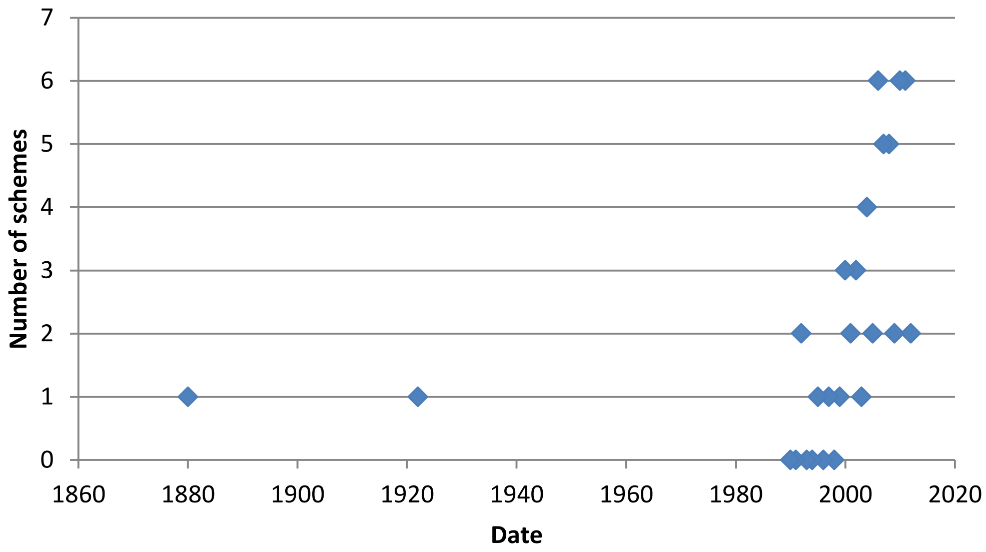


Figure 4: Dates of establishment of micro-hydro schemes in the UK

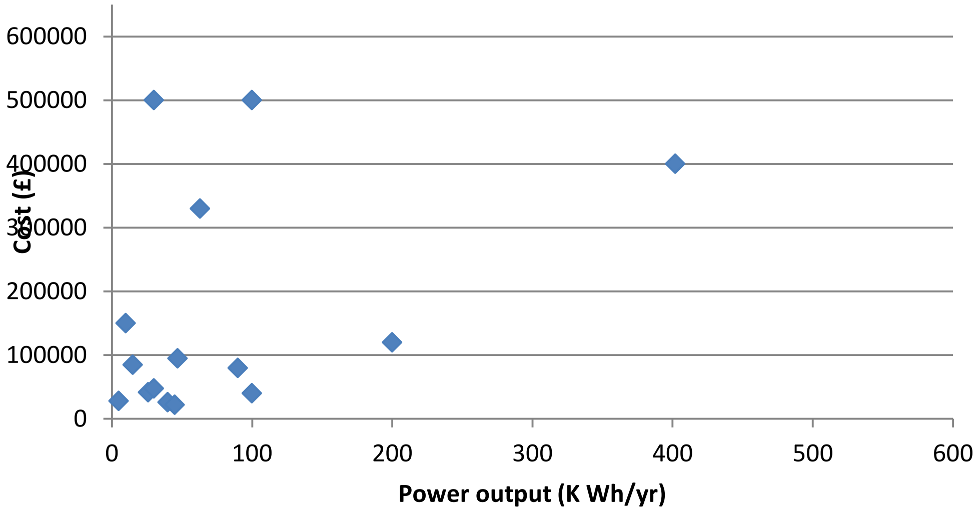


Figure 5: Power output and cost of micro-hydro schemes in the UK

We also explored the role of governance in establishing micro-hydro schemes in the UK. Figure 6 demonstrates that almost 50% of schemes reported are community based, with another 30% having been established by individuals. Only approximately 10% of schemes in the UK have been established by organisations. For schemes established by individuals power tended to be returned locally over short distances to the person developing the scheme. For community schemes power output tended to be sold to the grid to ensure the best possible financial return and the profit was then either ploughed back into the community to further support 'green initiatives', or given to shareholders as dividends. In this way management and the responsibility for maintenance and running tended to rest with the individual or group responsible for development of the scheme. For communities responsibility was organised collectively and transparently through Industrial and Provident Societies and communicated widely by websites and social media. Regulation took place through financial services agreements and environmental regulation via abstraction licence agreements. In terms of infrastructure and networking we found that the community led schemes tended to feed into the grid locally through national energy companies. This was seen as the way to secure the best possible financial return on investment.

