A methodology to quantify the environmentally compatible potentials of selected renewable energy technologies

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Front page picture: *Llyn Brianne 4.6MW_e hydropower plant in Wales © S Dagnall*

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Executive summary

This final report is submitted to the European Environment Agency in fulfilment of Task 2.4.2 – Renewable Energy of the EEA European Topic Centre on Air and Climate Change 2008 Work plan. The work was performed by AEA Technology with guidance from Hans Eerens of the Netherlands Environmental Assessment Agency (PBL) and Ayla Uslu of the European Environment Agency.

This project set out with the aim of defining the European Union's "environmentally compatible potential" for a number of renewable energy technologies. A preliminary project in 2007 sought to define what is meant by "environmentally compatible potential" and reviewed the environmental impacts from a range of electricity and heat producing renewable energy technologies. The current report reassesses the definition and proposes a more rigorous methodology for calculating potentials. It also demonstrates how the methodology can be applied to small-scale hydropower. It then goes on to provide a more in-depth review of methodologies used to assess hydropower potential, and the extent to which environmental constraints are accounted for. The effect of the Water Framework Directive is examined and the emergence of schemes that certify the environmental sustainability of hydropower discussed.

The ultimate purpose of estimating resource potentials is to provide a realistic picture of the contribution that renewable energy can make to future EU energy demand. To do that requires a common approach across different resources and a common approach to data collection across the EU. Modelling the contribution is undertaken as part of the Commission's Green-X project, which bases its 2020 projections on "realisable potentials", a measure of the resource that should be available for deployment in 2020. However the realisable potential is not the same as the environmentally compatible potential, as the latter does not take into account the social impacts of increasing deployment. Experience shows that technologies like wind energy can reach a saturation point beyond which further deployment no longer has public support. We believe therefore that any methodology should encompass all of the key factors that can constrain renewables deployment.

Our proposed methodology therefore defines four potentials and seventeen factors that should be taken into account. The *technical potential* is the highest level, based on overall resource availability, man's ability to extract energy from it and the maximum likely deployment density. It assumes a maximum exploitation cost beyond which deployment is unlikely to take place. By taking into account any limitations imposed by legal provisions such as geographical designations, legislation and regulations one can specify the *environmentally compliant potential*. The next step is to define environmental good practice in deployment and assume that only resource that can meet that standard makes up the *environmentally compatible potential*. Finally this is further constrained to take into account social and other factors, to give the *realisable potential*.

This systematic methodology provides a rigorous way of calculating the realistically available potentials across all renewables. It requires a series of assumptions to be made about: the economic cut-off figure to apply; the maximum deployment densities to apply for the purpose of estimating the technical and realisable potentials; the acceptability of deployment in legally designated areas; the impacts of legal constraints (directives, regulation, etc); what constitutes "environmental good practice" and the impact of applying any mitigation measures required. We believe that industry trade associations should initiate the process of specifying the various assumptions, in consultation with regulatory bodies and other relevant stakeholders. Once the assumptions have been agreed for all the main technologies, it would be highly worthwhile to reassess the EU potentials, drawing on expertise (and interpretation) at a national level.

Following consideration of the interim report, it was decided to take a deeper look at the position for hydropower. This is an interesting example, due to the potential for conflict between two clear EU objectives: the goal to treble the contribution from renewable energy by 2020 and the goal to improve the environmental quality of Europe's water bodies as prescribed by the Water Framework Directive. There is no established methodology for quantifying hydropower potential and a wide variety of approaches have been used. Where environmental constraints are taken into account, it is mainly through the exclusion of certain categories of designated land. A computer based procedure developed in the US is conceptually similar to that proposed in this report, however it would require technical potentials for hydropower to be available on a common EU-wide basis.

The influence of the Water Framework Directive on hydropower operation and future potential is discussed and the evidence indicates that the directive could have a significant impact on these and on the cost of hydropower relative to other electricity options. Considerably more work needs to be done to quantify the impact on a national/regional level.

Finally the emergence of schemes to certify the environmental sustainability of hydropower projects is assessed. Whilst these will add to the cost of hydropower, they should allow the kind of criteria stipulated by the Water Framework Directive to be incorporated and thereby provide a structured basis for hydropower to go forward.

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1 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 should be seen in the context of the recently published proposal for a directive requiring the European Union to obtain 20% of its final energy demand from renewable energy sources by 2020[1]. Renewable energy can be derived from a diverse set of resources and technologies, supplying energy across the full range of energy markets at potentially hugely different scales. Whilst renewables are generally seen as one of the main ways of reducing the EU's dependence on fossil fuels, thereby limiting the associated emission of greenhouse gases, there is no doubt that individual renewable energy technologies have their own environmental impacts, usually at a more local level. If renewables are going to achieve their potential deployment, this must be done without causing unacceptable harm to the environment.

The task of defining their environmentally compatible potential is therefore a very important one, as well as a very challenging one. The field is still in its relative infancy and there is no accepted definition of what constitutes an environmentally compatible potential. Indeed there are no internationally accepted definitions for measuring renewable energy resource potentials in general. The challenge is therefore to carefully assess the data that exist and consider what factors need to be taken into account to decide the share that can be described as "environmentally compatible".

This too is difficult, as environmental "compatibility" can be a very subjective concept. Whilst there may be environmental constraints that absolutely preclude the exploitation of a resource, maybe in a particular location, many other constraints are based on the value judgements of people. For a field as new as renewable energy, there are often few precedents on which to base policy. In addition peoples' views can change with time and are far from uniform across society, or geographically. It is necessary to differentiate between resource that is "environmentally compatible" and that which is "socially compatible" though, in reality, the two constraints are often closely interlinked.

One of the challenges is to ensure a common approach across different renewable energy resources. In 2006 the EEA published a report "How much bioenergy can Europe produce without harming the environment?"[2] (EEA Report No 7/2006). A further report focusing on agriculture (No 12/2007) was published by the EEA in 2007. The ETC/ACC has also been undertaking a detailed assessment of the environmentally compatible potential for wind energy – this work is nearing completion.

Recognising that other renewable energy resources are also likely to make significant contributions to energy supplies in 2020 and beyond, a task was initiated in 2007 to assess their "environmental compatibility". The environmental/social impacts of these technologies were reviewed and a qualitative assessment made of the constraints these impacts are likely to impose on deployment. An attempt was made to define "environmentally compatible potential" and it was concluded that, for some technologies (like hydropower and tidal energy), environmental constraints were likely to be significant while for others (like solar energy and ground source heat pumps) the constraints were likely to be relatively small. The present report provides an updated definition.

The wider context for this work is the modelling that the European Commission is undertaking to underpin the renewables deployment estimates for 2020 and beyond. These have been based primarily on the Green-X model, managed by the Energy Economics Group at the Vienna University of Technology[3]. This model draws on the current "achieved potential" (based on the current level of deployment) and adds to that the "additional realisable mid-term potential" (the extra capacity that can be deployed by 2020 if all existing barriers can be overcome and all driving forces are active). The sum of these two is called the "realisable potential" and must refer to a particular year.

[1] The directive reached political agreement on xx December 2008; its text is available at
[2] EEA Report No 7/2006, ISSN 1725-9177, available from http://reports.eea.europa.eu/eea_report_2006_7/en/eea_report_7_2006.pdf
[3] The report "Potentials and cost for renewable electricity in Europe - The Green-X database on dynamic cost-resource curves", published February 2006 is available from http://www.optres.fhg.de/results/Potentials%20and%20cost%20for%20RES-E%20in%20Europe%20(OPTRES%20-%20D4).pdf

2 The current study

The purpose of the current study is to take the qualitative approach mentioned above for the "other renewables" one step further, by quantifying the impact that environmental constraints may have on the EU's technical potentials for these. The resources/technologies that are worthy of consideration include the following:

- Large-scale hydropower
- Small-scale hydropower
- Geothermal electricity
- Photovoltaics
- Solar thermal electricity
- Tidal power
- Wave power
- Solar thermal
- Geothermal heat

The starting point for a quantitative assessment is the potentials that have been used so far in the Green-X modelling. However it is important to note that it is often unclear to what extent environmental and social factors have already been taken into account for these. The data that have fed into Green-X have come from a wide range of sources and they are not based on a systematic set of resource definitions.

The current study approaches the challenge of defining the EU's "environmentally compatible potential" for the above renewables in two stages:

Stage 1: Derive a set of clear definitions for resource assessment, with the objective of taking the high-level (or technical) potential and narrowing it down to a realisable potential (in 2020 or 2030) as adopted in the Green-X modelling. To further establish a set of principles or guidelines that can be used to account for the environmental and social constraints on the achievement of that potential, i.e. what are the factors that will limit deployment in practice? Whilst it may be possible to derive some generic guidelines that apply across all technologies, the key will be to consider how these should be interpreted for individual technologies. This will then allow a more quantitative approach to be used on a technology by technology basis.

Stage 2: Apply the approach developed in Stage 1 quantitatively to a number of individual technologies. The extent to which this can be done will depend principally on the availability of source information. However the important thing is to establish a clear methodology that can be replicated more widely.

An interim draft of this report was produced in June 2008 for discussion at the Eionet meeting on 3 & 4 July 2008 (the interim report was essentially sections 3 to 5 of this report). This developed the generic principles for Stage 1 and applied these on a pilot basis to small-scale hydro. Following consideration of the draft by the European Environment Agency, it was agreed to focus efforts on hydropower (both large and small-scale). Section 6 therefore presents the outcome of a literature review to determine what methodologies have been used worldwide to assess hydropower potential and the extent to which they explicitly take into account environmental constraints (and how).

Hydro is a very interesting case, partly because it is already subject to widespread deployment worldwide, but largely because its environmental impacts have become a source of significant concern and opposition in recent years, thereby limiting the potential for further expansion in EU countries. Moreover the EU's relatively new Water Framework Directive (2000/60/EC), which establishes a framework for the protection of all waters with the goal of achieving a "good status" of all Community waters by 2015, has an inevitable impact on hydro potential. Not only will it limit the deployment of some new hydro projects (both large and small-scale), it is also likely to have a constraining effect on the energy generation potential from existing hydro sites as environmental mitigation measures are implemented. Mitigation measures will add to the costs of electricity generation, further limiting the economic potential.

There is little reliable information from which to quantify the magnitude of the impact, however increasing concern has been expressed by the hydropower industry. There is a need to get a better understanding of the impact, in order to provide those responsible for developing and implementing energy and environmental policy with a better basis for reconciling the need to maximise the use of a significant renewable energy potential with the need to minimise the environmental impacts of such use.

3 Methodology

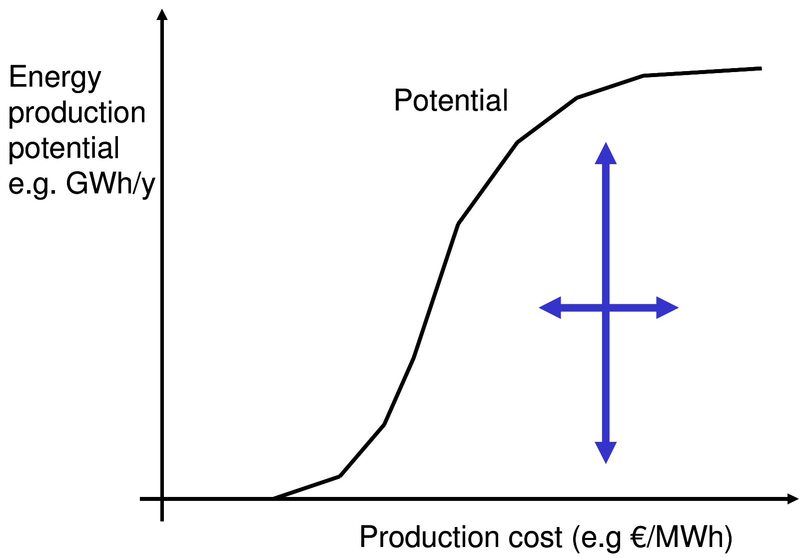
This section concentrates on the methodology for Stage 1, covering all the renewable energy technologies mentioned in Section 2. Whilst it is accepted that the focus of this project is on the "environmentally compatible potential", the need for the modelling to have the "realisable potential", and the need for clarity as to which factors influence which potential, have led us to include both areas below.

As previously stated, the quantification of realisable renewable energy potentials is a notoriously difficult task. There are many factors that will influence the deployment actually achieved in the future. Aside from the absolute availability of the given resource (e.g. the amount of solar energy falling on a given landmass per year) the following factors must be taken into account:

Economics: Energy from renewables must compete in the market place. Whilst a small number of renewables can do so without any intervention, in many cases they can only compete with the benefit of market incentives of various sorts. The most effective way of picturing the impact of cost on the amount of resource that is economically viable to deploy is through a resource cost curve, as shown in Figure 1 below. It demonstrates, for a given resource definition, the total energy production potential that would be economically viable (on the basis of defined criteria such as discount rate) as production cost increases.

Figure 1: Resource cost curve for a renewable energy resource

(sometimes called a production curve)



The arrows indicate that the curve can move in various directions depending on the constraints that are applied or removed. For example limitations imposed on the siting of plant (e.g. no hydro plant in national parks) will move the curve downwards; a requirement for a particular technology to adopt a certain impact mitigation (e.g. underground cabling to connect to the electricity network) will move the curve to the right. Such curves provide a very convenient way of visualising the impact of different resource definitions and constraints. They also provide an idea of the amount of additional resource that can be made available if market incentives are applied, as well as the total annual cost of those incentives. In the absence of a resource cost curve, one can still take into account economic factors by placing an arbitrary upper limit on the cost that the market is willing to bear, however this economic "cut-off" must be clearly stated.

Practical constraints: The generally diffuse nature of renewables means that well defined criteria must be used to ensure that resource estimates take into account the practical deployment of these technologies. For example the deployment of building integrated solar thermal is effectively limited by the total available roof area (though even that is subject to debate). In other cases renewables have to compete with other forms of land (or water) use and sometimes with each other. The key is for the underlying assumptions to be clearly stated so that the methodology is fully transparent. In general the high-level or "technical" potential is one that takes into account the main physical and practical limitations.

Environmental constraints: This is the focus of this study and these must therefore be defined with great care. If they are to be seen as separate from the social constraints then it is important to have objective criteria to apply to the technical potentials. For example certain land area may be restricted from development as a result of geographic designations (e.g. the Natura 2000 network of protected sites or national parks). Where there is a potential conflict between renewables deployment and other EU policies, a clear judgement must be made concerning the impact of these on the extent of deployment (the same can be true for national environmental protection legislation and regulations). Examples could include the impact of the Water Framework and Waste Incineration directives. There may be instances where adverse environmental impacts can be mitigated through the use of "end of pipe" technologies or other means. This can have an interesting effect on the resource cost curve, pushing it to the right (due to the increased cost of exploitation) but also increasing the resource available at higher exploitation costs (see later).

We propose to define the environmentally compatible potential in two steps. The first step is to exclude any resource that is unlikely to comply with legal provisions such as geographical designations or directives. We call this the **environmentally compliant potential**. Next we judge what share of that resource can be deployed within requirements for "**good practice**", taking into account impacts on eco-systems, impacts of any associated infrastructure (such as grid connection) and the potential to mitigate environmental impacts. This we propose is the **environmentally compatible potential**.

