ENVIRONMENTAL ASPECTS OF IMPLEMENTATION OF MICRO HYDRO POWER PLANTS – A SHORT REVIEW

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ABSTRACT

The economic importance of micro hydro power plants is obvious around the world and the development trend will continue well into the future.

Unfortunately the effects on the local lotic systems habitats and biocoenosis are not studied, and in some cases or are known only to a small degree.

A variety of taxa were identified in the study case areas as being significantly affected by the micro hydro power plants: macrophytes, macroinvertebrates and fish.

ZUSAMMENFASSUNG: Mikrohydrozentralen – ein wirtschaftliches und oekologisches Problem.

Die wirtschaftliche Bedeutung der Mikrohydrozentralen ist weltweit augenscheinlich und ihre Entwicklungstendenz wird sich sicherlich auch in Zukunft fortsetzen.

Leider sind ihre Auswirkungen auf die lotischen Habitate und Biocoenosen fallweise nicht untersucht worden oder sind lediglich graduell unterschiedlich bekannt.

Zu der grossen Vielfalt taxonomischer Gruppen, die von den Mikrohydrozentarlen in den Bereichen der Fallstudien als erheblich betroffen eingestuft wurden, gehoeren die Makrophyten, Makrinvertebraten und Fische.

REZUMAT: Microhidrocentralele – o problemă economică şi ecologică.

Importanţa economică a microhidrocentralelor este evidentă în toată lumea iar tendinţa de dezvoltare a acestora va continua cu certitudine în viitor.

Din păcate, efectele acestora asupra habitatelor şi biocenozelor sistemelor lotice nu sunt studiate în unele cazuri sau sunt cunoscute în diferite grade.

O varietate ridicată de grupe taxonomice au fost identificate în aria studiilor de caz ca fiind afectate semnificativ de microhidrocentrale: macrofite, macronevertebrate, peşti.

Economic context

Implementation of Micro Hydro Power Plants

The power captured from moving water has been a source of energy for thousands of years. In the last 500 years more interest has blossomed within the energy arena for hydropower with the invention of the overshot wheel, which efficiently converts the power of falling water into useful mechanical energy. Micro hydro represents a small, but technically secure and reliable source of energy that we should be utilized as part of our drive to promote renewable energy. (*, 2005)

Micro hydro is characterized, as a plant between 10 kW to 200 kW, it is a small scale, decentralized energy supply technology used in many countries. In certain situations micro hydro can be successful in economic terms; while in others, unprofitable plants can display positive impacts on the lives of people and the environment that legitimize the financial aid. (Fulford et al., 2000)

The field of micro hydro is developing, especially in relationship to the interest of project planners. Currently, the most primary installations were the outcome of a technology push. This knowledge has influenced the technical soundness of the micro hydro systems, decreased their expenses, and increased their technical quality. Micro hydro is now a rather advanced technology that has been significantly improved by low cost turbine designs, electric load controllers, and the use of plastics in pipe work and penstocks.

Allocation of resources

Financial incentives are chiefly intended to expand the adoption of micro hydro, and it has to be economically viable within the geographic location in which it will be situated with sufficient consumer demand for the bulk of the power generated. This could also involve the sale of energy where there is an ease of access to the grid and significant consumer demand. Nonetheless, communities who lack the resource but can incur the cost of the energy frequently live a great distance from those with the considerable necessities.

Strategies for implementation

If the expense of micro hydro is too large for poor communities, involving the community in the project development can decrease the cost (Gurung et al., 2013). It allows people to contribute their labour (or another communally possessed asset such as land to the project). If people are under-employed, this favourable circumstance allows the expense of the work to be decreased; involving the whole community to facilitate the richer entities (wealthy donors, landowners, mills and shop owners, etc.) to carry the cost, and allow the impoverished members of the community to contribute to the trading price (a “lifeline tax”); growing the number of people associated with the project can decrease the price for everyone when the micro hydro project has reached economies of scale.

While the involvement of the community is an indispensable situation for a favourable outcome of the project, and decreasing development costs, the process itself is expensive and is time consuming.

Worldwide financial institutions are now taking an interest in micro hydro. In the 1960’s and 1970’s worldwide assistance agencies contributed financial support to rural electrification, but this was done primarily through grid enlargements. This practice suggests a hesitancy to fund new projects that do not distribute power over less concentrated systems. However, they have begun to reassess decentralized energy alternatives, stimulated by their new attraction in renewable energy.

