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The facilitation of mini and small hydropower through institutional mechanisms for development

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Abstract

Mini and small hydropower is a renewable, clean and efficient resource for the production of mechanical and electrical power. By offsetting thermal generation, it can be a leading technology in climate change mitigation and sustainable development. Small hydropower plants combine the advantages of hydropower and decentralised power generation. There are limited environmental costs, marginal costs for the electricity transport, minor need for expensive maintenance and independence from imported fuels. Small (and mini) hydropower can be combined with other infrastructures, such as flood protection, potable and irrigation networks. Compared to other renewable energy sources SHP has a significantly higher energy payback ratio and in average lower production costs. The technology is mature although the projects are not cost-efficient under the current framework conditions, characterised by the non-internalisation of external costs of energy production (e.g. GHG emissions). SHP therefore requires adequate frameworks (e.g. streamlining of procedures, adequate financial mechanisms, etc.) to be implemented under economically viable conditions. There is also a demand for a strategy that includes sustainable spatial planning in the process of large scale implementations of SHP, to reduce the risk of irreversible environmental impacts in large regions.

The paper aims to identify and develop policy shaping institutional mechanisms (including spatial planning) to facilitate mini and small hydropower. SHP can contribute strongly to electrification, to improve the local economic situation (e.g. jobs), to reach the Millennium Development Goals and to protect the environment.

Keywords: mini and small hydropower, institutional framework, spatial planning

Table of Content

Table of Figures

Table of Tables

Glossary

SHP	Small Hydropower
MHP	Mini Hydropower
RES	Renewable Energy Sources
MDG	Millennium Development Goals
WFD	Waterframework Directive
CDM	Clean Development Mechanisms
GHG	Greenhouse Gases
CER	Certified Emissions reductions
TGC	Tradable Green Certificates
ETS	Emission Trading Schemes
SFOE	Swiss Federal Office of Energy

1. Introduction

Climate change and sustainable development are top priorities worldwide today. Access to electricity is one of the keys to development, as it provides light, heat and power for productive uses, health services, education, security and communication. Today, 1.7 billion people in developing countries do not have access to electricity, most of them living in rural areas. This number is still increasing. In addition, about 3 billion people are without access to clean cooking energy. The World Bank published this year, a paper on infrastructure endowments which shows the huge lacking behind of Sub-Saharan Africa, but also South Asia and East Asia and Pacific (Table 1). 80% of the world's population lives in developing countries, but they consume only 20% of the global commercial energy (ESHA and IT Power, 2005, p. 3). According to the World Bank, most of the world's poor people spend more than 12% of their total income on energy, which is more than four times what a middle-income family in the developed world spends (ESHA and IT Power, 2005, p. 3). Achieving the Millennium Development Goals will require significantly expanded access to energy in developing countries. In this context, mini and small hydropower must be used as a key tool for development.

Region	**Electrical generating capacity (MW per 1 million people, 2003)**	**Access to electricity (% of households with access, 2004)**
Sub-Saharan Africa	70	18
South Asia	154	44
East Asia and Pacific	231	57
Latin America and Caribbean	464	79
Middle East and North Africa	496	88
Europe and Central Asia	970	-

Table 1: Infrastructure endowments by world region (Yepes, Pierce et al., 2009)

The growth of the world's population, especially in developing countries, will require the appropriate infrastructure for irrigation, water supply and flood protection, and even productive fishery. The addition of a mini hydropower (MHP) or small hydropower (SHP)[1] component to such a project is economically sensible and has no major environmental or social impacts. Instead, it has a broad range of benefits through ensuring decentralised energy supplies (ESHA, 2006, p. 5), e.g. additional revenues for the local population (prevention of migration into cities), or benefit from CO_2-compensation mechanisms (Clean Development Mechanisms (CDM), Adaptation Funds).

During the 20th century, interest in mini and small hydropower reduced drastically due to the progress of other technologies, the success of large generation schemes and large grids bringing down costs, mass production of small diesel sets that were both portable and easily installed, and easy access to affordable diesel fuel. In the more recent past, climate change, energy poverty in developing countries, and commitments for achieving the MDGs, have led to a rethink. The depletion of oil and natural gas deposits will lead to higher generation costs for thermal plants. By offsetting thermal generation, small hydropower can be a leading technology in efforts to reduce greenhouse gases.

Small scale hydropower is one of the most cost-effective energy technologies for rural electrification in developing countries as it is a main energy source for decentralised and off-grid electricity production.

[1] This paper looks at mini and small hydropower together as their facilitation concerns similar mechanisms and aspects. To facilitate the reading, only the term small hydropower (SHP) will be used, except in cases where it concerns specifically mini hydropower, in which case MHP is used.

There are no huge investments for establishing transmission and distribution grids. Unlike with wind or solar power, SHP doesn't require storage capacity (e.g. battery) in the case of run-of river plants.

SHP plants have the most chance of being economically viable if they provide power to productive end-users (e.g. mill, local manufacturer), during the day, and if they are socially accepted (e.g. fulfil a role within social infrastructure such as public lighting at night, which is considered in the same way as a safe water supply, school or health program) .

The main advantages of SHP are:

- It does not involve a process of combustion, therefore avoiding CO_2 emissions, acid rains and smog; it is a **clean resource**;
- The fuel is water, which is not consumed in the electricity generation process; it is a **renewable resource**;
- SHP is available within the borders of one country and not subject to disruption by international political events, and, because it is a domestic resource, it is not subject to market fluctuation like fuel or natural gas; it is a **secure resource**;
- It can satisfy energy demand with no depletion of the resource and with little impact on the environment; it is an **efficient resource**;
- Usually, it does not require the creation of large lakes, thus avoiding sedimentation problems and the filling of the reservoir; it is a **sustainable resource**.

