Small-scale hydropower: how to reconcile electricity generation and environmental protection goals?

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Front page picture:
This hydro-dynamic screw small-scale hydropower plant was installed at River Dart Country Park in Devon, England in 2007, the first time this technology was used in the UK. It is based on the Archimedes screw, but works in reverse – river water drives the screw, gearbox and generator. The use of the screw overcomes the major problems of screening water-borne debris and fish that other systems have to cope with. Extensive research showed that the screw has no adverse affect on fish and it is fully approved by the Environment Agency. In its first year of operation, the screw generated over 330,000 kWh.

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Executive summary

This final report is submitted to the European Environment Agency (EEA) in fulfilment of Task 2.9.2 – Renewable Energy of the EEA European Topic Centre on Air and Climate Change 2009 Work plan. The work was performed by AEA Technology with guidance from Hans Eerens of the Netherlands Environmental Assessment Agency (PBL) and Philippe Crouzet and Anca-Diana Barbu of the EEA.

The purpose of this project is to assess the environmentally compatible potential of small-scale hydropower (SHP) in Europe. The recently agreed target for 20% of the EU's energy consumption to be derived from renewable energy sources by 2020 is providing a strong added impetus to deploy technologies such as SHP, however there is also growing recognition that such deployment must not cause unacceptable harm to the environment.

In the case of hydropower the environmental focus is further accentuated by the Water Framework Directive (WFD), which is gradually being implemented by regulatory authorities and encourages significantly higher environmental standards to be adopted than those implemented by the majority of existing SHP plant. It is becoming increasingly clear that the WFD is likely to limit the growth of new SHP plant required to meet the renewables deployment goals. Furthermore the WFD could have an impact on existing SHP plant, which currently provide 9% of the EU's electricity from renewables sources. Modelling by others suggests that SHP could provide a 50% increased contribution by 2020 but it is unclear to what extent environmental constraints have been taken into account.

There is therefore a need to understand the impact that increasing environmental standards will have on the contribution that SHP can make to the renewables target. In order to do this it is necessary to have an agreed methodology to assess SHP potential and an agreed approach to factoring down the potential to account for environmental constraints. In essence the goal is to calculate a technical potential using hydrological data available across Europe and decide how to account for the environmental constraints, which fall into two categories:

- A requirement to implement mitigation measures such as fish passes, flow control or the undergounding of transmission wires will generally increase the cost of electricity production, making it potentially uncompetitive in the electricity market.
- Technically viable SHP sites may need to be excluded because they lie within a geographically designated area (e.g. a Natura 2000 site or national park), would result in too high a deployment density or conflict with policies set by relevant authorities.

The combined effect of these constraints may result in a much smaller number of technically viable sites actually being realistically viable, which is what dictates the contribution that SHP will make in practice. It is also clear that the process of taking these constraints into account is not a simple one; quite a few judgements are required and the way in which constraints are applied will vary considerably from one place to another. There are no agreed standards for what constitutes an acceptable SHP project, no agreed good practice guidelines, not even an agreed methodology to calculate technical potentials.

The project therefore faces a significant challenge in meeting its objective. During 2009 an assessment was made of various SHP resource assessment methodologies to identify whether any of them would be suitable for calculating the SHP technical potential across different European countries based on hydrological data available electronically in the public domain. A number of software packages have been developed over the years to undertake SHP resource assessment but most of these have either relied on site specific information or were designed for use in specific countries. We believe one of these may be adaptable for use across European countries, however this will require further investigation.

The other major activity during 2009 was the organisation of a stakeholder workshop bringing a range of parties together to review SHP's environmental impacts and discuss how these should be factored into calculating its environmentally compatible potential. This took place on 27th November in Brussels and full information is provided in this report's appendices. The feedback from this workshop, coupled with the work described above on resource assessment methodologies, lays the groundwork for a concerted effort in 2010 to develop a workable methodology and apply it on a pilot basis to at least one representative European river catchment.

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1 Introduction and background

The European Environment Agency (EEA) has been asked by the European Commission to help define the "environmentally compatible potential" for renewable energy in the period to 2030. This must be seen in the context of the recently agreed Renewable Energy Directive 2009/28/EC requiring the European Union to obtain 20% of its final energy demand from renewable energy sources by 2020[1] from a starting position of 8.5% in 2008. This is a very challenging mandatory target and all actors at European, national and local level will need to work together to secure its achievement. Each Member State has been assigned its own binding target based on its current level of deployment and its capacity to bring forward new projects. Member States are currently preparing national action plans for submission to the Commission in June 2010[2]. These need to set out detailed estimates of deployment and energy generation for each renewable energy technology on a yearly basis from 2010 to 2020.

Like all forms of energy, renewable energy technologies have their own environmental impacts, mostly at a local level. If renewables are going to achieve their potential deployment, this must be done without causing unacceptable harm to the environment. However there is no consensus as to what constitutes an acceptable level of impact. The EEA has therefore sought to look across the various renewable resources that might contribute over the coming years and define what might be their environmentally compatible potential. Given the nature of the subject it is inevitable that this will encompass some level of subjective judgement, however the purpose is to initiate debate and hope that a consensus can be reached between all interested parties.

This report describes work undertaken by the EEA's European Topic Centre on Air and Climate Change (ETC/ACC) during 2009, which has focused entirely on small-scale hydropower (SHP). This follows on from projects in previous years that have sought to quantify the environmental constraints on bioenergy[3] and wind energy[4]. Previous work has also provided a qualitative assessment of the environmental constraints on other renewable energy technologies and, in 2008, the work started to focus on the environmentally compatible potential of SHP[5], which is generally recognised as hydropower schemes with a power output below 10 MW.

Hydropower is of particular interest as the EU adopted (in 2000) the Water Framework Directive[6] (WFD) establishing a framework for Community action in the field of water policy and pursuing for the first time an integrated approach to European water policy. In contrast to previous directives, the WFD is not usage-oriented but has a strongly ecological focus. Its objective is to improve and preserve the environmental condition of EU water bodies, which inevitably results in possible conflict with economic uses of those water bodies, including hydropower. Reference 5 provides a brief overview of the WFD and signposts to extensive information on the Internet. What has become clear in recent years is that the full implementation of the WFD (which will take many years) is likely to have a profound effect on the prospects for new hydropower plant. It has also focused attention on the environmental impacts of existing hydropower schemes and there is now increasing pressure to mitigate these.

Foremost amongst the impacts is the barrier that hydropower schemes can create for fish migration, along with changing the water regime (hydropeaking) and the river habitats. Of course hydropower schemes are far from the only obstacles placed in the way of migrating fish, however there are plenty of examples of hydro schemes where inadequate provision has been made to facilitate up and down-stream migration and prevent damage to fish from plant equipment and operation. The debate has brought into sharp relief the trade-off that can occur when a renewable energy resource is developed without sufficient concern for the resulting impacts. Hydropower is one of the longest established renewable energy technologies and many of the schemes currently in operation were built many decades ago at a time when little regard was paid to the resulting impacts. As environmental issues have risen the general agenda in recent years, so the impacts of hydro have entered the spotlight. Much of the debate has centred on large-scale hydro with the resulting need for dams and storage,

[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF
[2] The template for the national RE action plans can be found at http://ec.europa.eu/energy/renewables/transparency_platform_en.htm
[3] http://www.eea.europa.eu/publications/eea_report_2006_7
[4] http://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential
[5] http://air-climate.eionet.europa.eu/reports/ETCACC_TP_2008_16_pots_ren_energy_techn
[6] http://ec.europa.eu/environment/water/water-framework/index_en.html

and the potential displacement of human settlements, however in the minds of opponents there may be little differentiation based on scale.

Many people therefore see the goals of the WFD as an opportunity to reverse such impacts and return water courses to something closer to their former natural state. It is clear that it will be difficult to reconcile this goal with that of increasing the deployment of small-scale hydropower. It is of course possible to implement hydro schemes in an environmentally sensitive way and thereby mitigate many of the impacts, however there is likely to be a cost associated with this which could be considerable, indeed significant enough to render some schemes uneconomic.

The aim of this project is therefore to consider the various impacts and start the process of defining how environmental protection goals can be reconciled with those of increasing renewable energy generation. We would hope that out of this process could emerge some good practice guidelines that would inform and facilitate dialogue between the hydropower industry and those responsible for implementing the WFD and protecting water courses. Ultimately this will also allow an estimate of the environmentally compatible potential to be made for small-scale hydropower, though realistically this is likely to take some time. What is more important in the short term is to improve the understanding of whether and how environmental improvements can be compatible with continuing deployment of small-scale hydropower, and how to facilitate this process.

The status and potential of small-scale hydropower

Compared with some other sources of renewable electricity, hydropower is essentially a firm source of power, capable of both delivering power in a couple of minutes and having some capacity of energy storing (as potential). It is much less subject to the intermittency of sources like wind power or solar PV. This predictability and readability makes it more attractive to the electricity supply system, though it is recognised that climate change could affect this in the longer term.

The BlueAGE study reported that in 2000 there were slightly more than 17,400 SHP schemes installed in the 26 European countries they surveyed (including Norway and Switzerland), corresponding to a capacity of about 12.5 GW of SHP[7]. The average size of a SHP plant was 0.7 MW in Western Europe, and 0.3 MW in the Eastern European countries. The study also reported that almost 45% of SHP plants in EU countries are over 60 years old and 68% over 40. To put the position of small-scale hydropower into context, the most recent data indicate that SHP produced 46 TWh in 2005 in the EU-27, 9% of the renewables electricity and 1.4% of gross electricity demand. By comparison large-scale hydropower generated 297 TWh or 58% of renewable electricity, however it is accepted that environmental restrictions will severely limit the construction of new large-scale hydropower schemes.

The latest modelling under the EU Green-X project shows that there is a potential for an additional 23 TWh to be generated from SHP in the EU-27 in 2020, a 50% increase in output over the 15 years and contributing 4.3% of the total renewables electricity in 2020. The additional electricity production would require an additional installed capacity of approximately 5,800 MW to be deployed by 2020. Given that small-scale hydropower schemes are on average below 1 MW, this could mean over 10,000 new installations by 2020. In comparison output from large-scale hydropower is projected to increase by 14%. It is unclear to what extent environmental constraints and mitigation have been taken into account to reach these projections.

It should be noted that the 2020 growth rate projected for hydropower is modest compared with that for most other renewable energy sources, reflecting the fact that much of the potential has already been exploited and there are perceived to be environmental constraints on further deployment. Nevertheless a 50% increase in SHP energy production involving many thousands of new schemes is significant. Given the age of many of the existing schemes, it is likely that much of the growth will come from the refurbishment and upgrade of these, providing a welcome opportunity to build environmental mitigation measures into the redevelopment.

[7] Lorenzoni A. (2001). Blue Energy for a Green Europe – final report. EU Altener II Programme, http://www.esha.be/fileadmin/esha_files/documents/publications/publications/BlueAGE.pdf

The Water Framework Directive

The Water Framework Directive[8] came into force in 2000 but its full implementation spans the period to 2027. Some of the key milestones set out by the directive are:

2003: Transposition into national legislation; Identification of River Basin Districts and Authorities

2004: Characterisation of river basins: pressures, impacts and economic analysis

2006: Establishment of monitoring network; start public consultation (at the latest)

2008: Present draft river basin management plans

2009: Finalise river basin management plans, including programme of measures

2010: Introduce pricing policies

2012: Make operational programme of measures

2015: Meet environmental objectives (i.e. the achievement of "good ecological status"); on reasonable grounds the deadline for achieving "good ecological status" can be extended by two periods of 6 years – i.e. until 2027 at the latest.

2021: Second management cycle ends

2027: Third management cycle ends, final deadline for meeting objectives

Evidence is that this timetable is already subject to delays in many Member States, however it shows that the current focus should be on finalising river basin management plans, which is requiring the competent authorities to consider economic interests and designate certain water bodies as a "heavily modified water body" (HMWB)[9]. For these the objective is no longer "good ecological status" but "good ecological potential".

Article 4.7 of the WFD, reproduced in the box below, provides some guidance on how development such as hydropower should be viewed under the directive.

[8] http://ec.europa.eu/environment/water/water-framework/index_en.html
[9] The Commission document "Identification and Designation of Heavily Modified and Artificial Water Bodies" provides extensive guidance at http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/guidance_documents/guidancesnos4sheavilysmo/_EN_1.0_&a=d

Water Framework Directive Article 4.7:

Member States will not be in breach of this Directive when:

- failure to achieve good groundwater status, good ecological status or, where relevant, good ecological potential or to prevent deterioration in the status of a body of surface water or groundwater is the result of new modifications to the physical characteristics of a surface water body or alterations to the level of bodies of groundwater, or
- failure to prevent deterioration from high status to good status of a body of surface water is the result of new sustainable human development activities

and all the following conditions are met:

(a) all practicable steps are taken to mitigate the adverse impact on the status of the body of water;

(b) the reasons for those modifications or alterations are specifically set out and explained in the river basin management plan required under Article 13 and the objectives are reviewed every six years;

(c) the reasons for those modifications or alterations are of overriding public interest and/or the benefits to the environment and to society of achieving the objectives set out in paragraph 1 are outweighed by the benefits of the new modifications or alterations to human health, to the maintenance of human safety or to sustainable development, and

(d) the beneficial objectives served by those modifications or alterations of the water body cannot for reasons of technical feasibility or disproportionate cost be achieved by other means, which are a significantly better environmental option.

This article therefore allows the modification of water bodies and/or a deterioration of ecological status to allow for economic development, but requires full mitigation of adverse impacts, prior inclusion in the river basin management plan, a case of “over-riding public interest” to be made and a case to be made that (in the case of hydropower) the power cannot be generated by an alternative “better environmental option”. These are demanding requirements and, depending on how rigorously they are enforced, likely to limit hydropower development. The current evidence is that there is a backlash against hydropower in some countries. The situation needs careful monitoring and could become a major constraint on the contribution that small-scale hydropower will be able to make to the 2020 renewable energy target.

The following aspects of the Water Framework Directive are particularly relevant to hydropower operators:

- Undisturbed fish migration is one of the central requirements of the directive. The ability of fish to pass migration hindrances, both for upstream and downstream migration, is a heavily debated topic. Sediment transport can also play a role in connection with the undisturbed migration issue.
- The requirement for the flow regime to be based on ecological criteria. This requirement is to be interpreted in such a way that the discharge, both in quantitative terms and with respect to its dynamics, must meet the needs of the water body ecology. For operation of hydropower plants this affects both the plant’s residual flow and the issue of surge (hydropeaking), if applicable.
- The destruction of free-flowing river habitats that result from the creation of a series of large and small dams is poorly documented in the latter case; there is likely to be a certain impact whose effects are difficult to assess and very difficult to monitor. The sources of habitat destruction are multiple and their consequences on river ecology are not immediate. In all circumstances, it can be ascertained that “good ecological status” cannot be met once the habitat conditions have dramatically changed.

The directive also restricts morphological changes to rivers caused by use of the water body. The directive specifies stringent objectives with respect to these criteria because its overall objective is that of the “natural water condition”. The issue is to distinguish which morphological changes are caused uniquely by SHP schemes.

One aspect that must be considered is the need to take a holistic approach at the river basin level, as required by the directive, in particular when considering fish migration. There are many tens of thousands of obstacles to migration on Europe's rivers, of which only some are hydro plants. Their cumulative effect has been to greatly limit fish migration to spawning grounds. Some of these obstacles are in particularly unfortunate locations in the lower reaches of river basins, thereby effectively sterilising the whole river basin. There may well be scope to engender a "win-win" situation whereby removal of such a structure (which may well be an existing hydropower plant but can also be a navigation device) opens other stretches of the river basin to hydropower development whilst reinstating other stretches to fish migration. There have already been examples of such an approach, for example in France[10]. It is therefore important to use the opportunity of producing river basin management plans to undertake such an assessment, preferably in co-operation with representatives of the hydropower and other user industries. There is currently little evidence of water management and energy authorities undertaking such dialogue.

Structure and contents of this report

The objective of this report is to describe the work undertaken by the EEA's European Topic Centre on Air and Climate Change (ETC/ACC) during 2009, which has fallen into two main areas:

- Initial work focused on developing a methodology to estimate the technical potential for small-scale hydropower based on data that will be readily available, preferably in electronic form. There have been methodologies developed by others and some of these have been assessed for their applicability to our needs. Previous work[5] reviewed hydropower resource assessments that have been published and noted that there is no generally accepted methodology, and little systematic approach to accounting for environmental constraints. This work is still ongoing and we are not yet in a position to put forward a definitive approach for calculating the technical potential. The progress that we have made to date is described in Section 2.

- The second work package (presented in Section 3) focused on understanding the range of environmental impacts from small-scale hydropower and therefore the factors that will influence its uptake. The ultimate goal is to be able to apply these as quantitative constraints on the technical potential, in order to be able to calculate the environmentally compatible potential. However we must first have a clear understanding of what these are and how they influence the potential. The graph in Figure 1.1 overleaf (known as a resource cost curve) shows this in a diagrammatic way. The technical potential shows the cumulative energy output from projects (represented by blue crosses) that can be developed at increasing cost (the most economically attractive projects are therefore those on the left of the curve). The red arrows represent the two ways in which environmental factors must be taken into account. The first, mitigation measures, shows that measures to e.g. optimise fish migration, control flow and mitigate the impacts of grid connection will increase generation costs, thereby pushing the curve to the right[11]. The second, site exclusion, recognises that many of the sites identified as technically feasible will not be environmentally acceptable due to unsuitable location, excessive deployment density or some other reason. The combined effect is to produce the blue curve, representing the environmentally compatible potential. At a given electricity price it can be seen that the environmentally compatible potential can be very much lower than the technical potential. A stakeholder workshop was held on 27 November 2009 to review the environmental impacts of small-scale hydropower and help us decide how to apply these quantitatively (the workshop documents, presentations and conclusions/recommendations are presented in Appendices 1 – 3).