One of the better examples of an application of a strategy for micro hydro has been the project developers themselves. In numerous countries, micro hydro projects are profitable. However, there are cases where individual entrepreneurs have advanced their own projects. Disregarding the strategies of governments and aid agencies, because have they have the financial resources to bring all the proper elements of a micro hydro project together and execute the development project through to operation.

Necessary conditions

The best geographic areas for exploiting small-scale hydro power are those with steep river gradients flowing all year round, for example, the hill and mountain areas of countries with high year-round rainfall, or the great mountain ranges and their foothills, like the Andes and the Himalayas. Islands with moist marine climate, such as the Caribbean Islands, the Philippines and Indonesia are also suitable. The low-head turbine types have been especially developed for small-scale exploitation of streams and rivers where there is available a small head but enough flow to provide the needed power.

To evaluate the appropriateness of a potential site, the hydrological characteristics of the site needs to be known and a site monitoring carried out, to determine the real flow and head data. The load factor is the amount of power used divided by the amount of power that is available, if the turbine were to be used continuously. Unlike technologies relying on costly fuel sources, the fuel for hydropower generation is free and therefore the plant becomes more cost effective if run for a high percentage of the time. Water turbines, like gas or diesel engines, will vary in speed as load are applied or relieved. Although not as great of a problem with machinery, which uses direct shaft power, the speed variation will greatly affect both frequency and voltage output from a generator.

Benefits

If the proper site can be identified, there are strong reasons to support the implementation of micro hydro. It only takes a small amount of flow, as little as two gallons per minute or a drop as low as two feet to generate electricity with micro hydro. The electricity can then be delivered far away from the location for use (Borkowski and Wegiel, 2013).

Hydro produces a continuous supply of electrical energy in comparison to other small-scale renewable technologies. Micro hydro is considered to function as a run-of-river system, meaning that the water passing through the generator is directed back into the stream with relatively little impact on the surrounding ecology.

Micro hydro systems can be a very effective source of energy in the right context. Building a small-scale hydropower system can range from 1,000-20,000 Euro, depending on the site requirements and location. Maintenance fees are relatively small in comparison to other technologies.

Given the low-cost versatility and longevity of micro hydropower, it can be a great energy solution. It is probably best suited in developing countries; if they have the ability to develop and implement the technology to help supply much needed electricity to small villages.

Installed Kw costs

Data was gathered from five different countries in which they evaluated the capital costs of micro hydro plants. In the study evaluated, it is important to note that the installed kilowatt is higher than what other resources claimed in their numbers. In studies with lower numbers, they did not evaluate the local labour costs.

In the examples examined in, the capital cost of micro hydro plants limited to shaft power, ranged from US$714 (Nepal, Zimbabwe) to US$1,233 (Mozambique). The average cost is US$965 per installed kilowatt. The installed costs for electricity generation schemes are much larger. The installed cost per kilowatt ranged from US$1,136 (Pucara, Peru) to US$5,630 (Pedro Ruiz, Peru) with an average installed cost of US$3,085 (Khennas, 2000).

Potential ecologic problems

There are some problems with micro hydro, some of which are obvious and some that may not be as easily identifiable but can create problems if not appropriately addressed. In order to take advantage of the electrical potential, a suitable site must include favourable factors such as the distance from power to source, or where the energy is needed. The stream size, including flow rate, output, drop, and also the balance of systems components are factors to consider when evaluating prospective sites, as well as trying to identify the potential need of expansion and whether or not it would be feasible for the stream and system to support.

Given the source of this power is based on the free flow of water, what is the summer time implications associated with seasonal variability from decreased run off and water flow of the site location (Khennas, 2000).

Building on that, last but for sure not least, how do these projects affect the local ecosystems? The ecological impact of small-scale hydro is sometimes minimal but sometimes significant as the following study cases reveal; however the low level of environmental effects must be taken into consideration before construction begins. Stream water will be diverted away from a portion of the stream and proper caution must be executed to ensure there will be no damaging impact on the local ecosystems or civil infrastructure.

Small hydropower plants can have environmental impacts, some of which start as soon the construction phase. Habitat degradation associated with tree cutting, excavation, fill areas, road construction, blasting, construction of water storage systems, construction of supply canals, excavations, loss of riparian zone and destruction of wetlands is a main environmental concern in hydropower plants under construction (Başkaya et al., 2011). Such activities are carried out in pristine areas, which can lose their associated tourist attractiveness.