This paper is part of ongoing research projects which have been interlinked in order to complement each other. The aim of the paper is to identify and develop institutional mechanisms to facilitate mini and small hydropower in developing countries, in order to provide significant economic development benefit in rural areas, where small amounts of energy – in the form of electricity, heat, and mechanical power – can have very positive impacts on income, education, health, and food security. To prevent an uncontrolled spread in space and time, an appropriate and well approved (in Switzerland) instrument shall be developed. One, that suggests, based on sustainability, possible service sites of SHP and their spatial distribution on a local as well as on a regional scale. It shall allow the proposal of solutions showing future scenarios with different intensities of exploitation. All this contributes to achieving the MDGs.

2. Mini and small hydropower

Mini and small hydropower plants combine the advantages of hydropower with those of decentralised power generation. There are limited environmental costs, no costly transport of electricity and minor need for expensive maintenance. However, most projects are not cost-efficient and require an adequate institutional framework to be implemented with contributions from the private sector.

2.1 Definition and history

The definitions used in this paper correspond with International Energy Agency (IEA, 2003, p. 31) and World Bank definitions, as well as with most of the European regulations:

- Mini hydropower (MHP): 100 – 1'000 kW or 0.1 – 1 MW
- Small hydropower (SHP): 1 – 10 MW

SHP has a long history. First hydraulic machines in China and the Mediterranean basin date from 200 B.C (Andaroodi, Schleiss et al., 2005, p. 20). The first hydroelectric scheme was installed in Wisconsin, USA in September 1882 only three years after Thomas Edison invented the light bulb. In the early 20th century, there were thousands of MHP and SHP plants across Europe. In the case of Switzerland, more than 90% were rated below 300 kW and consisted of water wheels and mini turbines (Leutwiler, 2006). Plants were also built in developing countries, but today the potential is far from being used (see Section 2.3). History shows that MHP and SHP are mature technologies.

2.2 Technology

Hydropower-turbines convert water pressure into mechanical power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of head and flow rate. The simplified formula for hydro system power output is:

$$P = e \cdot g \cdot Q \cdot H \tag{1}$$

Where:

- P stands for Power [kW]
- e describes the overall efficiency of the system (generally around ~80%)
- g is the gravity acceleration [9.81 m/s^2]
- to simplify the formula, factor 8 can be introduced taking into account e and g
- Q is the volume flow rate passing through the turbine [m^3/s],
- H is the effective pressure head of water across the turbine [m].

A hydropower scheme is given in Appendix 1 with the different classification for SHP.

High head hydro generally provides the most cost-effective projects, since the higher the head, the less water is required for a given amount of power and therefore smaller and hence less costly equipment is required. However, high head sites tend to be in areas of low population density where the demand for electricity is small, and long transmission distances to the consumer can nullify the low cost advantages of remote high head systems. Therefore the greatest scope for expanding the use of SHP is the increasing use of low head sites.

SHP has a high energy payback ratio. For each power generation system, the “energy payback” is the ratio of energy produced during its normal life span, divided by the energy required to build, maintain and fuel the generation equipment. If a system has a low payback ratio, much energy is required to build and maintain it and this energy is likely to produce major environmental impacts. Run-of-river hydropower has an energy payback ratio of 30 to 267; biomass 3-27; wind power 5-39; solar photovoltaic 1-14 (ESHA, 2006, p. 6). The payback ratios do vary significantly for renewable energies due to variable site conditions (e.g. topography in the case of hydropower, quality of the wind, intensity of solar radiation for solar energy).

Compared to other RES, SHP has, on average, lower production costs (including financial costs). As example, Chandrasekhar published a survey of the economics of renewable energy in India, summarised in the following table.

Energy source	**Capital cost (US$ Million/MW)**	**Cost of generation (US cent/kWh)**
Small Hydro	0.9 – 1.3	5 – 6
Wind	0.95 – 1.1	6 – 7
Biomass Power	0.8 – 1.0	5 – 6
Biogas Power	0.6 – 0.8	5 – 6
Solar PV	5.2 – 6.2	19 – 41

Table 2: Economics of renewable energy (Chandrasekhar, 2006)

As with other RES projects, hydropower projects have a high initial investment followed by low operational costs.

For plants with an installed capacity below 300 kW, standardised construction and standardised electromechanical equipment are possible. Plants above 300 kW require individual design specific to the geographical site.

Newly designed SHP plants can be well integrated environmentally and respect issues of the water intake, minimum instream flow (downstream of the water intake) and fish pass (fish ladders and environmentally friendly runner blades). On a worldwide level, SHP is one way to enable people to have electricity and to protect the environment.

In the case of MHP projects, no resettlement is usually needed although in a small number of cases some households may have to move. However, the scale of this is naturally linked to the capacity of the plant which is mini.

Some of the main strengths and weaknesses of SHP are summarised in the following table:

Strengths	Weaknesses
> decentralised production - Small power demand (small industries, farms, households and rural communities) - Connection to the national grid	**> limited expansion** - Maximum useful power output is attached to a given hydropower site.
> high efficiency - Long-lasting and robust technology (≥ 50 yrs)	**> variability in discharge** - Considerable variety in seasonal discharge especially in monsoonal and mountain climates, limiting the power output to a rather small fraction of the possible peak output.
> local manufacturing - An international technical quality level is possible (technology transfer North-South and South-South), contributing to economic growth and increasing sustainable operation and maintenance.	**> flat areas** - Maximum useful power output is limited due to small pressure heads
> local economy promotion - A major part of SHP project costs are civil works, which contribute to the local economy if local construction companies exist which helps to diminish opposition risk.	**> environmental impact** - Except where there has been reasonable planning in advance
> renewable energy source	
> multipurpose infrastructure - Possibility to integrate SHP in existing infrastructure	