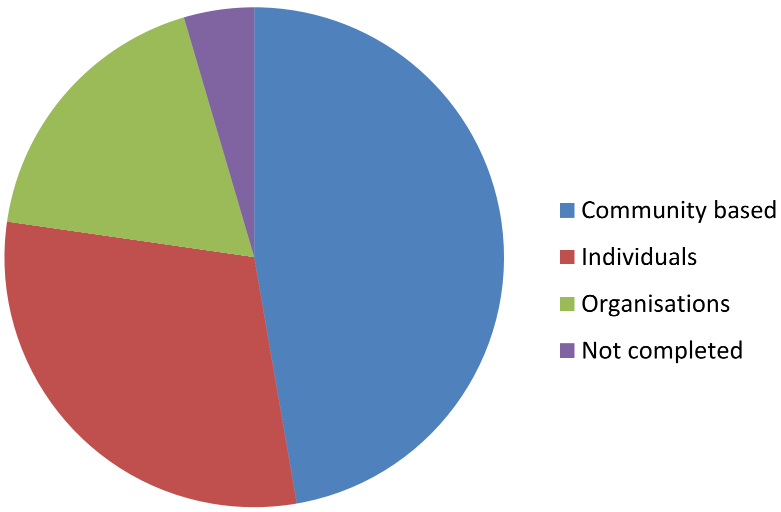


Figure 6: The role of different types of governance in establishing UK micro-hydro schemes

Micro-hydro in the UK is thus a form of energy provision that is currently dominated by forms of ownership that are often advocated as a means for achieving 'buy-in' to the development of renewable energy resources (Walker and Devine-Wright, 2009). Such ownership provides a means for developing alternative forms of energy economy but also as a means of securing community benefits. Understanding how micro-hydro is operating in practice therefore provides a potentially critical testing ground for these emerging discourses about how and why community-based renewables should be developed in the UK.

5 The practice and politics of micro-hydro

In both Settle and Ruswarp, we found that the practice of micro-hydro was highly contested between and within expert and public communities. Here, we discuss each scheme in turn, considering the 'hardware', 'software', and environmental aspects that have been central to the design and implementation of the schemes, and the ways in which these socio-technical and socio-environmental processes have become politicised in the making of micro-hydro projects.

5.1 Settle

5.1.1 Hardware

Existing infrastructure in and around the river was used to develop the scheme which uses a 50kW Archimedean screw at Settle Weir. The screw was installed close to the original waterwheel and uses part of the existing millrace. The community group were meticulous when designing the project, ensuring only the best materials were used in a hope to keep the wider community on side with the project. The community group were aware that development of the scheme had the potential to be controversial and they did not want the development to be undermined by controversy over building materials. The community group thus spent more money than was necessary to make sure the building works were finished to a very high standard. The group also intended to make the area attractive to visitors.

5.1.2 Software

The Settle Scheme was initiated by a community group who came together to develop the project with an aim to bring more people into the area who wanted to know more about sustainable energy generation. The scheme was designed to:

> *"boost community empowerment so residents could take responsibility for their own future". Development Group Member*

Hence the purpose of the scheme was not only power production. The backbone of expertise to the project was provided by h2oPE (consultants) who conducted a feasibility study, and based designs on other schemes in which they had been involved. The popularity of the scheme was emphasised:

"As you can imagine we get numerous requests for information and help, most of which I turn down because I simply don't have the time. ..... I have had 8 requests so far this week." Development Group Member