[10] See http://www.rivernet.org/general/dams/decommissioning_fr_hors_poutes/stedvig.htm
[11] In many cases these measures will also constrain electricity output

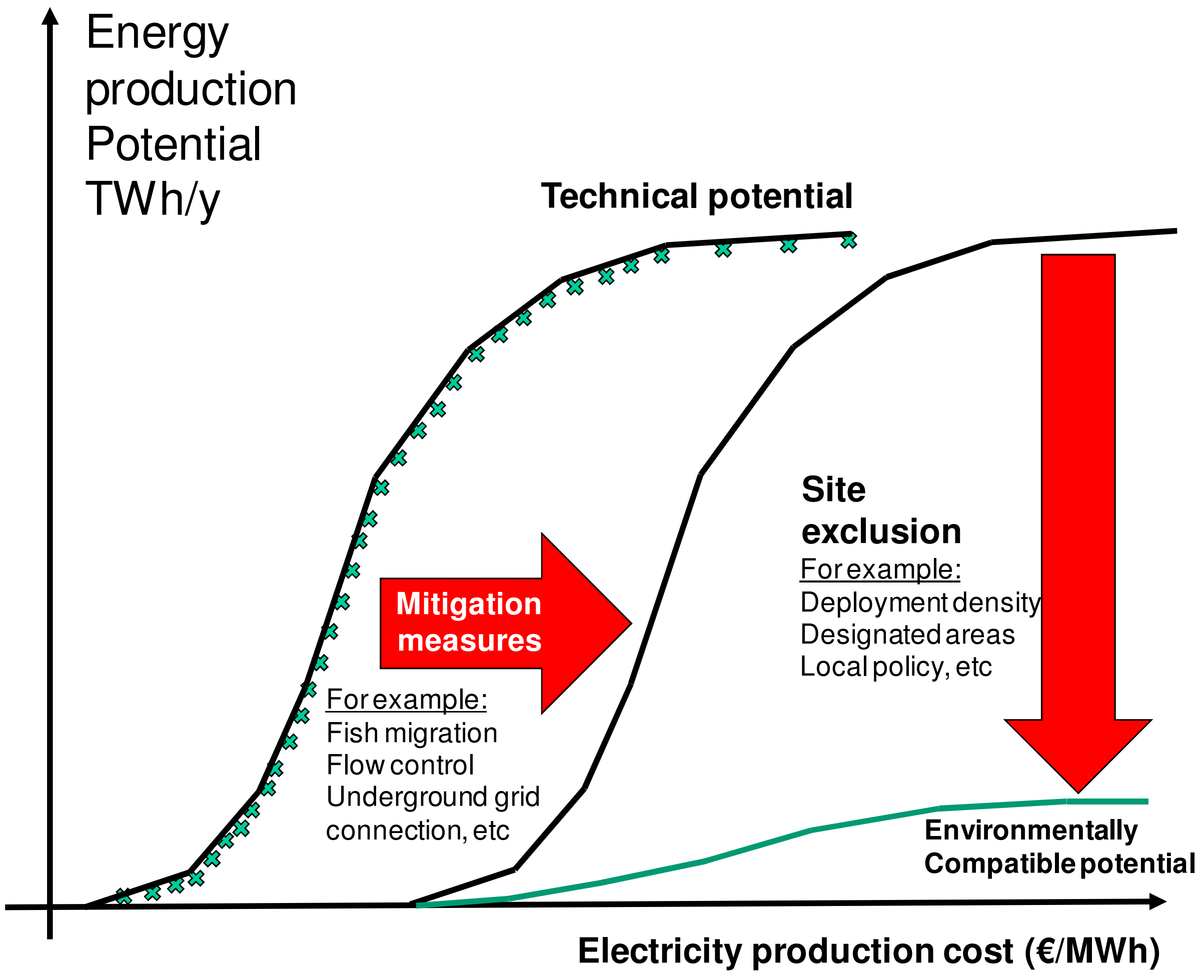

Figure 1.1: Resource cost curves for small-scale hydropower production, showing the factors that must be taken into account to calculate the environmentally compatible potential from the technical potential

Finally Section 4 presents the conclusions and recommendations from this work and focuses on the best way of taking it forward. As previously mentioned there may be merit in pursuing initially the qualitative aspects leading to some practical guidelines as this may provide more benefit to decision makers than a focus entirely on calculating the environmentally compatible potential.

2 Calculating the technical potential of small-scale hydropower

2.1 Definition of small-scale hydropower

The objective of this study is to determine the small-scale hydropower (SHP) across 27 member states of the European Union (EU) and three other countries that fall under the umbrella of the European Environment Agency (EEA). A generation capacity for a single SHP needs to be selected to ensure uniform consistency across the EU. For the purposes of this study SHP is defined as single generation plant up to 10 MW. In reality this definition may vary across Europe depending on the average size of individual scheme within different countries. An arbitrary threshold is therefore essential.

It is also important to recognise that the design of SHP schemes vary depending on the vertical head and flow. Since different designs have implications for the methodology and environmental impacts it is important to refine the definition of SHP into different categories.

High head schemes have extraction points some distance from the SHP generation plant. A leat or pipe transfers the water to the power plant depleting the stretch of river between the abstraction point and the SHP generation plant. The greater the vertical height between the abstraction point and the SHP generation plant the greater the power output. This distance between the abstraction point and the SHP generation plant might be several kilometres. Some high head plant relies on continuous abstraction which is dependent on the natural flow in the river (run-of-river). These schemes are generally subject to seasonal and yearly variability depending on rainfall and, in some areas, snow melt.

SHP can also be directly linked to storage which provides the operator with some degree of flexibility to circumvent the restrictions imposed by direct abstraction. In these cases water is abstracted either from an artificial reservoir created by a dam or a natural lake. In the latter case additional storage capacity can be achieved by raising the lake's water level with embankment.

The other main category of SHP is low head hydro. For the purposes of this study these sites have a maximum vertical head of 10m. Generally low head SHP is built either adjacent to or even on top of existing structures (dams or weirs) previously constructed across rivers or canals to control flow. In these cases SHP exploits an artificial head created by the weir. The scheme design may require varying degrees of civil structures to divert water into an adjacent SHP generation plant. They can also vary in scale from ~5 kW to 10 MW.

2.2 Definition of technical potential

The hydropower technical potential takes into account man's ability to extract energy from the resource and basic practical constraints such as availability of suitable locations. It takes into account the technological, physical and practical constraints associated with exploiting a particular renewable energy resource and requires some common-sense assumptions to be made concerning the maximum deployment density ever likely to be acceptable. Some assumptions about deployment density are discussed in the context of the methodology to estimate the technical potential. It is also assumed that there will always be some residual flow within depleted sections of rivers. For the purposes of this study the maximum rate of extraction never exceeds Q_{95} (i.e. the flow exceeded for 95% of the time, and used as a marker of low flow)[12]. In reality the extraction rate may vary according to the necessity to meet environmental criteria. The impact of this variation will be examined in the section on estimating the environmentally compatible resource.

The technical potential assumes that SHP could be built at any location irrespective of any environmental or conservation designations. For low head sites it is assumed that SHP would only be developed on existing weirs or dams. The cost of new large-scale civil structures would be prohibitive purely for SHP and they have therefore not been considered. It is also assumed that potential exclusion for planning purposes or proximity to the grid would be considered at a later stage.

[12] http://www.environment-agency.gov.uk/static/documents/Business/Low_Head_Hydropower_August_2009.pdf

2.2.1 Review of existing methodologies to estimate technical potential

A number of different methodologies have been developed to estimate SHP in different countries. The main aim of these methodologies is to provide regional and national estimates of this form of renewable energy. Some models are only concerned with estimating technical potentials whereas others also include environmental impacts. The suitability of some existing methodologies was examined for this study.

Salford study (UK)

In 1989 the University of Salford was contracted by the UK Government's former Department of Energy to estimate the UK's SHP resource. An upper threshold of 5MW was assumed and a minimum vertical head of 3m used (or 2m where existing infrastructure existed). Sites were selected by direct analysis of UK Ordnance Survey maps. Data flow rates were taken from either existing gauging stations or estimated flows based on mean rainfall. A parametric method was used to estimate the capital cost of individual schemes. By combining capital cost and power output from individual sites it was possible to estimate the unit cost of generation using a discounted cash flow (DCF) analysis over 20 years. The aggregated power output and unit cost of generation were then complied to form a national resource cost curve.

This methodology was the first attempt to quantify the UK's SHP potential and it helped to identify some of the most economic SHP sites. However, the methodology relies on a labour intensive approach and does not attempt to apply either the impact of deployment density or environmental constraints.

US Hydroelectric Power Resources Assessment

The hydropower potential of the US has been collated into a Hydroelectric Power Resources Assessment (HPRA) database[13]. This is an inventory of national hydropower potential. It contains information about all sites that have been subjected to any Federal Energy Regulatory Commission (FERC) hydropower license application. The HPRA database also contains information on project sites that have been identified by FERC, or other agencies, as having development potential even if no license application has taken place. The HPRA database serves the hydropower resources assessment primarily by providing a list of project sites.

This database can be used to estimate either state or federal hydropower potential. Environmental factors can now be attributed to specific sites and a "suitability factor" calculated based on different attributes. Up to 20 variables can be entered into the database for any one site. These variables range from different land designations to specific environmental sensitivities such as fisheries. A probability factor is assigned to each variable which collectively produces a weighting that can indicate the suitability of the site for development. Whilst this is a useful methodology for determining the environmental compatibility of different sites it is based on pre-existing hydropower resource data. Calculating the environmental impacts of SHP at national or European level would be more effectively achieved by identifying areas within river basins that either have specific designations or are known to have environmentally sensitive characteristics such as migratory fish populations.

HydroBot (Scotland)

The development of SHP in the UK has relied mainly on consultants surveying conventional sites. This approach is expensive and does not necessarily lead to development. In Scotland the Forum for Renewable Energy Development in Scotland (FREDS) commissioned a study to assess the nation's remaining SHP potential. In contrast to previous methods a new software model called Hydrobot[14] was used as a more cost-effective alternative to site surveys. This is a GIS and financial assessment tool that can identify and calculate the value of hydropower at any given location. Hydrobot is based on a surface flow model derived from elevation data in a 10m x 10m grid across the entire country. The annual flow duration curve has been modelled for every watercourse. The accuracy of predicted flows has been tested against measured flows from established gauging stations. For low head sites the model selects sites on existing weirs. Turbine size and therefore power output are based on head and flow at any given site. The costs are then calculated taking into account site conditions based on empirically derived cost data. The power output is calculated using one of four turbine efficiency

[13] Uniform Criteria for U.S. Hydropower Resource Assessment. Hydropower Evaluation Software (HES) User's Manual. Prepared for the U.S. Department of Energy, Idaho Operations Office, June 2002.
[14] Getting to the bottom of it. Hydrobot software model to assess Scotland SHP potential. International Water Power & Dam Construction, January 2009.

curves. Annual power output is then used to calculate the unit cost of generation using a discounted cash flow (DCF) analysis.

Where there is no existing infrastructure potential SHP sites are selected on the basis of a minimum slope. Hydrobot then simulates a 20m penstock and assumes the cost and power output to derive the unit cost of generation. The model then extends the penstock to 40m and repeats the exercise up to a maximum length of 1.5 km. The model can generate a series of simulations so that the most profitable scheme design can be identified. Multiple intakes can also be simulated by joining nearby tributaries into a single scheme. The surrounding terrain can be assessed to identify potential dam locations. The model compares existing valley profiles where hydropower dams have been built in Scotland and then compares the profile to similar areas.

Hydrobot has identified over 1,000 potential SHP sites across Scotland of up to 5 MW. Clearly Hydrobot is a useful and accurate way to estimate SHP potential. Its limitation is the necessity for detailed resource information and the cost of adapting the software for other countries.

HydrA

During the mid 1990s the European Small Hydro Association (ESHA) in collaboration with five EU countries developed a software package called 'HydrA' to estimate SHP potential. The software was developed for specific countries based on the run-off characteristics of these. It has now been superseded by 'Low_Flows' which compares gauged catchments with ungauged catchments based on 1 km grid run-off (rainfall – predicted evaporation). It can be used to predict mean flow but currently only for catchments within the UK. For European-wide flow regimes the package would need to be modified to take account of regional variations. It would also require basic information on annual rainfall, soil/rock type, evaporation levels for different climatic regions of Europe. Unfortunately the HydrA software package is no longer available. For the UK the basic version of Low_Flows is available for GBP900 + GBP400/year for a three year lease.

SHERPA

In 2008, ESHA in conjunction with Associazione Produttori Energia Da Fonti Rinnovabiu (APER) and with funding from Intelligent Energy Europe developed the Small Hydro Energy Efficient Promotion Campaign Action (SHERPA). One aim of the SHERPA project[15] was to propose a methodology to assess hydropower potential at river basin level. The methodology incorporates the objectives and targets set by the WFD and the Renewable Energy directives. The proposed methodology is designed to give a first approximation of hydropower potential defined as the maximum natural potential. This is effectively the technical potential but it is only based on the theoretical energy from the head and flow (discharge) within a river basin. The energy output is calculated from the total natural discharge at an arbitrary closure point. The vertical head is the mean elevation of the river basin from the closure point. The methodology assumes an energy efficiency conversion factor of 0.8 throughout a single year. Extraction for other purposes is taken into account and is defined as the anthropic discharge. The total anthropic discharge is subtracted from the natural hydrological discharge to produce a revised estimate termed the anthropic residual hydropower production. The methodology then applies further refinements. Firstly, the residual technical potential which is the SHP power output given currently available technology. This is followed by the residual economic potential which takes account of economic constraints and finally the realistic potential which takes account of environmental constraints.

The SHERPA project includes a case study of the Magra river basin in northern Italy. The application of the methodology concluded that even if environmentally sensitive areas were excluded the basin's capacity could be increased by between 10-15% from 37 MW to 41-43 MW. This increase in generation capacity would yield around 15 GWh per annum.

This methodology can provide a rough approximation of SHP potential. However, it is not based on actual sites and makes no attempt to differentiate between high and low head SHP. For this reason the estimated SHP potential is likely to be too high. It is also unclear how the impacts of environmentally sensitive areas or other constraints are factored into the methodology.

[15] Assessment, at river basin level, of possible hydropower productivity with reference to objectives and targets set by WFD and RES-e directives, APER, ESHA, Intelligent Eenergy Europe, sherpa, 2008.

2.2.2 Proposed methodology to estimate technical potential

As previously stated one of the main purposes of this project was to develop a methodology for defining the SHP hydropower across the EU and three associate countries.

To do this the first stage is to generate a resource-cost curve for the technical potential and generate a GIS plot of where potential SHP schemes might be located. The methodology needs to be applied by catchment and then aggregated to eventually produce resource values for the entire European resource. The methodology needs to be able to generate reasonable estimates of the resource i.e. based on a series of specific locations within each catchment area. It is then possible to estimate the cost of each site based on a series of assumptions about the design of the site. The resource (power output) can then be calculated if the Flow Duration Curve (FDC) at each site is either known or can be estimated.

Initially we were going to develop and test the methodology in a single catchment area and then use this output as a basis for discussion at a workshop. We have reviewed previous methodologies that have been used to estimate SHP resource. Most of these methodologies rely on proprietary software which is not publicly available. Other methodologies, for example the one developed by Salford University, selected sites by simple physical inspection of topographic maps. The technique would be unsuitable for resource estimation on a European scale.

Water resource methodologies have also been reviewed. To determine SHP potential at any point in a catchment will require data input on average rainfall, evapo-transpiration and runoff rates to calculate the FDC. The ability to calculate the FDC, especially from ungauged catchment areas, is also important to assess the implications of the Water Framework Directive (WFD).

We have concluded that to achieve consistent results an existing proprietary software package should be used to calculate FDCs, such as the ''Low_Flows' package mentioned above, but note that this would need to be adapted for use in different geographic areas. An established methodology should be acceptable to the EEA and other European-wide regulatory authorities. Ideally the methodology would use digitised topographical data from ECRINS (a database of European river basins) that could be analysed to derive specific locations.

A series of SHP sites that represent the technical potential could be generated based on technology criteria. SHP sites could be categorised into arbitrary vertical head bands (<10m, 10m-100m, >100m). These bands equate to the operational range of different turbine designs. Further refinement can be added by applying a distance restriction between the point of abstraction and the point of generation. For low head sites (<10m) it is assumed that development would be confined to existing weirs or dams with a head of at least 2m. For high head sites between 10-100m and >100m an arbitrary separation distance of 2 km would be applied. This approach provides a basis for identifying sites for SHP plants and their energy output.

Digital representation of a river profile can be used to segment it into a series of linear sections. The slope and vertical height of each section can then be used to partition each river into the three vertical head bands. Provided it is possible to process the digital representation of the river profile a series of hypothetical SHP sites can be plotted for each catchment.

The position of existing dams, weirs and hydropower plants also needs to be collated.

A GIS plot of hydropower plants within each catchment will show their cumulative effect. The technique will also be able to show their distribution relative to restricted areas, grid, road networks and urban areas. Many potential SHP sites will be impractical to develop because of their environmental impact or proximity to infrastructure. However, the technical potential assumes that there are no environmental or other constraints although it would assume a Q95 residual flow.

The next stage is to calculate the hydropower resource at each SHP site. This will need the application of the proprietary software to calculate the FDC at each point of abstraction based on each catchment's water resource characteristics. The annual energy output at each location will need to assume an abstraction rate, the head and the size of the turbine.

The capital costs will need to be formulated on a parametric basis. The methodology will be based on the three head categories to reflect the different turbine technologies and capital costs. Operating and maintenance costs will be assumed to be a percentage of the capital costs. The unit cost of generation can then be calculated by performing a discounted cash flow analysis. The final stage is to produce a resource-cost curve (as shown in Figure 1.1) for each catchment or larger area.

Further refinement of the SHP resource can then be applied to specific catchments to calculate the environmentally compatible resource. The rate of abstraction might be limited for environmental reasons. Higher capital costs might be imposed to comply with fish passage or deterrence systems. Once a SHP resource methodology has been developed these modifications will be relatively easy to apply. Reducing the abstraction rate and meeting other compliance measures will have the effect of increasing the unit cost of energy and shifting the resource cost curve to the right (Figure 1.1). It is also possible that SHP could be excluded from river systems with a special conservation or exclusion designation, diminishing the resource. The methodology for estimating the environmentally compatible resource is discussed in greater depth in Section 3.