Table 3: Strengths and weaknesses of SHP

2.3 Potential

Hydropower (large, small and mini) remains by far the most important RES for electricity production worldwide. At the “International Network on Small Hydro Power Conference 2006” it was said that 82% of total technically feasible hydropower potential is exploited in USA, 65% in Canada, 73% in Germany, 23% in China, but only 5% in Africa and 13% in Asia as a whole. The World Hydropower Atlas 2000 (International Journal of Hydropower and Dams, 2000) estimated the world’s technically feasible hydro potential at 14,370 TWh/year, which is 90 % of the global electricity consumption of 2006 (IEA, 2008). The economically feasible proportion of this has been considered to be 8080 TWh/yr. In 2006, RES represented 18 % and hydropower 16% of the electricity generation, (IEA, 2008).

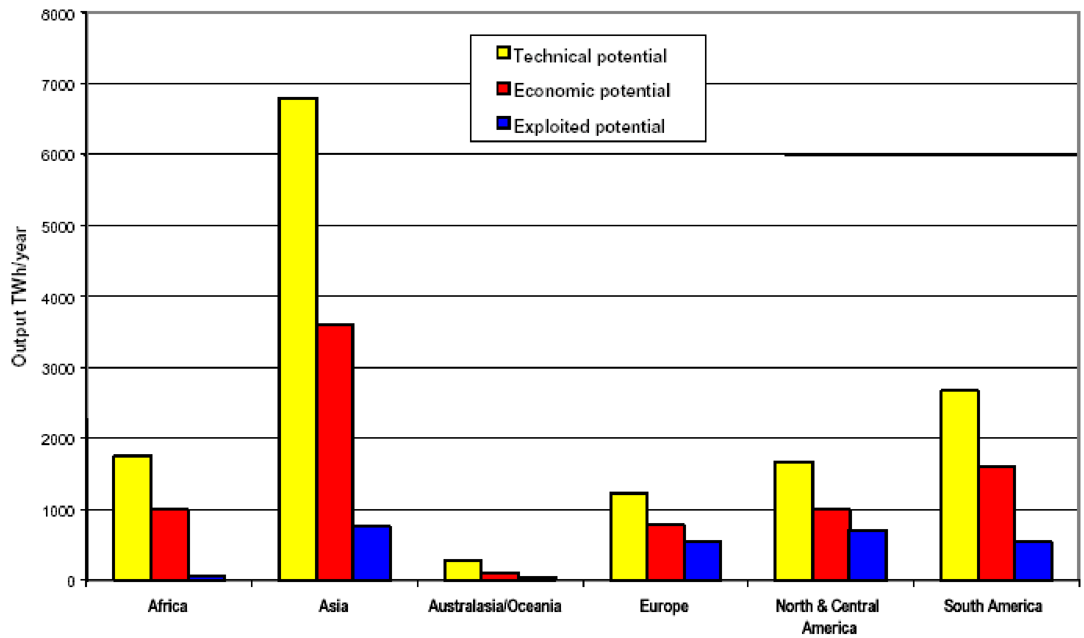

Figure 1: Total hydropower potential by continent (International Journal of Hydropower and Dams, 2000)

There remains a large potential for hydropower (including SHP and MHP) most especially in Asia and Africa.

3. Institutional framework and financial mechanisms

Today, there is a shift on investment patterns in renewable energy away from traditional government and donor sources to greater reliance on the private sector (e.g. public private partnerships). Markets are created and need to be sustained. Liberalisation and privatisation processes in the infrastructure industries can be found in many developing countries. This tendency will increase as the public sector does not have the necessary funds to rehabilitate old and build new infrastructures such as in the electricity sector. In addition, development cooperation is likely to move to more private involvement as suggested by Dambisa Moyo (2009).

Due to the liberalisation process, the institutional framework has changed from a public utility-oriented system towards a market-oriented system even though electricity is still seen as an essential service. The liberalisation process of the electricity sector focuses on institutional changes, such as deregulation, reregulation, unbundling, introduction of competition at the production level and sales. Transport and distribution remain monopolies which need to be strictly regulated. The aim behind the liberalisation process is to increase the economic and systemic efficiency as well as the quality. The process, even in Europe, is pointing in the direction of the development of decentralised and small-scale power production, which requires less investment and is perceived as being less risky (Künneke, 2008, p. 235). SHP is one technology to assure such production.

A reason why most MHP and SHP projects are not economic profitable under the current framework conditions is that the external costs of energy production (e.g. pollution such as GHG emissions) are not internalised. Costs tend to be significantly higher than those of conventional sources of energy. Consequently, SHP and RES in general require two essential elements for a growing deployment: (i) a stable regulatory framework to reduce uncertainty and attract investors, and (ii) price support mechanisms that enable renewable producers to enter the market and make a reasonable profit whilst respecting environmental constraints

The following section introduces briefly the theoretical framework.