Whilst this definition may be sufficient for the purposes of defining environmental compatibility, it does not take into account a range of social and perceptual constraints that have great influence on the final "**realisable potential**":

Social constraints: This is where a wide range of more subjective constraints need to be taken into account and is therefore the most difficult area to account for quantitatively. Whilst renewables are often seen as a "good thing" in terms of their global environmental benefits, they can be met with fierce resistance locally when individual projects are put forward. Those responsible for strategic planning and the approval of projects at a local/regional/national level can be faced with very difficult decisions. The imposition of a "20% by 2020" binding target may provide the impetus and framework to accelerate deployment, however it may also stiffen the resolve of those opposed and lead to intensified conflict. The constraints that must be considered under this heading include:

Deployment density: Is there a saturation point at which support for further deployment declines or even disappears? To what extent does this vary regionally/nationally or with time? This will often be tied in with the cumulative effect of the other impacts that follow. The nature of renewables is such that increasing deployment will often be accompanied by the need to strengthen electricity grids, build new access roads, etc. It is possible that these, rather than the renewables projects themselves, are the focus of opposition.

Visual impact: This has come into sharpest focus with wind energy but is likely to affect many other renewables with time. Although a lesser issue, noise can also be a concern.

Competing land/water use: Deployment of renewables may preclude other forms of development, or impact on the amenity use of an area.

Cultural perceptions: Across Europe there is already evidence of major differences in the attitudes that local populations have had towards increasing renewables deployment. There may also be specific local factors that can have a major influence, such as politics, experience with specific projects or the actions of local groups (for or against).

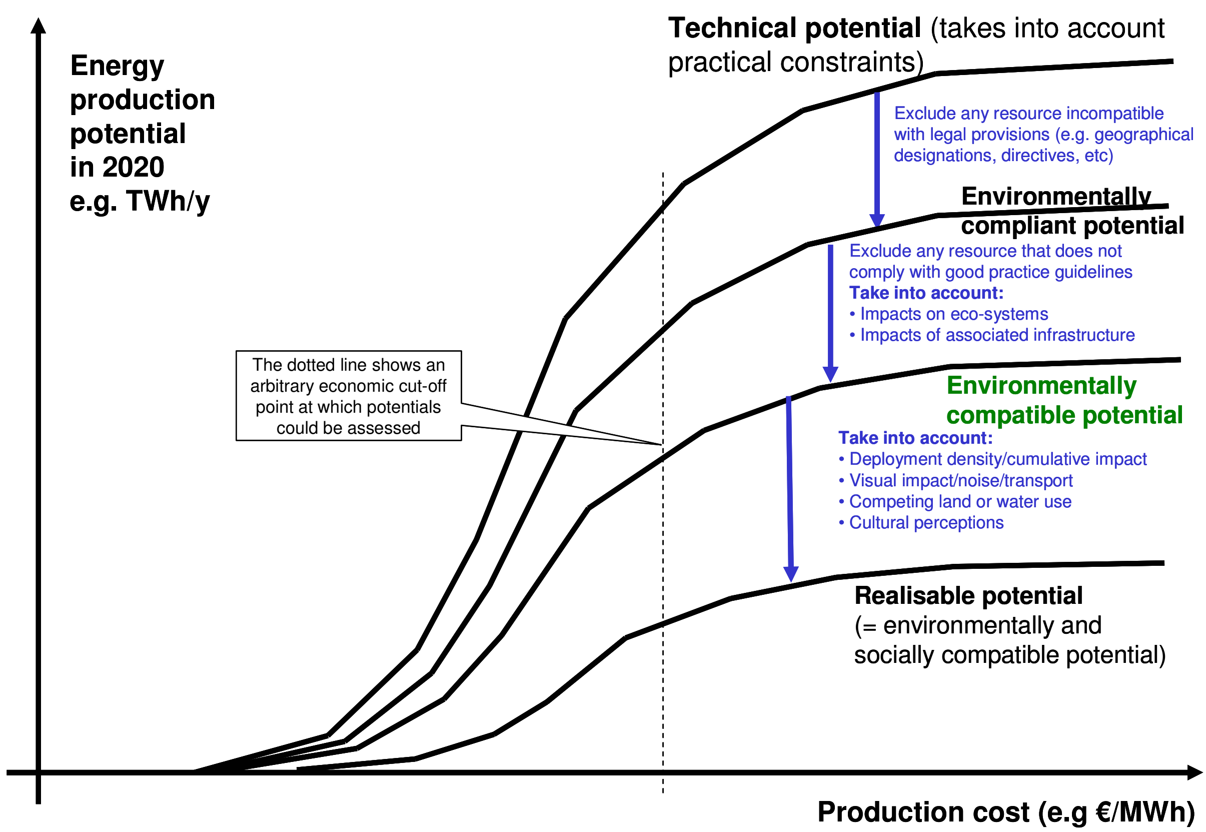
In general these various issues get played out either when strategic development plans are drafted or when specific renewables projects are proposed. Environmental impact assessment of proposed projects helps to clarify the issues and should facilitate the decisions, as should clear renewables planning guidance from central authorities. However one cannot escape the fact that many of the above factors are highly subjective, which means that decisions will never be clear cut. In particular the effect of cumulative impact is difficult to foresee.

The impact of these more subjective issues on realisable potentials is very difficult to quantify with any real confidence. The best that can be done is to develop a clear set of assumptions for individual technologies based on current trends and reasonable expectations of how these will develop. There should be strong support for local/regional planning authorities to do detailed assessments of the renewable energy resource in their area and produce clear guidance for developers. Such studies and policies can be used subsequently to calibrate the above assumptions.

3.1 Proposed methodology

From the point of view of projecting the realistically available renewable energy resource in 2020 or 2030 for modelling purposes, all of the above factors must be taken into account. In other words the "realisable potential" for 2020 as used in the Green-X modelling must take into account the practical, environmental and social constraints described above. This is shown in terms of the resource cost curves in Figure 2 below. The top level technical potential takes into account the basic practical constraints that should be imposed. The middle level "environmentally compliant" and "environmentally compatible" potentials take into account respectively, resource excluded by legal provisions (geographical designations and environmental legislation or regulations), and resource that fully complies with environmental good practice deployment guidelines. The bottom level "environmentally and socially compatible potential" (or realisable potential) takes into account all of the factors listed above and is the realistic estimate of what can be deployed by the stated year.

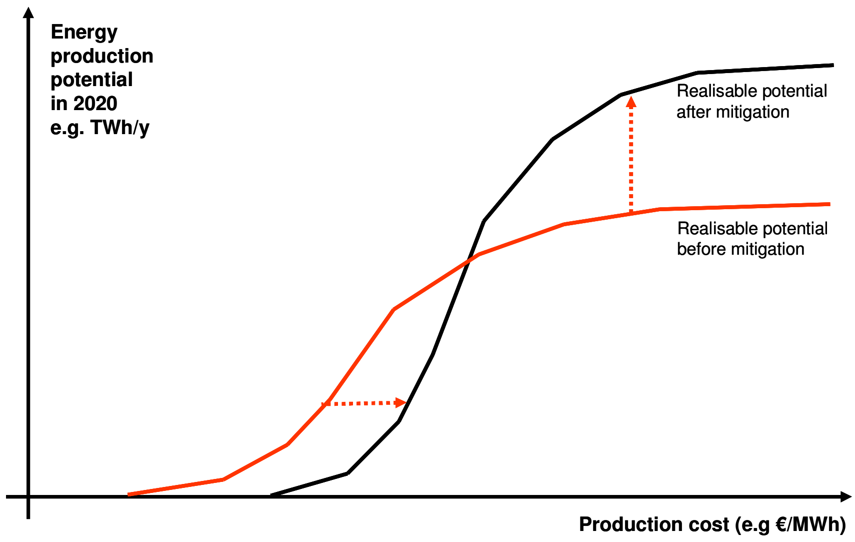
Figure 2: Constraints to take into account when calculating the realisable potential from the technical potential



The dotted line shows an arbitrary production cost which could provide the basis for specifying the economic cut-off; this would need to represent the maximum cost resource that is expected to be exploited in the given year (in the case above, 2020).

The resource cost curve is also a helpful way of showing how the realisable resource might be affected by the imposition of environmental mitigation measures (see Figure 3). The curve is pushed to the right, thereby reducing the potential at lower production costs. However the potential may also be increased due to the resulting increased acceptability (examples to visualise this could be the imposition of emissions control equipment on small-scale biomass boilers, or 'green hydro' criteria on small-scale hydro plant). For the policy making debate, this is very helpful information.

Figure 3: Impact on realisable potential of imposing mitigation measure



4 Resource definitions and potentials

This chapter provides a set of generic resource definitions and discusses the factors and constraints that need to be taken into account when applying these to specific renewable energy resources. The principle we propose is to start with the highest level potential and systematically apply a series of constraints that take into account the practical, environmental, social and economic factors that limit the deployment that can be realised in practice. As many of these factors change with time, it is important to quote the date associated with any quantitative estimates.

4.1 Generic resource definitions

Building on the approach described earlier, we propose the following generic definitions for renewable energy resource potentials. In all cases it is assumed that a defined economic upper limit applies such that any resource whose deployment cost falls above this limit will not be exploited.

Technical potential

The 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.

Environmentally compliant potential

This 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.

Environmentally compatible potential

This is the environmentally compliant potential, reduced to remove any resource whose deployment would not comply with good practice guidelines for that technology.

Realisable potential (or environmentally and socially compatible potential)

This is the environmentally compatible potential, factored down to take into account the share that is considered socially acceptable. Inherent in this is a value judgement concerning the maximum deployment density that is likely to be acceptable at a given point in time.

The next section examines the generic factors that should be taken into account when estimating the potentials against these definitions for individual technologies

4.2 Generic factors limiting the deployment of renewables

4.2.1 Introduction

The ultimate goal is to define the mid-term '**realisable potentials**', i.e. the maximum realistic potential that is available for deployment at a given future date, including existing deployment. These are the figures that matter from the perspective of modelling the contribution that renewables can realistically make in the future. It requires a similar approach to be adopted across all renewable energy technologies if the overall deployment potentials are to be meaningful.

Listed below are 17 potential constraints (or factors) that should be taken into account when estimating the potentials for individual resources. They are divided into the four resource headings introduced above. Chapter 5 then considers how these factors should be applied to small-scale hydropower.

Technical potential

1. Setting an upper cost limit

In general the deployment potentials are strongly influenced by economics, i.e. the maximum price that society is willing to pay for the energy. Ideally this can be taken into account through the use of resource cost curves, however the extensive data required to produce these are often not available. In their absence it is important to state clear economic assumptions that underlie any resource estimates, for example an economic cut-off point above which the resource is considered too expensive to exploit. This should be done at the outset and again requires a common approach to be adopted for all technologies.

2. Where can the technology be deployed? What are the physical/practical limitations?
Clear assumptions need to be specified as to how and where the technology could be implemented to achieve maximum deployment. This must take into account the obvious physical and practical limitations on deployment.

3. What is the sensible maximum physical deployment density?
A crucial issue is the **maximum deployment density** that is being assumed. It is likely that opinions on this may differ but it should be stressed that the figure assumed here is different from the one in Step 10 below that represents the "socially acceptable" density. The figure here should set an **upper limit** beyond which additional deployment is unlikely to ever take place. The most important thing is to spell out in detail any **underlying assumptions**. These assumptions are best developed by the relevant industry trade associations in consultation with appropriate regulatory authorities.

4. Do technical potentials for different RE technologies overlap?
Due to the nature of renewables it is possible for a number of resources to overlap and therefore be mutually exclusive. This can be taken into account through the deployment densities assumed; again, explicit assumptions should be stated. For example, PV and solar hot water projects both require the same roof area, so double-counting must be avoided.

5. Is deployment limited by maximum demand for output?
In most cases energy supply potential from renewables will be well within the demand requirements, so this limitation does not apply. However in a few cases, such as domestic solar hot water, exploitation of the full roof space may exceed demand for hot water. Therefore applications need to be sized appropriately. Whilst technical solutions such as inter-seasonal storage may overcome demand limitations, it is quite possible that the cost of these will exceed the economic threshold.

Application of legal constraints ("*environmentally compliant potential*")

There is a range of environmental legislation and regulations at EU, national, regional and even local level designed to provide protection from unacceptable development. The constraints these may impose on renewable energy deployment must be taken into account to ensure that renewables are seen as fully compliant (however interpretation may be required for specific technologies).

6. Geographic designations of land/water/sea
There is a wide range of **geographic designations** that can apply to land, aquatic and marine environments. The EU designates Natura 2000 sites under the Habitats and Birds directives, national authorities designate national parks, areas of outstanding natural beauty or sites of special scientific interest. For each technology it is essential for assumptions to be made concerning deployment in these areas; in some cases deployment may need to be excluded or factored down for resource calculation purposes (though this may not always be the case in reality).

7. International or national legislation/regulations
Renewables must be seen as fully compliant with both EU and national legislation and regulations. Examples at the EU level include the Waste Incineration Directive and the Water Framework Directive, which can have a significant influence on the deployment of, respectively, bio-wastes and hydro/tidal/wave energy resources. The constraints these impose may not always be clear, so the key is to **specify the assumptions** that are being made. In some cases the constraint may be removed or relaxed through the use of environmental mitigation, however it is important to take into account the economic impact of this.

Complying with environmental good practice ("*environmentally compatible potential*")

It should be noted at the outset that this is the potential which the European Environment Agency wishes to quantify for all renewable energy technologies. The guiding principle is that, not only must the technology be fully compliant with legislation and regulations (as above), but it must also conform to **accepted guidelines for environmental good practice**. As before, in the absence of strict guidelines on good practice, clear assumptions need to be stated and the effect of applying mitigating measures taken into account.

Constraints imposed by competing land/water use should be considered. For example agricultural land converted from food to energy crop production raises issues of ethics and environmental sustainability. Hydropower and tidal barrage projects may greatly influence the amenity value of a particular location. Such competing pressures must be taken into account when stating the assumptions. Those renewable energy technologies subject to the greatest environmental scrutiny are often classified thus due to their potential impact on local eco-systems, for example migratory fish for hydropower, estuarine eco-systems for tidal, etc.

8. <u>Achieving environmental good practice</u>
Environmental "good practice" needs to be defined for each technology and the effect of implementing good practice needs to be taken into account on the resource potential. The cost of environmental mitigation measures necessary to achieve good practice is potentially a very important factor (by how much is the potential reduced if "good practice" mitigation is assumed, due to the resulting increased cost, or is the potential actually increased as more sites become acceptable?).

9. <u>Environmental impacts of associated infrastructure requirements</u>
Renewables deployment must often be accompanied by infrastructure necessary to build and maintain the project (e.g. access roads) and connect the project to energy demand (e.g. grid expansion, transformer stations). The environmental impacts of these may be as significant as the project itself and they too need to meet good practice guidelines with their resulting cost implications (for example the possible need to bury electricity cables).

Accounting for social and perceptual constraints ("*realisable potential*")

Experience has shown that one of the most significant constraints on the deployment of certain renewable energy technologies, and one of the most difficult to quantify, is the **acceptability of deployment to people**. This is generally taken into account through strategic spatial planning at the national or regional scale and through the planning system for individual projects. Concerns are not always environmental, though different issues are often interlinked.

10. <u>What is a socially acceptable deployment density (the "saturation point")?</u>
A key issue is estimating the **deployment density** above which significant public support is lost, i.e. is there some kind of quantifiable **social saturation point** that implies a deployment limit for the technology? Views as to what that might be are likely to vary widely, so the key is to assume a figure that can be justified wherever possible with evidence. The density assumed here **may be considerably lower** than the maximum figure assumed in Step 3 above. It is important to take into account the cumulative effect of all of the impacts that will be of concern to people (visual, noise, construction, transport, etc). It is also important to note that the limit may well change with time (upwards as people become accustomed to the new technology or increasingly concerned about climate change; downwards if attitudes towards renewables harden with time).