The disruption of longitudinal connectivity by dams can have severe impacts on migratory fish, especially salmonids (Stakėnas and Skrupskelis, 2009). Significant reductions in the numbers of salmonids were observed after the construction of small hydropower plants on small mountain rivers (Almodóvar and Nicola, 1999; Ovidio et al., 2004). Thus, one of the principal environmental challenges, which face small hydropower plants, is efficient fish passage (Therrien and Bourgeois, 2000). E.g., among the studied fish passage facilities in Portugal, only 44.4% were found to be suitable for target fish species (Santos et al., 2006). The populations fragmented by dams are often characterized by lower genetic diversity, higher morphological asymmetry, and a lower effective population size compared with populations below dams (Morita and Yokota, 2002). However, dams of small hydropower plants seem to cause a lesser effect on fish than large dams on large rivers because of their smaller size. Usually, the escape of a certain number of fish from upstream into downstream populations occurs through fish passes or with high water during flood periods that can be sufficient to prevent genetic divergence between these populations (Santos et al., 2006).

Another problem associated with small hydropower plants is the reduction in stream flow, which can have a substantial ecological impact. Flow reductions can cause up to 90-95% removal of the average annual discharge that can affect the physical characteristics of a stream (e.g. water velocity, water temperature, suspended solids, fine particles and nutrients) and alter the quantity and quality of aquatic habitat, with cascading impacts on stream biota (Anderson et al., 2006; Vaikasas et al., 2015). Such alterations can affect not only fish but also macroinvertebrate communities in terms of abundance, species composition, and the ratios of their different ecological groups (Xiaocheng et al., 2008). However, some authors noted that the regulation by small dams did not impoverish the invertebrate fauna but sometimes induced subtle changes in faunal composition (Pett et al., 1993; Almodóvar and Nicola, 1999). The impacts on water quality and macroinvertebrate communities may be significant but usually are local (Vaikasas et al., 2015). Nevertheless, the lack of control over environmental flow remains a highly serious problem in already functioning small hydropower plants (Başkaya et al., 2011).

Ecologic context – study cases

Capra Stream (Southern Romanian Carpathians) study case

The analysed Capra Stream ecological state based on biotic integrity indexes (HBI and EPT/C) and IBI Carpathian Fish Index revealed that the impacts of micro hydro-power plants development (Fig. 1), dams, and pollution are significant in space and time.

Figure 1: Heavy construction equipment work in the Capra Stream.

The macroinvertebrate and fish fauna are directly affected by the lithological substrate change (in conditions of which they and their trophic base depend on the substrate) and by the flow regime changes. As an effect of the human impact along the Capra Stream there are three main ecological zones. The first ecological zone is characterised by a good ecological state due to the insignificant anthropic impact. The second is characterised by an unsatisfactory ecological state mainly because of the micro hydro-power plants system construction and of the untreated wastewater discharges in the stream have a hydrological and morphological change which generate stress for the aquatic communities, which determines changes in their structure, the river banks configuration change also determined the river bed deepening due of the rotational flow with negative effect on the aquatic communities.

The third ecological zone is better than the previous one from the ecological point of view because of the left and right tributaries contribution of the Capra Stream. In this sector the anthropic impact is still significant because of the development of micro hydro-power plants, the tributaries connection blocking and the untreated wastewater discharge. The building works simultaneous with the significant river bed damage determined the *Cottus gobio* local extinction and the drastic reduction of *Salmo truta fario* individuals (the presence of *Salmo truta fario* in just one river sector of 17 sampling stations).

After finishing the micro hydro power plants chain on this stream it is compulsory to repopulate with trout and bullhead, which before had stable populations. The extinction of every fish species in all sampling stations except one with low abundance though is due to major interventions of the micro hydro-power plants construction.

The final situation resulted due to factors with synergic effects that have accumulated throughout time such as lodges rafting in the first part of the XIX century, fractioning the ichthyofauna connectivity because of the anti-bottom sediments dams without the construction of a fish ladder built on the tributaries (especially the one built on Capra at the Vidraru Lake edge); damage of the river bed for pipe burial constructed for the micro hydro-power plants chain in different states of development; the secondary impact of the untreated wastewater discharges of Piscul Negru chalet (in the last two decades) (Curtean-Bănăduc et al., 2014).