3.1 The co-evolution between technology and institutions

The conceptual framework for analysis in Section 3is the literature on the co-evolution between institutions and technology in the case of network industries such as electricity (Finger, Groenewegen et al., 2005; Groenewegen, 2005; Hodgson, 2006; Künneke, 2008; Künneke, Groenewegen et al., 2008; Ménard, 2009). The framework of co-evolution between institutions and technologies describes the general process of changes within them and highlights the necessity to align these changes. It does not provide a framework to measure and compare institutions and technologies nor measure the impact of the changes. Figure 2 summarizes this framework:

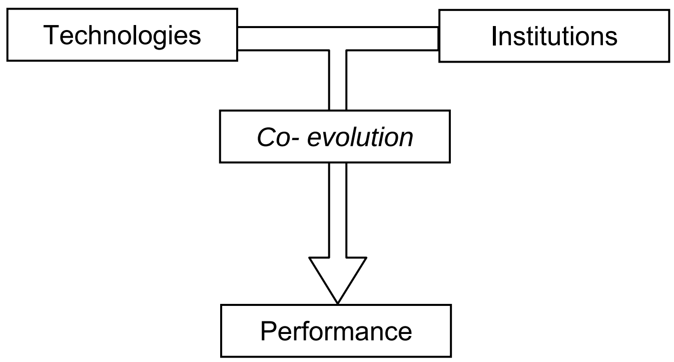

Figure 2: The relationship between technologies, institutions and performance (Finger, Groenewegen et al., 2005, adapted by the authors)

According to the Oxford English Dictionary (2000) the definition of the term "technology" is "scientific knowledge used in practical ways in industry".

North defines institutions as "the rules of the game in a society or, more formally, the humanly devised constraints that shape human interaction. In consequence they structure incentives in human exchange, whether political, social, or economic. Institutional change shapes the way societies evolve through time and hence is the key to understanding historical change." (North, 1990, p.3)

The co-evolution should lead to aligned changes and thus increase the performance of the infrastructure (technical, economic, social, environmental). In the case of SHP, the technology can be seen as mature and therefore very constant. Consequently the institutions should evolve in such a way that SHP is facilitated as an RES and its overall performance increased. This has to be put in the broader context of the liberalisation trends within the electricity sector as described above and taking into account small-scale and decentralised generation.

3.2 Financial mechanisms

Cost-recovery tariff structure is essential to ensure commercial viability of the service providers for SHP schemes to a local community. In practice, it is usually unrealistic to expect full cost-recovery tariffs, given the low ability to pay in rural areas. Worldwide, almost all rural electrification programs involve some forms of subsidies. In Europe, RES benefit from other financial mechanisms such as feed-in tariffs or quotas. In a more private sector and business approach similar mechanisms should be implemented in developing countries. If possible, the opportunity of benefiting from Tradable Green Certificates (TGC) or CO_2-credits (CER currently within the Clean Development Mechanism) should be taken. If subsidies remain, then it should only be to cover the public value of the installation (e.g. public lightening), to pay for the capacity building for the electricity infrastructure development and to reflect external costs (see below).

Feed-in tariff

The feed-in tariff involves the obligation of the utilities to purchase energy at a full production cost of the energy and guaranteeing it for a certain period (20 to 30 years). The feed-in tariff is widely used in the EU (France, Germany, Austria, Greece, Spain, etc.). Most of these mechanisms depend just on the installed capacity (in the Greece case also on the connection/non-connection to the grid). In Switzerland, the tariff depends on the installed capacity, the head and a bonus linked to the hydraulic construction. Similar tariff structures should be pursued in developing countries. Low head SHP schemes represent most of the potential and their facilitation must be part of the design of the feed-in tariff. The tariffs should also take into account if the hydropower component is added or combined with another infrastructure such as drinking water network or irrigation. Procedural costs should be kept as low as possible (see below).

An additional idea is introducing a **modular tariff** (like in Austria). This is a type of feed-in tariff which allocates a high financial value to the first kWh followed by decreasing financial values to the kWh produced afterwards. This offers more financial security when taking into account the hydrological uncertainty of the overall production.

Hydropower can adapt very quickly and easily to an increase in electricity demand. If the supply of **peak electricity** is a main aim, then the tariff should offer more remuneration for kWh produced during peak hours. This would enable additional investment in the design and construction of the plant to add the storage capacity and, if technical and ecological feasible, the pump capacity as well.

The importance of storage capacities will increase in future due to climate change modifying hydrology. With the storage component and within multipurpose plants, the water supply can be regulated and flood protection implemented.

The financing of the feed in-tariff can be made through a fund which is supplied by a CO_2-tax on fossil fuel. If such a funding is not feasible because a country still depends heavily on fossil fuel and cannot tax it further, then financial schemes around TGC and CO_2-credits should be put in place.

Tradable Green Certificate (TGC)

A green certificate actually represents the “greenness” of a unit of RES production such as SHP. This divides the unit into two parts: the physical electricity, traded on the conventional physical electricity market, and its associated “greenness”, traded on a market for the TGC (Mitchell and Anderson, 2000). TGC could be traded with companies in countries where there is a required quota of RES production and when such companies do not fulfil their quota target. Such a mechanism would need to be introduced on the worldwide level at international climate conferences (e.g. Copenhagen).

CO_2-credits

In today’s Kyoto protocol the existing Clean Development Mechanisms (CDM) allows certain countries (so called non Annexe 1) to trade Certified Emissions Reductions (CER). CER can be obtained with RES power plants. There are SHP plants, mainly in China, which benefit today from such CER, but the number is very limited. For SHP, and especially for MHP, the certification and procedure costs, which are a fixed amount per project, are in relative terms very significant. These costs must be reduced (see below).

At the Copenhagen conference the post-Kyoto framework has been designed in its main shape. One of the 4 main discussion points in Copenhagen is the technology transfer. SHP as a technology for developing countries should be facilitated by generating CO_2-credits with limited transaction costs. A regional or global Emission Trading Schemes (ETS) could be an alternative to the continuation of the CDM. Within the CDM it has to be made sure that the “additionality” as a condition to get CER is guaranteed.

In addition, adaptation funds could partly finance multipurpose SHP plants with flood protection. Such funds could be financed through a GHG-tax or a small tax on the ETS transactions.