11. <u>Cultural perceptions (feeds into socially acceptable deployment density)</u>
Perceptions can vary widely from country to country, region to region or urban to rural. They may depend on the degree of "ownership" that people feel for renewables projects proposed near them. It is therefore necessary for assumed deployment densities to take into account such variations.

12. <u>Constraints imposed by competing land/water/air use and amenity value</u>
Competition for resource use covers a wide range of issues, some of which can be very sensitive. Even if the proposed deployment meets guidelines for environmental good practice, there may be considerable resistance for other reasons (for example impact of wind farms on aviation radar

systems, exploitation of resources in undeveloped regions or increasing concern over the impact of energy crops on food production). Such competing pressures must be taken into account when calculating the realisable potential.

Other constraints

13. Ease of technology use (e.g. microgeneration vs conventional)
Certain renewable energy technologies operating at the small-scale may be seen by their users as less convenient (and therefore less desirable) than their conventional counterparts. While this may alleviate with time, it could well impose a significant constraint on deployment in the short to medium term. This factor could be compounded if early customers of the technology experience poor performance or reliability by equipment or suppliers. It may be necessary to use regulatory or incentive mechanisms to overcome such views.

14. Regulatory inertia (including consenting procedures)
A long-standing historical complaint from developers of renewables projects is the time it can take to obtain all the required consents to build and operate plant. While this is an institutional constraint that governments are being encouraged to actively address, it is likely that it will remain a factor in determining the future extent of deployment. It may mean that more marginal sites do not get developed unless the incentives to do so are sufficiently great (i.e. a lower economic cut-off should apply).

15. Competing non-energy demand for resource
For some renewable energy resources (e.g. biomass feedstocks) it is also necessary to take into account the potential impact of competing non-energy demand for the resource (for example reuse and recycling of organic wastes, competing demand for wood, straw and other bio materials). The fraction of available resources that can be ascribed to energy conversion will depend largely on the relative economic values of the feedstocks within the competing markets and the influence of any market incentives that might be available. In addition, for a sector as varied as that of bioenergy, the competition for feedstock between different energy conversion routes needs to be taken into account.

16. Commercial availability of technology
Some technologies are still at a relatively early stage of development and commercialisation (e.g. wave and tidal stream energy). Whilst vigorous RTD&D efforts may accelerate their commercial deployment, deployment potentials will only be reached when the market is fully confident with the performance and reliability of the technology, which may take some considerable time. Realisable potentials must take into account the likely time scales for full commercialisation, including the ability of the equipment supply chain to deliver the required rate of deployment for the year specified.

17. Resource intermittency
For some renewable energy technologies their intermittency may be a limiting factor in the short and medium term. Electricity distribution systems are currently designed to operate with firm, centralised generating plant and will require significant investment to be able to accept large amounts of intermittent power, much of which is generated locally rather than centrally. The speed with which this evolution takes place may well be a significant limiting factor on the deployment of some renewable energy technologies. It is also often unclear how the costs of such a transition are to be borne (if by the technologies, then this must be reflected in their costs).

5 Applying the methodology to small-scale hydropower

This chapter applies the generic factors introduced in Chapter 4 to small-scale hydropower. It can be seen from Chapter 4 that applying the constraints requires a large number of assumptions to be made. It would seem appropriate that the detailed assumptions should be developed by the relevant industry trade associations in consultation with appropriate regulatory authorities and other interested bodies. Chapter 6 then goes on to review methodologies that have actually been adopted to quantify hydro potentials and evidence for the impact of the Water Framework Directive.

The latest Green-X modelling indicates that small-scale hydropower currently produces 46 TWh/y in the 27 members of the European Union and that there is potential for an additional 23 TWh/y in 2020[4]. Together this represents 4.3% of the EU's 2020 RES-E potential. 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 plant are on average below 1 MW, this could mean over 10,000 new installations by 2020.

In the preliminary 2007 report, the environmental constraints on small-scale hydropower were rated as medium to high. Implementation of the Water Framework Directive will affect small-scale hydro and its impacts are likely to be mainly economic: potentially the need for additional measures that can render schemes uneconomic (for example new licensing fees, additional mitigation measures such as fish passes, stipulations regarding residual and peak flows, uncertainty over future requirements, etc). Although the environmental impact of small-scale schemes is often low, it may be difficult to deploy them in designated areas such as national parks (though a well integrated scheme may be preferable to importing electricity). Small-scale hydropower usually requires the power station to be connected to the electricity grid, often through countryside of high scenic value.

Table 5.1 shows how the generic factors can be applied to small-scale hydropower. Estimation of a meaningful technical potential for small-scale hydropower really requires a "bottom-up" assessment of all feasible sites, with some knowledge of likely deployment costs so that the economic cut-off can be applied. An economic cut-off of €120/MWh is proposed (for 2020), however this may be seen as too limiting.

For the purposes of calculating the environmentally compliant potential, the proposed assumption is that deployment is excluded from designated areas. This is clearly a first approximation and should not be seen as implying that this will in fact be the case – there may well be instances where installations inside designated areas are viewed as perfectly acceptable, even desirable. Taking into account the impact of the Water Framework Directive is much more difficult; again this requires consultation between industry trade associations and the relevant regulatory authorities.

So too does the definition of environmental good practice for the purposes of estimating the environmentally compatible potential. For small-scale hydropower the position is made simpler by the fact that a standard for "green hydropower" has already been developed in Switzerland[5]. It has been adopted as a "green energy standard" under the EUGENE label (European Green Electricity Network) and therefore provides an excellent starting point.

Table 5.1 also provides initial guidance on the factors necessary to take into account social and perceptual constraints, as well as the range of "other" constraints described in Chapter 4. As these do not directly impact the environmentally compatible potential they will not be discussed here, however they must be taken into account if a realisable potential is to be calculated for deployment modelling purposes.

It is clear that a number of key assumptions must be made for this process to be applied to calculating the environmentally compatible potential and that these must be framed in quantitative terms. The most important ones are summarised here:

- Agreement on the economic cut-off figure to apply;

[4] Personal communication, Gustav Resch, 2008

[5] See http://www.eugenestandard.org/mdb/publi/14_Clean-E%20hydro%20factsheet%20final3.pdf

Table 5.1: Factors limiting the deployment of small-scale hydropower

Physical and practical constraints (technical potential)	Generic guidance for all technologies	Guidance for small-scale hydro
1. Setting an upper cost limit	In general the deployment potentials are strongly influenced by economics, i.e. the maximum price that society is willing to pay for the energy. Ideally this can be taken into account through the use of resource cost curves, however the extensive data required to produce these are often not available. In their absence it is important to state clear economic assumptions that underlie any resource estimates, for example an economic cut-off point above which the resource is considered too expensive to exploit. This cut-off should be specified at the outset and requires a similar approach to be adopted for all technologies. This area needs careful consideration.	An economic cut-off of €120/MWh is proposed for 2020 (might be too limiting). Economic impacts of mitigating measures required by the Water Framework Directive need to be accounted for.
2. Where can the technology be deployed? What are the physical/practical limitations?	Clear assumptions need to be specified as to how and where the technology could be implemented to achieve maximum deployment. This must take into account the obvious physical and practical limitations on deployment.	Assume that the cut-off for small-scale is anything below 10MW (note that cut-offs between 5 and 30MW are used in different countries). Initial technical potentials should be based on the mean annual precipitation, land area over which it falls and elevation, taking into account principal geographical constraints.
3. What is the sensible maximum physical deployment density?	A crucial issue is the maximum deployment density that is being assumed. It is likely that opinions on this may differ but it should be stressed that the figure assumed here is different from the one in Step 10 below that represents the "socially acceptable" density. The figure here should set an upper limit beyond which additional deployment is unlikely to ever take place. The most important thing is to spell out in detail any underlying assumptions. These assumptions are best developed by the relevant industry trade associations in consultation with appropriate regulatory authorities.	This may be taken into account above, but assumptions need to be explicitly stated. Ideally it should come from a bottom-up assessment of suitable locations for schemes, if one has been made, taking into account their techno-economic feasibility. These assumptions are best developed by the relevant industry trade associations in consultation with appropriate regulatory authorities.
4. Do technical potentials for different RE technologies overlap?	Due to the nature of renewables it is possible for a number of resources to overlap and therefore be mutually exclusive. This can be taken into account through the deployment densities assumed; again, explicit assumptions should be stated. For example, PV and solar hot water projects both require the same roof area, so double-counting must be avoided.	Not relevant for small-scale hydropower.
5. Is deployment limited by maximum demand for output?	In most cases energy supply potential from renewables will be well within the demand requirements, so this limitation does not apply. However in a few cases, such as domestic solar hot water, exploitation of the full roof space may exceed demand for hot water. Therefore applications need to be sized appropriately.	May be relevant for very remote locations for which grid connection is not economic but where small-scale hydro can meet a limited local energy need. Not a significant factor.
Legal constraints (environmentally compliant potential)		
6. Geographic designations of land/sea	There is a wide range of geographic designations that can apply to land, aquatic and marine environments. The EU designates Natura 2000 sites under the Habitats and Birds directives, national authorities designate national parks, areas of outstanding natural beauty or sites of special scientific interest. For each technology it is essential for assumptions to be made concerning deployment in these areas; in many cases deployment may well need to be excluded for resource calculation purposes (though this may not always be the case in reality).	Assume that new small-scale hydro deployment is excluded from all designated areas. This may well not be the case in practice, however it provides a useful first approximation to the impact of sensitive areas on resource availability. In some cases providing a stand-alone small hydro plant in a designated area could well remove the need for grid connection to supply local power.

7. International or national legislation/regulations	Renewables must be seen as fully compliant with both EU and national legislation and regulations. Examples at the EU level include the Waste Incineration Directive and the Water Framework Directive, which can have a significant influence on the deployment of, respectively, bio-wastes and hydro/tidal/wave energy resources. The constraints these impose may not always be clear, so the key is to specify the assumptions that are being made. In some cases the constraint may be removed or relaxed through the use of environmental mitigation, however it is important to take into account the economic impact of this.	Need to take into account impact of the Water Framework Directive (though requirements for hydro are not clear). Factors to account for: fish bypass, residual water flow, new licensing fees, loss of habitats, protecting drinking water, flood protection, local amenity, grid connection, sedimentation, trash removal, impact on ground water. The assumptions are best developed by the relevant industry trade associations in consultation with appropriate regulatory authorities.
Complying with environmental good practice (environmentally compatible potential)		
Principle: conforms to all requirements for environmental good practice	This is the potential which the European Environment Agency wishes to quantify for all renewable energy technologies. The guiding principle is that, not only must the technology be fully compliant with legislation and regulations (as above), but it must also conform to accepted guidelines for environmental good practice. As before, in the absence of strict guidelines on good practice, clear assumptions need to be stated. Constraints may be reduced by potential to apply mitigation technologies, however these are likely to increase costs.	
8. Achieving environmental good practice	Environmental "good practice" needs to be defined for each technology and the effect of implementing good practice needs to be taken into account on the resource potential. The cost of environmental mitigation measures necessary to achieve good practice is potentially a very important factor - by how much is the potential reduced if "good practice" mitigation is assumed, due to the resulting increased cost, or is the potential actually increased as more sites become acceptable?	Apply the EUGENE standard for "green hydropower". Need to estimate what impact on potential this will have - increased costs will rule out some sites but increased acceptability may bring in sites that would otherwise be ruled out. See: http://www.greenhydro.ch/level0/index_e.html http://www.eugenestandard.org/mdb/publi/14_Clean-E%20hydro%20factsheet%20final3.pdf
9. Environmental impacts of associated infrastructure requirement (e.g. grid expansion, access roads, etc)	Renewables deployment must often be accompanied by infrastructure necessary to build and maintain the project (e.g. access roads) and connect the project to energy demand (e.g. grid expansion, transformer stations). The environmental impacts of these may be as significant as the project itself and they too need to meet good practice guidelines with their resulting cost implications (for example the possible need to bury electricity cables).	Remove x% of small-scale hydro resource due to unacceptability of the associated development (especially grid connection). Say 5%?
Accounting for social and perceptual constraints		
10. What is a socially acceptable deployment density (saturation point)?	A key issue is estimating the deployment density above which significant public support is lost, i.e. is there some kind of quantifiable social saturation point that implies a deployment limit for the technology? Views as to what that might be are likely to vary widely, so the key is to assume a figure that can be justified wherever possible with evidence. The density assumed here may be considerably lower than the maximum figure assumed in Step 3 above. It is important to take into account the cumulative effect of all of the impacts that will be of concern to people (visual, noise, construction, transport, etc). It is also important to note that the limit may well change with time (upwards as people become accustomed to the new technology or increasingly concerned about climate change; downwards if attitudes towards renewables harden with time).	Assume that only y% of the environmentally compatible small-scale hydro potential will be considered acceptable for deployment (say 50%? - likely to vary nationally and regionally). Main factors will be impacts on amenity (visual, noise, fishing)

11. Cultural perceptions (feeds into maximum deployment density)	Perceptions can vary widely from country to country, region to region or urban to rural. They may depend on the degree of "ownership" that people feel for renewables projects proposed near them. It is therefore necessary for assumed deployment densities to take into account such variations.	Acceptability of small-scale hydro may vary considerably depending on a wide range of factors. Taken into account through the factor used in 10 above.
12. Constraints imposed by competing land/water/air use and amenity value	Competition for resource use covers a wide range of issues, some of which can be very sensitive. Even if the proposed deployment meets guidelines for environmental good practice, there may be considerable resistance for other reasons (for example impact of wind farms on aviation radar systems, exploitation of resources in undeveloped regions or increasing concern over the impact of energy crops on food production). Such competing pressures must be taken into account when calculating the realisable potential.	Taken into account through the factor used in 10 above.
Other constraints		
13. Ease of technology use (e.g. microgeneration vs conventional)	Certain renewable energy technologies operating at the small-scale may be seen by their users as less convenient (and therefore less desirable) than their conventional counterparts. While this may alleviate with time, it could well impose a significant constraint on deployment in the short to medium term. This factor could be compounded if early customers of the technology experience poor performance or reliability by equipment or suppliers. It may be necessary to use regulatory or incentive mechanisms to overcome such views.	May be relevant for the smallest-scale projects where potential users may be daunted by technology, but this is not likely to have a significant effect on the total resource.
14. Regulatory inertia (including consenting procedures)	A long-standing historical complaint from developers of renewables projects is the time it can take to obtain all the required consents to build and operate plant. While this is an institutional constraint that governments are being encouraged to actively address, it is likely that it will remain a factor in determining the future extent of deployment. It may mean that more marginal sites do not get developed unless the incentives to do so are sufficiently great (i.e. a lower economic cut-off should apply).	This is an area of significant concern for small-scale hydro, due to the large number of consents often required (water abstraction, electricity generation, planning, fisheries, etc)
15. Impact of competing non-energy demand for the resource (e.g. biomass feedstocks)	The need to set an upper cost limit on deployment that is broadly similar across technologies and resources was stressed in the introduction. For some renewable energy resources (e.g. biomass feedstocks) it is also necessary to take into account the potential impact of competing non-energy demand for the resource (for example reuse and recycling of organic wastes, competing demand for wood, straw and other bio materials). The fraction of available resources that can be ascribed to energy conversion will depend largely on the relative economic values of the feedstocks within the competing markets. In addition, for a sector as varied as that of bioenergy, the competition for feedstock between different energy conversion routes needs to be taken into account.	Competing economic interests (amenity, agriculture, water supply, etc) may reduce the available small-scale hydropower resource.
16. Is the technology fully available commercially?	Some technologies are still at a relatively early stage of development and commercialisation (e.g. wave and tidal stream energy). Whilst vigorous RTD&D efforts may accelerate their commercial deployment, deployment potentials will only be reached when the market is fully confident with the performance and reliability of the technology, which may take some considerable time. Realisable potentials must take into account the likely time scales for full commercialisation, including the ability of the equipment supply chain to deliver the required rate of deployment for the year specified.	Small-scale hydro is a mature and fully commercial technology, with little scope for cost reduction. However consideration should be given as to whether suppliers will be able to achieve the required installation rates by relevant dates.
17. Is intermittency a limiting factor?	For some renewable energy technologies their intermittency may be a limiting factor in the short and medium term. Electricity distribution systems are currently designed to operate with firm, centralised generating plant and will require significant investment to be able to accept large amounts of intermittent power, much of which is generated locally rather than centrally. The speed with which this evolution takes place may well be a significant limiting factor on the deployment of some renewable energy technologies. It is also often unclear how the costs of such a transition are to be borne (if by the technologies, then this must be reflected in their costs).	Not relevant, but note that annual load factors are dependent on precipitation patterns. In colder regions small-scale hydropower can be a more seasonal resource.