Shypit River (Ukrainain Carpathians, Zakarpattia region) study case

The issue of small hydropower plant construction drew attention in Ukraine, when in 2009 the Ukrainian government introduced the so-called “green tariff” for power plants producing electricity from alternative energy sources, which was aimed at stimulating the operation and development of renewable energy sources. The green tariff introduced a guaranteed minimum feed-in tariff for electricity produced from small hydropower power plants with the generation capacity not exceeding 10 MW. In addition, a number of tax incentives were implemented for producers of electricity from renewable energy sources.

As a result, these initiatives boosted the development of new small hydropower projects in the Ukranian Carpathians. E.g., the “Programme of the multipurpose use of water resources in the Zakarpattia (Transcarpathian) region of Ukraine” adopted in 2011 envisaged the construction of 330 small hydropower plants in the region.

The Tur’ya-Polianska hydropower plant (48°44’26.88” N, 22°50’19.17” E) of run-of-river type (Fig. 2) with the projected power generation capacity of up to 1.2 MW was built in 2012 in the middle part of the Shypit River, four km upstream of the Tur’ya-Poliana Village. The Shypit River is a typical mountain stream of 20 km in length with river bed width of 5-10 m. The construction resulted in the creation of a reservoir with an area of approx. 1,700 m^2 and a depth of up to 4.6 m. The hydropower water intake was equipped with a fish pass structure, however, it was not functional during the first years of operation and was rebuilt in 2014.

Figure 2: Tur'ya-Polianska small hydropower plant.

A significant amount of water is now diverted into a three km penstock placed underground that reduced the water content in a three km river reach located immediately downstream of the reservoir. The residual flow is sometimes insufficient to fill this river reach with water especially during dry months. Local people started complaining on decreased water levels in their wells that may be related to the reduced soil moisture level beneath the stream bed. However, some claim that this was due to dry years.

The newly created reservoir of the small hydropower plant is located on a mountain river with rapid current and erosion processes along the shore that results in the accumulation of sediments and creation of a new biotope, which is not typical for mountain rivers and where anaerobic processes develop (Kovalchuk et al., 2013). Relatively rapid sedimentation results in a decrease in the volume of the reservoir that may require the removal of sediments in the future. Rearing of trout in a cage containing up to 1.5 tonnes of fish was practiced in the reservoir that formed additional organic input in water. However, it was discontinued in 2015.

The small hydropower plant was built in a transient zone of the river where the trout zone inhabited mainly by brown trout (*Salmo trutta fario*) and Siberian bullhead (*Cottus poecilopus*) gradually changes into the grayling zone inhabited by European grayling (*Thymallus thymallus*) and Carpathian barbell (*Barbus carpathicus*) (Harka and Bănărescu, 1999). A fish survey of 2009 conducted on the river reach located approx. 0.5 km upstream of the current site of the reservoir showed the presence of all these species. The same fish species were recorded upstream of the reservoir in 2012, a couple of months after the hydropower plant was built.

However, neither European grayling nor Carpathian barbell were recorded upstream of the reservoir in 2013 (Kovalchuk et al., 2013). After the fish pass was reconstructed, these two species reappeared in the sampling site immediately upstream of the reservoir (Kovalchuk et al., 2013). In addition, certain amounts of brown trout are stocked artificially in the river reaches upstream and downstream of the reservoir every year. However, local people complain that the amount of fish decreased considerably in the river after the small hydropower plant was built.

In 2013, the residents of Tur'ya-Poliana raised against the second phase of the small hydropower plant construction on the Shypit River. One of their main concerns was the absence of direct economic benefits for them and their village. Nevertheless, the second small hydropower plant Shypit-2 was built in 2015 approximately 4.8 km upstream of the first plant.

When the construction of small hydropower plants began in the Carpathian region of Ukraine, environmental activists and NGOs raised concerns about their negative effects on the environment. In fact, the programme for their construction was adopted in violation of the legislation of Ukraine without discussion and approval by the competent state authorities because many small hydropower projects were planned to be built in ecologically sensitive areas inhabited by rare and endangered species. In 2014, the Administrative Appeal Court declared illegal the plans for the construction of 330 small hydropower plants in the Zakarpattia region. As a result, the construction of at least four plants was recently cancelled and few more are still disputed.

Bystrzyca River (Lublin Upland, eastern Poland) study case.