Much of this interest seemed to come from people beyond the local area interested in the development due to the number of prizes it has won and marketing carried out by Settle Hydro. Three tourists engaged in conversations about the scheme knew about the micro-hydro development before visiting the area and appreciated the potential environmental and economic worth of the Settle scheme to the local community. In contrast four local residents spoken to were aware of the scheme but felt it did not impact on local business in any way, although there was a general feeling that people, especially tourists, stop to have a look at the scheme. Initial field results therefore suggested the Settle scheme was a mode 3 development: one which is implemented by the community that is a 'smaller scale, locally appropriate and environmentally and socially benign' (Walker and Cass, 2007; p461). However interview data proved that the scheme was not environmentally or socially benign and had resulted in local controversy. Controversy was sparked around the software but also the environmental concerns around the scheme. At the planning stage there had been local objections from the EA and anglers, which meant that the first planning application was refused. The nature and extent of controversy emerged from interviews conducted with two recreational river users. The main issues which sparked controversy were: i) the financial gains from the scheme; ii) the impact on fluvial processes by introducing barriers into the stream; iii) the impact of barriers on fish and stream habitat; and iv) the operating conditions relative to flow levels and how they feedback to impacts on fluvial processes and biodiversity. In this section we consider the financial issues as part of the software of the scheme; the next section explores the environmental issues.

The key issue for debate around the financial gains was that interviewees did not think it clear what the benefits of the scheme were. They believed that no dividends had been paid to those that had invested in the scheme. The interviewees also raised the issue of a trade off between the worth of a salmon in the river and the money raised from fishing licences versus the potential for green energy production and community dividends. This was summed up in one response as follows:

"Game fishermen invest considerable amounts of money in maintaining fish stocks and improving riverine habitat. They also spend considerable sums of money local to the rivers in

the form of rent for fishing rights, hospitality expenses etc. and without an adequate stock of fish such investment in local enterprises will cease" Recreational River User 1

This demonstrates that the value placed on the environment and biodiversity is important when considering renewable energy production. Thus a relationship exists between the software and environmental aspects of the micro-hydro scheme.

5.2.3 Environmental Aspects

Controversial environmental aspects of the Settle scheme that emerged from interviews were focused on: i) the impact of the weir; and ii) determining Hands off Flow (HOF); the level of river flow at which abstraction must stop, particularly to prevent damage to fish. We propose that these issues do not fit within understanding the hardware of a development because socio-ecological processes become politicised in the development of micro-hydro projects, especially when negotiating and selecting the hardware.

The arguments around weirs operating as barriers to both fluvial processes and fish centred on the obstruction posed by the weir and Archimedes screw. Research has determined that inadequate passage solutions past micro-hydro schemes may have drastic consequences for fish species distribution and recruitment (e.g. Lucas *et al.*, 2009; Alexandre and Almeida, 2010; Branco *et al.*, 2011). The EA and recreational river users were well aware of the issues (raised by experts) and were concerned about the impact of the development on fish. More complicated was the controversy around design. It could be argued that this issue should be considered under hardware, but since it is driven by a consideration of ecology we feel it should be raised under environmental aspects. Initially the angling organisations had not been opposed to the Settle scheme and had been involved in its design and development. However there was disagreement over the desired HOF. This led to objections from local angling organisations and the EA which were upheld. However, on the third application planning permission was agreed and conditions were written into the abstraction licence about HOF.

Despite the abstraction licence and planning permission being secured, the controversy continues. Ongoing issues are about requirements for design and that the scheme is not operating in line with the abstraction licence granted. For instance one recreational river user noted that:

“the requirements for fish passes such as height, velocity of water leaving the pass etc for old fish passes, including the one at Settle, do not meet the modern requirements” Recreational River User 2

This person had a huge amount of both local knowledge and expertise in the design and working of the micro-hydro scheme and felt he knew exactly why the turbine was operating at flow levels where it had been designed to stop working:

“The sluice gate is supposed to be automated so that abstraction of water for the turbine automatically stops at 900l/s, but it isn’t. Water gets under the sluice gate because the hump which was originally the same height as the weir, has been lowered and the gate in front of the screw leaks, so water builds up in the pool between the sluice gate and gate in front of the screw. The turbine starts, the pool empties and the turbine stops.” Recreational River User 2

In this way the build up of water in the pool tells the system that flow is high enough for micro-hydro turbine to run, although this is not the case in practice. The questioning of the technical details had led to an audit being conducted by the EA who found that there were numerous contraventions of the abstraction licence. However these were deemed minor and hence the Settle scheme continues to operate and controversy and dispute continues.