2.2.1 Potential longer-term impact of climate change on technical potential

All forms of hydropower, including SHP, will be affected by climate change, in particular changing precipitation and snow/glacier melt patterns, and changing water use practice. This form of renewable energy is dependent on the annual mean flow in rivers but to a lesser extent in artificial water bodies. The impacts of climate change are likely to vary across Europe. Those areas which currently experience high rainfall may well experience higher precipitation. They are also predicted to have more frequent extreme events of high rainfall over shorter periods. Increased rainfall should lead to higher annual mean flows and therefore greater power output. To estimate what the scale of this increase would be, the annual rainfall in different regions needs to be predicted.

Areas of Europe which experience hot dry summers could see these conditions accentuated, depleting the SHP output from existing schemes and reducing the future potential. One study has predicted that annual hydropower output in countries in southern and south-eastern Europe could decline by as much as 25%[16].

[16] The impact of global change on the hydropower potential of Europe: a model-based analysis http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V2W-4B8BMSB-1&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=e2d78ab9f160abfce5cc1956d8823d78

3 Factoring the potential to achieve "environmental compatibility"

3.1 Stakeholder workshop

The European Environment Agency's European Topic Centre on Air and Climate Change organised a stakeholder workshop on 27th November 2009 in Brussels entitled "How can we define the "environmentally compatible potential" for small-scale hydropower?". The workshop aimed to bring together a range of practitioners in the renewable energy and water resources management sectors in order to debate the issues raised by the implementation of the Water Framework Directive with respect to small-scale hydropower.

Appendix 1 presents the workshop participants, the invitation from the EEA, the agenda and a pre-meeting paper that was circulated to participants in advance. Appendix 2 presents the workshop conclusions and recommendations and Appendix 3 provides the presentations made to the workshop.

The discussion and the main conclusions from the workshop have been subsequently taken into account to refine the proposed methodology to determine the environmentally compatible potential.

3.2 Defining good practice for small-scale hydropower

The environmentally compatible potential for SHP is the technical potential, reduced to remove any resource whose deployment would not comply with requirements brought about by legal provisions such as geographical designations and environmental directives or regulations. It is also assumed that schemes will meet environmental good practice guidelines (though these need to be defined). There are some specific considerations for SHP, summarised in Appendix 1 (Table A1.1), that need to be taken into account to refine this definition and provide a basis for modifying the technical potential.

The introduction of the WFD is of particular relevance to SHP development. Firstly there is the requirement for the flow regime to be based on ecological criteria. In essence the flow regime in depleted stretches of river or downstream of a hydropower plant should, ideally, mirror each river's natural flow regime. For SHP operators this means that abstraction rates need to be carefully controlled and sudden surges, for example, to meet peak demand should be avoided or made neutral to the river.

Secondly, the WFD implies that undisturbed two-way fish migration should be possible. Each new scheme would therefore need to incorporate an approved fish passing facility and /or a deterrence system depending on the scheme design if migratory fish populations are known to be present. A big difficulty with classical "fish passes" is that they are often tailored to a certain species (and even to some age classes of that species) or simply not effective.

For the purposes of estimating the environmentally compatible resource there are two key considerations. How much will the flow available for power generation be limited and how much will capital costs have to be increased to ensure two-way fish migration? How should the management of the fish migration facility be specified, including appealing flow during the migration periods? Ideally, the flow regime within a catchment area will be known as well as the flow duration curve (FDC) at the point of abstraction. For each site the base case should assume that the flow available for power generation is equivalent to Q_{95}. Unless there are catchment or even river specific data on the flow regime, annual energy output would be based on the annual flow available but averaged over 15 years. A sensitivity analysis could simulate the impact of environmental constraints. For each site the annual energy output could be recalculated assuming Q_{75} and Q_{50} to quantify the impact. Reduced energy output would be reflected in more expensive electricity production costs.

To model the impact of compliance with fish migration measures the cost of fish passes or deterrence measures would need to be assumed and added to the capital cost. For high head sites without dams or other structures, it is assumed that only deterrence measures would be necessary to avoid accidental intake of fish[17]. It is assumed that any new low head SHP would be developed on existing weirs. Some weirs may not need a fish pass but where there is a vertical difference above an agreed

[17] This needs to be checked with ESHA and the British Hydropower Association (BHA)

threshold the installation of a fish pass would need to be assumed. The cost of these measures is then incorporated into the parametric costing for low head sites and the unit cost of energy recalculated. This approach can be further refined. If there are catchments where there are no migratory fish then it could be assumed that a fish pass is not required. Parametric methods can only give approximate cost estimates. It is prudent to apply a sensitivity analysis of $\pm$10% of the base case for each site and then generate revised resource-cost curves.

Fish passing is a rather complex issue that cannot be just addressed as a yes/no response. The ecological objective of fish migration is that a sufficient proportion (passing ratio) of mating fish actually accesses their spawning areas at the appropriate period (limited delay) in good physiological conditions (fatigue / stress). If several "individually almost neutral" obstacles are met on a route, the cumulative effect is equivalent to a single locking obstacle, the first of the three factors jeopardising the migration. For example, a series of good fish passes, but that each induce a significant delay, result together in the slow extinction of the population on that river. This cumulative effect on different antagonist factors is probably the most difficult issue to consider in the development of a generally applicable methodology.

The EEA has developed and tested a calculation model that takes these three factors into account. Its application however depends on the availability of small dams over many different rivers systems and appropriate biological data.

The development of SHP is likely to have less impact on other environmental factors. Sediment movement and artificial replenishment are important considerations for large-scale hydropower. The workshop concluded that this is not a significant issue for SHP.

Hydropeaking or the sudden surge in flows from hydropower plants is known to have detrimental effects. Workshop discussion on this topic revealed the potential impact of thermal shock caused by the release of water from hydropower plants over exposed river beds during hot dry weather. The extent of this practice in relation to the operation of SHP is not known. However, for the purposes of estimating the environmentally compatible potential it needs to be assumed that SHP would be operated without surges and that abstraction would always be consistent with the variation of the natural flow regime. In practice this may not be possible especially where SHP is linked to storage[17].

The estimate of the environmentally compatible potential for SHP also needs to consider the impact of landscape designations. It is likely that the conservation status of some landscape designations would preclude any SHP development. The consensus that emerged from the workshop was that only those conservation designations that are specifically related to riverine habitats should preclude development. The SHP resource should be estimated for regions with landscape designations such as national parks. This does not infer implicit development but it does allow the resource in such areas to be considered as part of the bigger picture. The SHP resource can therefore be quantified at two levels: including and excluding such designated areas.

3.3 Quantifying the environmental constraints and costs

To determine the environmentally compatible SHP resource the cost of mitigation measures needs to be factored into the methodology for estimating the technical potential. There are three main impacts which need to be taken into consideration. Firstly, the flow available for power generation. Secondly, the installation of suitable fish passes or deterrence systems; and thirdly cumulative impact.

Table A1.1 in Appendix 1 summarises the main environmental impacts of SHP. It also outlines the legislation, mitigation measures and implications for the SHP resource. The table is not intended to be a definitive list.

To model the impact of restricted flow the technical potential would be recalculated assuming that the maximum available flow would be set at Q_{75} and Q_{50} instead of Q_{95}. The annual energy output would be decreased which would have the effect of increasing the unit cost of power generation. The impact of restricting flow would be represented by re-plotting resource-cost curves. Ideally the abstraction rates should be based on the regional characteristics of different river basins, however this information may not necessarily be available.

The impact of mitigation measures that would facilitate fish migration could be estimated by including the cost of fish passes and deterrence systems. It is assumed that new low head sites would be built on existing weirs or dams. For the purposes of quantifying compliance with the WFD it would be assumed that new fish passes also need to be installed. The cost would be included in the parametric model and the unit cost of generation recalculated. This impact could again be demonstrated by producing revised resource-cost curves. The exercise would be repeated for high head sites but assuming that only deterrence systems were installed.

To demonstrate potential restrictions imposed by cumulative impact a spatial analysis using GIS could be applied. The technical potential assumes that SHP could be developed without restriction. The methodology proposed here would generate a series of locations within each river basin. An assumption would then need to be applied for areas where SHP would be completely or partially excluded. Ideally, rivers which are known to be environmentally sensitive or already have a specific conservation designation would be selected. The SHP sites in these areas would be either completely or selectively excluded and a revised resource-cost curve generated to quantify the impact.

Each of the three impacts could be combined to demonstrate the cumulative effects of each measure as illustrated in Figure 1.1.

4 Conclusions and recommendations

4.1 Conclusions

This study has reviewed different methodologies for estimating the technical potential for SHP. It has also considered those factors which need to be taken into account to estimate the environmentally compatible resource. This second resource category was discussed at a stakeholder workshop on 27th November 2009 and the conclusions and recommendations below reflect those discussions. There are some key conclusions and further actions that need to be implemented before a resource methodology can be developed.

Definition of SHP

The accepted definition for SHP is individual sites with installed capacities not exceeding 10 MW however this is an arbitrary definition. More information is required on different types of SHP across different European countries. For example a distinction needs to be made between high head SHP with and without storage. It is also assumed that new low head sites with heads of <10m will be confined to pre-existing weirs or dams. This needs to be confirmed with ESHA.

Methodologies for estimating SHP potential

This study has reviewed previous methods for estimating SHP potential. Two previous studies, Salford (1989) and the US Hydroelectric Power Resources Assessment are based on site-specific criteria which have been derived from analysis of individual sites. This approach provides a detailed basis for a SHP resource assessment but it would be impractical to apply on a European scale. ESHA in collaboration with five EU countries have developed a software package called HydrA to estimate SHP potential. This software package has now been superseded by 'Low_Flows' but this is only currently available for the UK. New proprietary software (HydroBot) has also been developed for estimating SHP in Scotland. This software was developed as an assessment tool to determine the commercial viability of potential SHP sites. It would need to be modified for other European countries at potentially high cost. The SHERPA project has also developed a methodology that could be used to quantify the technical potential. However, it only provides a broad approximation of the SHP resource and is not based on specific sites.

Methodologies to estimate the SHP technical potential are complex because they need to take account of the slope profile and vertical height at any given location. They are also reliant on the flow duration curve (FDC), ideally at specific locations. There are proprietary software packages which could be used to estimate the EU's technical potential but this approach could require substantial resources. A new methodology could be developed but the basis needs to be investigated and reviewed to ensure that the underlying data can be accessed. This approach is presented as one of the options for the forward programme.

Criteria for defining the Environmentally Compatible Resource

The following recommendations are proposed for SHP operational good practice and criteria to define the environmentally compatible resource:

- Assume Q_{95} flow but apply sensitivity e.g. – 20% Q_{75}, i.e. the flow available for generation would be restricted to demonstrate the impact of constraint. Flow in rivers needs to be based on normalised flow averaged over 15 years.
- Flow variability in depleted stretches should mirror the natural flow regime of each river.
- Operators should avoid sudden surges in flow especially in hot weather conditions as exposed heated river beds could induce a thermal shock.
- Maintaining flow regimes is also important where there are adjacent habitats with high humidity.
- Probes that are used to monitor flows in rivers need to be regularly checked to ensure they are not transmitting spurious data and at least be designed or operated so that short term changes are recorded.
- Hydropeaking and sediment movement are not considered to be major issues for SHP.

- Environmental monitoring has been carried out where novel SHP has been installed, for example Archimedes screw systems.
- The restoration to a good ecological status might require a minimum flow equivalent to 20% of the natural flow regime.
- Good practice should be shared across the EU. There should be full transparency on all the issues related to SHP development and its impacts.
- There are differences across EU on running costs. In Austria for example there are no water abstraction charges.
- The ESHA perspective has highlighted new stringent restrictions. For example in Poland a moratorium on all SHPs was introduced in November 2009. Previously issued permits have now been withdrawn. In Slovenia it was reported to the workshop that a new directive to increase ecological flow has led to the reduction in energy output of between 30% - 60%.

Fish Migration and Fish Passage

Fish migration and movement remains a contentious issue. There are 28 diadromous (sea – fresh water migratory) species of fish in European rivers plus resident species which are also known to move up to ~100 km. Continuity within a catchment area and unimpeded two-way migration across artificial barriers are fundamental to sustaining fish populations.

Different species of fish have different breeding cycles and habitats. For example Sturgeon only ever breed in large rivers whereas Salmon must reach the upper reaches of river systems to breed. SHP impacts are therefore dependent on the species naturally present in a certain river.

Although low head 2-3m weirs should not present a problem if adequately equipped, bad designs such as vertical sheet piled structures can be highly detrimental with much smaller heads. Migratory fish attempt to leap over them but end up being injured by them, leading to mortality.

For all new SHP it is assumed that two-way passage is feasible. The environmentally compatible resource estimate would need to include the cost of installing new fish passes on existing infrastructure.

Cumulative Impacts

The environmentally compatible resource assessment should not necessarily exclude Natura 2000 sites and other national designations including national parks. This does not imply that SHP would be developed in these areas, but it would demonstrate how much SHP resource exists in these areas. The resource estimate for each country would quantify the SHP within these areas as well as the undesignated areas.

Those sites which have designations specifically related to riverine habitats need to be taken into account as they may be affected by new SHP development.

Deployment density needs to be made on a specified assumption, including all existing low head sites on weirs currently without SHP.

4.2 Recommendations

The forward programme needs to develop a methodology for estimating the environmentally compatible potential for SHP. The methodology should be applicable to all 27 EU member states plus the three other European countries that are covered by the EEA. However, the development of this methodology may be too complex given all the variables that need to be considered for a resource estimate at this scale. It is therefore proposed that the development of the methodology should initially be based on a single river basin. Two different options are presented: one is based on a parametric method, the other is a ‘bottom-up’ appraisal of three sites in an existing river basin. In both cases we would want to consult industry associations such as the British Hydropower Association (BHA) and European Small Hydropower Association (ESHA) concerning the performance and cost of both generating plant and environmental mitigation measures.

Option 1: Development of a parametric method for estimating the technical potential and the environmentally compatible potential for SHP.

The proposed methodology for estimating the technical potential relies on the quality of data on river profiles within each catchment area and the flow regime within it. To develop the methodology the following tasks are proposed:

- Select a river basin preferably with both high head and low head SHP potential, ideally one that is well known. Assess the data quality and accessibility. Review the ECRINS database and the hydrological data for the river basin and ensure that it can be interpreted.
- Analyse the slope profile of each river within the catchment area so that each river can be represented as a series of progressively steeper gradients.
- Select low head hydro sites from the location of pre-existing weirs and dams. The vertical height of each dam or weir needs to be compiled if this is known.
- For high head sites a parametric method needs to be applied. The method needs to distinguish between sites with a maximum vertical head of 100m and those with a vertical head of more than 100m. An arbitrary separation distance would be applied between each site depending on the scale of the river basin.
- Determine the flow regime at each site. This needs to be determined either from pre-existing data or by the application of proprietary software[18].
- A parametric method needs to be developed to estimate the capital cost and performance of different SHP turbine designs. The cost of fish passes and deterrence systems would be excluded at this stage. It is proposed that the cost and turbine efficiencies are checked with both the BHA and ESHA.
- Calculate the annual energy output for each SHP site in the river basin based on the vertical head and annual flow. Calculate the unit cost of generation using a standard discounted cash flow analysis (DCF) for each site based on the capital costs and assuming that the operation and maintenance costs are 2% of the capital costs.
- Generate a resource-cost curve i.e. plot the unit cost of generation against the total energy output for all the sites.

Estimating the environmentally compatible potential for SHP.

The key operational criteria for SHP, outlined in the conclusions, need to be confirmed with ESHA, the European Small Hydropower Association.

- Estimate the impact of restricting the flow regime. The energy output from each SHP site would be recalculated assuming that abstraction rate is restricted (equivalent to Q_{75}) although the level could be varied. A resource-cost curve would then be replotted to demonstrate the effect of thus restricting the resource.
- Estimate the impact of installing fish passes and deterrence systems. Add the cost of installing fish passes to existing dams and weirs with heads of more than 2m to the capital cost of each scheme. Replot the resource-cost curve to demonstrate the impact of including these mitigation measures. It is proposed that the cost of these mitigation measures is discussed with EHSA and the British Hydropower Association.
- Assessment of the cumulative impact. The distribution of all the SHP sites within the river basin would be assessed. Those sites within environmentally sensitive designated areas would be selectively identified and the resource recalculated assuming that these sites are excluded. Another resource-cost curve would be plotted to demonstrate the effect of preferential exclusion.

[18] To calculate the technical SHP potential the flow regime needs to be estimated within each basin. It is recommended that existing the 'Low_Flows' software should be used as it is already available for the UK at a reasonable cost of GBP900. However the software would need to be adapted for other European river basins. The cost of modification is not known but could be around EUR4,000. The advantage of using this software is that it provides a reasonably accurate estimate of the hydrological resource at a reasonable cost.

- The main output of this project will be the presentation of the results in a report which quantifies the technical potential and then the impact of each environmental mitigation measure. The report will also quantify the cost of implementing each environmental mitigation measure and the implications for the commercial viability of SHP.

The advantage of developing a parametric method for estimating the SHP technical potential is that once developed it can be applied across all EU countries. Although the method can only provide an estimate it is more representative of the SHP potential than simple estimates based on flow regime alone. The methodology can also be used to model the SHP potential within existing infrastructure. Once the methodology has been developed it is relatively straight forward to apply a sensitivity analysis by varying the costs or the flow or both. The disadvantage of Option 1 is that it will need to be developed and tested. It is not clear how complicated it will be to integrate with the ERCINS database or the hydrological data. There is a risk that the cost of development may be higher than the initial estimate. The advantage is that it would provide results for the whole river catchment.

Option 2: Development of a 'bottom-up' method for estimating the technical potential and the environmentally compatible potential for SHP.

In contrast to using a parametric method this option would select a river basin preferably with both high and low head SHP potential. Three sites would be selected based on three different vertical heads (<10m, 100m, >100m). Each site would be evaluated site-specifically to determine the unit cost of generation with and without environmental mitigation measures. It is proposed that the project is undertaken in collaboration with ESHA who would provide the technical information and validation.