Polish accession to the European Union resulted in the need to adjust Polish legislation concerning the management and protection of water to the applicable Community legislation. On 22 December 2000 entered into force on Water Framework Directive (WFD/2000/60/WE), whose main aim was to protect water resources for future generations. The Directive indicated that it was necessary to integrate the protection and sustainable management of water with other branches including energy

Poland does not have good conditions for the hydropower development, due to slight declines in land, low rainfall, and high permeability grounds (Warać et al., 2010).

Generally hydroelectric power plants are divided into groups of small and large. Most adopt a definition of small hydro based on the total installed generators. In Poland, small hydropower plants are facilities with a capacity is five MW (installed capacity: micro – hydro power plants 100 kW, mini – one MW and small – from one to five MW)

In Poland in the 30s of the last century there were about 8,000 various types of plants using water energy, currently operate only 743 hydropower plants (Warać et al., 2010).

Small hydro power plant on the Bystrzyca River (Fig. 3) was built in 1974, whereas in 2013 was modernized. The power generation capacity amounts to 27.5 kW. Construction of the dam reservoir (Zemborzycki Reservoir) would help to increase the retention and protection of water in the basin of the river, as well as protect Lublin city from floods (Michalczyk, 1997).

The Bystrzyca River (51°11'36.09" N, 22°32'9.96" E) has a length of 70.3 km, its basin is dominated by farmland (70.7%), forests cover 10.8% and 8.4% urban areas. The Bystrzyca Basin inhabited 0.5 million people.

Figure 3: Small hydropower plants on Bystrzyca River.

Construction of the dam reservoir and their functioning for more than 40 years led to the creation of new ecosystems which are subject to rapid degradation.

The Bystzyca River above Zemborzycki Reservoir is a mountain river with the typical fish species: trout and grayling (IBI index indicate very good ecological state). After crossing 27 km flows into three other rivers that change its character (IBI index moderate). Complete reconstruction of the structure of fish fauna occurs in dam reservoir. Every year, the reservoir is stocked with predatory species (pike, perch). This is related to these treatments in the tank biomanipulation, in order to improve its ecological potential. The reservoir is now very high eutrophic. Often in the summer devoid of recreational function due to the presence of toxic blue-green algae blooms.

In the Bystrzyca River and the dam reservoir occurred 30 fish species. There are no fish pass on the Zemborzycki Dam (Radwan, 2006). Macrophyte communities occurred particularly at the mouth of the river to the reservoir creating here the most favourable conditions for fish spawning (Sender, 2007). Isolation causes the depletion of fish fauna below the dam (only 10 species) The ecological status according to IBI index, on the section 50 m from the dam was defined as moderate, whereas in the next sections (municipal) as poor.

The cause considerable depletion of the fish fauna and macrophytes communities below the dam are unnatural fluctuations in water level caused by the work of SHP. Water level changes significantly reduce the occurrence of macrophytes, and thus spawning grounds.

The creation of the stagnating reservoir above the damming caused major changes in the environment of the river (Radtke et al., 2012). Rheophile fish species lost here their habitat. The fragmentation of the watercourse prevented fish and other organisms (e.g. *Lampetra planeri* and *Astacus astacus*) migration, resulting in the isolation of the population.

Džepska River (Southeastern Serbia) – study case

In the Law on Spatial Planning of the Republic of Serbia from 2010 to 2020 ("Official Gazette of RS" no. 88/2010), in the chapter Sustainable development of the technical infrastructure, it was found that the potential of small river flows on which it is possible to build small hydropower plants is 4.7% of total electricity production in Serbia, or around 15% of energy produced in hydropower plants. Possible locations for the construction of small hydropower plants and the potential production of electricity are determined based on the Cadastre of small hydropower plants of Serbia from 1987. This cadastre determined 856 potential locations for construction of small hydropower plants with a total output of 450 MW, with the production of 1.590 GWh per year (http://www.srbijavode.rs/home/Aktuelno/mhe.html).

Based on available data from November 2014, on the territory of Serbia there are 44 sites with already constructed small hydropower plants. On the basis of two public calls that the Ministry of Energy announced in 2013 it was granted a total of 293 additional locations for construction of small hydropower plants (Vasić and Jahić, 2014, http://www.javno.rs/baza-podataka/mini-hidroelektrane-u-srbiji/detaljna-pretraga).

Džepska River is the right tributary of Južna Morava. It is formed out of two smaller watercourses Garvanica and Mutnica that rise on the western side of the mountain Čemernik. Džepska River and its tributaries represent typical salmon water. Brown trout (*Salmo trutta*) is present in the whole system, while the cyprinid species occur only near the confluence with the Južna Morava, with the dominance of brook barbell (*Barbus peloponnesius*), shcneider (*Alburnoides bipunctatus*) and chub (*Leuciscus cephalus*).