The controversy over HOF is an example of a knowledge controversy (Whatmore, 2009). This raises questions about who has the technical knowledge but also the detailed knowledge about the flow and environmental processes at this particular location. On one hand the Settle scheme was designed by professionals with certified expertise (i.e. the consultants and the EA), but it is the local community who spend more time utilising the river and are situated in the local environment and so are aware of how the scheme is working on a day to day basis (experiential knowledge). This raises a key issue whether the ‘expertise’ conveyed as ‘standard’ can ever cope with a dynamic river environment and hence will there always be a gap between expertise and how something works in practice.

5.2 Ruswarp

5.2.1 Software

As with the Settle scheme the key issue around software was the likely financial returns. Concerns about the financial returns were expressed slightly differently than those at Settle. The concerns came from people who were against the proposed development, not in terms of there not yet being any profit from the scheme, but rather that £1 million was a lot to invest in a development which is likely to provide enough electricity to only power 15 homes:

> "*for the damage being done to the environment and the view of the houses overlooking it a lot of money is being spent for only 15 homes worth of electricity". Local Resident 1*

These people were not against micro-hydro power generation *per se* suggesting that if the scheme produced more power it would be more beneficial and they may then not be against the development.

> "*it has the potential to be good since it produces power by a reasonable means that doesn't impact on ecology, which has to be a good thing". Local Resident 2*

These people all live locally to the river and undertake leisure activities around the river (walking and fishing) so understood that the river is unlikely to run in flood very often, especially in light of the low flows which had been a problem in the year preceding the interviews. Hence these interviewees were knowledgeable about flow conditions in the river and appreciated that the turbine would not be able to work in low flows which led them to question the predicted power output of the scheme.

One key issue not voiced about Settle Hydro but raised around the Ruswarp scheme was the visual impact. Many objections to the original planning application were made about the look of the scheme; felling trees to make development possible, the visual impact of the turbine house and the potential noise of the scheme when built. Some interviewees felt strongly about damaging the view from their own property but there was wider concern too:

> "*if you're going to be green you can't just chop trees down." Local Resident 1*

Yet the perspective of the development group was that the location of the scheme was on an old industrial site so there was no visual impairment. The development group also felt that everything possible had been done to reduce any impact of noise from the turbine and that any noise would be below the natural background noise of the river.

Another aspect of controversy that arose at the Ruswarp scheme was around communication. There were a number of instances where communication seems to have been contentious, especially between the development group and other local residents. The development group appeared to try hard to involve as many people as possible and communicate intentions and design as widely as they could. The development group evolved from a community energy group which met to discuss and work towards reducing carbon usage within the area. The development group emerged due to a slightly narrower focus on micro-hydro with a core of about six people who were actively engaged in pushing the project forward. This group were comprised of people with wide ranging expertise around engineering, finance and planning. The group commissioned a survey by a hydrology expert to explore the potential energy production of a number of weirs on the River Esk. The group advertised the initial meetings and aim of the group in the local press, but also held advertised events to talk to people as widely as possible about ideas and plans for developing micro-hydro in the River Esk.

Yet the people we interviewed who were opposed to the scheme felt that they had not been consulted and that the first they had heard about the proposed scheme was when:

> "*they saw someone official from the EA and NYMNPA scouting about on site" Local Business Owner*

One local resident even felt they had had to persuade the NYMNPA to contact those on the opposite side of the river to comment on the planning application since this was not land in the NYMNPA so residents would not be automatically informed but they would obviously overlook the development. Hence those against the scheme only heard about it once a planning application was submitted. Some of the people we interviewed had submitted formal objections to the plans, but remained disappointed that they had not been directly contacted by the development group to discuss the proposal in detail, although they had been invited to a meeting to discuss the share initiative to support the scheme. The councillor knew more about the scheme and its development and noted that they had been involved in discussions through council business, but they had also been aware of adverts in the local press.