The project would consist of the following tasks:

- Select a river basin preferably with both high head and low head SHP potential, ideally one that is well known. Assess the data quality and accessibility for three sites.
- Select an existing dam or weir for the low head site. Two high head sites would be based on analysing the slope profile of rivers within the basin and the flow regimes.
- Estimate the cost of each site based on its site specific characteristics and the current cost of turbines, generators, switch gear and grid connection. The capital cost of mitigation measures would be excluded at this stage.
- Calculate the unit cost of generation for each site based on its capital cost, operating cost and annual energy output using a DCF analysis.
- The next stage is to quantify the impact of environmental mitigation measures.
- Estimate the impact of restricting flow. The annual energy output would be recalculated assuming restricted abstraction equivalent to Q_{75}. This level can be varied to reflect actual practice in the selected country.
- Estimate the impact of installing fish passes and deterrence systems. For the low head site the cost of installing a fish pass and deterrence systems would be estimated and added to the capital cost of the scheme. For the two high head sites it is assumed that there are no barriers and only deterrence systems would be employed. The cost of these would be added to each scheme. The unit cost of generation would then be recalculated to quantify the impact.
- The main output of this project will be the presentation of the results in a report which quantifies the impact of each environmental mitigation measure at the three sites. The cost of each site and its unit cost of generation will be contrasted before and after mitigation measures are applied to quantify their impact.

The advantage of this option is that it is based on an actual example and three sites where specific conditions should be well defined. This approach should, therefore, provide an accurate benchmark for future comparison. The impact of environmental constraints on energy output and cost should also be more realistic. It will also be easier to draw general conclusions from which good practice guidance can be formulated than Option 1. The disadvantage is that it will not provide overall technical or environmentally compatible potentials for the whole river basin and an example from one basin is not necessarily representative of SHP across different EU countries. Obtaining site-specific information from a utility company may prove difficult especially if operational and cost data are regarded as commercially confidential. The option also demands the full co-operation of authorities responsible for the management of the river basin.

Our recommendation

We recommend proceeding with Option 2 as it is simpler to implement and should provide an accurate benchmark. It also avoids the complexities of developing or modifying software. However we would welcome discussing the options for taking this project forward in 2010 with the European Environment Agency before deciding on the final implementation plan.

5 Appendix 1: Workshop documents

The European Environment Agency's European Topic Centre on Air and Climate Change organised a stakeholder workshop on 27th November 2009 in Brussels entitled "How can we define the "environmentally compatible potential" for small-scale hydropower?". The workshop aimed to bring together a range of practitioners in the renewable energy and water resources management sectors in order to debate the issues raised by the implementation of the Water Framework Directive with respect to small-scale hydropower.

This Appendix presents the workshop participants, the invitation from the EEA, the agenda and a pre-meeting paper that was circulated to participants in advance. Appendix 2 presents the workshop conclusions and recommendations and Appendix 3 provides the presentations made to the workshop.

The workshop participants are listed in the table below.

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A wider group of stakeholders were invited to the workshop but were not able to be present. However we were fortunate to have representatives from key sectors: policymakers, regulators and implementers (in the form of the trade body, the European Small Hydro Association). Over the course of the last two years there have been a number of other workshops that have considered the impacts of the Water Framework Directive on the prospects for hydropower[19],[20],[21] (the conclusions of the Berlin workshop (June 2007) and Austrian-French workshop (July 2008) are presented as appendices in Reference 5). This workshop aimed to build on the discussions that took place at those, though its primary purpose was to see whether we are in a position to define what we mean by 'environmentally compatible potential' for small-scale hydropower.

[19] The documentation for the WFD and Hydropower workshop in Berlin in June 2007 is available from http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/implementation_conventio/workshop_hydropower&vm=detailed&sb=Title
Workshop conclusions are available at http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/implementation_conventio/workshop_hydropower/hydro-morphology/_EN_1.0_&a=d

[20] Austrian-French workshop, July 2008 - see the workshop programme at http://www.ambafrance-at.org/IMG/pdf/Seminaire_Eau_prog_final_4_et_5_juillet_2008.pdf The workshop papers are available at http://rp7.ffg.at/umwelt_va_wfd

[21] "Heavily Modified Water Bodies: Information Exchange on Designation, Assessment of Ecological Potential, Objective Setting and Measures", Common Implementation Strategy Workshop Brussels, 12-13 March 2009, http://www.ecologic-events.de/hmwb/index.htm

European Environment Agency

27 October 2009
PJE/ADB/PCR/hfu

Invitation to workshop:

How can we define the “environmentally compatible potential” for small-scale hydropower?

27th November 2009, Committee of the Regions, Rue Belliard 99-101, B-1040 Brussels, Belgium

Dear colleague

The European Environment Agency supported by its topic centre for air and climate change (ETC/ACC), would like to invite you to take part in a stakeholder consultation on defining a methodology to estimate the environmentally compatible potential for small-scale hydro in Europe.

Current energy and environment policies in the European Union call for a significant increase in renewable energy in the European energy mix. Hydro power will continue to have a large share but expectations are that future developments will rely particularly on small-scale hydro.

At the same time, the Water framework directive calls for the incorporation of a number of environmental objectives (general protection of the aquatic ecology, specific protection of unique and valuable habitats, protection of drinking water resources, and protection of bathing water, etc) into river basin management.

Given its environmental footprint, small-scale hydropower can find itself between a rock and a hard place when it comes to meeting simultaneously the energy and environmental objectives.

Consequently, the objective of the workshop will be two-fold:

- To review the policy drivers and constraints influencing the deployment of small-scale hydropower, and
- To agree on the main elements of a methodology to assess the environmental impacts that should be factored into estimates of the environmentally compatible potential from small-scale hydropower by 2020 and beyond.

The debate will have, as a starting point, the recent reports produced by the European Environmental Agency (some of which with the support of the ETC/ACC), namely:

- *A methodology to quantify the environmentally compatible potentials of selected renewable energy technologies*, ETC/ACC Technical Paper 2008/16, available at http://air-climate.eionet.europa.eu/reports/ETCACC_TP_2008_16_pots_ren_energy_techn
- *How much bioenergy can Europe produce without harming the environment? available at* http://www.eea.europa.eu/publications/eea_report_2006_7
- *Europe's onshore and offshore wind energy potential available at* http://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential.

The debate will be structured around a limited number of questions which will be sent to the participants closer to the time of the workshop.

Should you be interested to participate, please confirm by **15th November 2009** to Mrs. Helle Furbo at Helle.Furbo@eea.europa.eu.

For any logistical questions, please do not hesitate to contact Mrs. Furbo. For any question concerning the substance of the workshop, please contact Philippe Crouzet at Philippe.Crouzet@eea.europa.eu and Mike Landy at mike.landy@aeat.co.uk.

Best regards

Dr. Peder Jensen
Head of Energy and Transport Group
Air and Climate Change Programme

Stakeholder Workshop: How can we define the “environmentally compatible potential” for small-scale hydropower?

Friday 27th November 2009, 9.30 - 16.30

Committee of the Regions, Rue Belliard 99-101, B-1040 Brussels, Belgium

Agenda

09.00 – 09.30	Registration and coffee/tea
09.30 – 09.45	Welcome and brief introductions of participants
09.45 – 10.10	Introduction - purpose of workshop, background, approach for the day. Balancing energy versus environmental goals. The renewables and water framework directives. Mike Landy, AEA
10.10 – 10.50	What are the key environmental impacts of small-scale hydropower? What are the mitigation options and their costs? Cumulative and synergistic impacts. Existing schemes and potential for new schemes. Philippe Crouzet, EEA
10.50 – 11.15	The small-scale hydropower industry's view; how to contribute to energy goals whilst minimising environmental impacts. Lauha Fried, ESHA
11.15 – 11.30	Break
11.30 – 12.00	The regulator's view - how to strike the right balance. Catherine Wright, Environment Agency (UK)
12.00 – 12.30	The "Green Hydro" approach - does this provide the answer to defining good practice? Can we define universal requirements and supplementary measures for "green hydro"? Giulio Conte, Ambiente Italia
12.30 – 12.50	How to estimate Europe's environmentally compatible potential of small-scale hydropower: a proposed outline approach. Dr James Craig, AEA
12.50 – 13.50	Lunch
13.50 – 15.00	Discussion of the key environmental criteria for acceptable hydro with the aim of achieving a consensus. Key issues are: - optimising hydropower with other water uses on a river catchment basis - optimising small-scale hydro for migratory fish - acceptable residual and peak flows - impact of land designation - impact of legislation/regulations - associated impacts (grid connections, access, amenity, construction, etc) - acceptable deployment density - cumulative and synergistic impacts. Can we define "environmental good practice" for small-scale hydropower? Can we categorise rivers/catchments as to their acceptability for hydro? Discussion facilitated by James Craig, AEA and Philippe Crouzet, EEA
15.00 – 15.15	Break
15.15 – 16.00	Discussion continues, with the aim of specifying the criteria that can be implemented as part of the modelling.
16.00 – 16.30	Workshop conclusions and recommendations

EEA workshop: How can we define the "environmentally compatible potential" for small-scale hydropower?

Pre-meeting paper

This note is a pre-meeting paper to the European Environment Agency workshop "How can we define the environmentally compatible potential for small-scale hydropower?" on 27th November 2009, and aims to set the scene for the workshop. This workshop is based on work performed by the EEA's European Topic Centre on Air and Climate Change and contributes to the EEA's goal of assessing the environmentally compatible contributions that renewable energy technologies can make to European energy supplies.

The future of hydropower in Europe is uncertain. On the one hand the EU has agreed a challenging new target for the deployment of renewable energy by 2020, and hydropower is one of the most established technologies able to contribute to its achievement. On the other hand the environmental impacts of hydropower have become increasingly recognised in recent years and the EU's Water Framework Directive requires a new, tougher approach to the management of water resources. Reconciling what may appear to be these opposing goals is a major challenge for policymakers and implementers alike.

This workshop will aim to explore the middle ground, focusing specifically on small-scale hydropower (<10 MW). As the workshop's title implies, our goal will be to examine the impacts of small-scale hydropower (SHP) and see whether a consensus can be reached on how these impacts can be managed in the future. The goal is <u>not</u> to produce guidance that will be translated into regulation, but to inform a methodology to quantify the environmentally compatible potential of SHP in Europe. Nevertheless we hope that conclusions from the workshop will help those responsible for implementing policy for SHP at all levels.

The goal of the workshop is therefore to:

- Review the status and impacts of small-scale hydropower (morning), and
- Debate the impacts (afternoon) with the aim of reaching a consensus on how they should affect realistic estimates of future SHP potential.

The rest of this note provides a little background on the impacts of SHP and the factors that the afternoon's discussion will need to focus on. This paper also poses some of the questions that will be used to guide the discussion; we would be grateful if participants could think about these in advance and come prepared to debate them. Please let us know of other key questions that you think require answers. The report that we drafted a year ago[22] provides considerable background information, if already a little out of date.

We look forward to lively and constructive discussion on November 27 and thank you in advance for your contributions.

Mike Landy and James Craig

AEA, on behalf of the
European Topic Centre on Air and Climate Change

[22] As mentioned in the invitation to the workshop, the report "A methodology to quantify the environmentally compatible potentials of selected renewable energy technologies", ETC/ACC Technical Paper 2008/16, is available at http://air-climate.eionet.europa.eu/reports/ETCACC_TP_2008_16_pots_ren_energy_techn

Introduction

1. There is a strong imperative to develop renewable sources of energy and the EU has now set itself the legal target of renewables achieving a 20% contribution to energy consumption by 2020, from a starting point of around 10% today. The directive makes no distinction between different sources of renewable energy but to meet this challenging target there will need to be a significant expansion in all energy sectors. The EU has also introduced a number of directives to strengthen protection of the natural environment. One of these, the Water Framework Directive (WFD), has major consequences for hydropower, both existing and new schemes. It is in this context that this project with the European Environment Agency (EEA) has been initiated.

2. This project has the goal of quantifying the "environmentally compatible potential" for small-scale hydro in Europe. To do this it must first establish the technical potential, which takes into account man's ability to extract energy from the resource and basic practical constraints such as availability of suitable locations[23]. Work is ongoing to do this on a semi-automated basis, using hydrological data available in the public domain. The goal of the stakeholder workshop is to gain **consensus** on the principles of a practical methodology for translating the technical potential into an **environmentally compatible potential**. What factors do we need to take into account and how?

Background

3. The workshop will only cover SHP and therefore excludes large-scale hydropower that has already been developed or planned. The BlueAGE study reported that in 2000 there were slightly more than 17,400 SHP schemes installed in the 26 European countries they surveyed (including Norway and Switzerland), corresponding to a capacity of about 12.5 GW of SHP. The average size of a SHP plant was 0.7 MW in Western Europe, and 0.3 MW in the Eastern European countries. The study also reported that almost 45% of SHP plants in EU countries are over 60 years old and 68% over 40.

4. To put the position of small-scale hydropower into context, the most recent data indicate that SHP produced 46 TWh in 2005 in the EU-27, 9% of the renewables electricity and 1.4% of gross electricity demand. By comparison large-scale hydropower generated 297 TWh or 58% of renewable electricity, however it is accepted that environmental restrictions will severely limit the construction of new large-scale hydropower schemes.

5. The latest modelling under the EU Green-X project shows that there is a potential for an additional 23 TWh to be generated from SHP in the EU-27 in 2020, a 50% increase in output over the 15 years and contributing 4.3% of the total renewables electricity in 2020. The additional electricity production would require an additional installed capacity of approximately 5,800 MW to be deployed by 2020. Given that small-scale hydropower schemes are on average below 1 MW, this could mean over 10,000 new installations by 2020. In comparison output from large-scale hydropower is projected to increase by 14%.

6. Compared with some other sources of renewable electricity, hydropower is essentially a firm source of power, less subject to the intermittency of sources like wind power or solar PV. This predictability makes it more attractive to the electricity supply system, though it is recognised that climate change could affect this in the longer term. In addition the very controllability of hydropower can lead to one of its undesirable impacts - large variations in water flow rates ("hydropeaking") as hydro capacity is brought on and off line.

7. The other major consideration that affects SHP development is its environmental impacts, summarised in Table A1.1 (in Appendix 1). There are a number of EU directives, in particular the Water Framework Directive (WFD; 2000/60/EC) that increasingly impact on the use of this resource. The WFD is a legal framework to protect surface and groundwaters and for the first time pursues an integrated approach to European water policy. It sets out to prevent further

[23] The technical potential takes into account the technological, physical and practical constraints associated with exploiting a particular renewable energy resource and requires some common-sense assumptions to be made concerning the maximum deployment density likely to be acceptable.

deterioration of existing water bodies; protect and enhance aquatic ecosystems; ensure that there are sustainable water supplies; reduce pollution and mitigate against floods and droughts. Article 4.7 of the WFD, highlighted in the box below, provides some guidance on how development such as hydropower should be viewed under the directive.

Water Framework Directive Article 4.7:

Member States will not be in breach of this Directive when:

- failure to achieve good groundwater status, good ecological status or, where relevant, good ecological potential or to prevent deterioration in the status of a body of surface water or groundwater is the result of new modifications to the physical characteristics of a surface water body or alterations to the level of bodies of groundwater, or

- failure to prevent deterioration from high status to good status of a body of surface water is the result of new sustainable human development activities

and all the following conditions are met:

(a) all practicable steps are taken to mitigate the adverse impact on the status of the body of water;

(b) the reasons for those modifications or alterations are specifically set out and explained in the river basin management plan required under Article 13 and the objectives are reviewed every six years;

(c) the reasons for those modifications or alterations are of overriding public interest and/or the benefits to the environment and to society of achieving the objectives set out in paragraph 1 are outweighed by the benefits of the new modifications or alterations to human health, to the maintenance of human safety or to sustainable development, and

(d) the beneficial objectives served by those modifications or alterations of the water body cannot for reasons of technical feasibility or disproportionate cost be achieved by other means, which are a significantly better environmental option.

8. Other relevant directives include the Birds Directive (79/409/EEC), the Habitats Directive (92/43/EEC) and the Natura 2000 network of protected areas. It is recognised that any form of SHP development should adhere to good practice planning conditions. Unfortunately this has not always been the case in the past.

Impact of EU/national legislation on SHP resource - issues for the workshop

9. EU environmental legislation, especially the WFD, will have profound effects on the use of water resources including hydropower. The implementation of the WFD is meant to achieve "good ecological status", or "good ecological potential" for "heavily modified water bodies". The WFD requires water authorities to prepare river basin management plans including measures to protect the status of water bodies and, where necessary, improve them. Consequently, the directive will not only influence new hydropower development but also existing operations. One of the main impacts will be to increase the costs for both existing and new hydropower plant, making it more difficult for these to compete in the electricity markets. The key aim of our workshop is to review the implications of these directives and produce some guidance on how these impacts will affect what can be described as the environmentally compatible potential of small-scale hydropower.

10. The implications of the WFD on hydropower have been the subject of several previous workshops[24],[25]. These meetings have concluded that pan-European standardisation is necessary that also takes account of site-specific mitigation. Compliance with catchment management plans has also emerged as a pre-requisite. The next step is to examine the key environmental criteria and quantify the impact of WFD and other directives on the SHP resource. Ideally this exercise will identify the cost implications for SHP and the extent to which it can be developed. Ultimately constraints imposed on SHP will define the environmentally compatible resource initially within individual catchments, but eventually also at pan-European level.

11. The issues itemised in Table A1.1 raise a number of questions which the workshop needs to consider to help define the Environmentally Compatible Potential (i.e. what factors need to be taken into account to reduce the Technical Potential).

Questions for the Workshop

There is already a good deal of material that identifies the impacts of hydropower and proposes good practice guidelines for new hydropower plant. Many of these are incorporated in the criteria used by "green hydro" certification schemes and it appears quite likely that these will be expected for all new projects in due course. The questions below are examples of some of the key ones that need answering, classified under the main impacts. The last one refers to the difficult question of what to do when certain existing schemes have a disproportionate impact on areas like fish migration.

<u>River flows</u>

Can minimum performance standards be set for hydropower plant with respect to minimum flow, hydropeaking and sediment transport? What impact would these have on SHP operations and costs?

<u>Fish passage and protection</u>

Is it reasonable to expect that all new small-scale hydropower plant should allow fish to migrate unimpeded? What standards should be set for existing plant?

<u>Protection of designated areas</u>

Is it reasonable to state that certain geographical designations (for example Natura 2000 sites, national parks, etc) should be excluded for the purpose of estimating hydro resource potential, even though decisions whether or not to actually develop in designated areas should always remain with the relevant statutory authorities?