Technical label

Today's incentive mechanisms have an upper limit concerning the installed capacity (e.g. 10 MW). This can lead to the design of smaller plants which receive incentives instead of designing one or several bigger plants which are technically and ecologically the optimal solution for a given site. A quality label could be introduced. Called maxEnergy, it would be given to the plant with the optimal technical and ecological solution that uses the maximum available energy for a given head and flow, while respecting environmental constrains. maxEnergy could be a condition to get feed-in tariffs, TGC or other financial mechanisms.

Mini-credits for mini hydropower

The facilitation of SHP does not only require mechanisms to generate enough revenue, but also the investment capital to fund it. To attract private funding, the confidence of investors must be guaranteed. This can be done by guaranteeing a stable regulatory framework for SHP (see section 3.3) and a stable situation over many years for the generation of the revenue (see points above). The facilitation of investment could be reached by creating an investment pool for MHP projects based on the principles around micro-credits – just with bigger amounts. Based on existing networks (such as www.myc4.org) private capital could be attracted from all over the world. To a certain extent local capital should also contribute to finance MHP projects increasing the local ownership.

Subsidy

Certain external costs (e.g. GHG emissions) are currently not taken into account in the electricity generation. If the involved organisations want to reflect the real price of electricity generation, additional mechanisms internalizing external costs need to be implemented such as a specific subsidy for RES.

An overall cost-benefit analysis should be done taking into account the parameters of pollution, the grey energy and social impact such as local employment. This would show that SHP is competitive with other energy sources and based on this analysis the amount of required subsidy could be defined. The funding of the subsidy could come from a tax on pollution factors[2] and grey energy[3] factors.

If a SHP project includes public value such as public lighting, subsidies could be funded through the normal tax system.

Most of SHP projects in developing countries will require a soft part, so called Capacity Building (institutional and legal framework development, organisational development, the elaboration of management structures, human resource development). The costs for this are initially very high and decrease significantly with time. These costs could be funded through Official Development Assistance (ODA) as the public sector is best suited to build up such capacities.

3.3 Regulatory framework

Standardisation and streamlining of procedures

The facilitation of SHP requires stable mechanisms in time and space. The time scale is provided by a stable regulatory framework over time. From a space perspective, laws, regulation, concession rights, financial incentives, offices, etc. concerning SHP should be at least uniform across a country. A high level of standardisation and streamlining of procedures reduces transaction costs and concerns application and process for feed-in tariffs, TGC, CO_2-credits etc, as well as construction permit application, concession application etc.

[2] A standard method to correct for an externality is to impose a (linear) tax at the rate of marginal external damages on the use of the entity responsible for the externality.
[3] All the energy to produce a good (production, transport, storage). Typically higher in the case of solar power than MHP.

The number of actors and organisations for a SHP project should be as low as possible. The smaller the number of actors and organisations, the smaller the transaction costs and potential communication misunderstandings.

A further option to reduce transaction costs is to deal only with group projects (e.g. within the same riverine zone) and not with single projects. This would increase the regional grid stability as a certain minimum electricity generation could be guaranteed from a group of projects

Technical and environmental regulation

Where fish migration is natural and the SHP plant includes a dam, that dam should not become an obstacle impossible to pass, but fish passes need to be installed. Minimum instream flow downstream of the water intake needs to be guaranteed for environmental reasons. The value for such a minimum instream flow is, for example, constant in the Swiss law, but could be made dynamic to increase electricity production at peak demand and still be environmentally sensitive.

Economic regulation

From an economic regulation perspective, the markets need to be sustained and not simply created (e.g. market for RES in the case of SHP). Most of the time there is only one electricity distributor. It is a monopolistic market. In theory, there should be competition for the market instead of in the market, but in reality even this is very limited. Producing electricity with a SHP plant and being fully dependent on the unique electricity distributor for the income is a risky business. To reduce risks, it requires a stable legal framework for independent power producers (e.g. contracts and effective means of their enforcement). Alternatives are to sell the electricity directly to different end-users who in the best case are co-investors of the SHP plant or, one end-user who are co-investors and can give financial guarantees for the promised payment of the electricity. In some cases, the public may be able to give financial guarantees and support the plant (e.g. public lightening).

Political regulation

The political regulation must deal with the universal service regulation (consumer protection; as far as possible) and the security of supply. SHP has to contribute to the required domestic production and contribute to the grid stability which is the case as decentralised production units.

The overall regulation should contribute to reduce uncertainty and increase transparency so as to attract private investment if that is a political aim.

4. Spatial planning

4.1 Balance of profit and risk

Regulatory frameworks and financial mechanisms facilitate the implementation of SHP, but it does not follow that the technology establishes autonomy. Therefore the effective available potential of SHP has to be identified and associated aspects considered.

Today’s world is progressive and fast growing. Any available energy potential is going to be exploited, a fact seen in the exploitation of fossil oil (combustion and material production) or deforestation (wood export and agriculture). Therefore, once the potential of SHP has been assessed, its exploitation and especially the consequences should be considered. This becomes even more important when the potential refers to a region or even a whole country. To tap the SHP potential fully, (i.e. the technical exploitation to the maximum and to its full spatial extent) will lead automatically to a change of scenery and natural spaces. It is therefore reasonable to detect emerging conflicts between the priorities of preservation and exploitation as well as given boundaries at an early stage and balance them against the overall benefit. Interventions should be planned and implemented purposefully to avoid irreversible changes that could affect the scope of action of further generations. A holistic future strategy shall help to negotiate and prevent reaching a deadlock. As such an instrument has not yet been available; a first attempt may be done within an ongoing research project “Investigation of the SHP Potential in Switzerland” sponsored by SFOE. Research will be conducted in Switzerland at the Institute of Geography, University of Berne, until 2012.