- The maximum deployment density to apply for the purpose of estimating the technical potential;
- Assumptions concerning acceptability of deployment in legally designated areas;
- Assumptions concerning the impacts of legal constraints (directives, regulation, etc);
- Definition of what constitutes “environmental good practice” and the impact of applying any mitigation measures required.

In addition the difficult assumption of what constitutes the maximum socially acceptable deployment density is required if the resulting potentials are to be used for modelling purposes.

Achieving agreed parameters for these requires consensus to be reached between the industry and the relevant regulatory authorities and other interested parties. We propose that the process should be initiated by the trade associations (in the case of small-scale hydropower, the European Small Hydropower Association - ESHA), as these organisations are closest to the issues being encountered by project developers. They can put forward initial proposals and debate these with the relevant organisations or authorities. In some cases this might be at the European level (e.g. with the Commission or the EEA) whilst in others it may be necessary to apply the subsidiarity principle and consult at the national level.

Whilst there may well be diverging views expressed, it is considered important to reach a consensus on the key issues as an input to future planning activities. Such a debate needs to take place and the approach outlined provides a rigorous framework within which this can take place. By adopting a similar approach across different technologies and resources we can ensure that the resulting resource estimates can be viewed on a comparable basis. Furthermore if Member States can be encouraged to re-assess their renewable energy potentials on the basis of the resulting methodologies, the Commission will have a much more rigorous basis for assuring itself of the contribution that renewables can make to EU energy demand and the main factors that influence these. We believe that adopting the proposed approach can have significant long-term benefits for the European Union.

6 Hydropower potential assessment and impact of environmental constraints

As mentioned in Section 2, it was agreed with the EEA following review of the interim report to focus the remainder of this study on a literature review to determine what methodologies have been used worldwide to assess hydropower potential and the extent to which they explicitly take into account environmental constraints (and how). Initially we present a summary of the data on existing deployment and additional realisable EU potentials used in the modelling of 2020 potential, and the extent to which environmental constraints are taken into account in these. We review the literature for published methodologies of hydropower assessment, with an emphasis on their treatment of environmental factors then we present some of the evidence available on the impact of the Water Framework Directive. Finally we look at some of the approaches that have been proposed to define a standard for “green” or “environmentally compatible” hydropower.

As always there is a vast literature available on all of these matters and it has not been possible to assess this exhaustively. It is therefore possible that there remains relevant material to complement that presented below. However it is clear from the literature that there are significant tensions between the desirability of exploiting the hydro potential as a source of low-carbon electricity and the desirability to preserve and improve the environmental quality of Europe’s water courses. Much of the hydropower development in Europe has taken place before environmental sensitivities rose high on the agenda and there is an acceptance that, not only must standards of future deployment be higher, but there is also a need to raise the standards for existing installations. Reconciling this with the goal of maximising renewable energy production remains a major challenge, especially for those EU countries with a significant hydro resource.

6.1 EU current deployment and remaining potential

Hydropower is one of the oldest renewable electricity generating technologies and currently provides by far the largest contribution to EU27 renewables electricity: 342 TWh/yr in 2005 out of a total 510 TWh/yr (67%)[4], of which 297 TWh/yr from large-scale and 46 TWh/yr from small-scale (<10MW). The BlueAGE study[6] reported that in 2000 there were slightly more than 17,400 small hydropower plants (SHP) 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 0.7MW 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.

The Green-X modelling undertaken for the European Commission[3] draws its data for future potentials from the TERES II study[7] for large-scale hydro and from the BlueAGE study for small-scale hydro, in both cases updated with additional national data where available. The latest modelling results for the EU27’s “additional mid-term potentials (up to 2020)” are 42.4 TWh/yr from large-scale and 22.7 TWh/yr from small-scale, representing increases of 14% and 50% respectively. These are relatively modest increases relative to those foreseen for some other renewable energy technologies, reflecting the fact that much of the potential has already been exploited and there are perceived to be significant constraints on further deployment, especially environmental. Given the age of the existing plant, a significant share of the potential may come from plant refurbishment, providing the opportunity for capacity upgrade and environmental improvement.

The OPTRES study[3] on which the Green-X modelling is based recognises the influence of economic and environmental constraints on the hydro potential and has tried to take these into account. However it is unclear from the source material referenced below how environmental factors were taken into account. The BlueAGE study on small-scale hydro is more explicit: it envisages that around 50% of the technical potential will not be developed due to economic and environmental constraints. However there is no explanation of the relative impact of these two factors, nor is there a description

[6] 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

[7] ESD/DGXVII (1996). TERES II – the European Renewable Energy Study. Report & CD-ROM by ESD et al. (1996) – on behalf of the European Commission, DG TREN.

of how environmental constraints were taken into account. The likelihood is that different approaches were used in different countries and therefore the country results are not strictly comparable.

The position for large-scale hydro is even less clear. In any case the position for both will have changed in recent years with the advent of the Water Framework Directive. It is clear that individual countries have been reassessing their hydropower potentials in the light of the directive (see later) however no evidence has been found of an agreed basis for assessing the reductions likely from application of the directive, nor of any study seeking to assess the impact on a European-wide basis.

6.2 The assessment of hydropower potential

Whilst it may be relatively simple to assess the theoretical potential for hydropower on the basis of recorded precipitation, hydrological factors and topography, this information on its own is of limited use. To calculate the technical potential requires a more detailed assessment of the hydrology and topography on a regional basis: flow rates of rivers and streams (and their annual variability), locations that might be suitable for hydropower plant, access for construction and grid connection, etc. Taking into account the factors presented in Section 4.2 implies some specific assumptions about maximum deployment density and economic cut-off. A reliable assessment of technical potential therefore implies some “on the ground” survey of possible sites and their electricity generation potential. In this respect the advent of geographic information systems (GIS) software is of enormous use as a way of capturing the range of information required. However there appears to be no accepted methodology for calculating the technical (high-level) potential, or translating a high-level potential into one that is realisable. Different studies have adopted different approaches, based on the nature of their objectives and the availability of input data.

The European SPLASH project

An example of the use of GIS is given in the SPLASH project (Spatial Plans and Local Arrangement for Small Hydro)[8], funded within the ALTENER element of the EU’s Intelligent Energy Europe programme, which used a variety of approaches during 2003 - 2005 to prepare pilot spatial and policy plans for small hydropower in five EU countries. Different partners used different approaches, from a bottom-up (or inventory) approach based on the study of individual sites to a top-down (or “sieve map”) approach that starts from a large area of territory and focuses in on a section of river. These approaches were aimed at assessing the realisable potentials, and the authors emphasised the need for a multidisciplinary team to be involved, as well as the importance of reliable input data.

Study of Scottish hydropower potential

An example of a recent study is the one published in August 2008 on the potential for development of hydropower resources in Scotland[9], commissioned by the Scottish Government. The study was undertaken in a series of phases, the first of which was to provide a theoretical maximum potential for hydropower based on the country’s rainfall and topography. The annual flow pattern was calculated for all watercourses in Scotland, using topographical and gauged flow data. The other stages involved a more practical assessment of the potential using a GIS-based computer model, which allowed for an economic evaluation of all likely hydro configurations on rivers within 60 separate rainfall catchments.

Schemes were first optimised by sizing equipment to suit the location. Options for storage dams and multiple intakes were also considered at each site. A further dataset of existing weirs was also analysed by the model. The schemes were evaluated using up-to-date costs and taking realistic prices for electricity and other variables. The watercourses supplying existing schemes with an installed capacity of 700kW or more were identified, so that affected weirs, dams and reaches of river could be excluded. Other abstractions greater than 100 litres/second were also taken into account by excluding sites from the analysis where the abstraction would have a significant impact on available flow. Further constraints related to the distribution grid, the transport network and land designations.

It is instructive to consider the results of such a detailed analysis. The theoretical potential was calculated to be as high as 47 TWh/yr (based on a capacity of 5.4 GW), though presented only for comparative purposes. The model then identified 36,252 separate sites that were deemed practical and technically feasible, with a total capacity of 2.6 GW. Reducing this to financially viable schemes, the baseline scenario of the study used input values appropriate to a typical commercial hydropower

8 See http://www.esha.be/index.php?id=30 and http://www.esha.be/fileadmin/esha_files/documents/publications/articles/Splash.pdf
9 See http://cci.scot.nhs.uk/Topics/Business-Industry/Energy/19185/FREDSHydroResStudy

investment. This indicated that there are 1,019 potential schemes across Scotland. These include run-of-river schemes and new storage schemes with a total installed capacity of 657 MW that could deliver 2.77 TWh of electricity annually.

As part of the process of site selection, areas designated for their natural heritage value were incorporated into the model and the hydro potential in these areas was reduced to reflect the level of environmental protection the designation implied. Without such reductions, the analysis indicates that around 337 potential hydro schemes could be located in designated areas, and would be capable of providing 357MW of power. Using a modest level of protection, the potential in designated areas would reduce to a potential power of 227 MW. Approximately 480 MW of potential lies outside designated areas, bringing the total power to the 657 MW figure reported above. Appendix 6 of the report reviews the environmental impacts of hydropower and provides details on how these were taken into account by the model. It also provides a useful review of the impact of the Water Framework Directive and its application in Scotland. The effect of natural heritage land designations upon the success rate and size of hydro schemes was one of several areas the authors said are in need of further research.

A similar study is currently being undertaken by the British Hydropower Association for England and Wales but unfortunately the report was not available in time for presentation here.

Re-assessment of French hydropower potential, 2006

France is significant in that it has one of the highest installed hydro capacities and potentials for new capacity in the EU. The French study[10] was performed for the Ministère de l'économie, des finances et de l'industrie, to update information gathered between the 1970s and 1990s. It involved all main stakeholders and is similar to the Scottish one in that after estimating the technically and economically feasible potential, environmental constraints are accounted for and further reduce the achievable potential. For this evaluation, the study considered three representative Water Basins from which it was then possible to extrapolate to the rest of France.

Land designations such as natural parks, area of special environmental importance, etc account for the environmental constraints. It is interesting to note that the majority (88%) of the potential is located on land with some kind of environmental designation, so the final result is very dependent on the nature of the deployment assumptions made for individual land designations. The report states that it was not possible to account for all local environmental impacts, as it would have implied commissioning engineering work beyond the scope of that study.

From a maximum additional feasible potential of 28.4 TWh/year, environmental constraints (if the main land designations prevent the development of hydropower) only allows for 13.4 TWh/year to be generated. This result appears fairly typical of other studies that have roughly halved their potentials when taking account of land designations (the main environmental constraint generally accounted for). The study mentions the introduction of the Water Framework Directive but does not attempt to quantify its impact on existing capacity or new potential.

Re-assessment of Austrian hydropower potential

It is worth prefacing this section by saying that much of the information on Austrian potential came from an Austrian-French workshop on 4/5 July 2008 on "Hydropower in the context of implementing the EU Water Framework Directive"[11]. A summary report from this workshop is presented as Appendix 1 and the presentations and paper abstracts are available[12]. The information on Austrian potential comes from a re-assessment of Austria's hydro potential by Pöyry in early 2008[13], which updated a 1982 study on the theoretical potential by Schiller. The key data are summarised in a presentation to the workshop by Bertram Weiss, Verbund –AHP, "Hydropower potential of Austria in context with the Renewables Energy Directive and WFD"[14].

The re-assessment of theoretical potential was very close to the original study, amounting to some 75 TWh/yr. Existing hydro production is 38 TWh/yr, representing some 60% of electricity production in Austria. Of the existing production, 91% of the production comes from 156 large-scale (>10 MW)

[10] Sur les perspectives de developpement de la production hydroelectrique en France, Ministère de l'économie, des finances et de l'industrie, 2005, http://lesrapports.ladocumentationfrancaise.fr/BRP/064000471/0000.pdf
[11] See the workshop programme at http://www.ambafrance-at.org/IMG/pdf/Seminaire_Eau_prog_final_4_et_5_juillet_2008.pdf
[12] The Austrian-French workshop papers are available at http://rp7.ffg.at/umwelt_va_wfd
[13] Bertram Weiss, Verbund – AHP, personal communication, referred to in his workshop presentation, Session 3. The report is titled "
[14] http://www.ffg.at/buk/va/Downloads/8626B6DA.pdf

plants, out of a total 2,300 installations (not including around 2,000 privately owned "micro-hydro" plants). It is also worth noting that 73% of the existing production comes from run of river plant, and only 27% from storage plant. The report estimates that optimisation of existing plant could yield a further 3.5 TWh/yr, however this is unlikely to be realised due to future residual flow restrictions and local restrictions. Indeed Stigler et al in 2005 calculated that production losses from existing plant of 2 to 7% could result from implementation of the Water Framework Directive[15]; the report states that similar losses can be expected for the remaining techno-economic potential.

The Pöyry report then uses a range of parameters to translate the theoretical potential into a technical potential for Austria: 56 TWh/yr, which implies that a techno-economic potential of 18 TWh/yr remains to be deployed. The report does not provide a detailed assessment of the environmental constraints, however it states that, as a first estimate, the over 5 TWh/yr of resource located in national parks and world heritage sites can be excluded, reducing the realisable potential to less than 13 TWh/yr. The Austrian Government would like to see the development of 7 TWh/yr by 2020 in order to meet its obligations under the recently agreed renewable energy directive. However it recognises that this may be incompatible with achievement of the Water Framework Directive and further studies are now underway. The Government recognises that exploitation of hydropower has already had a serious impact on the environmental quality of Austria's waterways. The presentation by V. Koller Kreimel to the workshop stated that, for example, meeting the conditions for minimum residual flow could require an investment of up to Euro 230 million and result in annual production losses of up to Euro 66 million.

Small hydropower potential for Italy

It has not proved possible to locate a detailed resource assessment for Italy, however a paper presented to ESHA's Hidroenergia 2008, Bled, Slovenia, 11th-13th June 2008, looked at the Italian maximum and remaining potential[16], using GIS software. The residual potential accounts for water usage: drinking, irrigation etc. There appears to have been no consideration of environmental constraints at this stage. However the resulting maps are helpful for local administrations and project developers.

Evaluation of environmental constraints on the US hydropower potential

The US DOE and the Idaho National Engineering and Environmental Laboratory (INEEL) have developed a software method of assessment, the Hydropower Evaluation Software[17]. This software is intended to determine the suitability of potential sites to be developed. It uses environmental attributes and federal land codes data to generate a Project Environmental Suitability Factor (PESF: 0.1 = unsuitable and likely rejection of the development, 0.9 = very suitable and likely approval). INEEL derived the following 19 environmental attributes from the Nationwide Rivers Inventory. The corresponding suitability factors are fully explained in Appendix 2.