<u>Cumulative impacts</u>

Is it possible to define a reasonable limit for deployment density or will this always depend on local factors?

<u>River classification</u>

Should rivers at the pre-planning stage be classified with respect to their suitability for hydropower development, for example as "suitable", "less favourable" or "non-favourable"?

<u>Good practice</u>

Can we define good practice guidelines for hydropower development? Do they already exist in a form that can be widely adopted?

[24] Water Framework Directive & Hydropower, Common Implementation Strategy Workshop Berlin, 4-5 June 2007, http://www.ecologic-events.de/hydropower/
[25] Austrian-French workshop 4-5 July 2008, http://rp7.ffg.at/umwelt_va_wfd

Should it be assumed that all new small-scale hydropower schemes will need to conform to basic “green hydro” standards?

Existing hydropower schemes

Would it be reasonable for river basin management plans to allow for new hydropower developments to proceed only if certain existing plants in particularly sensitive locations are removed? If so, how should these be compensated?

Table A1.1: A summary of the main environmental impacts caused by SHP.

It also outlines the legislation, mitigation and implications for the SHP resource. The table is not intended to be a definitive list. It is intended to outline the key criteria for discussion at the workshop.

Impacts	EU/National Regulation	Mitigation	Implication for SHP Resource
Environmental Factor: Flow Regime			
Run-of-river SHP partial depletion of water course & alteration of flow regime. Pulsing caused by erratic & or poorly controlled abstraction. Storage/Intermittent generation – Hydro peaking caused by sudden changes in flow	Water Framework Directive (WFD) to achieve/ maintain good ecological status. Habitats Directive Birds Directive EIA Directive Protection of Natura 2000 sites	Residual Q_{95} flow must always be maintained. Flow regime in the depleted stretch ideally matches the pre-existing natural flow regime. Weirpool levels are maintained and do not fluctuate widely. Abstraction is continuously monitored and intervention to meet licence requirements is immediate. Abstraction must take account of catchment management plans including future increases in demand. Good design e.g. SHP built on existing weirs or within water supply infrastructure should limit impacts on flow regime	Restrictions on abstraction rates will limit power conversion relative to capital cost. Abstraction monitoring & control will impose higher costs on operating cost. SHP linked to storage may be restricted to maintain tolerable fluctuations in reservoir/lake levels. Good design to limit/minimise impact of SHP could increase capital cost.

Table A1.1 continues on next page

Table A1.1 continued

Impacts	EU/National Regulation	Mitigation	Implication for SHP Resource
Environmental Factor: Erosion, transport deposition			
SHP schemes linked to dams/weirs may lead to retention of sediment and depletion & erosion in lower catchments	Water Framework Directive (WFD) to achieved/ maintain Good Ecological Status. Habitats Directive Birds Directive EIA Directive Protection of NATURA 2000 sites	Sediment can be dredged from reservoirs/lakes and re-deposited downstream of barrier. Applies to large-scale hydro but could it also apply to SHP. Apply natural river regime e.g. “Espace de Liberté”. 200km of Loire and 220 km of Allier rivers function without artificial intervention. Green Hydro certification incorporates sediment management.	Control of sediment movement will add to operating cost. Removal of dams/weirs will reduce SHP resource and may have negative environmental impacts. Rivers which are allowed to sustain a ‘natural’ regime will effectively lock-out and future SHP development.
Environmental Factor: Riverine/ Aquatic ecosystems			
Large dams and weirs present significant barriers to migratory species mostly but not exclusively diadramous. Some vulnerable species have specific conservation and commercial value (Salmon/ sea trout). Some once common species such as eels are affected by down stream obstructions. Cumulative impacts. Riverine and adjacent habitats might be affected by depletion especially isolated regions with species adapted to high humidity e.g. Snowdonia	Water Framework Directive (WFD) to achieved/ maintain good ecological status. Habitats Directive EIA Directive Protection of Natura 2000 sites Salmon and Freshwater Fisheries Act European Management plan (requires specific improvement to obstructions).	Where migratory species exist there must be approved fish passes. Uninterrupted flow must always be maintained. Design of SHP should ensure flow to scheme is minimised so that fish are directed to maximum flow away from turbine. Fish lifts, ramps, locks and/or deterrence systems could be employed. Improved management of existing SHP e.g. Dordogne & Garonne Rivers have improved protection of salmonoid spawning areas. Catchment management plans that limit cumulative impact by restricting SHP development.	Fish passes and design of SHP to minimise the impact on fish will increase capital costs. Mitigation measures will add to operating costs. In areas where SHP is established then changes to operational regime (e.g. to limited impact of hydropeaking) might reduce existing resource. New SHP development is probably unlikely. Catchment management plans could impose significant restrictions on SHP resource especially if cumulative impacts are suspected.

6 Appendix 2: Workshop conclusions and recommendations

Questions for the small-scale hydropower workshop

To help define the environmentally compatible potential for SHP the workshop was asked to discuss a number of key environmental criteria that need to be considered before new SHP can be developed (as set out in the pre-workshop document – see Appendix 1). The workshop was broken into a series of topics. In each case the workshop was asked to consider a number of questions on the implications of meeting good environmental or 'Green' hydro standards and compliance with the Water Framework Directive (WFD) – see the final presentation in Appendix 3.

The following key topics for consideration were discussed:

- Flow regime/ riverine environment
- Fish passage and protection
- Designated areas
- River Classification
- Cumulative impacts
- Good practice
- Future SHP development

<u>**River flows**</u>

Question: Can minimum performance standards be set for hydropower plant with respect to minimum flow, hydropeaking and sediment transport? What impact would these have on SHP operations and costs?

- High head i.e. >10m – usually with hundreds of metres of depleted section
- Residual Q_{95} flow[26] must always be maintained.
- Flow regime in the depleted stretch ideally matches the pre-existing natural flow regime.
- Weirpool levels are maintained and do not fluctuate widely.
- Abstraction is continuously monitored and intervention to meet licence requirements is immediate.

Workshop Response

Good practice should be to maintain a residual 'hands off' flow in the depleted stretch of river. Flow *variability should mirror the natural flow regime in a river with SHP schemes. Operators should also* avoid sudden surges of flow especially where exposed downstream sections become heated, as this can cause a harmful thermal shock. Maintaining flow regimes is also important for adjacent wet habitats with high humidity and to sustain oxygenation.

Q_{95} is taken as a standard benchmark for the maximum level of abstraction. But the measure needs to be carefully defined. Q_{95} flow in a river is the normalised flow (average) over 15 years. In the UK the operator is responsible for monitoring flow i.e. the amount of abstraction relative to power output. Regulators may periodically check that the licence conditions are being adhered to. Monitoring flow in the depleted stretch is also important. Probes that relay data to monitoring stations can be unreliable and should be checked regularly.

Some SHP projects abstract water from weir pools. Some fluctuation in weir pool levels is acceptable. But sudden changes in flow, for example, when a SHP begins operation can lead to thermal shocks (+5ºC).

[26] A Q_{95} flow is the flow equalled or exceeded in 95% of the daily mean flows in a record and is a descriptor of the low flow of a river.

Sediment movement and monitoring

Question: Sediment can be dredged from reservoirs/lakes and re-deposited downstream of the barrier. This applies mainly to large-scale hydro but could also apply to SHP – this is identified as a "green" hydro standard. How is the environmental impact of new SHP assessed?

Workshop Response

For SHP (<10 MW) hydropeaking and restricted sediment movement are not really issues. But more information is required on the different types of SHP across Europe and their distribution (for example, high head sites with and without storage). Information is also required on variations in operational practice. For example, are they only periodically operated to meet peak demand? There needs to be a comparative basis for SHP.

In the UK low head is generally taken to be <4 m.

In the UK flood risk also needs to be taken into consideration. Some schemes can involve raising a weir level, however, this might increase the flood risk by raising upstream water levels.

Monitoring environmental impacts should be carried out, especially where novel schemes have been installed. In one instance the construction of a SHP (~50 kW) Archimedes screw plus an adjacent fish pass opened up a small Welsh river where a pre-existing weir had blocked migratory fish.

The restoration of rivers to a 'good ecological status' might require a minimum flow equivalent to 20% of the natural flow regime. The flow rate is defined as the mean minimum daily flow rate measured over a 15 year period. There should also be continuity throughout the year. In instances where flooding depletes fish populations, recolonisation may be impeded if there is no continuity. Two-way movement is therefore important.

Fish passage and protection

Questions:

- Is it reasonable to expect that all new small-scale hydropower plant should allow fish to migrate unimpeded? What standards should be set for existing plant?

- What are the mitigation measures for SHP implied by the WFD?

Fish migration is a contentious issue for SHP. Within European rivers there are 28 diadromous (migratory) species of fish plus fresh water species which can move ~100 km within a river system. Their breeding behaviour also varies which needs to be taken into account when considering mitigation measures. For example, sturgeon only ever breed in large rivers whereas salmon need to reach the upper reaches of small tributaries. SHP impacts are consequently dependent on the migratory species present. Where migratory species exist there must be approved fish passes. Uninterrupted flow must always be maintained by SHP operators.

There are two important considerations: appropriate mitigation for new SHP schemes and the impact of existing barriers. In the latter instance low head (2-3m) weirs should not present a problem for fish if correctly designed (i.e. they should have a low gradient). A fish pass may not therefore be necessary. However some existing low head weirs are highly detrimental to fish. There are instances of structures (~3m head) built from a series of sheet piles. Some migratory species are able to reach the top of these barriers only to be killed from the impact of hitting the top of the piles.

Mitigation measures to meet the requirements of migratory fish may make SHP uneconomic.

The introduction of the WFD has important implications for mitigation. For example in Austria it has been estimated that up to 2,500 new passes may be necessary with an estimated investment of ~€240 M required to meet these. The retrofitting programme is likely to take up to 2027 which means an investment rate of €8 -10M per year. Any new barrier including SHP related development must now be licensed. One condition of new licences is the provision of continuity.

Cumulative impacts where there are multiple barriers are a concern, especially for long distance migration. Species which need to breed in the upper reaches of river systems must be able to arrive in sufficient numbers to sustain their populations. If 10% or 20% of a migratory population fails to progress past a barrier then by the time the tenth barrier is reached there is only 1/3 to only 1/10 of the initial population able to reach beyond the final barrier. Crucially young fish must also be able to migrate downstream so that the life-cycle can be sustained.

There are some dams built in the early nineteenth century in France and more recently which are permanent barriers to migratory fish. Upstream catchments are consequently deprived of these species.

Poor fish pass design is another factor that can restrict migration. Designs do not always take account of fish behaviour or the necessity for two-way migration. The cost of fish pass construction will be published shortly in a new British Hydropower Association guide.

Obsolete dams and weirs could be completely removed without any detrimental effects. This would improve the prospects for migratory fish.

The EEA's ECRINS database can be used to model where fish populations might be vulnerable. It could also be used to identify where mitigation may not be necessary, for example, where there are no migratory fish present because of a large downstream obstruction. The database can also be used to identify the extent of river basin connectivity.

One key factor should not be over looked - the dramatic decline in some species of fish due to external factors that are unrelated to river migration.

Protection of designated areas

Question:

- Is it reasonable to state that certain geographical designations (for example Natura 2000 sites, national parks, etc) should be excluded for the purpose of estimating hydro resource potential, even though decisions whether or not to actually develop in designated areas should always remain with the relevant statutory authorities?

Workshop Response

Natura 2000 sites do not necessarily need to exclude new SHP development. Only those sites where a vulnerable aquatic habitat has been identified need to be considered. It could be that development could proceed in these areas if it was WFD compliant.

Rather than assuming complete exclusion from designated areas, the SHP potential in these areas should be estimated. Then the environmentally compatible potential could be estimated with and without SHP potential in such designated areas.

There are also some areas where a pristine environment still exists, for example in the Piedmonte region in northern Italy. However, these areas are likely to be relatively small. Nevertheless it would be worth identifying where they exist.

River classification

Questions:

- Should rivers at the pre-planning stage be classified with respect to their suitability for hydropower development, for example as "suitable", "less favourable" or "non-favourable"? For example, how to classify a river with a 'Special Area of Conservation' (SAC) designation with vulnerable species of migratory fish? Does "non-favourable" mean complete exclusion?

- If a natural river regime is applied, e.g. “Espace de Liberté” – does this imply complete exclusion of SHP? This could be extensive e.g. 200km of the river Loire.

Workshop Response

Regulating deployment density of future SHP is becoming increasingly difficult. For example the Environment Agency in the UK is obliged to process all applications for SHP development. The EA has reviewed the SHP potential in England and Wales and identified preferred locations for SHP (mainly low head sites on existing weirs).

There are catchments that are already over abstracted and where the authorities would be unwilling to allow further water abstraction or where deployment of SHP would be uneconomic.

In Austria utility companies are opposed to the establishment of any classification system that might direct them to certain areas. They prefer to have the option of exploring any location that might be suitable for hydropower development.

Cumulative impacts

Question:

- Is it possible to define a reasonable limit for deployment density or will this always depend on local factors? If catchment management plans incorporated WFD requirements, will the designations defined by WFD restrict SHP development?

Workshop Response

Cumulative impacts will to an extent depend on the preferential development of the most favourable sites (i.e. those with access to the best resource).

Access to electricity networks might also restrict new SHP development because of the high cost to connect to the electricity grid and the lack of accessible connection points.

Good practice

Questions:

- Can we define good practice guidelines for small-scale hydropower development? Do they already exist in a form that can be widely adopted?

- Can we define a green standard for SHP, which might cover:
  - Minimum flow regulation
  - Hydropeaking
  - Reservoir management
  - Bed load management
  - Power plant design?

- Surveillance / operational monitoring – should this be part of impact assessment?

- Should there be a requirement for SHP plant to be re-certified after 5 years – demonstrating evidence of implementation of mitigation measures?

- Should it be assumed that all new small-scale hydropower schemes will need to conform to basic “green hydro” standards?

- Compliance with basic requirements and monitoring: are these disproportionately high? Should the additional cost of mitigation measures be embedded within the electricity tariff?

Workshop Responses

A requirement for re-certification may discourage SHP development. Instead developers should monitor the impact of operational SHPs. In the UK a licence is issued for 12 years.

Good practice should be shared across the EU. There should be full transparency on all the issues related to SHP development and its impacts.

There are significant differences across the EU on running costs. In Austria for example there are no water abstraction charges.

ESHA provided a perspective on recent developments in two EU countries:

- Poland: in November 2009 a moratorium on all SHPs has been introduced. Previously issued permits have now been withdrawn.
- Slovenia: a new directive to increase ecological flow has led to the reduction in energy output of between 30% - 60%.

Conclusion

The workshop was very useful in helping to focus on the key environmental impacts of small-scale hydropower and get a clearer understanding of how the requirements of the Water Framework Directive are likely to affect both existing and new SHP plant. It is clearly a complex area with much room for interpretation and it will take some time for a clear picture to emerge. The workshop responses will be an important factor in helping to guide the workplan in 2010, with the hope that some guidelines can be produced that will show how deployment of small-scale hydropower can continue to proceed in a way that is compatible with the Water Framework Directive.

7 Appendix 3: Workshop presentations

This appendix provides the presentations that were made to the stakeholder workshop ‘How can we define the “environmentally compatible potential” for small-scale hydropower?’ that took place in Brussels on Friday 27th November 2009. The first six are the presentations that were made during the morning session. The seventh is the questions that were used to prompt the discussion during the afternoon session.

1. Introduction - purpose of workshop, background, approach for the day. Balancing energy versus environmental goals. The renewables and water framework directives. Mike Landy, AEA.
2. What are the key environmental impacts of small-scale hydropower? What are the mitigation options and their costs? Cumulative and synergistic impacts. Existing schemes and potential for new schemes. Philippe Crouzet, European Environment Agency.
3. The small-scale hydropower industry's view; how to contribute to energy goals whilst minimising environmental impacts. Lauha Fried, European Small Hydropower Association.
4. The regulator's view - how to strike the right balance. Catherine Wright, Environment Agency (England and Wales).
5. The "Green Hydro" approach - does this provide the answer to defining good practice? Can we define universal requirements and supplementary measures for "green hydro"? Giulio Conte, Ambiente Italia.
6. How to estimate Europe's environmentally compatible potential of small-scale hydropower: a proposed outline approach. James Craig, AEA.
7. Discussion of the key environmental criteria for acceptable hydro with the aim of achieving a consensus. Facilitated by James Craig, AEA and Philippe Crouzet, EEA.

How can we define the "environmentally compatible potential" for small-scale hydropower?

Introduction

Mike Landy
AEA and ETC/ACC

European Topic Centre on Air and Climate Change

Workshop objectives

- Review the status and environmental impacts of small-scale hydropower
- Debate the impacts with the aim of reaching a consensus on how they should affect realistic estimates of future SHP potential
- Inform a methodology to quantify the environmentally compatible potential

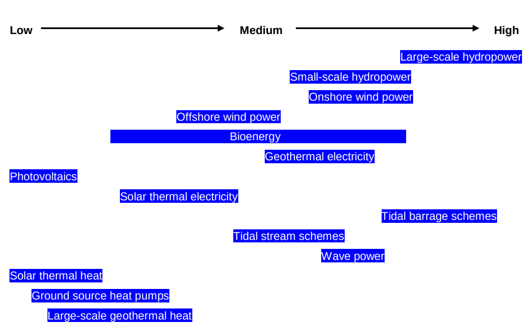
Hydropower

- Well established technology
- Essentially a firm source of power
  - Control over output
  - High load factor
  - Reasonably predictable annual patterns (but subject future climate change)
- Best sites already developed
- Significant environmental impacts

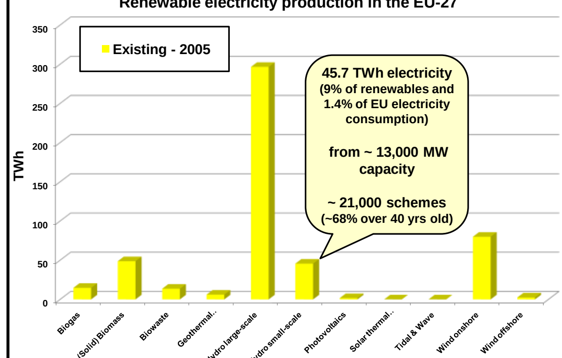
A little background

- EU directive 2009/28/EC (the Renewables Directive) requires the EU to double the contribution from renewable energy to 20% by 2020 (with no easy options)
- EU directive 2000/60/EC (the Water Framework Directive) aims to protect and enhance European water bodies.