The final area of software controversy is around regulation and legislation which can be divided into two aspects, firstly around design and development, and secondly concerning funding. One interviewee opposed to the scheme noted the confusion he felt in communication with the EA. He had found it very difficult to understand information sent to him from the EA concerning the planning process, negotiation of abstraction plans and reasons for EA decisions. Supporters of the scheme and those involved in the development group also noted the problem of working through the necessary regulation and securing the necessary permissions. As one supporter noted:

"*The biggest obstacle was government bureaucracy." Development Group Member 1*

One of the development group stated that:

"Dealing with the EA was a nightmare and the worst part. It takes a long time to get through all the regulatory processes" Development Group Member 2

For micro-hydro schemes to be developed permission is needed from the landowner, an abstraction licence needs to be granted (from the EA in England and Wales and from SEPA in Scotland) and planning permission needs to be granted which includes the checks outlined in Figure 1. Interviewees from the development group said it had taken two and a half years to negotiate the abstraction licence for the scheme. They realised this had been protracted because they had done this themselves rather than employing a consultant to do it for them, but felt they had secured a more favourable outcome and an abstraction level that helped enable the scheme to work as much of the time as possible. They had also fought over the terms of the licence. Normally, as in Settle Hydro, abstraction licences are given in terms of HOF, but the Ruswarp development group argued for a more simple depth of river reference term below which the scheme would not be used to produce power. The group felt this was easier to understand and enabled better project design rather than having to include messy calculations to relate stage to HOF.

The second aspect of regulation and legislation concerns the difficulty in securing funding for a micro-hydro scheme and understanding feed in tariff regulations. Securing funding was a major challenge in itself, but despite the professional experience and wide ranging expertise of the Ruswarp development group, understanding what they could and could not do with grant money was a big issue. Two members of the group commented that each different source of funding had different guidelines but also interpreted EU legislation differently. The bulk of funding secured allowed money only be spent on capital investments which meant it was difficult paying for environmental audits and studies to assist in securing the necessary permissions. The added difficulty of this was that the development group wanted to secure independent expertise where possible since they thought this would be more professional and help persuade others of the overall worth of the scheme. The development group also had difficulty in understanding the point of legislation that made development more difficult, for instance if they secured grants for developing the scheme then they couldn't claim the best feed in tariffs. One interviewee summed up the difficulty as follows:

> "*the pedantic interpretation of EU law precludes taking money from people who would happily give it and doing feed in tariffs, this is absurd." Development Group Member 1*

Difficulties in securing funding and understanding regulations were compounded by the length of time taken to develop the micro-hydro scheme at Ruswarp which meant that changes in funding bodies and legislation were continually experienced. The biggest disappointment was that initial funding for the scheme had been secured from the regional development agency (RDA) (£750k), but with a change in government the RDA had been disbanded and hence funding was lost. In light of changes to funding the development group had decided to raise the majority of the funding through a share scheme. Reaction to this was mixed between those thinking it was an 'obvious' direction to go in and those that felt that the scheme would not make any money. Managing the demands of changing funding and regulation underlined the importance of the core group evolving to include new skills and new energy;

> "*Grant laws changed at least three times. Injections of new blood were essential since the initial members were exhausted by the goal posts continually moving." Development Group Member 2*

5.2.2 Environmental Aspects

As with the Settle scheme concerns were raised over: fluvial impacts; impacts on biodiversity; and operating conditions. Concern about the impacts on the river were focused on the flow conditions, with a number of those interviewed expressing concern about the impact of the scheme on the water level and implications for local businesses focused on the river. This concern was raised by people other than those directly linked to such businesses with people concerned about the negative impact on tourism. Members of the development group had tried to directly respond to this concern by educating people that this would not be the case because they had negotiated a depth of flow with the EA below which the turbine would not work. Hence water would not be allowed to flow into the turbine route during low flow, keeping water in the main river. Yet those concerned about the micro-hydro scheme altering flow levels were not reassured and remain worried.