4.2 Method

Sustainable development

The method aims to create a holistic perspective in terms of SHP implementation. That is to consider ecological, social and economical aspects as well as land management on regional scale. To ensure the holistic perspective it is based on the principles of sustainable development set in the Brundtland-Report 1987. Furthermore, the whole decision making process needs transparency, transfer of knowledge and particularly participation of all affected stakeholders (Stremlow and Pfister, 2003; Bolliger, Charollais et al., 2002). The challenge is to detect common problems and to find collective solutions.

To accomplish this goal we suggest the following approach (see Figure 3):

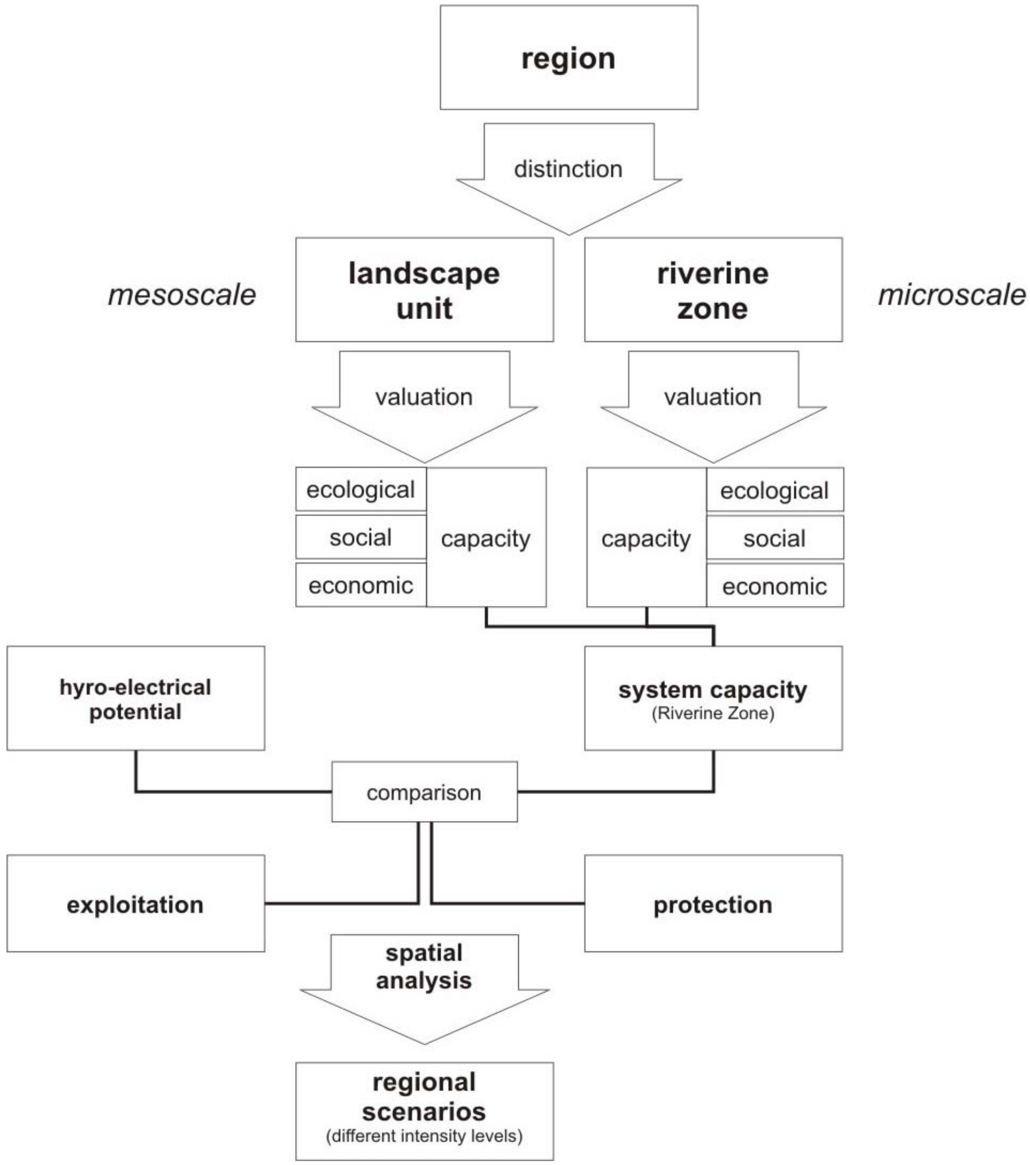

Figure 3: Structure of the method

Calculation of the hydro-electrical potential

In a simultaneous analysis the effective usable hydro-electrical potential, i.e. the energy that is technically feasible, will be identified across the whole stream network of Switzerland. As the data is based on GIS-layers, the visualisation in Google Maps will be possible. These maps reveal the specific capacity [kW] per meter for all points of the grid at a distance of 50m[4]. Thus the hydro-electrical potential has a distinct value. Its quantity is measurable in contrast to the value of the surrounding riverine zone[5], which would also be affected in case of a SHP project. A satisfying evaluation system for riverine zones, that assigns a countable value to the area, is not yet available, although many different approaches have been

[4] http://www.netzwerkwasser.ch/aktivitaeten/projekte/aktuelle-projekte/wasserkraftpotential/ (21.09.2009)
[5] The zone that includes the river channel and the adjacent land directly connected with the river.

elaborated and applied (e.g. Grêt-Regamey, Walz, et al., 2008; Roth, Zeh, et al., 2005; DuPasquier, Cataneo, et al., 2007; Stuber, 2008).

Assessment of the status quo

The proposed method shall be made applicable to both industrial and developing countries. However, planning and initial application will be conducted in Switzerland, in a Swiss alpine region. This decision is based on data availability and the need for a solution to handle the large amount of recently submitted SHP petitions in Switzerland. It is assumed that the method can be easily adapted to prevailing conditions in developing countries.