Figure 4: Garvanica water intakes
of hydroelectric power plant Džep.

According to cadastre from 1987 in the Džepska River system, 11 locations are provided for construction of small hydropower plants, three of which were approved and one was constructed (Fig. 4). Built hydropower plant Džep, has the power of one MW, with the production of 883 KW of electricity. It is built about one km from the mouth of Džepska to Južna Morava River at the altitude of 340 m (42°45’58” N, 22°05’49” E). For the purposes of hydropower plant, two water intakes with the tubes were built at about three km from hydropower plant, one of which is on Mutnica at the altitude of 428 m (42°46’18” N, 22°07’56” E) and the other on Garvanica at the altitude of 430 m (42°45’59” N, 22°07’52” E). Intensive construction work on the whole system completely devastated natural habitat to about four km of river flow.

Genetic analysis of phylogeographic structure of brown trout from the territory of Serbia (Marić et al., 2006), in the middle part of the Džepska River detected a new haplotype Da*Dž. So far, this river is the only site of mentioned haplotype across the species area. Kohout et al. (2013), named this haplotype DaBS9, and stated that beside that haplotype there are three more present in the lower part of the river. This finding suggests that the lower part was probably stocked with allochthonous material. However, last year’s analysis of 17 samples from the upper part of Garvanica, detected the presence of only DaBS9 haplotype, suggesting that the upper part of the Džepska River system is inhabited by indigenous trout.

Marić et al. (2006) and Kohout et al. (2013) reported that DaBS haplotypes form a separate group within the Danubian phylogenetic lineage of brown trout, which as such deserves a special conservation treatment. Introduction of the alochthonuous materials and constructing of small hydropower plants, i.e. genetic contamination and deterioration of habitat can certainly threaten the survival of indigenous population. In terms of conservation of this population, the upper part of the Džepska River system is very important, and thus the above mentioned activities should be prevented.

La Realidad micro hydroelectric plant (México) – study case

In México, the installed hydroelectric capacity in 2012 was 11,603 MW, generated by 181 hydroelectric plants, representing almost 20% of the country’s electric energy; the country’s growth potential is five times this figure. More than 40% of the realized capacity comes from the power plant complex located along the Grijalva and Balsas rivers basins (from the power plants called Angostura, Chicoasén, Malpaso, Peñitas, Caracol, Infiernillo and La Villita). Mexican government’s long term objective for the year 2025 is to reach 35% of installed sustainable capacity, which means an additional 18,716 MW to the existing power. This renewable energy will rely on eolic (60%) and hydraulic (24%) generators, including mini and micro hydroelectric plants (Ortega-Méndez and Diez-León, 2013).

There is limited information concerning the micro-hydraulic potential power in Mexico. An estimate made in 1995, indicated that roughly 2.5% of such potential (3,200 MW) was developed by approximately 57 micro-plants, with an average power of 364 MW (Valdéz Ingenieros, 2005, 2006; Ramos-Gutiérrez and Montenegro-Fragoso, 2012; González-García, 2014). In 2013, the installed power generated by micro-hydraulic systems was 980 MW (Valdéz-Báez, 2008) and the challenge for the next 20 years is to double the current capacity (Liu et al., 2013). Although there is a favorable legal and political climate for achieving this goal, there is also a pressing need to assess the totality of the hydraulic network in Mexico (more than 130 rivers and tributaries), which is the base for an adequate energy generation planning.

The mini and micro-hydraulic power is mainly concentrated in Puebla, Veracruz, Chiapas and Oaxaca, although there are at least another four states with potential for generating energy at this scale. Actually, 17 small power plants (224 MW) are already operating in damns of Michoacán, Chihuahua, Nuevo León and Guerrero. A few mini and micro-hydraulic plants are owned by the Federal Government (through the Federal Commission of Electricity) but they mostly belong to foreign particulars. In terms of cost-benefit, the axial type turbines have proven to be an adequate kind of small sized hydroelectric technology for domestic; depending the plant capacity costs vary between $8,000 USD (three kW) and 13,000 USD (eight kW; González-García, 2014). In Mexico, important societal and environmental benefits of using these kinds of plants are access to renewable energy by isolated human settlements, reduction of dependence to large-scale power plants and to fossil fuels, comparatively small-sized facilities and, thus, minimization of habitat alterations (Hernández-Huitrón et al., 2013).