There was a lot of disagreement over the impact on wildlife. One supporter not involved in the development of the scheme summed up the impact as negligible saying that;

> "*it's just parcels of water moving downhill. If you dropped a salmon in [the turbine] at the top it wouldn't come out as minced salmon at the bottom." Councillor*

Yet, local residents, anglers and the EA were all worried about the impact on biodiversity. Concerns focused on the possible negative impact on migratory fish, drawing on information gathered from reading angling literature. Concerns were not just around damage to fish that went through the Archimedes screw, but included technical issues such as whether the turbine would be distressing to fish, allow safe passage of fish, whether in-channel flows would be managed to attract fish to go down the fish-pass rather than through the turbine, whether fish numbers would build up below the turbine if flows weren't managed correctly. Local residents were also concerned about impact on birds such as cormorants and herons. The people involved in the design of the scheme had worked hard to limit negative environmental impacts, especially on the flow and biodiversity. They had many negotiations with the EA and had commissioned feasibility studies to ensure the scheme was designed as well as possible. In the research and design phase the people involved in initiating the scheme found that the existing fish pass was not working well and therefore thought the new scheme would improve many aspects of biodiversity.

The development group were well aware of the environmental concerns of local residents and anglers and had tried hard to engage these people and inform them of benefits of the scheme and felt that:

> “*Opposition was from people who misunderstood what we were trying to do. Once they knew or read more they became supporters.” Development Group Member 1*

The supporters interviewed hence felt they had overcome some opposition particularly that from the EA, however, the local residents and anglers interviewed still commented on their concerns around biodiversity.

6. Discussion and Conclusions

This is the first study to examine the role of communities in developing micro-hydro power in the UK. The research outlined in this paper demonstrates that there is rapid expansion of micro-hydro in the UK. Individuals and communities are fundamental to initiating and developing micro-hydro schemes. This suggests that people understand and acknowledge the need to diversify energy production and that micro-hydro energy conversion is thought to be economically viable under current regulatory and institutional environments in the UK. Communities are composed of different types of expertise which is drawn on differently in different situations. In one case the community had a range of professionals with relevant training and experience to develop and operationalize micro-hydro power generation. In the other case expertise was brought in by engaging a consultant to assist in project development. Common to both examples was the controversial nature of micro-hydro power development within the community and how expertise was questioned and debated.

Until now research around micro-hydro has been dominated by technical approaches. This perspective has led to micro-hydro being defined solely in hardware terms, such as the power output of schemes. We suggest this needs to be revised in light of their important social and environmental dimensions; we cannot understand the potential of micro-hydro without understanding these aspects as co-constituted (physical capacity without social or environmental does not lead to generation of power). Perhaps more than other small renewables, micro hydro is ‘embedded’ within landscapes (broadly understood), and to realise its potential needs an explicitly sociotechnical/socioenvironmental approach.

In terms of software of micro-hydro schemes our analysis highlights that ownership/control is highly ‘community based’, but this does not necessarily mean that ‘community’ is engaged in broad terms. Community projects cause controversies within communities; community ownership is not a panacea. Expertise is also a critical aspect of the software, which is highly distributed (multiple agencies, multiple publics) and much of it private (consultancies, private individuals) as well as public (EA, rivers trusts, societies of various kinds). Once again results suggests that who ‘owns’ the project is not clear cut, and projects emerge as an amalgam of expertise which can readily fracture under pressure.

We propose a third dimension to Walker and Cass’s (2007) classification of renewable energy developments: the environmental dimension. Renewable energy projects are recognised in the literature as raising environmental challenges, but much of the literature does not examine these in detail, and rather sees them as a social controversy (e.g. birds and wind). We suggest this dimension of micro-hydro is critical, both in terms of the extent to which resources can be realised (flow, head, existing river infrastructure, fish) and the ways in which it might attract controversy; indeed, in the study cases it was these socio-environmental dimensions that were critical and caused most controversy. Our results suggest that hardware, social and environmental aspects of developing renewable energy resources are overlapping and feedback to each other; none should be considered in isolation.

An important barrier to the development of micro-hydro schemes is the complexity of regulation and legislation around the permissions needed to develop a scheme (planning permission and an abstraction licence) but also in securing and spending funding. If potential for micro-hydro is to be realised in the UK then this needs to be clearer, able to proceed more quickly and financial and environmental regulation needs to remain stable rather than constantly changing. If these changes were made then communities and individuals may be able to realise their aspirations for generating electricity from micro-hydro schemes without such personal costs in terms of energy time and enthusiasm.

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