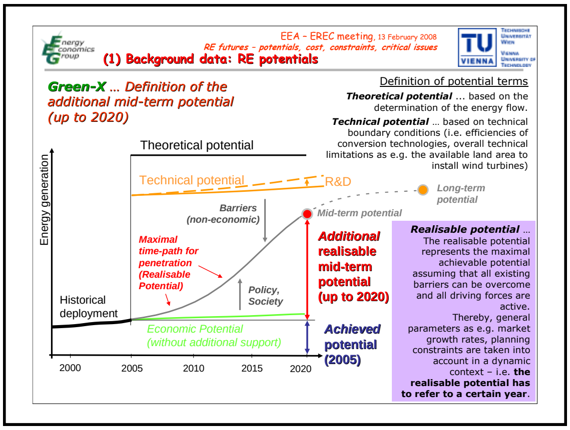
Environmental constraints on renewable energy deployment

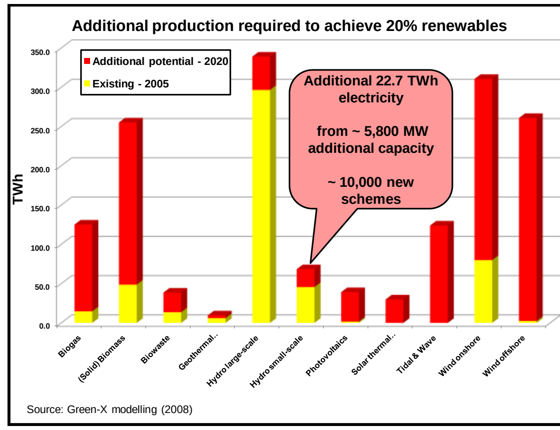


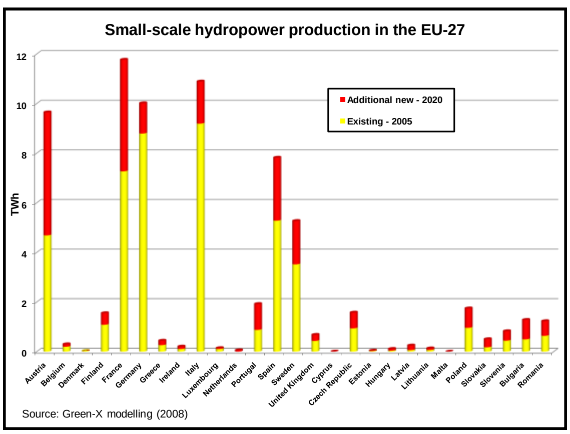
Renewable electricity production in the EU-27



Source: Green-X modelling (2008)

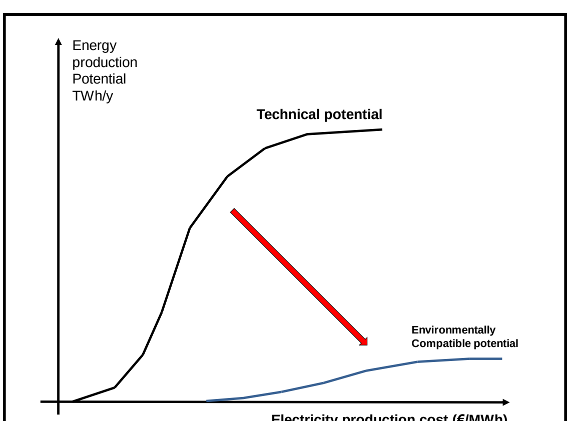


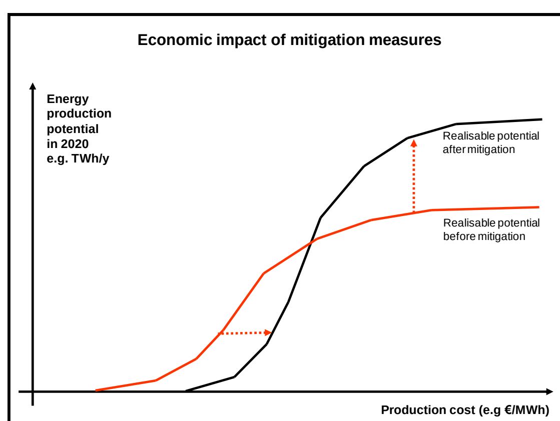


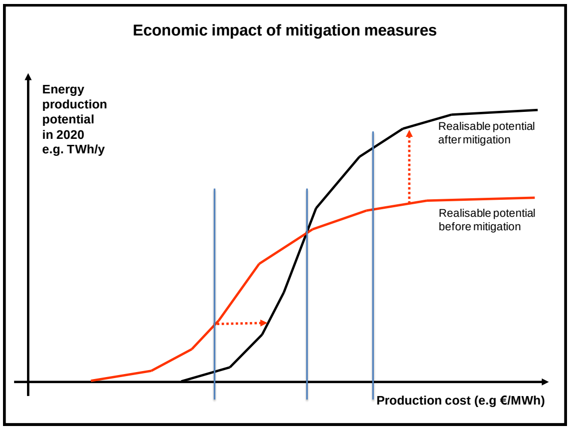


Small-scale hydropower issues

- River flows
  - Minimum flow, hydropeaking, sediment transport
- Fish passage and protection
  - Biological continuity
- Wild/scenic protection
- Recreation value & other water uses
- Connection to the electricity grid
- Cumulative impact of multiple schemes
- Poorly sited existing schemes







Today's programme

- Review environmental impacts / WFD
- An industry view
- The regulator's challenge – striking the right balance
- The "Green Hydro" approach
- Quantifying Europe's SHP potential
- Open discussion: reaching a consensus on the standards to apply

Defining the "Environmentally compatible" potential for small hydropower in Europe.

Impacts on hydrosystems

Philippe Crouzet,
European Environment Agency

Working frameworks

- EEA's mission is "*to support sustainable development and to help achieve significant and measurable improvement in Europe's environment, through the provision of timely, targeted, relevant and reliable information to policy-making agents and the public*"
- Permanent conceptual frameworks: DPSIR and MDIAK
- Two prominent production frameworks (for hydrosystems): SEBI and Environmental Accounts (in 2010, becoming "international statistical standard")
- Legal framework for water: WFD, its daughter directives and non-repelled directives
- A dual regulatory framework: EIONET (the European information network) and SEIS, in its exploratory and building phase

Issues related to river obstacles and their exploiting

- **Activities impacting water and aquatic life are many:**
  - River management, canalization, suppression and fragmentation
  - Water Quality and habitats
  - Fishing and poaching
- **Fragmentation of hydrosystems**
  - Fish migration, habitats changes
  - Sediment budgets
  - Hydrological regimes (in close relationship with the Water Accounts),
  - Hydraulics of river systems (in relation with habitats)

Fragmentation, water quality, rehabilitation of habitats and water balances are key issues driving the success of failure of WFD goals, - achieve good ecological status / potential – and biodiversity targets 2010 along with ensuring sustainable availability of water resources

Which basis, stakes, methodology, indicators documenting practical and policy issues to document and inform about these issues at the relevant level?

Necessary integration of approaches and data collection to maximize outcomes

Obstacles impact: nesting the scaling issues

level / Question	**Biology: migrations, habitats**	**Sediments: budgets, reservoir clogging**	**Water regime : Management, Accounts**
Watershed	*Ex.: does salmon re-colonise river X?*	*Ex.: river budget, specific reservoir clogging*	*Ex.: local water management, protection against inundations*
Regional	*Ex.: SEB what is salmon status in Europe? What is the rate of habitats change?*	*Ex.: sediment budget per marine area, life expectancy of reservoir systems*	*Ex.: Water accounts, comparisons, risks of shortages*
Global	*Ex.: is salmon present in its natural extension area?*	*Ex.: intersystems comparisons (cf. GWSP)*	*Ex.: global changes, water ageing, sensitive regions*

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Knowledge, calibration

Comparison, policies

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Knowledge, calibration

Comparison, policies

ECP domain

ECP domain

Framing the issue

- Austrian example: dominated by hydropower, many small plants: the 64 TWh are produced 2/3 by hydropower
  - French example: 2008 production of 549 TWh, dominated by nuclear (418.3) then by Hydropower (68 TWh) by ~700 large plants as well many small plants (number unknown, likely to produce 7 TWh with supplementary potential of TWh)

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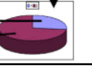
Structure of hydropower generation in Austria

	maximum capacity	No of plants	% of total No	GWh	% of total hp gen
small hydro-power	< 200 kW	1442	63	337	0,8
	200 - 500 kW	292	13	385	0,9
	500 kW–1 MW	184	8	468	1,1
	1 – 2 MW	118	5	598	1,4
	2 – 5 MW	73	3	745	1,8
	5 – 10 MW	34	1	881	2,1
	total	*2143*	*93*	*3.414*	*8,1*
large hp	> 10 MW	156	7	38.000	91
TOTAL		*2299**	*100*	***41.000***	*100*

* > 2000 very small plants (only private supply) to be added



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What are the issues?

- Hydraulic works create obstacles to aquatic organisms (fish mainly) , sediment and to some propagules, (local to regional) = fragmentation
- Presence of works create low energy river stretches (changes in habitats) = lotic -> lentic
- Operation of works change water regime (large reservoirs) and provoke hydropeaking (large and small, if no compensation pond).

Rivers are systems with strong upstream – downstream dependencies, making it necessary to analyse impacts at system level as well as at local level.

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Fragmentation: what to model?

- **All fish move between 1 to >>100km/year:**
  - From e.g. counting on Garonne system (2.8 million fish over 11 years, 25 species, including not known as migratory).
- **Migratory fish (=diadromous) must**
  - a) Reach target area in good time, in sufficient number and good physiological status
  - b) Spend their river life cycle time in good conditions (c.f. "resident fish"), phase involving moving and appropriate conditions
  - c) For certain species, return back to sea, in sufficient number and good condition

  = more "system" impact analysis
- **"Resident fish" must**
  - Benefit from enough life space around any place of their distribution area and appropriate conditions

  =more "local" impact analysis

Modelling should aim providing quantitative results on these different characteristics to turn them into indicators

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Modelling fragmentation: obstacles

- **Modelling is prerequisite to assessment because number of obstacles and time dimension**
- **Only transversal obstacles considered (access to river annexes non considered)**
  - Obstacle definition is driven by the issue (fish, sediment, etc.)
- **Obstacle characteristics**
  - Process only documented obstacles (underestimation bias) or all thanks to characteristics modelling (uncertainty)

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Modelling fragmentation: obstacles

Nouvel *Emosson* dam on river Barberine (CH / FR), no impact on fish

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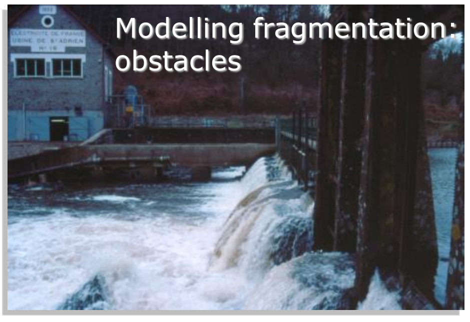
Modelling fragmentation: obstacles

Dry-out on the Cebron dam watershed (FR)

Modelling fragmentation: obstacles

Savarière dam on river Jaunay (FR): fish fragmentation potential

Modelling fragmentation: obstacles



Small hydropower dam on river Blavet (FR)

Fragmentation *vs.* Fish: modelling and calculations

- Model has to be based on sound although “affordable” scientific concepts, especially regarding data requirements
- Statistical approaches (frequent in scientific publications) are not suitable for dam related issues, because position in the river system is the paramount issue
- Three classes of ingredients for modelling:
  - River GIS (connected AND routed) = ECRINS for EU level assessment, not suited to local scales
  - Information about obstacles **placement** AND **characteristics,** with **date**, to assess the passing capacity, that is very varying in small works, poorly documented in our data base
  - Biological data:
    - Fish passing capacities (general data)
    - **Historical distribution areas (can be global or local data), stepwise completed by ETC/BD (28 species in Europe!)**

Fragmentation: derived and computed variables

- Problem simplified by considering three lumped variables, possibly calculated:
  - P(ermeability): % of fish passing obstacle (multiplicative, threshold 0,1% ≅ 0)
  - D(elay) : average delay caused by obstacle (additive, threshold max 365 days)
  - F(atigue) : decrease in physiological capacities required by migration (subtractive, threshold under assessment >=0%)
- Data per obstacle derived from observations
  - Individual data: some tens to some hundreds obstacles
  - Modelled from dimensional characteristics several hundreds
  - Set to default value several thousands
- Applied to routes (per species) to compute cumulated impact at time T

Fish ladders: solution or just constraint?

- Fish passes can work for head loss <10m and must be attractive
- Attractive means loosing power
- Passing effectiveness not synonym to migration performance

Fish ladders: solution or just constraint?

PRINCIPLES OF FISH PASSES

TO BREAK UP THE DAM'S FALL INTO SEVERAL DROPS

TO BUILD AN ARTIFICIAL STRUCTURE WITH DROPS AND AREAS TO DISSIPATE THE FLOW'S POWER

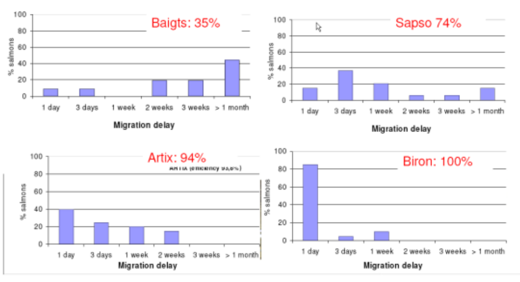
Fish ladders: solution or just constraint?

THE PROBLEM OF ATTRACTION FLOW

- Efficiency of FP strongly related to the attraction of flow
- Poor performance of fish passes is generally due to insufficient attraction
  - ✓ Unsuitable location of the entrance in relation to weir or to the outlet of turbines
  - ✓ or the discharge at the entrance is too low
- Recommendations:
  - ✓ Minimum flow of 2-5% of the competing flow,
  - ✓ Possibilities for two entrances
  - ✓ Two or three FP may be necessary (dam, hydropower house)

Fish ladders: solution or just constraint?

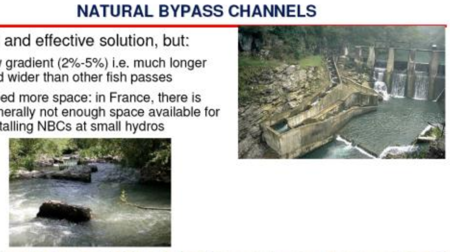
GAVE de PAU - FISH PASS EFFICIENCY
(3 years radio-tracking)



Fish ladders: solution or just constraint?

NATURAL BYPASS CHANNELS

- Good and effective solution, but:
  - ✓ low gradient (2%-5%) i.e. much longer and wider than other fish passes
  - ✓ need more space: in France, there is generally not enough space available for installing NBCs at small hydros

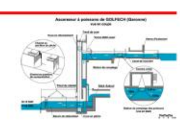


Specificity of large dams

- Large dams (>10 – 15 m) both create high wall and large impoundments, seldom passable. Only active fish passing techniques can apply;
- "Egg and hen" justification for fish lifts: historically many large dams were placed where fish had already disappeared (smaller dams, pollution, overfishing, etc.).

Specificity of large dams

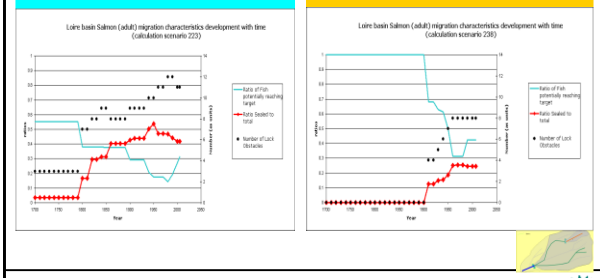
FISH LIFT



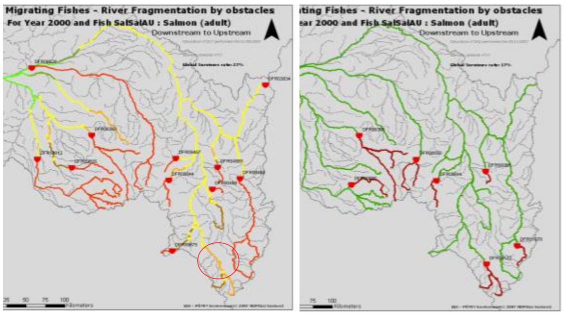
- Fish trapped in a large pool and crowded over the tank just before raising
- Efficient for all species except small ones (eel). Very efficient for shad
- Up to 100,000 shad/year at Golfech lift (Garonne)
- Adapted to high dams or sites with insufficient space
- High maintenance costs

Aggregated results for SEBI: dam source relevance

All dams (Onema source) | Large dams (Icold) only



Aggregated results for SEBI: dam source relevance



Downstream migration is critical

- Up to recent, most preoccupations on upstream migration (design of fish passes).
- Downstream migration often critical: preventing smaller fishes from water intakes

DOWNSTREAM FISH FACILITIES

- Difficulty of installing fine mesh screens (1-1.5 cm)
- Efficiency of behavioural barriers (electricity, light, bubbles, sound…) very limited
- Use surface bypasses in association with existing protection trashracks (spacing between bars 2.5 - 4 cm)
- **Efficiency: from <10% to >80% depending on:**
  - ✓ spacing of the bars
  - ✓ location of the bypass entrance (close to the trashrack)
  - ✓ flow pattern at intake and near bypass entrance

ONEMA

Flow regime issues

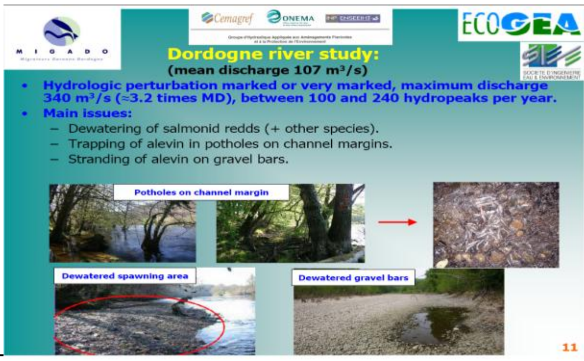
- Most (in number) of hydropower plant produce electricity to respond to peak demand -> hydropeaking.
  - From hydrobiological point of view, hydropeaking is extremely devastating, even damages not spectacular,
  - From economical point of view forbidding Q surges is jeopardizing the facility.