- Wild/Scenic Protection
- Wild and Scenic Tributary or Upstream or Downstream of a Wild and Scenic Location
- Cultural Value
- Fish Presence Value
- Geologic Value
- Historic Value
- Recreation Value
- Scenic Value
- Wildlife Value
- Other Value

[15] As reported in Steiner, H, "Research activities of Verbund with regard to the Water Framework Directive of European Union", http://www.oen-iad.org/conference/docs/1_introductory/steiner.pdf
[16] See http://www.esha.be/fileadmin/esha_files/documents/workshops/hidroenergia_2008/HE08_Presentations/day_2/4._Julio_Alterach_-_Evaluation_of_the_residual_potential_hydropower_production_in_Italy.pdf
[17] See http://hydropower.inel.gov/resourceassessment/index.shtml for the main site on resource assessment. The page includes a link to http://hydropower.inel.gov/resourceassessment/software/ from which the Hydropower Evaluation Software can be accessed. There is also a link to the "Virtual Hydropower Prospector", a geographic information system (GIS) tool designed to help locate and assess natural stream water energy resources in the United States.

- Threatened and Endangered Fish
- Threatened and Endangered Wildlife

US Federal Land Codes:

- National Park, Monument, Lakeshore, Parkway, Battlefield, Or Recreation Area
- National Forest or Grassland
- National Wildlife Refuge, Game Preserve, or Fish Hatchery
- National Scenic Waterway or Wilderness Area
- Indian Reservation
- Military Reservation
- Not on Federal Land

A combination of attributes results in a lower suitability factor because multiple environmental considerations reduce the likelihood that a site may be developed to its physical capacity. Based on previous work assessing the overall technical potential for each state and ultimately the USA as a whole, the software enables the user to account for environmental, legal and institutional constraints.

The actual exercise of assessing the hydrological resources involved all the main interested parties, government department, local authorities, scientific and university organisations, natural and wildlife preservation organisations etc. Past efforts to identify and measure the undeveloped hydropower capacity in the United States had resulted in estimates ranging from about 50,000 MW to almost 600,000 MW. None of these historical estimates had been universally accepted, partly as they failed to consider the environmental, legal, and institutional constraints to developing hydropower projects.

Modelling of the undeveloped hydropower resources in the United States using the Hydropower Evaluation Software, based on environmental, legal, and institutional constraints, identified 5,677 sites that have a total technical potential of about 68.8 GW[18]. This includes 381 already developed hydropower sites with power generation, 2,527 developed sites without power generation and 2,766 completely undeveloped sites. States and local agencies were involved in assigning the PESF to each project based on the 19 criteria. Once these were applied the realisable resource was more than halved to 29.8 GW.

Of all the hydropower resource assessment methodologies encountered, this one most closely mirrors the approach suggested in the early sections of this report. It combines a systematic approach to dealing with a wide range of constraints with a consultative approach using local decision makers.

Miscellaneous other studies

Other studies have been carried out at national or local scale to assess hydro resources but most consider only the technical and economic potential. For instance India are using remote-sensing data for small-scale hydropower[19]. Turkey has also reviewed its hydropower potential on the basis that hydro can be a real asset in its energy portfolio in view of global drives to reduce GHG emissions[20]. Negative environmental impacts are simply acknowledged and probably integrated in the planning system to some extent.

There is however relatively easily accessible information on how different countries' legal frameworks apply to hydropower development and how thoroughly environmental issues are taken into account (e.g. Norwegian ministry of petroleum and energy[21], UK's Environment Agency[22]).

It is worth finishing by mentioning RETScreen, a piece of Microsoft Excel based software developed by Natural Resources Canada and available free from their website[23]. RETScreen enables the user to

[18] U.S. Hydropower Resource Assessment Final Report, December 1998, http://hydropower.inel.gov/resourceassessment/pdfs/doeid-10430.pdf
[19] Assessment of small hydropower potential using remote sensing data for SD in India (S. Dudhani, A.K. Sinha, S.S. Inamdar), Energy Policy, Volume 34, Issue 17, November 2006, pages 3195-3205.
[20] Re-evaluation of Turkey's hydropower potential and electric energy demand, Omer Yuksek, Energy Policy, Volume 36, Issue 9, September 2008, Pages 3374-3382.
[21] FACTS 2006 Energy and Water resources in Norway, the legal framework for hydropower development: http://www.regjeringen.no/en/dep/oed/Documents-and-publications/Reports/2006/Facts-2006-Energy-and-water-resources-in-Norway.html?id=419523&epslanguage=EN-GB
[22] EA Hydropower handbook, http://www.environment-agency.gov.uk/commondata/103599/hydropower_handbook_1676435.doc
[23] The RETScreen Clean Energy Project Analysis Software is available free from http://www.retscreen.net/ang/home.php

facilitate project development in various renewable energy and energy efficiency projects. This includes assessment of the potential for hydro based on hydrological characteristic of the site. It also works out the main financial information for the project including initial capital cost and payback. However it is site specific and the site location and its key characteristics are therefore a pre-requisite to the use of this software. Environmental characteristics are not accounted for, thereby assuming that they should have been assessed and mitigation measures agreed before hand or separately, which is the role of the planning and environmental authorities. RETSreen's main use therefore is to allow users to undertake pre-feasibility studies, not assess potential on a wider basis.

Conclusion

Of the hydropower potential assessment methodologies published in the open literature, there are few that state explicitly how environmental constraints are accounted for. In the majority of cases the potential is reduced by either excluding or factoring down the resource located in areas with land designations. The US approach is the exception: here they have sought to combine a wide range of factors on a systematic basis. It is very difficult to say to what extent the additional mid-term potentials for hydropower used in the Green-X modelling account for environmental constraints.

It is clear from the literature that the Water Framework Directive will have a major impact on both existing and new hydropower projects, however there is as yet little reliable information on its likely impact on national generation potentials. The next section summarises the ways in which the directive will influence hydropower.

6.3 The Water Framework Directive and hydropower

"Directive 200/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy"[24] agreed on 23 October 2000 (Water Framework Directive or WFD) came into force with its publication in the Official Journal of the European Communities dated 22 December 2000 (L 327/1). Following many European directives in the aquatic environmental field over previous decades, it pursues for the first time an integrated approach to European water policy. 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. We are not aware of any systematic assessment of the impact the directive is likely to have on EU hydropower potential. However it is clear that the hydropower industry is very concerned that, not only will the directive limit the generating potential from existing and new sites, it will also have a significant cost burden that could limit the competitiveness and therefore deployment of hydropower[25].

The Water Framework Directive applies across the board to all European water bodies – to surface water bodies including coastal waters, as well as groundwater – irrespective of their use or their size. The directive looks at the water bodies themselves, their floodplains and catchment areas as one unit. At the same time it covers the interaction between ground and surface water. The directive therefore accounts more strongly than before for the ecological function of water bodies as a habitat for different species of plants and animals, and thus also includes nature conversation objectives.

The basic principles of the WFD in the area of surface waters can be summarised as follows

Ecological focus

In contrast to previous directives, the WFD is not usage-oriented but has an ecological focus. In the forefront is the objective of restoring or preserving the habitat for water type-specific biotic communities.

Catchment-related approach

Bodies of water are seen in the context of their corresponding catchment, which is especially relevant to the goal to create water type-specific model zones and development of management plans.

Water type-specific approach

[24] See http://ec.europa.eu/environment/water/water-framework/index_en.html DG Environment provides a comprehensive web service covering a wide range of aspects related to the directive. There is a library of documents covering all aspects of the directive that can be accessed via http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive&vm=detailed&sb=Title

[25] This section draws heavily on a report by VGB PowerTech e.V. titled "Water Framework Directive - and its Possible Effects on Hydropower", 2005, available from http://www.vgb.org/data/vgborg_/TC%20Renewables/Startseite/EU%20Water%20Framework%20Directive

Rivers, lakes, transitional waters and coastal waters are to be characterised according to the criteria listed in Annex II of the WFD and assigned to water body types. For rivers, for example, the use of the following criteria is mandatory: ecoregion, altitude, catchment area size, geology. Other criteria can also still be applied, such as flow category and stream order number.

Bio-indication

The focal point in assessing the ecological condition of water bodies is an examination of the aquatic ecosystems; in the case of rivers, for example, phytobenthos, macrophytes, phytoplanktons, macrozoobenthos and fish are to be examined. The assessment is made based on a comparison of the status quo with a water type-specific reference condition, which corresponds to the largely natural water body condition with, at most, minimal disturbance.

Evaluation of the ecological condition

The ecological condition is evaluated within a five-stage classification scheme, whereby Class I ("High Ecological Status") represents the reference condition and Class II ("Good Ecological Status") the minimum quality standard to be achieved.

The key objectives of the Water Framework Directive are as follows:

- "Good ecological status" or "good ecological potential" and good chemical condition of surface waters;
- Good chemical and volume condition of groundwater;
- Broad cost coverage for water services (including the economic analysis of water usage).

These objectives are to be achieved Europe-wide within specified deadlines[26] (see below). The Water Framework Directive provides for the following tools to achieve the goals:

- Preparation of management plans, which are to be co-ordinated for the entire river basin area and must contain programmes of measures to attain the objective.
- Compliance with a general ban on deterioration and the need for a reversal in the pollution trends of water bodies.
- Extensive involvement of the public in planning and implementing the measures.

For implementation and goal attainment, the directive provides for a tight implementation plan with the following deadlines:

- Within 3 years (by end of 2003), the directive must be transposed into national legislation. It is clear from the Commission's website that the majority of Member States failed to meet the required deadline and that, in general, they are struggling to fulfil many of the requirements stipulated for them by the directive.
- The stocktaking and analysis of river basin units must be concluded within 4 years (December 2004), with reporting to Brussels by March 2005.
- Monitoring programmes and monitoring institutions based on the status quo analysis by the end of 2006.
- Preparation of management plans with programmes of measures by end of 2009.
- Implementation of the programmes of measures in river basin units by December 2012.
- Achievement of "good ecological status" for surface waters, groundwater and in protected areas by the end of 2015. 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.

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

- 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).

[26] See the Commission's website on Transposition and Reporting - progress in the Member States: http://ec.europa.eu/environment/water/water-framework/transp_rep/index_en.htm

- 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 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 the overall objective is that of the "natural water condition". To take into account uses of water bodies, the directive has introduced another water body type – the "heavily modified water body" (HMWB)[27]. For a stretch of water where there is significant use of the water, there is the option of classifying it as a Heavily Modified Water Body and the objective is then no longer "good ecological status" but "good ecological potential". Member States were required to carry out risk assessments and report bodies of water they wished to classify as HMWB by March 2005 and some (e.g. Austria, Scotland) have sought to protect their hydro resource by reporting significant numbers[28]. The initial reporting is important as the Commission has said that retrospective designation of a water body as HMWB will be discouraged, thereby making it difficult to build a new hydropower plant on a water body that has not been so designated.

It is not yet fully clear to what extent Member States have taken the interests of hydropower into account in their reporting of HMWB. Certainly the need to reconcile the WFD requirements with the ambitious renewable energy deployment goals recently agreed presents governments with a challenge and a dilemma.

The implementation of the Water Framework Directive raises a number of shared technical challenges for the Member States, the Commission and EEA Countries as well as stakeholders and NGOs. In addition, many of the European river basins are international, crossing administrative and territorial borders and therefore a common understanding and approach is crucial to the successful and effective implementation of the directive. In order to address the challenges in a co-operative and coordinated way, the Member States, Norway and the Commission agreed on a Common Implementation Strategy (CIS) for the Water Framework Directive five months after the entry into force of the Directive. The Commission's website[29] has links to a number of key documents, including:

- Strategic document (May 2001): "Common Strategy on the Implementation of the Water Framework Directive"
- Strategic Document (December 2006): "Improving the comparability and the quality of Water Framework Directive implementation – Progress and Work Programme 2007-2009"

The Water Directors, who are the representatives of the EU Member States with overall responsibility on water policy, established in November 2005 an EU Strategic Steering Group (SSG) to address the issue of better integration of policies. The aim of the group's work is to put forward suggestions on how best to manage synergisms and antagonisms between the management of hydro-morphological alterations in river basin management planning and the requirement of other policies, focusing on hydropower, navigation and flood management. To do so, the group used two approaches: a technical approach, targeted to the identification of potentially relevant experience and good practice measures[30], and a political approach targeted to policy recommendations for a better integration between the different policies[31].

Germany, the UK and Austria are the lead countries of the CIS activity on "Water Framework Directive and Hydromorphological Pressures". As part of the work programme they organised a workshop in Berlin on 4-5 June 2007 on the "Water Framework Directive and Hydropower"[32]. More than 100 delegates participated in this event including nominated representatives from the EU Member States,

[27] 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
[28] The Commission's staff working document accompanying its first assessment report on implementation of the directive in 2007 provides further information on the designation of HMWB at http://ec.europa.eu/environment/water/water-framework/implrep2007/pdf/sec_2007_0362_en.pdf
[29] DG Environment's website on Implementing the EU Water Framework Directive: http://ec.europa.eu/environment/water/water-framework/objectives/implementation_en.htm
[30] See "Good practice in managing the ecological impacts of hydropower schemes; flood protection works; and works designed to facilitate navigation under the Water Framework Directive" at http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/thematic_documents/hydromorphology/technical_reportpdf/_EN_1.0_&a=d and "Case Studies potentially relevant to the improvement of ecological status/ potential by restoration/ mitigation measures" http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/thematic_documents/hydromorphology/technical_studiespdf/_EN_1.0_&a=d
[31] See the policy paper "WFD and Hydro-morphological pressures - Focus on hydropower, navigation and flood defence activities Recommendations for better policy integration" available from http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/thematic_documents/hydromorphology/hydromorphology/_EN_1.0_&a=d
[32] See http://www.ecologic-events.de/hydropower/

the European Commission, relevant European-level organisations and stakeholder groups. Focus of the workshop was on hydropower use and the relationship to hydromorphological changes. The workshop aimed at the exchange of information and views on good practice in hydropower use, strategic priorities on the catchment level as well as instruments to promote hydropower and to improve water status. Its results contribute to the second phase (2007-2009) of the ongoing CIS activity on "WFD and Hydromorphological Pressures", whose activities focus on the exchange of information via workshops rather than the production of further documents.

The documentation for the Berlin workshop is available from the Commission's website[33] (including a preparatory issues paper and a workshop summary report). The workshop's key conclusions are also presented in Appendix 3. The workshop noted that hydropower should take into account future climate change impacts. For example a paper by Lehner et al presents a model-based approach for analyzing the possible effects of global change on Europe's hydropower potential at a country scale[34]. Discussion focused on mitigation and other measures (e.g. pre-planning) that will help both existing and new hydropower plant meet the requirements of the WFD but there appears to have been little that will allay the concerns of plant operators and developers with regard to the impact of the directive on existing operations and future potential.

The conclusion seems to be that the industry and the regulators will need to reach a consensus over these matters, one which may require compromise from both ends. The resource assessment methodology proposed earlier in this report may be one way of ensuring such dialogue, though it is recognised that many of the issues are site specific. There is a tremendous amount of work required to implement the detail of the Water Framework Directive and relevant parties are strongly encouraged to work together to seek solutions that achieve a reasonable balance between environmental improvement and energy/climate change goals. The next section discusses progress in setting up schemes to certify hydropower schemes that meet high environmental standards, one way of ensuring such a balance.