To conquer the challenge of giving a certain value to a spatial component, the area of interest is divided into its subordinate catchments (Figure 3). Subsequently a delimitation of areas at two different observation levels is performed. On the mesoscale level the areas are called *landscape units*[6], whereas at the microscale level they are called *riverine zone*. The distinction of the former is mainly based on the ideas of Steinhardt, Blumenstein, et al. (2008) and Forman (1995), whereas the latter uses Hütte and Niederhauser (1998) as support. The mentioned concepts are complemented by additional criteria according to requirements.

In another step, landscape units and riverine zones are evaluated separately by means of three different criteria raster: one that refers to ecological aspects, one that focuses on social aspects (e.g. recreation) and a third one that relates to economic aspects. The criteria are derived from the targets in Roth, Klooz, et al. (2007) and the Water Framework Directive WFD (EU 2000), and specified by laws as well as by instruments such as Kraftwerksvertreter and Umweltverbände (2009), BAFU (1998), Michor, Moritz, et al. (2006), Jones (2007). Scales are then added to cover the variability within a single criterion and to weight the particularly important ones. At the end of the assessment process each area is provided with a calculated value, which represents either its ecological, social or economic capacity at the actual stage (status quo) depending on what is most important for this specific area. It is important that the evaluations are as objective as possible.

Spatial analysis

Furthermore the system capacity of an area is contrasted with the hydro-electrical potential (Figure 3). All the areas which could possibly be used for SHP have to be located as well as the areas which should definitely be protected. This includes revealing the different intensities of exploitation. An analysis of these results follows in association with spatial aspects considered from a regional point of view. Single riverine zones are combined to larger units to raise homogeneity. This process has to be well balanced, as it provides clear definitions of limits of SHP as well as of the extent of protected zones.

Finally, different scenarios showing varying intensities of use should help decision makers to determine future landscape management (Figure 4). It is left to them to decide whether they focus either on protection, on SHP or on both equally. The scenarios support decision making exemplifying different versions of use.

[6] An area (few km^2) being representative for the characteristics of the communities and for aesthetical values of a landscape.

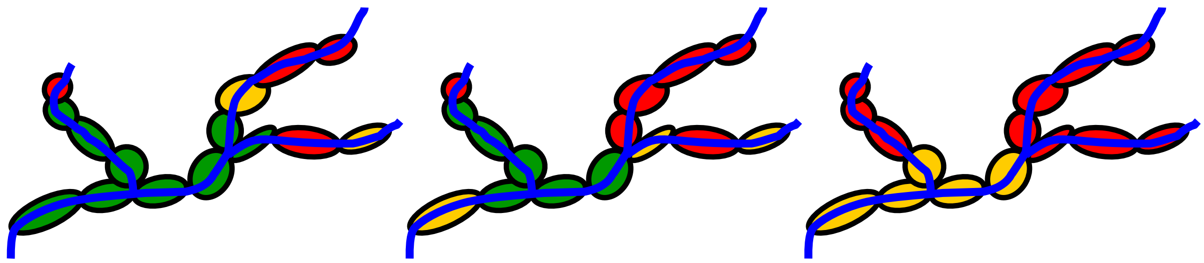

Figure 4: Scenarios with different intensities of use (riverine zones)

Before definitive scenarios are suggested, the method for detecting different areas of protection and utilisation are tested in Switzerland. Chosen criteria and scales shall be adjusted and confirmed.

Supporting measures

To facilitate the above presented strategy an adequate mechanism providing interesting incentives is needed. This shall include the claims from both, the EU Water Framework Directive (WFD) and the environmental organisations: Preserve the natural state of a river and facilitate renewable energies. A first trade-off solution meeting this policy and the balance between protection and exploitation reveals the idea to give incentives to bodies, not using the water resource at a technically feasible site. Instead the natural state of the river is preserved. That non-use of a site could be financed by the greening requirement of another site, which needs to balance out its benefit-damage assessment to obtain TGC, feed-in tariffs or other financial mechanisms.

An example shall be given to illustrate the meaning: A valley keeps its river in a natural condition which is more attractive to tourists and can therefore generate other revenues; the other valley uses its river to the fullest for hydropower production. In that case both valleys would agree on a common partnership. This idea is based on the Swiss "landscape cents"[7]. At the same time tourists would have a valley with a completely natural river and they could consume RES electricity from the SHP plant in the adjacent valley.

4.3 Sustainability in land management

In industrial countries as well as in developing countries the facilitation of SHP should try to be sustainable and therefore planned in advance. Especially in rural and often remote natural regions, where decentralised energy production is particularly helpful, people should act with care. There is a risk to affect these regions irreversibly. To hinder uncontrolled spreading and increase efficiency over a whole region, the above mentioned method shall be applied. Favoured sites for SHP ought to be identified by purposeful planning in order to avoid a loss of pristine waters. This problem happens frequently in industrial countries, where financial mechanisms, e.g. feed-in tariffs in Switzerland, have already been introduced and there is a great demand for SHP.

5. Conclusion

Small hydropower technology includes the advantages of being small-scaled, decentralised, mature as well as renewable. SHP is therefore seen as a key tool for rural development and for the attainment of the Millennium Development Goals whilst respecting the environment.

There still exists a considerable unused technical potential of SHP and MHP. The authors suggest optimizing the institutional frameworks for SHP to maximise the exploitation of the remaining potential

[7] http://www.parlament.ch/D/Suche/Seiten/geschaefte.aspx?gesch_id=20083699 (16.10.2009)

under economically viable conditions and, considering the ecological standards in the framework of sustainability. Taking into account the current liberalisation of the electricity market and the involvement of the private sector, the government's goal to increase renewable energy sources rates, the post-Kyoto context and sustainable development, further evolution of the institutions is definitely required.