Flow regime issues

French context: ONEMA

- **Issue extent:**
  - More than 150 hydroelectric schemes managed by hydropeaking in France (≈ 8000 MW and 33 TWh).
  - Some schemes organized in line (eg: Durance, Dordogne).
  - Maximum turbine discharge generally between 2-3 times the river's mean discharge, and up to 5-6 times the mean discharge.
  - Affected river distance can be considerable (several tens of km, even 1 or 2 hundred km [eg: Dordogne river]).
- **Regulatory context:**
  - No legislative or regulatory provision included in French legislation for hydropeaking management (except minimum regulatory flow, such as in the case of bypass reaches).

Flow regime issues



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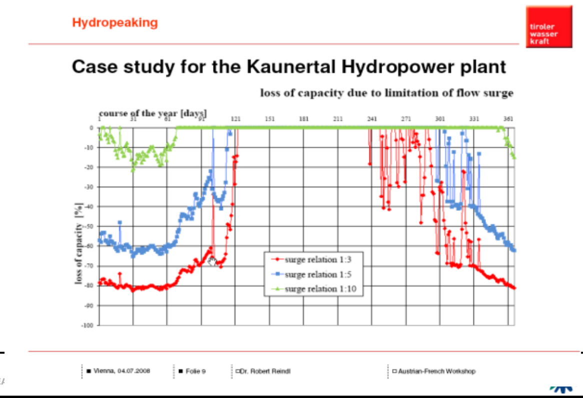
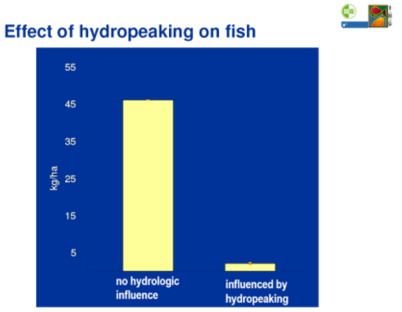
Flow regime issues



Flow regime issues



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Sediment storage and release issues

- Dam built to make it possible producing energy results in trapping sediments:
  - Reservoir clogging -> loss of capacity;
  - Downstream starvation -> change in river dynamics;
  - For large dams -> change is sediment balance to the sea
- Sediment flushing is a complex issue requiring appropriate devices and operating rules:
  - Setting which dams to manage,
  - Setting operational rules and surveillance

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Conclusions and suggestions for debate

- Defining "environmentally compatible potential" demands as prerequisite:
  - Addressing the huge gap between fish requirements and hydropower requirements,
  - Accepting that technology cannot solve all problems: the best fish pass is "no dam",
  - Assuming that choice (fish OR hydropower instead of fish AND hydropower) should be fully documented for responsible political response.
- The methodology must address the "SCH" in a basin wide context:
  - Cumulative and synergistic effects: migration distance is key; hence adequate indicators to set,
  - The term environmentally compatible implies sharing hydrosytem energy (fish pass, sediment management uses part of potential energy);
  - How analysing the overall economy of the system (renewable energy against ecology?)

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Thanks for your attention

Specific requests:

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EEA website:

www.eea.europa.eu

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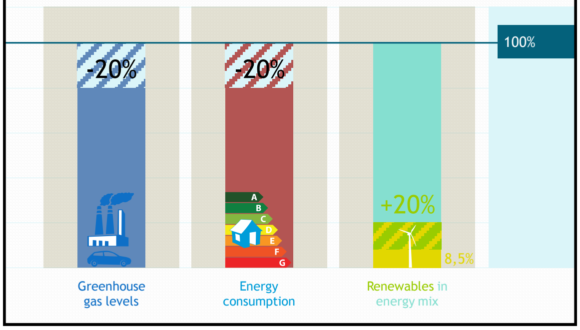
SHP industry view: How to contribute to energy goals while minimising environmental impacts

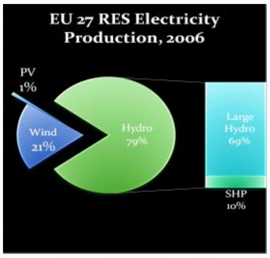
EEA ETC/ACC small-scale hydropower workshop
27 November 2009, Brussels
Lauha Fried, ESHA



The 20-20-20 EU policy by 2020



EU RES electricity production



Why SHP? (>10 MW)

- Generates 41 000 GWh of electricity and account to over 13 000 MW of installed capacity => enough to supply electricity for over 12 million households in Europe => reduces GHG emissions by 29,000,000 tons annually (41,400 GWh/ year x 700 tonnes/GWh)
- Provides back-up for grid increased volume of intermittent RE technologies
- Enables the use of local energy sources which increases local security of energy supply meaning shorter transport distances with reduced energy transmission losses & creates income sources and jobs
- Increased role with CC adaptation: Tool for flood prevention and control, irrigation needs

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High energy pay-back ratio

**ratio of the quantity of energy produced by an installation during its lifetime and the energy required manufacturing the installation, its operation and disposal including secondary energy.*

Plant	Yield factor
Small hydro	*80-100*
Large hydro	*100-200*
PV	*3-5*
Solar (thermal)	*20-50*
Wind	*10-30*

CONFLICTS?

WFD-2000/60/EC	**RED2009/28/EC**
⇩	⇩
RBMPs	**NREAPs**
⇩	⇩
Quality targets: Water	**20-20-20 targets: Energy**

⇩ ⇩

Hydropower?

WFD: Designation of HMWB

Ecological status

HMWB

1. X %? loss of production
2. Y% increase in operation costs
3. Z% of ?

GEP

WB

1. X %? loss of production
2. Y% increase in operation costs
3. Z% of ?

GES

Better environmental options?

- Replacement by other renewable energy (national level)
  - Difficult with another RES with the same characteristics (continuity, predictability, storage, etc)
- Replacement of peak load production/ ancillary services /security of electricity supply by other renewable energy
  - Which other RES?

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Expected impacts of the implementation of WFD

- Reduction of energy production due to increase of reserved flow (1%-2%-5%-10%-20%...?)
- Reduction of energy production due to sediment management (0%-1%...?)
- Increase in investment and operation costs due to new fish passages (0,1-1 M€?)
- Restriction in the water level management of storage basins (reduction in value of energy produced)
- Increase in investment and operation costs due to river restoration measures
- Closing down of some sites, impacts of water pricing

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Two 'real life' cases: I Poland

- Poland: "Moratorium on SHPs" - open letter to the Minister of the Environment insisting on imposing moratorium on building SHPs in Poland and withdrawal of the permits given before
- Justification: SHPs cause damage to rivers without substantial energy production
- Media, press & demonstrations
- Ministry: Plan of action to enable changing the law in order to forbid building any new weirs – only existing power plants & already approved permits will be checked

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Two 'real life' cases: II Slovenia

- New decree on ecological flow - Nov 2009
- Every water right has to apply new flow in 5 years time
- Will result to 30-60 % losses in production

  => Not profitable to build new SHP plants

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Minimum ecological flow

- European standards difficult due to large variability and individuality of rivers (even difficult at national level)
- However, some minimum performance standards can be set but site-specific analysis should be carried out
- Any regulation should respect both ecological and economic criteria
- For new plants easier as if a preliminary value of reserved flow is fixed the investor will take it into account in the design of the plant – with old plants loss of production can be more than proportion to the new minimum flow as the turbine has to operate for longer time away from its optimal design operation at reduced efficiency

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Sediment transport

- Closely related to storage basin and thus not relevant for SHP – however need for water storage will increase due to CC also with SHPs (main need not for hydropower but for water supply)
- The rule is to keep the sediment transport along the river as natural as possible – this needs to be taken into account in design for new plants and means:
  i) Additional cost for suitable for suitable sediment managment devices
  ii) Higher operation costs due to sediment management
- For existing plants likely that significant changes needed resulting to considerable extra costs

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Hydropeaking

- Very few SHPs operate under hydropeaking conditions
- Minimum performance standards can be set with impact on

  i) loss of income due to loss of production during peak hours when the value of energy produced is higher

  ii) if energy during peak hour is not produced by hydropower and the energy demand remains at same level – this amount of energy has to be produced by another source, typically gas turbines => environmental impact at global level in terms of CO_2

EEA ETC/ACC small-scale hydropower workshop- 27 November 2009, Brussels

Some SHP win win solutions

- New very/low-head small hydropower schemes
- Multi-purpose schemes: electricity production combined with flood control, irrigation channels, waste water treatment and recreational use
- Repowering and upgrading of existing sites (30TWh)
- Development of storage facilities to revalue other RES such as wind and solar
- Innovative methods of taking advantage of using energy from existing sites, for example using reserved flow for electricity production
- New innovations such as infrared fish fence, eel-friendly turbines

EEA ETC/ACC small-scale hydropower workshop- 27 November 2009, Brussels

Conclusions

- Possible regulations regarding minimum flow, hydro-peaking, sediment transport etc need to respect both ecological and economical criteria
- No harmonised approach in WFD implementation in EU-27 & SHP being very site specific makes it difficult to create European standards
- Some measures will be likely due to CC even if ‘against’ WFD principles
- Need for further R&D investment to further improve environmental integration

EEA ETC/ACC small-scale hydropower workshop- 27 November 2009, Brussels

Some conclusions

- Need for measures to streamline administrative & licensing procedures & public awareness & acceptance at local level
- In the end political decision – also future water resources may play significant role
- Balancing the targets of the RES Directive and WFD remains a critical objective for the sector
- Key challenges of hydropower relate to both economics and ecology. SHP can be successfully developed as long as produces electricity at competitive prices and under conditions that respect the environment

EEA ETC/ACC small-scale hydropower workshop- 27 November 2009, Brussels

Thank you!

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EEA ETC/ACC small-scale hydropower workshop- 27 November 2009, Brussels

Catherine Wright, Environment Agency, England and Wales

Hydropower
The Regulators View

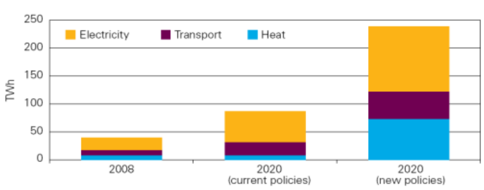
Catherine Wright
Head of Water Resources Management
Environment Agency, England and Wales

27 November 2009 - EEA Workshop

Introduction

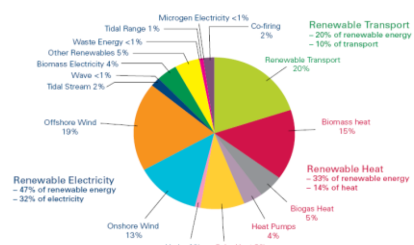
- UK context for renewables
- Our role as a regulator
- Good Practice Guidelines
- Further work

UK Renewable Energy Strategy



Source: Energy Trends June 2009 and DECC internal analysis

Hydropower's contribution



Our position

- Climate change mitigation is a key priority for the Environment Agency
- New corporate strategy commits us to enabling the deployment of sustainable low carbon energy

Our role as regulator

- Protect and improve the environment
  - WFD - good ecological status
  - Protection and improvement of fisheries
- Sustainable management of water resources
- Manage flood risk
- Good Practice Guide sets out requirements for hydropower schemes

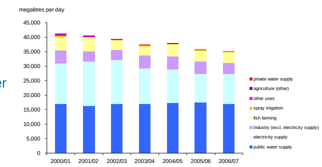
Catherine Wright, Environment Agency,
England and Wales

Managing environmental impacts

- Location
  - environmental sensitivity
  - flood risk

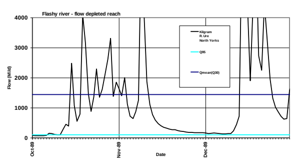
Managing environmental impacts

- Location
  - environmental sensitivity
  - flood risk
- Volume
  - local impact including other abstractors



Managing environmental impacts

- Location
  - environmental sensitivity
  - flood risk
- Volume
  - local impact including other abstractors
- Residual flows
  - deprived reaches
  - flow measurement



Managing environmental impacts

- Location
  - environmental sensitivity
  - flood risk
- Volume
  - local impact including other abstractors
- Residual flows
  - deprived reaches
  - flow measurement
- Ecology & fish
  - Turbines, screens, fish passes
  - Weir pools

Environmental check lists

tick box		A Water Resources Checklist	Note No.
YES	NO		
		Is the scheme non-consumptive i.e. will 100% of any water abstracted be returned to the water course from which it was taken?	1
		Is the scheme being built on existing infrastructure?	2
		Will the turbine be placed directly within the weir / water course rather than in a separate channel?	3
		Is there a flow-depleted channel?	4
		Is there a flow-depleted weir?	4
		Is it intended to increase the height of the impoundment?	8
		Do surveys reveal any existing abstractions, including unlicensed ones, which will be derogated by the proposal? (1)	5
		Is there an Environment Agency gauging station in the depleted reach or nearby that is likely to be affected by the scheme?	6
		Will the developer accept derogation consent within the proposed licence?	7

Hydropower scheme design

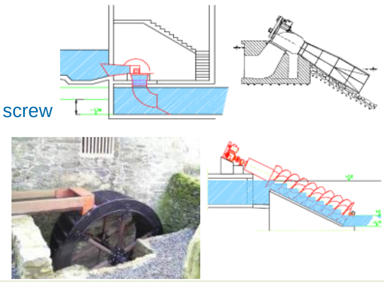
Preferred approach

- No depleted reach
- 'turbine in weir'
- fish pass required on migratory rivers – may be required on others
- fish friendliness of turbine will determine screen requirements

Catherine Wright, Environment Agency,
England and Wales

Turbines – how fish friendly?

- Crossflow
- Francis
- Kaplan
- Archimedean screw
- Waterwheel



Fish Screening

TURBINE TYPE	SCREEN REQUIREMENTS	
Water wheel Archimedes screw	Trash screen As appropriate (100mm)	
Kaplan & Francis turbines ≥ 1.5 m3/secs. &open flume Francis	Default 10mm screen - North-East, North-West, Wales, Southwest (devon/Cornwall) 12.5mm screen – Midlands, Anglian, Southern, Thames, Southwest (Wessex)	For large turbines A Risk Assessment for screen design may be undertaken in accordance with the Environment Agency GPG on screening
Kaplan & Francis ≤ 1.5 m3/secs., & Crossflow	Default 6mm screen - Recommended during period where young of year fry present in summer months otherwise 10/12.5mm as above	Work required on effectiveness of 10mm screens
Pelton	Drop through Coanda screens 3mm	

What else are we doing?

- Better regulation for hydropower
- Developing our evidence
- 'Win-win' hydropower opportunities
- Industry standards for hydropower developers

Better Regulation

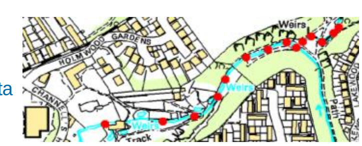
- Using GPG to assess permits, train staff, raise awareness
- Provide a point of contact
- Arrange a meeting, identify issues, site visit
- Review of permitting arrangements by October 2010

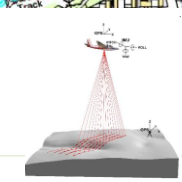
Improving our evidence

- Impact of flow & screening on fish
- Funding for community schemes
- Mapping hydropower opportunities

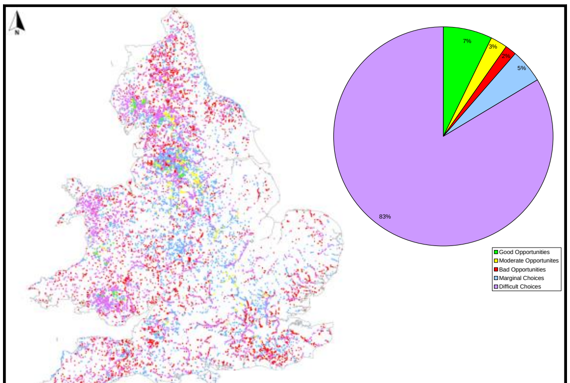
Mapping hydropower opportunities

- Identify barriers
- Assess height data & flow
- Sensitivity rating based on fish species present





Catherine Wright, Environment Agency,
England and Wales



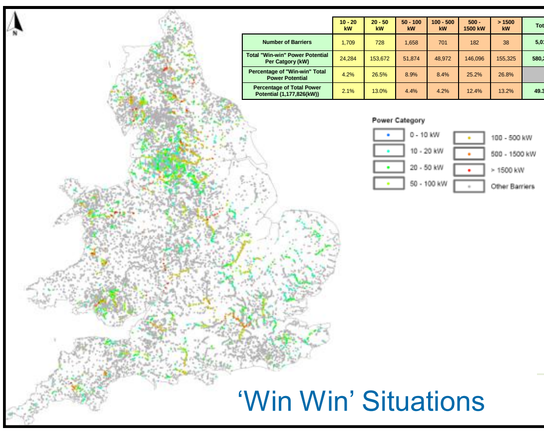
Opportunities in England & Wales

'Win-Win'

- The Water Framework Directive classifies some water bodies as Heavily Modified
- They have been identified as being at significant risk of failing to achieve good ecological status because of modifications to their hydromorphological characteristics
- There is potential for the creation of a hydropower barrier to be beneficial to the passage of fish upstream
- These are categorised as 'Win Win' situations

Environment Agency

	10 - 20 kW	20 - 50 kW	50 - 100 kW	100 - 500 kW	500 - 1500 kW	> 1500 kW	Total
Number of Barriers	1,709	728	1,658	701	182	38	**5,016**
Total "Win-win" Power Potential Per Catgory (kW)	24,284	153,672	51,874	48,972	146,096	155,325	**580,222**
Percentage of "Win-win" Total Power Potential	4.2%	26.5%	8.9%	8.4%	25.2%	26.8%	
Percentage of Total Power Potential (1,177,826(kW))	2.1%	13.0%	4.4%	4.2%	12.4%	13.2%	**49.3%**



'Win Win' Situations

Industry standards

- To qualify for Feed-In Tariffs
- Government certification scheme for hydropower developers

MCS
The Certification Mark for Onsite Sustainable Energy Technologies

*http://air-climate.eionet.europa.eu/reports/ETCACC_TP_2008_16_pots_ren_energy_techn

Environment Agency

Conclusions

- We are committed to enabling sustainable hydropower development
- Environmental impacts need to be managed and legislative requirements met
- Our approach must be based on good evidence

For more information:
http://www.environment-agency.gov.uk/business/topics/water/32022.aspx

Environment Agency

A 'win-win' for the environment?