A further workshop on the "Water Framework Directive and Heavily Modified Water Bodies" is scheduled to take place 12 - 13 March 2009 in Brussels[35]. The workshop will focus on information exchange on the following topics:

- Designation of Heavily Modified Water Bodies (HMWB): Exchange of experiences on practical application of HMWB designation processes in the Member States.
- Establishing Good Ecological Potential (GEP): Exchange experiences with the practical application of methods for deriving GEP.
- Objective setting and measures: Discuss experiences of Member States on objective setting for HMWB, including the application of exemptions, and exchange information about planned mitigation measures.

6.4 Certification of "green" hydropower

The divergence of goals between energy generation and environmental protection has been recognised by the industry for some time now, not least because of the difficulty it has faced implementing new projects. For example the International Hydropower Association published a set of sustainability guidelines in 2004[36] to "promote greater consideration of environmental, social and economic aspects in the sustainability assessment of new hydro projects and the management and operation of existing power schemes". In 1995 the International Energy Agency set up an Implementing Agreement whose goal is ""through the facilitation of worldwide recognition of hydropower as a well-established and socially desirable energy technology, advance the development of new hydropower and the modernisation of existing hydropower"[37]. One aspect of this work is to look at the environmental integration of hydropower schemes, large or small. Extensive work has been carried out in order to assess how hydro schemes impact their surrounding and the global

[33] http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/implementation_conventio/workshop_hydropower&vm=detailed&sb=Title
[34] See http://www.usf.uni-kassel.de/usf/archiv/dokumente/kwws/5/ew_8_hydropower_low.pdf and http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6V2W-4B8BMSB-1-K&_cdi=5713&_user=525224&_orig=search&_coverDate=05%2F31%2F2005&_sk=999669992&view=c&wchp=dGLbVtb-zSkWz&md5=df47bd1b4956f5334a43fd10d0bb5de3&ie=/sdarticle.pdf
[35] See http://www.ecologic-events.de/hmwb/
[36] See http://www.hydropower.org/sustainable_hydropower/sustainability_guidelines.html See also http://www.un.org/esa/sustdev/sdissues/energy/op/hydro_scanlon.pdf
[37] See http://www.ieahydro.org/agreement.htm

environment. Sources of impacts, effects and remediation, mitigation or compensation measures have been identified and for the latter their effectiveness has been assessed and recommendations made. The IEA activities included a number on the environmental and social aspects of hydropower[38], an activity to review good practice in hydropower[39], a report on assessment methods for small-hydro projects[40] and the website has a useful library of technical reports[41].

On a similar vein the European Small Hydropower Association (ESHA) has published a guide "Environmental Integration of Small Hydropower Plants"[42], including seven case studies from around Europe. In general the drive is to account for environmental and social impacts as early on in the planning process as possible and to involve all interested parties in the decision-making. There is however a uniqueness to each project and for this reason many environmental and social aspects cannot be used in a standardised hydropower potential assessment methodology. The effectiveness of mitigation measures implementation relies on many different factors. A development that would be considered to bear too heavy an impact on the environment – which means its potential would not be included in the study - could still receive planning permission if mitigation measures were appropriate. This is the role of national and local government to establish and maintain an effective planning process that enables the uptake of hydropower on one side and makes sure that all development considered are taking environmental and social issues into account on the other side.

Green hydropower

It is Switzerland that has pioneered the setting of specific standards to allow the certification of green or sustainable hydropower (principally small-scale). In 2001 the Swiss Federal Institute for Environmental Science and Technology (EAWAG) established a research project to achieve credible guidelines for hydroelectricity generated in an ecologically compatible manner. In a number of publications, Truffer et al set out to specify a systematic approach[43]. In order to differentiate between generalised criteria and those that would be more site-specific, they set up a two step process defining "basic requirements" applicable to all plants and "eco-investments", designed to allow for individually adapted mitigation measures. These are shown in the diagram below.

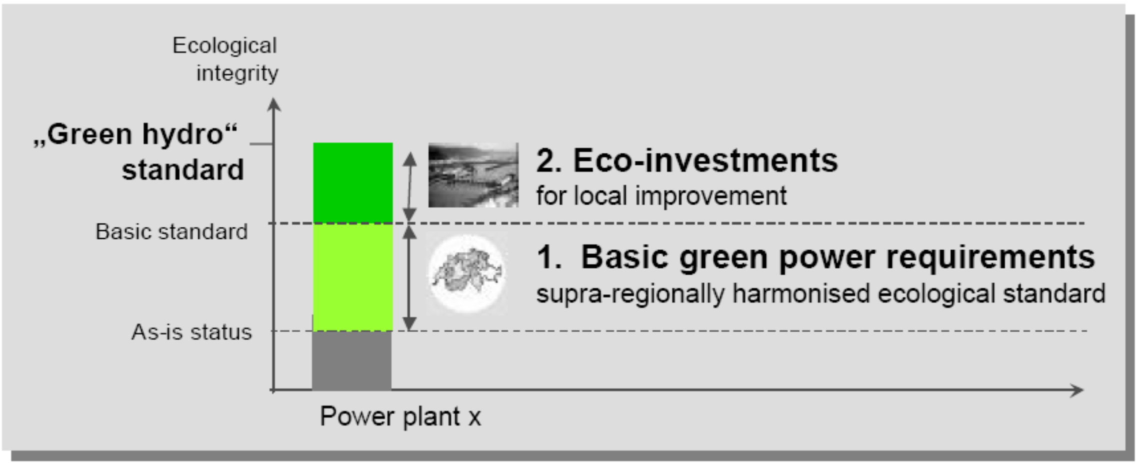


Figure 2: EAWAG's two-step approach to distinguish green hydropower from conventional production: firstly, an individual hydropower plant has to comply with basic requirements that guarantee a certain minimum of ecological function for all different types of hydropower plants. Secondly, the hydropower company must invest a fixed surcharge per kilowatt hour of green electricity in so called eco-investments to mitigate selectively the local degradation of river systems that produce hydropower. Certification will only be granted if both these conditions are met (Bratrich & Truffer, 2001).

[38] Annex III - Environmental and Social Aspects of Hydropower http://www.ieahydro.org/annex3.htm
[39] Annex VIII - Hydropower Good Practices http://www.ieahydro.org/annex8.htm
[40] Assessment Methods for Small-hydro Projects - http://www.ieahydro.org/reports/AnnexII_smallhydro_assessment_methods.pdf
[41] IEA Hydropower Agreement Technical Reports - http://www.ieahydro.org/tech-reports.htm
[42] Environmental Integration of Small Hydropower Plants - http://www.esha.be/fileadmin/esha_files/documents/publications/publications/Brochure_EN.pdf
[43] For example see "Green Electricity: Swiss Standard for Environmentally Compatible Hydropower" at http://www.tceworld.co.in/E-Library/Matulya%20Center/CD%20ROM%20References/Soft%20Copy%20of%20Seminars,%20Conferences/HydroVision%202002%20Conference%20Papers/Papers/091.pdf A more detailed report is available at http://www.oekostrom.eawag.ch/veroeffentlichungen/Issue_7_English.pdf

The Swiss certification procedure includes a participatory process for decision-making and round table discussions as an obligatory element of the procedure. In order to ensure an optimal use of eco-investments all relevant stakeholders are involved in determining measures and priorities for locally adapted mitigation actions. The authors developed a so-called environmental management matrix based on five topics selected to cover the most important aspects relevant to ensuring the ecological integrity of a river ecosystem. These are then formulated as requirements within the framework of five management concepts, as shown in the figure below (Figure 3 from Truffer et al).

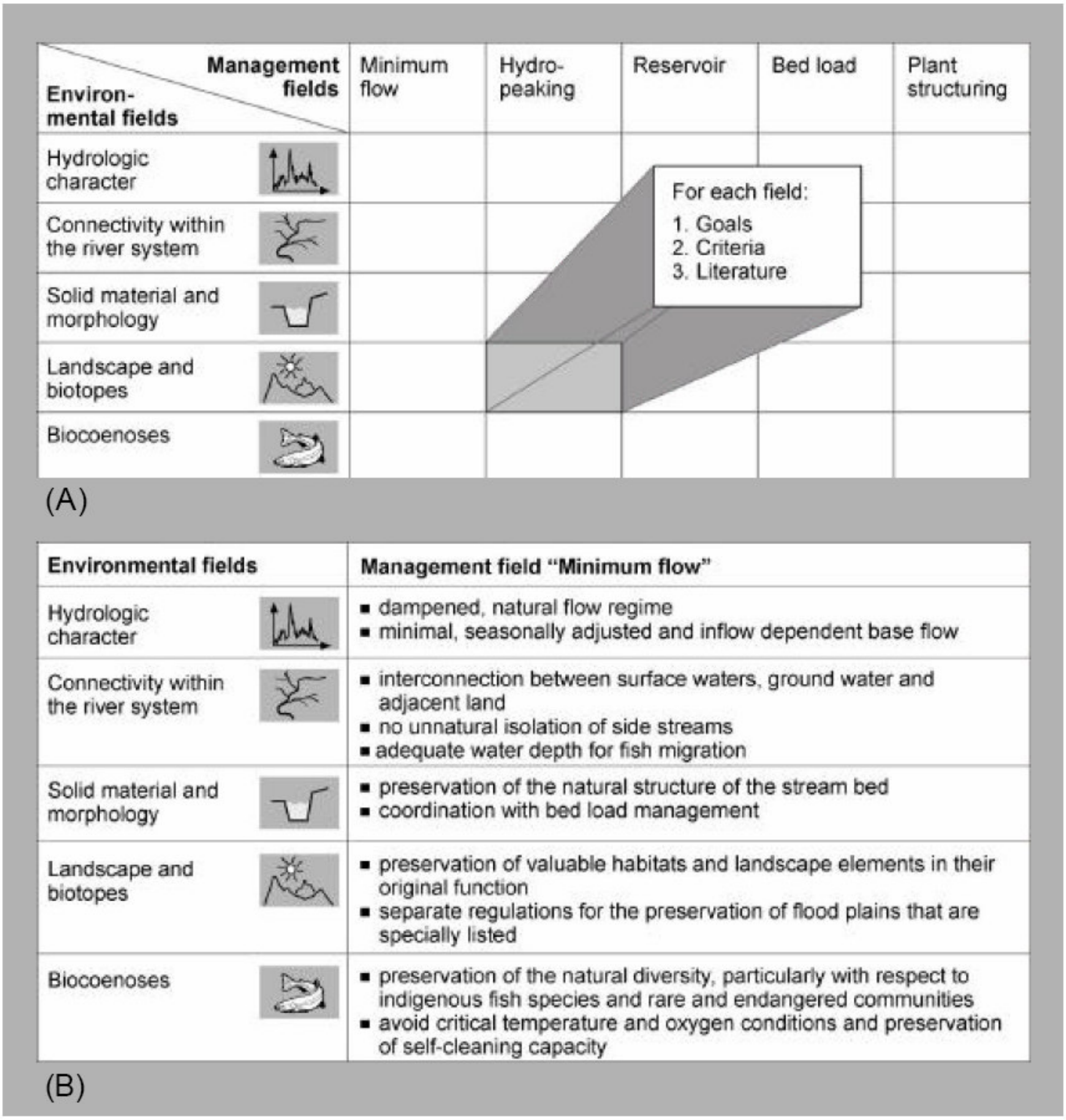


Figure 3: Basic requirements for environmentally compatible hydropower are formulated within an environmental management matrix; (A): General design of the matrix approach. (B): Example for the detailed investigation program: requirements to meet the standard of an ecologically compatible minimum flow regulation (Bratrich & Truffer, 2001).

EAWAG also set up the greenhydro.ch website to disseminate this approach[44]. The European Green Electricity Network (EUGENE) was set up in 2000 and published in December 2006 a fact sheet on

[44] See http://www.greenhydro.ch/level0/index_e.html

sustainable hydropower[45]. This was produced as part of the CLEAN-E project, supported by the Intelligent Energy Europe programme. The project had previously published a more detailed report in 2006 on the development of ecological standards for hydropower[46] and an overview of existing green power labelling schemes[47]. In 2007 the CLEAN-E project published its final report, summarising the overall position for hydropower and biomass[48]. The report recommends that labelling bodies should strive for ambitious eligibility criteria for hydropower plants based on the following three principles:

Principle 1: Basic requirements

All certified green hydropower plants should fulfil basic requirements, which are based on a set of scientific criteria. These criteria include but are not limited to the following:

- Power plants should be designed in a way that allows fish to migrate unimpeded.

- In terms of minimum flow, the hydropower plant has to ensure a discharge regime that closely reflects the natural characteristics of the river system involved.

- Hydropeaking should not seriously damage the river biocoenoses or cause any long-term biodiversity degradation.

- Power plants should enable sediment transport.

- Bank reinforcements and constructions should be designed to prevent deterioration of the connection between the riparian zone and the main river channel.

Principle 2: Eco-investments

The certified green hydropower plant should invest a fixed payment per kilowatt-hour produced (e.g. 0,1 ct/kWh), or sold respectively. These eco-investments should be used to restore, protect or upgrade the environment in the catchment area of the plant and are directly related to the sales of green power to end users. Eco-investments should be specific for each plant and how they will be used should be agreed upon in consultation with local and regional stakeholders.

Principle 3: Reliable assessment procedure

Compliance with conditions 1 and 2 should be assessed through an initial audit of each power plant. Follow-up audits should to be carried out at regular intervals. The audit and certification procedure should be clearly defined, transparent and should not discriminate any hydropower plant or operator.

The implication of the proposed approach is that the plant operator must charge a premium for its electricity to generate the additional income for the eco-investments. Unless this premium is in turn paid by electricity customers willing to pay extra for "certified green" power, it will need to be absorbed within the general cost of hydropower production. Thus green hydropower will be at a slight competitive disadvantage compared with the position of conventional hydropower in the past. Quantifying the size of the premium and the effect it could have on hydropower's market share (or potential for expansion) remains to be done and should be an important goal.

To complete discussion of the position in Europe, it is worth noting that the EU's Intelligent Energy Europe programme has recently approved a project with the name CH2OICE - Certification for Hydro[49]. With participants from Italy, Slovenia, France and Spain, it aims to develop a certification procedure for hydro power generation facilities of high environmental standard, in line with the requirements of the Water Framework Directive, in order to help reduce conflicts in the implementation of RES-e and WFD. It will develop sustainability criteria and a common, agreed general approach for WFD-coherent certification.

Green hydro in the US

The other example of a certification scheme that has been developed for sustainable hydro comes from the US. The Low Impact Hydropower Institute (LIHI) is a national independent environmental non-profit organisation established in 1999[50]. LIHI's mission is to reduce the impacts of hydropower through its Low Impact Hydropower Certification Program, a voluntary certification program designed

[45] Sustainability of Hydropower factsheet at http://www.eugenestandard.org/mdb/publi/14_Clean-E%20hydro%20factsheet%20final3.pdf
[46] See http://www.eugenestandard.org/mdb/publi/6_CLEAN-E%20WP%202.1%20Report%20%20(D2)%20final2.pdf
[47] See http://www.eugenestandard.org/mdb/publi/10_CLEAN-E%20WP%201%20Report%20labels%20%20final.pdf
[48] See http://www.eugenestandard.org/mdb/publi/20_CLEAN-E%20Final%20Report.pdf
[49] See http://www.esha.be/fileadmin/esha_files/documents/workshops/hidroenergia_2008/HE08_Presentations/Day_1/2._Gianluca_Tondi_-_Opportunities_for_SHP_within_the_Intelligent_Energy_Europe_programme.pdf
[50] See http://www.lowimpacthydro.org/

to help identify and reward hydropower dams that are minimizing their environmental impacts. Their objective is to encourage improvements at dams to help reduce their environmental impacts and help consumers seeking “green” electricity to identify hydropower sources that meet tough environmental protection standards.