The work of Micangeli and Cataldo (2013) is one of the few available documented studies on micro hydroelectric plants in Mexico; this study case is entirely based on such study. The project aimed at the implementation of a 50 kW micro hydro plant at “La Realidad”, a village in the Lacandona Forrest (Fig. 5), Chiapas. Taking into account the community needs, a Micro Hydro Plant was locally assembled. Then, the project continued with a second phase consisting in the installation of an OSEC system that uses the electricity generated from the Micro Hydro Turbine to produce chlorine, a very common good and the first choice to disinfect water in emergencies.

A zone with the presence of a small river together with some small waterfalls (18 m drop) was chosen as the place to intercept the water flow to the powerhouse. Considering the impact on the local environment of a complete deviation of the water flow, the community chose a solution with an embankment of grounds lots in the river and a nominal flow of about 400 L/s to the powerhouse. Floods could potentially carry away the lots, but it is quite easy and cost-free for the community to repair an embankment of lots while a small dam in reinforced concrete could become an environmental problem and could need an expensive repairing.

From the concrete intake, water is guided in a channel to a sedimentation tank. Then, from this tank water is received, through another channel, by a charge tank where the penstock begins. In the powerhouse, the turbine is coupled with a synchronous brushless alternator. The load control has been made with an electronic system working with five resistances of 10 kW, each resistance subdivided in 15 steps of 660 W. The power produced but not engaged by the loads connected to the grid is wasted on the resistances that are dipped in the water of the river exiting the turbine. In this way, the voltage is kept constant to the grid. Complex hydraulic or mechanical speed governors altered flow as the load varied, but more recently developed ELC has increased the simplicity and reliability of modern micro hydro sets. ELC has no moving parts and is virtually maintenance-free.

One of the main results of this project was that the community is now free from external energetic dependence and contributes to local self-development. This represents a success from the technological, political, and social point of views. The project is a good example of an efficient cooperation among different organizations and people coming from heterogeneous backgrounds.

No data was obtained till now on the effects of this micro hydroelectric plant in terms of the local biocenosis/ecosystems, fact that pinpoints an urgent need of basic ecological research.

Figure 5: Type of stream in the Lacandona Forrest, Chiapas, used for hydrotechnical works.

Sardabroud River (Kelardasht, Mazandaran Province, Iran) Case study

It is clear that using the sustainable hydropower energy has economic benefits, less environmental pollution compare to fossil fuel burning, solving the energy security issues of impassable villages, decreasing the cost of agricultural products and finally decreasing the use of fossil fuels.

Great potential exists in the Zagros and Alborz mountain ranges, the increasing demand and cost of energy, support of local markets, job creation, providing remote areas with energy, cost reduction of power transmission, and less diesel use for power generation are some reasons that have lead Iran's government to start using micro hydro power plants.

Due to the presence of large rivers in different areas of Iran, such as Karoon, Karkheh, Dez, Sefidrood, Arass and etc. there are plenty of large dams providing hydropower all over the country, but the education regarding microhydro power plants has lead to the identification and localization of over 2,500 suitable locations for construction of micro hydro power plants in Iran, which some are under construction and others are operational.

Sardabroud River is one of the important rivers of Mazandaran province due to the use of its water for urban and agricultural activities. This river originated from Alborz Mountains at the north side of the Iran's capital.

The Sardabroud small hydro power plant (Fig. 6) is located at the 25°36'29.36" N 2°51'6.51" E at the southeast of Kelardasht in Mazandaran Province, Iran (south of the Caspian Sea). The total capacity of power production of this plant is about five MW.

Figure 6: Sardabroud micro hydro power plant.

Environmental studies during the construction time showed that the most significant negative effect of this facility is the dust and soil destruction during the excavation and transportation activities. This also results in increasing water turbidity, depletion of oxygen content of water and mortality of fish fauna due to changes in water parameters (Abbasspour et al., 2010).

Other negative effects, was the decrease of the aquatic plants due to decreasing the water flow of the river downstream of the dam with negative effects on some herbivorous fish fauna such as the *Ctenopharyngodon idella*.

On the other hand, the reservoir of the dam made a suitable place for migratory birds coming from northern parts of the Caspian Sea to this region (which is located at the south of the Caspian Sea).