Environment Agency

Giulio Conte, Ambiente Italia, Manager of CH2OICE project

CH2OICE
Certification for Hydro: Improving Clean Energy

The "Green Hydro" approach – does this provide the answer to defining good practice?

Giulio Conte

Bruxelles, November 27th 2009

Intelligent Energy Europe

Sustainable hydropower throughout Europe

conflicting objectives

Increasing the production of renewable energy (often including hydropower) is a must to reduce CO_2 emissions

Reducing river flow alteration and other hydromorphological pressures is a must to improve river ecosystems

Certification for Hydro: Improving Clean Energy

what alternatives?

1) BaU "command and control" strategy:
- Power companies try to keep on producing as usual and to build new hydro plants to exploit maximum potential
- Public bodies force them to reduce their impacts on river ecosystems in existing and new plants with different kinds of constraints (e.g.: ecological flows)

- Results: lawsuits, conflicts with NGOs, poor effectiveness in reducing impacts of existing plants, excess of caution in licensing new plants

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what alternatives?

2) Involvement of producers on a voluntary basis:
- Power companies try to reduce their impacts, innovate technologies and improve management of existing plants to increase the value of their production; design new plants considering from the beginning environmental constraints and best management practices
- Public bodies monitor real improvement of river status, check reliability of labelling agencies, could use the "name, fame, shame", tool if needed

- Results: less conflicts; more efficiency and surplus value of more sustainable production can compensate for production constraints

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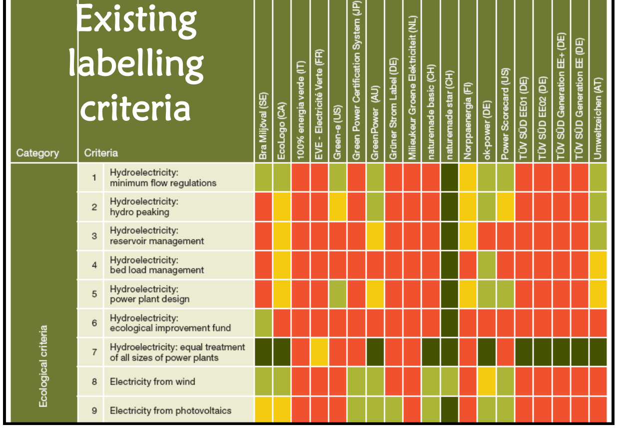
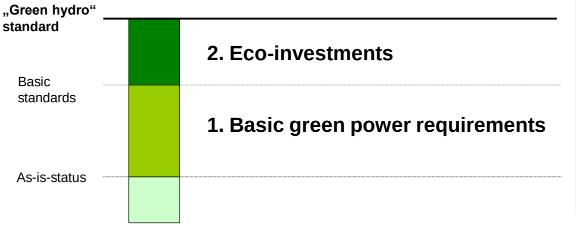
Sustainability Criteria – All Labels



Giulio Conte, Ambiente Italia, Manager of CH2OICE project

Greenhydro for Naturemade

Requirements for „greenhydro“



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Environmental management matrix

Environ-mental fields \ Management fields	Minimum flow	Hydro-peaking	Reservoir	Bed load	Plant structuring
Hydrologic character					
Connectivity within the river system					
Solid material and morphology					
Landscape and biotopes					
Biocoenoses					

For each field:
1. Goals
2. Criteria
3. Literature

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Greenhydro vs WFD

	greenhydro	WFD
mechanism	voluntary instrument	regulatory instrument
drivers	market incentives	legally binding
scope	power plant	river basin district

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Greenhydro fits with WFD

1 2 3 4 5 6 7 8 9 10 11 12 13

14 15 16 17 18 19 20 21 21 23 24 25 26

- Today: <u>9 (26) articles are relevant</u> for both WFD and *greenhydro* standard
- <u>*greenhydro* standard meets relevant WFD criteria</u> for river systems impacted by hydropower
- in some cases <u>*greenhydro* criteria exceed WFD</u> requirements

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Not matching criteria

- Greenhydro: sediments, bedload balance
- WFD: phytoplancton, macrophythes, specific pollutants (hazardous compounds)

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Giulio Conte, Ambiente Italia, Manager of CH2OICE project

Sustainability criteria for CH_2OICE certification

partners

Italy: Ambiente Italia, Centro Italiano per la Riqualificazione Fluviale (CIRF), WWF Italia, Associazione Produttori Energia da Fonti Rinnovabili (APER), Studio Frosio

Slovenia: LIMNOS Company for applied ecology Ltd., Holding Slovenske Elektrarne d.o.o., Institute for the Promotion of Environmental Protection, Slovenian Small Hydropower Association

Belgium: European Small Hydropower Association (ESHA)

France: Comité de Liaison Énergies Renouvelables (CLER)

Spain: Universidad Politécnica de Madrid

Slovakia: Regional Environmental Center for Central and Eastern Europe

Certification for Hydro: Improving Clean Energy

matching energy and river quality

CH_2OICE Project is developing a **certification procedure** for hydro power generation facilities of **higher environmental standard**, (through a methodology explicitly coherent with the requirements of the Water Framework Directive, including **biological and hydromorphological** technical criteria and **public participation**);

Energy produced by certificated plants could be embodied in "top quality" energy products for environmentally demanding markets (together with other high standard renewable energies) guaranteed through **existing or new "green energy" labels**

The **general procedure** is ready: country specific more detailed methods have been developed for **Italy and Slovenia** and will be tested in a few sites in the next months

Certification for Hydro: Improving Clean Energy

basic characteristics

1. coherent with WFD criteria
2. not based on general prescriptions/good practices, but site-specific and strictly connected to the effective impact on river ecosystems
3. mitigation/compensation measures have to be included in a management program for the plant and undergo monitoring
4. involvement of local stakeholders
5. simplified procedures for some plant categories

Certification for Hydro: Improving Clean Energy

basic characteristics

1. coherent with WFD criteria

BUT: it is not a "fulfillment certification" with respect to Dir 2000/60/EC !

It is a voluntary label allowing the final consumer to recognize hydro production with lowest impact on aquatic ecosystems (due to site and management practices)

Obviously voluntary objectives cannot be lower than those of the WFD (legal obligation)

Certification for Hydro: Improving Clean Energy

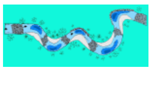
basic characteristics

1. coherent with WFD criteria

WATER QUALITY

BIOLOGICAL ELEMENTS

HYDRO-MORPHOLOGY



Certification for Hydro: Improving Clean Energy

basic characteristics

2. not based on general prescriptions/good practices, but site-specific and strictly connected to the effective impact on fluvial ecosystems

#

Certification for Hydro: Improving Clean Energy

basic characteristics

3. mitigation/compensation measures have to be included in a management program for the plant and undergo monitoring

- for each structural/management variable having significant impact necessary mitigation measures have to be identified
- possibile compensation measures, to restore the impacted stretch

Certification for Hydro: Improving Clean Energy

basic characteristics

4. involving local stakeholders

- to include in preliminary study and management programme all significant elements (often known by local actors)
- to reduce conflicts

I pescatori dicono "basta" «Non può sempre essere l'ambiente a fame le spese, certi episodi non devono passare in sordina»

Moria di pesci a Cadarese: «Le cause da chiarire»

Roberto Cutaia

Certification for Hydro: Improving Clean Energy

basic characteristics

5. simplified procedures for some plant categories

Es.: HPPs in totally artificial structures (aqueducts, treatment plants, etc)

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methodology

Environmental criteria

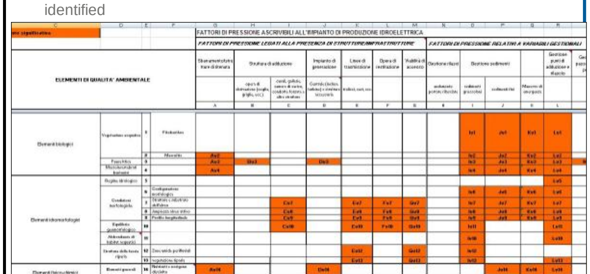
Biological elements	Fitobenthos
	Macrophite
	Fish fauna
	Zoobenthos
Hydromorphological elements	Flow regime
	Morphological status
	Morphological equilibrium
	Aquatic habitats
	Riparian vegetation structure
Chemical quality	Main pollutants
	Specific pollutants
Other impacts on biodiversity	Terrestrial habitat
	Bird fauna

Certification for Hydro: Improving Clean Energy

methodology

Analysis of environmental status and pressures

- all relevant environmental aspects and pressures; The cause-effect relationship between them; Best practice and mitigation mesures have been identified



methodology

Analysis of environmental status and pressures

Identification of significant aspects

	outflow	*hydropeaking*	*Bedload management*	*Fine sedim. management*	*Fish pass management*
Fitobenthos	**Objectives already reached**				
Macropfite		Low impact	Low impact	Low impact	Low impact
Fish fauna		To be mitigated	To be mitigated	To be mitigated	Low impact
Zoo benthos		To be mitigated	To be mitigated	Low impact	
Water quality	**Objectives already reached**				
Hydromorphology	Low impact	Low impact	To be mitigated	Low impact	

First ideas about hydro potential compatible with WFD

What will happen to hydropower?

Reduction of impacts that require less power generation

- all impacts that require increasing of minimum flow or more "natural" flow pattern in the revier (to reduce impacts on biological elements and water quality)
- morphological impacts that require some management of the dam/weir which implies a reduction of usable flow

Certification for Hydro: Improving Clean Energy

What will happen to hydropower?

Impacts reduction that may affect economic benefits without losing power production

- Impact of Hydropeaking could be reduced without losing power (even though it would imply economic loss)
- Al impacts that could be mitigated improving the system (improving fish pass, tools to reduce biological impact of turbines, etc.)

Certification for Hydro: Improving Clean Energy

What will happen to hydropower?

Unexploited potential?

- Artificial water bodies
- Heavily modified Water Bodies: not always Good Ecological Potential is affected by Hydropower

Certification for Hydro: Improving Clean Energy

CH2OICE

Certification for Hydro: Improving Clean Energy

To know more about CH_2OICE

www.ch2oice.eu

Intelligent Energy Europe

Development of SHP Potential Resource

James Craig AEA

European Topic Centre on Air and Climate Change

Objective

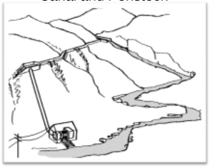
- To develop a methodology which can be used to estimate a the SHP Technical Potential – initially for a single catchment.
- To apply constraints that represent the Environmentally Compatible Potential.
- Apply further constraints that represent the Realisable Potential.
- Methodology designed so that it can be applied across EU 27

Methodology to develop a Technical Potential – 1

- Technical Potential – SHP resource that takes into account technological, physical and practical constraints including residual flow.
- Methodology is designed to build a resource profile from a series of individual sites to give realistic representation.
- SHP defined by vertical head and flow – arbitrary vertical head bands (<10m, 10m-100m, >100m)

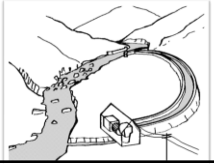
SHP configurations

Canal and Penstock

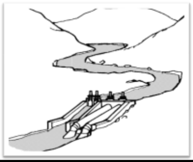


Penstock Only

Mill Leat



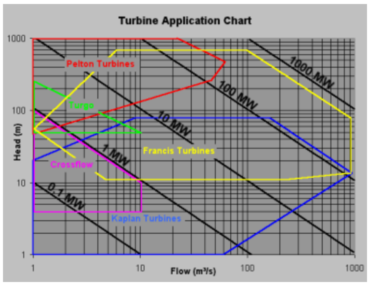
Weir or Dam

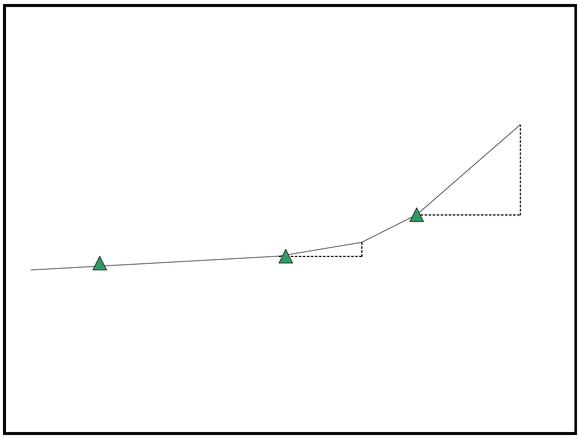


Methodology to develop a Technical Potential - 2

- For each river entire slope profile is digitised.
- Distance between abstraction point and power house needs to be selected. For low head sites (<10m) this might be 100m, but 1-2 km for the other two bands. Low head sites assumed to be on existing weirs/dams.
- Arbituary separation distance needs to be applied for high head sites.

Turbine selection



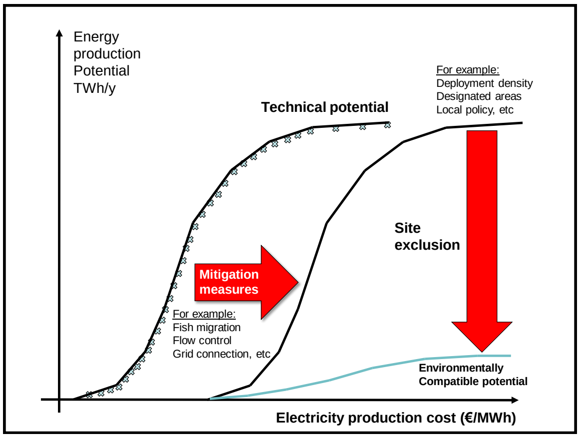


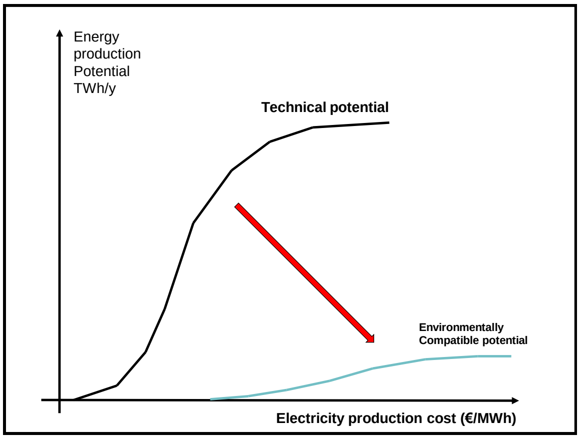
Methodology to develop a Technical Potential - 3

- Parametric methodology used to estimate capital cost of low (<10m), medium (10 – 100m) & high head (>100m) depending on turbine type.
- Estimate hydropower resource based on Flow Duration Curve – ideally at each site.
- Compile annual energy output and cost for each site to produce Resource-Cost Curve.

Methodology to develop a Environmentally Compatible Potential

- SHP needs to take account of increased capital costs e.g. fish passes
- Reduced or restricted abstraction – lower energy output.
- Increased running costs
- Complete exclusion from restricted zones





Workshop Discussion: Quantifying Impacts

European Topic Centre on Air and Climate Change

Objectives for the Workshop

- To define the Environmentally Compatible Resource by quantifying the impacts of key environmental criteria. In each case the workshop is asked to consider the cost of mitigation to meet "Green Hydro" standards, and compliance with the WFD, or the impact on resource.
- SHP $\leq$ 10 MW installed – existing and impact of future development

Topics for the Workshop

- Flow regime / riverine environment
- Fish passage and protection
- Designated areas
- River Classification
- Cumulative Impacts
- Good Practice
- Future SHP Development

Flow regime / riverine environment

- Residual flow of Q95 a minimum & always maintained? (High head schemes may have depleted sections of 100ms – km).
- Flow regime in depleted stretch ideally matches pre-existing natural flow regime.
- Weirpool levels must not fluctuate widely.
- Abstraction is continuously monitored – intervention must always meet licence requirements.
- Good Design – limit flow regime especially on low head sites.

Flow regime / riverine environment

- Estimating the direct impact of SHP on a rivers ecosystem & adjacent environment / landscape.
- Who monitors & how do you attribute changes caused by SHP?
- Abstraction must take account of Catchment Management Plans including future changes – how are water resources balanced?
- Sediment Management – should this apply to SHP with storage?

Fish Passage and Protection

- Should all SHP plant allow fish to migrate unimpeded?
- Where migratory species exist SHP operator must always maintain uninterrupted flow?
- Design SHP so that fish are directed away from tail race and intake.
- Fish lifts, ramps, locks &/or deterrence systems – how effective are these?
- Cumulative impacts – is SHP development constrained?

Designated Areas / Classification

- Should SHP be excluded from designated areas e.g. Natura 2000 sites, national parks etc for the purpose of estimating the SHP resource?
- Can rivers be classified into "suitable", "less favourable" or "non-favourable". Does non-favourable mean complete exclusion?
- If a natural river regime is applied, e.g./ "Espace de Liberté" – does this mean complete exclusion?

Cumulative Impacts

- Is it possible to define a reasonable limit for deployment density?
- If Catchment Management Plans incorporate WFD regulations will future SHP development be restricted?

Good Practice for SHP

- Can Good Practice guidelines for SHP be widely adopted across EU.
- Surveillance / operational monitoring – should this be part of impact assessment & what is the cost?
- Re-certification after 5 years – what are requirements for mitigation & evidence of implementation.
- Should all new SHP comply with "Green Hydro" standards?

Development of new SHP

- Is it reasonable for new SHP to proceed within a single catchment area only if existing plants are removed?
- If SHP is already located in a sensitive area should it be removed and how should the operator be compensated?

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