In order to be certified by the Institute, a hydropower facility must meet criteria in the following eight areas:

1. river flows
2. water quality
3. fish passage and protection
4. watershed protection
5. threatened and endangered species protection
6. cultural resource protection
7. public access and recreation opportunities

The eighth criterion requires that the dam not have been recommended for removal. The criteria standards are typically based on the most recent, and most stringent, mitigation measures recommended for the dam by expert state and federal resource agencies, even if those measures aren't a requirement for operating. A hydropower facility meeting all eight certification criteria will be certified by LIHI, and will be able to use this certification when marketing power to consumers.

The standards are designed to be tough but achievable and to reflect the best available analysis about a project’s impacts. LIHI wants to make sure that a certified Low Impact hydropower facility has minimised its impacts in its particular river context in accordance with the best available science applied to that project. According to its website, the Low Impact Hydropower Institute has certified 36 hydropower facilities to date.

Conclusion

This project started out by examining the factors that define the environmental compatibility of renewable energy technologies and assessing whether it is possible to develop a methodology that can be applied to the assessment of renewable energy resource potentials. It concluded that this is a challenging but worthwhile task, necessary if the potentials for future deployment are to be estimated and modelled on a common basis. One important principle is that definitions for the initial technical potentials need to ensure that the resulting data allow meaningful comparison between different resources and technologies. For example any economic cut-off used must be comparable.

The environmental constraints that are imposed to define environmentally compatible potentials will vary considerably between resources and technologies. Initially one must exclude any resource incompatible with legal provisions such as geographical designations and directives. Then we suggest that only resource that can be exploited in line with good practice guidelines should be included. Defining these guidelines is a significant challenge, best undertaken through a co-operative dialogue between industry representatives and regulatory bodies. Applying the proposed approach to small-scale hydropower suggested that it is workable, but unlikely to be speedy. In addition many of the provisions may need to take into account the subsidiarity principle.

Following consideration of the interim report, it was decided to take a deeper look at the position for hydropower. This is an interesting example, due to the potential for conflict between two clear EU objectives: the goal to treble the contribution from renewable energy by 2020 and the goal to improve the environmental quality of Europe’s water bodies as prescribed by the Water Framework Directive. There is no established methodology for quantifying hydropower potential and a wide variety of approaches have been used. Where environmental constraints are taken into account, it is mainly through the exclusion of certain categories of designated land. A computer based procedure developed in the US is conceptually similar to that proposed in this report, however it would require technical potentials for hydropower to be available on a common EU-wide basis.

The influence of the Water Framework Directive on hydropower operation and future potential is discussed and the evidence indicates that the directive could have a significant impact on these and on the cost of hydropower relative to other electricity options. Considerably more work needs to be done to quantify the impact on a national/regional level.

Finally the emergence of schemes to certify the environmental sustainability of hydropower projects is assessed. Whilst these will add to the cost of hydropower, they should allow the kind of criteria stipulated by the Water Framework Directive to be incorporated and thereby provide a structured basis for hydropower to go forward.

7 Appendix 1: Austrian-French workshop, July 2008

This appendix presents the summary report from the Austrian-French workshop on 4/5 July 2008 on "Hydropower in the context of implementing the EU Water Framework Directive. All presentations can be downloaded at http://rp7.ffg.at/umwelt_va_wfd

The workshop was held in Vienna on 4/5 July 2008. It gathered around 60 experts (scientists, policy-makers, operators, managers, and NGOs) in order to share experiences between Austria and France on research issues related to management of potential social, economical and environmental impacts of hydropower dams in the context of implementing the EU WFD, and to identify research priorities for the future. This report provides a short summary of the presentations, discussions as well as research priorities identified during the workshop.

Context

- Expectations

France (Ministry in charge of environment and Agency for Water and Aquatic ecosystems -ONEMA) and Austria (Ministry in charge of water management and environment) underlined the need to overcome the apparent incompatibility between the EU WFD objectives and the European Renewable Energy Directive and growing goals in renewable energies. With the relative highest share of hydropower generation (60-70 % of electricity production), Austria is a front-runner for a carefully balanced approach within the EU WFD. Austria strongly supports solutions beneficial for the environment as well as acceptable to the sector, i.e. supporting the share increase of renewable energies without watering down environmental objectives. Similarly, the objective set for France are 21% of electricity consumption from renewable energy. Hydropower has a key role in this respect, representing more than 90% of current electricity production from renewables. Options to develop hydropower in France are currently considered in line with the Renewable Directive's objectives. It is commonly accepted that these future developments need to take into account environmental protection criteria, notably related to the Water Framework Directive.
Austria and France's expectations for the workshop were to identify how research can contribute to define an integrative approach for water ecology objectives and renewable energy targets. Both countries were expecting to identify gaps of research and new scientific partnerships. Examples of these contributions were: improvement of river continuity (fishes and sediments), defining in more details needs for residual water, viable and economical solutions that will allow fishes to migrate at dams sites, as well as agreeing on appropriate solutions for a still acceptable level of hydro-peaking to maintain habitat diversity, and going deeper in the understanding of socio-economic drivers.

- Ecological status and potential of European rivers

The objective was to present research results on methods developed by scientists to assess the ecological status and potential of rivers in relation to Hydropower. Fishes are considered as having the highest potential to detect alterations of the good ecological status of rivers in relation with hydro morphological pressures. The ongoing EFI Plus project (http://efi-plus.boku.ac.at/) deals with the development of a fish based index for the assessment of river health in Europe, where the intensity of hydrological, morphological and connectivity pressures has been described to evaluate anthropogenic disturbances on ecological status relevant functions of the fish community. From the first results, it appears that EFI is sensitive mainly to the water quality (Comment:please check again, if this statement is correct). Interactions between water quality and habitat quality; reaction to connectivity alteration have to be further tested. It was furthermore underlined that further research was needed in the fields of interaction between hydropower and climate change, up-scaling local effects of hydropower use to catchment level and detangling effects in multi-impacted rivers.

In parallel, several initiatives are launched to assess the challenges raised by obstacles for fish migration in rivers. As an example, the European Environment Agency (EEA) presented the DamPos and FishPos projects which aim to help assessing some of the challenges raised by obstacles in rivers: fish extension domains (present and past), passing issues... The background is that any contributor can help placing, commenting dams, provided a simple, free, web based application with no host programme. Projects are under development at the EEA in close relation with Member States' entities involved in water management such as ONEMA in France.

Towards managing impacts of hydropower

The objectives were to look at how research can help to address major challenges due to dams: river fragmentation; residual water and hydropeaking; sediment transport and sedimentation and how research can help to design potential solutions: fish passes, regulation; transparency operations; draw-off…

- Consequences of river connectivity disruption on fish populations

A challenge is to consider for the assessment of the rivers, the official biotic indices AND the responses of particular species highly sensitive to connectivity disruption. The experts showed that different connectivity disruptions have to be considered as there is an important link with habitat quality in general and the degree to which dams or weirs have a strong fragmentation effect on a larger scale. Efficiency and building feasibility of fish passes and nature-like structures have also been discussed, showing that downstream facilities are less advanced than upstream ones and that the biological efficiency is not always easy to assess. The interest of restoration strategies at the catchment's level is clearly demonstrated, in particular to have a cumulative approach of the effects.

- Consequences of hydro-peaking on biological elements

In general, hydro-peaking will tend to be more and more erratic in the future. The balance between cost (loss of capacity) and ecological efficiency of measures to improve ecological status (changing the surge relation) seems not to be a linear relationship. Some optimal compromises have to be determined in the future. Studies related to hydro-peaking effects on both fish and macroinvertebrates fauna show the complexity and variety of situations. As an example, the river type probably influences the biological effect. In most cases, there is a lack of accurate information on the frequency and range of flow peaks. Similarly, inventory of all abiotic characteristics of the sites are very often missing or incorrect. That is why long term surveys are needed on a variety of sites. Finally, as aquatic communities are in most cases heavily affected by hydro-peaking operations, the experts also recommended to strengthen the efforts put on ecological knowledge to quantify in more detail the interaction between stress and impact.

- Consequences of minimum flow

Several methods to assess the biological effects of minimum flows have been developed during the last 20 years. Starting from the micro-habitat modelling, one trend is oriented towards the development of more sophisticated models (2D,3D,…), the second is related to statically based approaches. Results from a survey in France on several sites show contrasted situations. There is clearly the need to better consider the complexity of the hydro system and to consider not only fishes but macroinvertebrates and plants (when present). Moreover, tools based on population dynamic models of target species allow considering time-related effects and biotic interactions which could be of first importance. From these models, several biological scenarios in response to minimum flow change can be proposed. They help to evaluate the time required by a population to return to a range close to habitat saturation after an improvement of the minimum flow conditions. Minimum flow effect has not to be considered separately from the influence of the river morphology, (a)biotic parameters and also from the other types of pressure.

- Sediments management and research

This was mainly related to retention of sediment in large dams and the consequences of lack of sediment load downstream (river incision). Geomorphologic and ecological consequences of changes in fine and coarse sediment transport are quite different. In any way, a catchments scale approach is needed to improve the general knowledge on sediment budgets including the tributaries and the change in sediment supply capacity from the catchments itself to the river network. Hydro system and watershed (sediment supply) are heavily changing over time (especially in the Alps) and dams are an element inside this spatio-temporal dynamic system. This dynamic context: temporal changes in sediment load, progressive adaptation of river morphology, modification of the ecological functioning has to be discussed when setting the environmental objectives (in particular when designating heavily modified water bodies). The interest for development of green label for hydropower generation has been also discussed. And cost-efficiency analyses are in general needed.

Future of hydropower in a changing climate

- Hydropower potential

The future development of hydropower was fervently discussed; on one hand the discussion was strongly dominated by highlighting the potential of hydropower to contribute to meet the reduction targets for CO_2 emissions as well as the targets set to increase the share of renewable energy production in the context of climate change; on the other hand concerns were raised with regard to potential impacts of new installations on river ecology, without forgetting the evolution of the electricity market.
Consensus was that hydro power may contribute considerably to achieve these targets. For solving the conflict energy versus ecology, a first step on a promising roadmap was seen in the estimate of the remaining potential for hydropower generation, which was already started by both countries. A second step would include a more in-depth analysis, including an environmental appraisal of potential river stretches for future developments, culminating in decisions on the identification of favourable, less favourable and non favourable sites for additional facilities, based on a transparent approach and taking into account all stakes. This would help the investors to allocate their installations accordingly.

- Hydropower in a changing climate

Regarding direct impacts of a changing climate on hydropower, uncertainties remain in the forecast of influences and future changes in the water cycle as well as temperature patterns. However, climate models predict some important changes in overall annual precipitation for different parts of the Alpine area (South of Alps and the Mediterranean basin. Changes in the hydrological cycle are especially expected during spring and summer with decreased and autumn and winter with increased river discharges. The latter one is also expected to have an impact on aquatic life forms, and on the operation of thermal power plants.

In order to be able to better quantify expected future impacts of climate change on hydropower, further research needs could include putting a stronger focus on the increased understanding and handling of uncertainties, the quantitative impact of climate change on snow cover, glaciers and the entire water balance having a direct influence on seasonal operation of hydropower or new management tools to improve distribution and water-use efficiency. An integrated approach at basin level with trans-disciplinary research activities is considered as necessary in order to improve communication and a better understanding between scientists, stakeholders and policy makers.

Information, communication and socio-economic assessment needs

- Socio-economics R&D needs

Participants agreed on the need to develop knowledge on non-technological issues with regard to hydropower, notably on economics and social issues. Integration of hydropower has to be thought as a society choice. Priorities are to develop information and knowledge on costs, benefits, values and economic instruments as well as developing a better understanding of actor’s system, institutions, perceptions. The challenge would be to use this knowledge in a mature decision making process.

- **River ecology Vs energy targets: enhancing dialogue between stakeholders**

The final session provided an opportunity to have an open discussion on the issue of conciliation of river ecological objectives and promotion of renewable energies and reduction of CO2 emissions. Participants offered the view that WFD should be seen as an opportunity for hydropower, in order to improve efficiency of technologies, design WFD friendly future hydroplants and to refurbish existing ones. Fervent discussions occurred on the issue of development of new facilities: on one hand new facilities are advocated to help supplying the increasing energy demand. On the other hand, the question was raised to assess the real impacts on energy and GES reduction of developing any hydropower potential technically feasible. The issues of public acceptance and legislation adaptation were raised. Those issues could only be addressed through an enhanced dialogue and sharing of experiences between stakeholders from different backgrounds involved in hydropower. In this respect, dialogues should be initiated at any level: power plant ; water basins ; national level ; European and international level.

Conclusions and opportunities for further cooperation

Finally, one institutional meeting and a scientific one took place to identify further cooperation opportunities between France and Austria.

Institutional co-operation

Through this seminar, close contacts between France (Ministry in charge of Environment and ONEMA) and the Austrian Ministry in charge of environment have been established in the field of hydroelectricity in the WFD context. On the science-policy perspective, France invited Austria to consider a closer collaboration within the framework of water-related ERA Nets and to the participation in a “science – end users” platform at the European level, within the Common Implementation Strategy of the WFD. On a more general basis, French and Austrian WFD communities welcomed the opportunity to share experiences between managers and scientists based on a state of the art of current knowledge, methods and technologies. Finally, the European environment agency (EEA) invited France and Austria to develop further cooperation.

Scientific co-operation: common ideas for research topics on water and hydropower

The co-operation opportunities are the following : Austria is warmly invited to take part in the ERA-NET on water ; Austrian and French scientists could work together to influence the European commission by preparing research agendas with policy makers, agreeing on a minimum common road-map, acting together to influence the commission towards their common priorities ; organization of workshops in order for example to loop towards updating research road-map ; based on the presentations of the sessions 1 to 4 and on the road-map agreed during the meeting, French and Austrian scientists should propose one large co-operation project and two or three smaller ones during the autumn 2008, on the following themes:

- large project: Trade off between renewable energy Directive and Water Framework Directive for European waters
- smaller projects:
  a) Hydro-peaking
  b) Sediment and river bed morphology and stabilization
  c) Ecological continuity

The possibility to attract French-Austrian or European funding should then be explored after taking advice from end-users (ONEMA, European environment agency, Lebensministerium).

8 Appendix 2: U.S. Hydropower Resource Assessment

The following information is extracted from the U.S. Hydropower Resource Assessment Final Report, December 1998, available from http://hydropower.inel.gov/resourceassessment/pdfs/doeid-10430.pdf

Site Attributes and Suitability Factor Determination: Environmental, Legal, and Institutional Attribute Definitions

The Idaho National Engineering and Environmental Laboratory (INEEL) derived the following 19 environmental attributes from the Nationwide Rivers Inventory. The corresponding suitability factors are fully explained in the Suitability Factor Determination section below.

Wild/Scenic Protection
This attribute identifies project sites that are included in the federal wild and scenic rivers system, under consideration for inclusion in the federal system, included in a state river protection program, in a designated wilderness area, or protected from development under another program. Relatively few sites have this status, but those that do are highly unlikely to be developed. Projects at undeveloped sites on state or federally protected wild and scenic rivers, or in wilderness areas, must be assumed to be legally protected from hydropower development. Also, projects at sites under consideration for protection are highly likely to be opposed by state and federal resource agencies, and protection will be approved at many such sites before hydropower development could occur. Since it is possible, but highly unlikely, that development could occur at a site with wild and scenic river protection, the suitability factor assigned to all such projects at undeveloped sites is 0.1.