Also, increasing the aquatic plants upstream of the river near the reservoir which make a good place as a spawning and nursery ground for native species such as the *Salmo trutta fario*.

The other major fish species of the Sardabrud River are rainbow trout, *Oncorhynchus mykiss*; Spirlin, *Alburnoides bipunctatus* and *Luciobarbus barbulus* (Kiabi et al., 1999; Abdoli, 1994).

In total construction and operation of Sardabrud hydropower plant, there were some short term negative effects on fauna and flora of the river at the dam and its reservoir site. Due to minor chemical pollutions and small scale of the reservoir, it seems there will not be any serious long term effects on the aquatic and terrestrial organisms of the region.

Rui River (Perak, Malaysia) study case

Malaysia has abundant water resources with average rainfall about 3,549 mm annually (Shafie et al., 2011). Rivers in Malaysia originated from mountainous areas and become favourable for hydropower projects (Ahmad and Tahar, 2014). Malaysia has 12 large-scale hydropower and 50 mini-scale hydropower stations (Raman et al., 2009), making micro hydro power plant not significant in this country because most of the areas are well electrified. But, micro hydro power plant still very important as alternative renewable energy source in future. In fact, Raman et al. (2009) showed that a total of 109 sites have been identified as micro hydro potential sites.

There are a few numbers of micro hydro power plants in Malaysia. Some of them are inactive. One of the plant that still operated is Pong Micro Hydro Power Station that located near Gerik-Klian Intan road that was built around 1924 (Fig. 7). The dam, an ex-mining pond, was built in Rui River to generate electricity to mobilise the cable cars that transport tin ore from Klian Intan to tin smelter due to mountainous surface. The dam supplies about 11,000 kW of power per day for the tin mining operations.

Figure 7: Water intake of Pong Dam, Perak, Malaysia.

However, one of the challenges in macro hydro power plant is water scarcity that would expect to occur in the next 10-15 years due to sedimentation and water pollution. Siltation and sedimentation problems had resulted in chokage of microwire filters especially during rainy season (Wai and Abdullah, 2002). The silt abrasion on hydraulic installed at power plant due to the sedimentation reduced the energy capacity production. Changes in land use and vegetation cover in the catchment area could lead to major modifications in freshwater run-off, sediment transport and nutrient fluxes. Excessive siltation leads to suffocation of fish eggs, thus adversely affecting fish populations especially intolerant species such as Malayan mahseer (*Tor tambroides*) (Gordon et al., 1996). Besides, this river is known as a spawning ground for the Tiny scale barb (*Thynnichthys thynnoides*) (Amal et al., 2015).

The potential of micro hydropower in Malaysia is yet to be discovered. Micro hydropower is a good option for providing electricity in the remote areas at lower costs.

CONCLUSIONS

Micro hydropower can be a very cost effective and easy way for rural communities in developing countries to acquire electricity. Proper locations do need to be identified. Both social and environmental risks need to acknowledged and appropriately managed. As well, a system or scheme needs to be installed that can accommodate the local energy needs but not be scaled too large to where the costs for larger system exceed what is needed and what is affordable for the local community.

Costs associated with installation are fairly reasonable and there are ways of significantly reducing costs by utilization of local labour. The use of local labour to install systems not only brings the price down, but also gives a sense of ownership to the community. This ownership will create an inherent level of pride, which can be leveraged to the benefit for the longevity to micro hydro within the areas it is applied. Using local labour also creates the market for maintenance personnel, knowing how the system was built and operates, allows those who worked on the project to potentially gain employment as the individuals that maintain the systems.

Under the right conditions and in the right circumstance, micro hydro power plants can be the answer for a low cost, steady supply for localized energy needs. The greatest areas of applications are within developing countries with areas exhibiting significant topographic relief with decentralized power needs.

Current studies in the field of hydropower industry show that it can be considered an environmentally-friendly source of energy alongside other sources such as wind or solar, because it is generated in natural rivers.

The development of small hydropower construction has created mixed feelings in society and caused social tensions in the Carpathian region. To regulate conflicts of interests between local communities, businesses and environmentalists, it is necessary to take into account the protected areas with high conservation value and principles of priority and expedience when making decisions and selecting sites for construction. These principles should be based on environmental criteria and should not go beyond the local and international legislation.

Last but not least, it should be highlighted that the wrong ecological approach or know-how in these projects implementation can be a major cause for which the ecological costs are sometimes higher than the economic benefit!

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