One aim of this research is to contribute to the current policy development that targets a matching of renewable energies sources deployment such as hydropower and environmental management, not only in industrial countries but as well in developing countries. This paper provides several institutional mechanisms generating a framework to facilitate SHP. It focuses on financial mechanisms to promote SHP such as feed-in tariffs, CO_2-credits and labelling. Furthermore, solutions reducing transactions costs are presented as these costs are significant for small scale projects. In addition, a corresponding implementation strategy is shown, considering the consequences of large scale deployment of SHP on a regional level. Research will present more detailed and final results in 2012. One of the major benefits of this research is to present an overall strategy for the implementation of SHP in an environmentally reasonable and economical way in both industrial and developing countries.

The authors clearly value the benefit of adequate institutional frameworks for SHP. They emphasize its role in developing local economy, securing livelihoods and contributing to social infrastructure in developing countries. Integrating SHP projects into a country's rural electrification and poverty alleviation agenda is necessary for SHP to become a mainstream solution to rural energy needs. It is suggested to push SHP even more within the facilitation of renewable energy sources as SHP has a high energy payback ratio compared to other RES, as long as the production costs are lower than other RES. Considering the increasing energy demand and the mitigation of climate change, SHP provides renewable energy for the future.

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7. Appendix

7.1 Small hydropower scheme

There are different SHP systems. Two main classifications are used. The first one is the connection to a network. SHP plants can be off-grid, mini-grid or grid connected, depending on the number of users and distance to the main grid.

The second classification uses the head. High head SHP has a head of 100 m or more. The following figure shows the main components of such a plant.

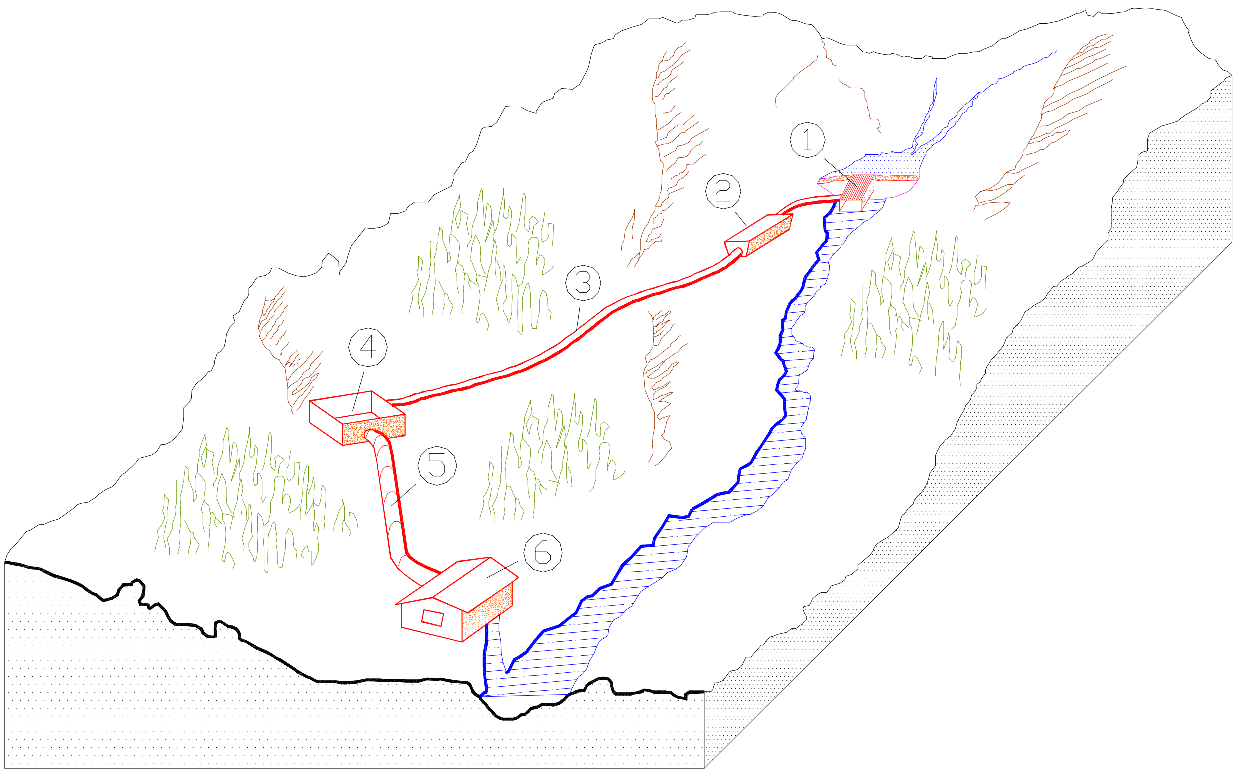

Figure: Main component of a high-head SHP plant (Andaroodi, Schleiss et al., 2005, p. 22)

The water is diverted through a water intake in the river bank or bed (1). A settling basin (2) is placed after the intake structure to remove sand particles from the flowing water. Then a headrace canal (3) follows the contour of the hillside to provide the required head for energy production. After that the water enters a forebay (4) and passes into a closed pipe known as a penstock (5). This last structure is connected at a lower elevation to a turbine located in the power house (6). At the outlet of the turbine, the water is discharged to the river, via the tailrace. Medium head SHP plants have between 30 m and 100 m head. Low head SHP plants have a head below 30 m. They are typically built in a wide and flat river valley, and function in most cases as run-of-river hydropower schemes producing base load for the electrical network.