It is highly unlikely that a project at an existing dam would be on a wild and scenic river since rivers are usually designated as wild and scenic only if they are free of developments such as dams. A suitability factor of 0.5 is assigned for such unusual cases.

Wild and Scenic Tributary or Upstream or Downstream of a Wild and Scenic Location
This attribute is assigned to a project if it is at the upstream or downstream end of a wild and scenic river reach or is on a tributary of a wild and scenic river. A project at a developed site would affect a downstream wild and scenic river if additional alterations to the flow regime resulted. A suitability factor of 0.75 is assigned for such projects. Projects at undeveloped sites are highly likely to alter the flow regime and may cause changes in downstream water quality, so a suitability factor of 0.5 is assigned to undeveloped sites.

Cultural and Historic Values
Project impacts on cultural and historic resources can often be mitigated (for example, by excavating archeological sites or relocating historic structures). Projects at existing dams are unlikely to affect such resources unless an increase in reservoir pool elevation occurs or major new structures are built. A suitability factor of 0.75 is assigned to such projects. Development of undeveloped sites is more likely to affect cultural and historic resources, so a suitability factor of 0.5 is assigned.

Fish Presence Value
A stream reach may or may not have legally protected fisheries. In either case, however, strong state opposition to new development must be expected if a valuable fishery resource exists. Relatively high instream flow release requirements can mitigate the impact on fisheries, but a high instream flow release would reduce the economic viability of the project. Projects at developed sites could have some impact, such as increased turbine mortality. A suitability factor of 0.75 is assigned to projects at developed sites. Development at undeveloped sites could have a major impact on aquatic habitat through inundation, migration blockage, turbine mortality, water quality, and altered flows. Some of these can be mitigated, but such mitigation could be expensive. A suitability factor of 0.25 is assigned to undeveloped sites.

Geologic Value
Geologic values such as rock formations are rarely protected legally and are not generally affected by small projects. Development at existing sites is not affected by geologic resources, so a suitability factor of 0.9 is assigned. Development at undeveloped sites may inundate geologic features, so a suitability factor of 0.5 is assigned.

Recreation Value
River recreation users tend to be effective opponents of hydropower development. Development at any storage dam would affect recreation by altering flow releases; mitigation typically includes higher flow releases during periods of high recreation use. Such releases can be made through turbines, but higher flow releases tend to occur when power demands are low. Projects at existing dams would have little effect on recreation besides flow alterations, so they are assigned a suitability factor of 0.75. Projects at undeveloped sites would inundate reaches, block the passage of boats, and reduce aesthetics. Because projects at undeveloped sites are likely to be strongly opposed, a suitability factor of 0.25 is assigned.

Scenic Value
Scenic values are not legally protected but must be considered in assessing the impact of a project. Scenic values are also important to recreational river users. The addition of power to existing dams would alter scenic values only through the addition of new structures and perhaps by reducing visually attractive spillage, so a suitability factor of 0.9 is assigned. New projects at undeveloped sites would have important effects on scenic resources because views would be altered by the project. Undeveloped projects are assigned a suitability factor of 0.5.

Wildlife Value
Terrestrial wildlife and wildlife habit are protected by fish and game agencies that are influential in determining mitigation requirements for hydropower projects. Development at existing sites would have little effect on wildlife unless reservoir pool elevations are altered or construction of major facilities is required. A suitability factor of 0.75 is assigned for projects at existing sites. Development at undeveloped sites could inundate wildlife habitat, and construction would cause a great deal of disturbance. It is difficult to mitigate for such impacts, so opposition to such a project could be strong. Undeveloped projects are assigned a suitability factor of 0.25.

Other Value
The effects of other values, such as the presence of rare wetland communities or consideration for wilderness designation, are assigned by using the most commonly assigned suitability factor for the other values. For projects at developed sites, the suitability factor is 0.75. For projects at undeveloped sites, the suitability factor is 0.5.

Threatened and Endangered Fish or Wildlife
The presence of threatened and endangered species near a project site requires additional consultations with wildlife agencies and can result in additional studies and mitigation requirements. The presence of threatened and endangered fish species may preclude development of new storage projects because new projects can involve the greatest alteration of aquatic habitat. Terrestrial threatened and endangered species are unlikely to be highly affected by run-rivers projects, but storage reservoirs could affect terrestrial habitat. For existing sites, a suitability factor of 0.75 is assigned when threatened and endangered species are present. For projects at undeveloped sites, a suitability factor of 0.5 is assigned when threatened and endangered species are present.

Federal Land Code 103: National Park, Monument, Lakeshore, Parkway, Battlefield, or Recreation Area
These lands are legally protected from development. A suitability factor of 0.1 is assigned for such projects.

Federal Land Code 104: National Forest or Grassland
These lands are not legally protected from development, but the managing agency has the right to impose additional mitigation requirements on projects. A suitability factor of 0.75 is assigned to projects at existing sites, since these projects typically have fewer impacts. A suitability factor of 0.5 is assigned for undeveloped sites.

Federal Land Code 105: National Wildlife Refuge, Game Preserve, or Fish Hatchery
These lands are managed for fish and wildlife habitats, and hydropower development would almost always be incompatible. A suitability factor of 0.1 is assigned for such projects.

Federal Land Code 106: National Scenic Waterway or Wilderness Area
These lands are legally protected from development. A suitability factor of 0.1 is assigned for such projects.

Federal Land Code 107: Indian Reservation
These lands are not legally protected from development, but Indian tribes have the right to impose additional mitigation requirements on projects. A suitability factor of 0.75 is assigned for projects at developed sites, and a suitability factor of 0.5 is assigned for projects at undeveloped sites.

Federal Land Code 108: Military Reservation
These lands are not legally protected from development, but the managing agency has the right to impose additional mitigation requirements on projects. A suitability factor of 0.75 is assigned for projects at developed sites, and a suitability factor of 0.5 is assigned for projects at undeveloped sites.

Federal Land Code 198: Not on Federal Land
This variable indicates that the project is not on federal land, so there are not any development constraints based on Federal Land Codes. The value for this variable is 0.9.

Suitability Factor Values
Suitability factors depend on the environmental attributes of the potential project site. They reflect the probability that environmental considerations can make a project site unacceptable, prohibiting its development. The suitability factors were developed in conjunction with Oak Ridge National Laboratory staff who are experienced in hydropower licensing cases. Five potential values were selected, as shown in Table 1. These suitability factors are appropriate only for the regional analysis of overall hydropower development capacity and are not useful for determining the ultimate viability of developing a specific project site.

Table 1: Valuation of environmental attributes

Effect of Environmental Attribute	Value of Project Environmental Suitability Factor (PESF)
Least impediment to development	0.90
Minor reduction in likelihood of development	0.75
Likelihood of development reduced by half	0.50
Major reduction in likelihood of development	0.25
Development prohibited or highly unlikely	0.10

Figure 1 overleaf illustrates all of the data requirements presented above in a report printout from HES. The cultural, fish presence, historic, and scenic values combine to give the sample site a project suitability factor (PESF) of 0.5.

Figure 1: Sample printout of Hydropower Evaluation Software resource database listing

Georgia Hydropower Resource Database Listing

FERC Number:	01218	*Plant Name:*	FLINT RIVER
Class:	P	*Stream:*	FLINT R
Owner:	GEORGIA POWER CO	*County:*	DOUGHERTY
		Basin:	APALACHICOLA RIVER BASIN

Name Plate Rating (KW)	*PESF*	*PESF*KW*	*Annual Energy Rating (MWh)*	*PESF Annual Energy Rating (MWh)*
2800	0.5	1400	8700	4350

Unit Type	*Plant Type*	*Project Status*	*Dam Status*	*Latitude*	*Longitude*
C	ROR	MO	W	3137	8406

Factor	*Exists*	*Prob*	*Factor*	*Exists*	*Prob*
Wild/Scenic Protection		0.9	*Wildlife Value*	Y	0.75
Wild/Scenic Tributary or Upstream/Downstream			*Threatened/Endangered Fish*		0.9
Wild/Scenic Location		0.9	*Threatened/Endangered Wildlife*		0.9
Cultural Value		0.9	*Federal Land Code 103*		0.9
Fish Presence Value	Y	0.75	*Federal Land Code 104*		0.9
Geologic Value	Y	0.9	*Federal Land Code 105*		0.9
Historic Value		0.9	*Federal Land Code 106*		0.9
Other Value		0.9	*Federal Land Code 107*		0.9
Recreation Value	Y	0.75	*Federal Land Code 108*		0.9
Scenic Value	Y	0.9	*Federal Land Code 198*		0.9

9 Appendix 3: Conclusions from the WFD and Hydropower workshop in Berlin, June 2007

Workshop held under the Water Framework Directive Common Implementation Strategy in Berlin, 4-5 June 2007

Key Conclusions[51]

General remarks

1. The benefits of hydropower as a highly reliable CO_2-free and renewable source of electricity production but also the need to maintain the ecological functions of hydropower-affected water stretches have to be taken both into account to achieve a proper and well-balanced approach to meet climate, water & nature protection objectives.

2. It is important to ensure that existing and forthcoming EU policies to promote hydropower ensure coherence with the Water Framework Directive/other EU environmental legislation and clearly consider the ecological impacts on the affected water bodies and the adjacent wetlands.

3. The discussion has shown that more holistic approaches for hydropower use are needed. The focus should be on catchment level and not only site-specific or on water body level.

4. During WFD implementation, an environmental assessment based on WFD criteria is required for all water bodies including those with hydropower plants. This assessment includes other environmental criteria and a socio-economic assessment. In addition, in the River Basin Management Plans, all water uses have to be taken into account.

5. Hydropower development should take into account future climate change impacts. Possible future conflicts between new hydropower priorities due to climate change impacts and the aims of the WFD to achieve GES or GEP should be taken early into account.

6. The Berlin workshop was the first occasion, where broad and intensive discussions took place on the European level between hydropower stakeholders and those responsible for the implementation of the WFD on the national level. There is a strong recommendation to continue the discussions to achieve sustainable solutions concerning hydropower and WFD requirements.

Instruments to promote hydropower & to improve water status

7. National and European instruments (such as tradable certificates, feed-in tariffs, support schemes for renewables or ecolabelling) to support and promote hydropower development should be linked to ecological criteria for the protection of water status.

8. There should be a clear insight into all costs & benefits of hydropower. This insight will help sustainable decision-making on hydropower projects and implementing the polluter pays principle.

[51] http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/implementation_conventio/workshop_hydropower/hydro-morphology/_EN_1.0_&a=d

9. The workshop identified 3 practical approaches for integrating good water status and utilisation of hydropower. For new plants, best available techniques (BAT) should be defined and utilised. For old plants which are to apply for new permits, environmental concerns should be addressed while issuing the new permit. For old plants with continuing long-term permits, financial incentives may be helpful. Monetary or nonmonetary compensation should be considered for long-term concessions.

10. The workshop participants recognised the advantages of pre-planning mechanisms to facilitate the (proper location) identification of suitable areas for new hydropower projects. These pre-planning mechanisms should take into account WFD and other environmental criteria as well as socioeconomic aspects, including other water uses. The use of such preplanning systems could assist the authorisation process to be reduced and implemented faster, provided that the criteria of WFD Art. 4.7 are met.

11. At least 3 categories of areas could be distinguished for pre-planning: suitable, less favourable and non-favourable areas. These categories should be identified with the involvement of all stakeholders based on transparent criteria, they should be monitored and revised within a period of time.

12. Small and large hydropower should be treated equally with regard to promotion. Promotion should be based on basin-specific as well as site-specific WFD criteria and global environmental criteria (climate change) and not on the size of the hydropower plant per se.

Technical approaches for good practice in hydropower use

13. Biological continuity (upstream and downstream migration) and ecologically acceptable flow were identified as priority considerations for the improvement of water ecological status. Hydro-peaking is also of importance (e.g. erosion and habitat degradation).

14. <u>Biological continuity</u>: For upstream migration, many solutions are available (e.g. fish passes and fish ladders, but also fish lifts, fish stocking, catch & carry programmes etc.) to mitigate the negative impact of migration barriers – but more work needs to be done on evaluation and monitoring of effectiveness. Much research leading to technical innovations has still to be undertaken, especially related to downstream migration in combination with turbine damage.

15. <u>Ecologically acceptable flow</u>: Approaches to determine ecologically acceptable flow have been developed and are being further developed by several European countries. There is no one-size-fits-all approach - a combination with other mitigation measures is often necessary.

16. The use of compensating measures together with mitigating measures is highly recommended.

17. <u>Hydro-peaking</u>: Some studies identify serious ecological consequences of hydro-peaking, but there are still knowledge gaps. Mitigation options are limited and often involve high costs due to the loss of peak-load capacity and their designated function. However, examples for the successful implementation of mitigation measures also exist (like coordination between hydropower plants).

18. Some degree of standardisation at European level is desirable, but solutions for mitigation measures will have to be largely site-specific (e.g. definition of ecologically acceptable flow). Exchange of information should be promoted on standards that have been developed by different countries or organisations (e.g. for continuity).

Strategies & priorities on catchment level

<u>New hydropower projects</u>

19. New hydropower projects are compatible with the WFD as long as they comply with the Art. 4.7 test.

20. For new hydropower projects, external effects – e.g. on the water environment – should be taken into account properly by the use of the Art. 4.7 test. There is relatively little experience across Member States with the use of this test. Exchange of experience is needed to develop a transparent approach.

Delivering improvements for existing hydropower

21. It was agreed that prioritisation of measures, catchment areas and rivers is compatible with the WFD but the Member States should deliver a proportionate programme of measures.

22. Criteria for prioritising action in regions affected by hydropower should consider different scales. On the European level, species and habitat issues of ecological importance should be identified, for example via the Natura 2000 designation process. Other criteria on an international level are lateral connectivity regarding wetlands and management of water and sediment flow. On the catchment and regional level, longitudinal continuity for key migrating fish is especially important. On the level of water bodies/groups of water bodies, we should also consider lateral connectivity, the geographical scale of impact and severity and we should identify trends (to prevent deterioration). Measures that bring the highest improvement potential, calculated as e.g. river length, should be prioritised.

23. We should aim at achieving self-sustaining populations of migrating fish species where possible/needed and where historically verifiable at the catchment level, in particular aiming at delivering interconnectivity in combination with habitat and spawning ground conservation/restoration. Interdependency of measures should be regarded as well as the risk of negative impacts of measures, such as introduction of alien species and climate change.

24. In addition to the definition of ecological priorities, we should use socio-economic analysis to define a cost-effective programme of measures. This work should ideally be undertaken at a catchment or sub-catchment level, so as to maximise the ecological potential and the energy production. Economic aspects for hydropower should include a wide range of benefits (e.g. economic importance of species, economic uses of water) and costs (financial cost of measures, environmental and resource costs). Social aspects also bringing benefits include recreational/amenity value, tourism, multifunctional use for hydropower, flood protection, fisheries as well as public views on the relative importance of benefits/costs (public participation).

25. The main advantages of prioritisation for all surface waters are:

    - Provision of technical basis for the prioritisation of measures to improve hydromorphology and ecology.

    - Establishment of a strategy on catchment level to ensure a coordinated and uniform approach for delivering ecological improvement and ultimately reaching GES/GEP in the River Basin Management Plans.

    - Ensuring the selection of cost-effective and ecologically efficient measures to deliver ecological improvement, e.g. biological continuity.

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