FEASIBILITY STUDY OF MULTIPLE HYDROPOWER PROJECTS: CASE STUDY OF BALTACI STREAM, TRABZON, TURKEY

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

BORAN EKİN AYDIN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

SEPTEMBER 2010

Approval of the thesis:

FEASIBILITY STUDY OF MULTIPLE HYDROPOWER PROJECTS: CASE STUDY OF BALTACI STREAM, TRABZON, TURKEY

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ABSTRACT

FEASIBILITY STUDY OF MULTIPLE HYDROPOWER PROJECTS: CASE STUDY OF BALTACI STREAM, TRABZON, TURKEY

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September 2010, 111 pages

High greenhouse gas emissions increased the importance of renewable energy resources. Hydropower is among the most widely used type of renewable energy. Oppositions to big hydropower projects with reservoirs increased the use of small hydropower plants. Development of a small hydropower project is a challenging engineering task. Different software's are developed and used to make initial estimations of energy generation and initial costs of the project. RETScreen Clean Energy Analysis Software which can be used worldwide allows the user to estimate initial energy output and costs. In this study, three consecutive hydropower projects (HEPP), namely, Kemerçayır, Üçhanlar and Üçharmanlar HEPP's and four alternative project formulations to these projects are evaluated using RETScreen. The results of the evaluations are compared and best formulation for the projects is identified. In addition to economical profitability, hydropower plants need to be evaluated in terms of their environmental impacts and sustainability aspects. Sustainable development is a fundamental concept of natural resources management. International Hydropower Association prepared the Sustainability Assessment Protocol to evaluate new or existing hydropower facilities with respect to various environmental, social and economic sustainability aspects. The Sustainability Assessment Protocol of IHA is used to evaluate Kemerçayır HEPP. Due to lack of necessary information, rather than conducting a sustainability assessment of a small hydropower project (SHP), necessary information required to conduct such a study is identified.

Keywords: Small Hydropower, Hydropower, Sustainability, RETScreen

ÖZ

ÇOKLU HİDROELEKTRİK SANTRALLERİNİN YAPILABİLİRLİK ÇALIŞMASI: BALTACI DERESİ ÖRNEĞİ, TRABZON, TÜRKİYE

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Eylül 2010, 111 sayfa

Yüksek sera gazı salımı, yenilenebilir enerji kaynaklarının kullanımını arttırmıştır. Hidroelektrik enerji en yaygın kullanılan yenilenebilir enerji kaynağıdır. Büyük ölçekli hidroelektrik santrallere karşı oluşan muhalefet, küçük hidroelektrik santrallerin kullanımını artırmıştır. Küçük hidroelektrik santrallerin planlanması zorlu bir mühendislik sürecidir. Hidroelektrik projelerinin ilk maliyet ve enerji hesaplarının yapılabilmesi için değişik yazılımlar geliştirilmiştir. RETScreen Temiz Enerji Analiz Yazılımı, tüm dünya çapında kullanılabilen ve hidroelektrik projelerinin ilk hesaplarını yapabilen bir yazılımdır. Bu çalışmada üç ardışık hidroelektrik projesi (Kemerçayır, Üçhalar ve Üçharmanlar Projeleri) ve bu projeler için oluşturulan dört değişik proje alternatifi RETScreen kullanılarak değerlendirilmişir. Değerlendirilmenin sonuçları karşılaştırılarak projeler için en iyi alternatif belirlenmiştir. Ekonomik kazanımlarının yanında, hidroelektrik projeleri çevresel ve sürdürülebilirlik açılarından da incelenmelidir. Sürdürülebilir gelişme, doğal kaynakların yönetimini için çok önemli bir kavramdır. Uluslararası Hidroelektirik Ajansı'nın hazırladığı Sürdürülebilirlik Değerlendirme Protokolu, yeni veya kullanılan hidroelektirik tesislerin ekonomik, sosyal ve çevresel konularda değerlendirilmesi için kullanılabilir. Bu protokol, Kemerçayır hidroelektirik santralinin değerlendirilmesinde kullanılmıştır. Gerekli bilgiler bulunamadığından değerlendirme tamamlanamamıştır. Bunun yerine değerlendirilmenin gerçekleşebilmesi için ihtiyaç duyulan bilgiler belirtilmiştir.

Anahtar Kelimeler: Küçük Hidroelektrik Santraller, Hidroelektrik, Sürdürülebilirlik, RETScreen

To My Mother and Father...

ACKNOWLEDGEMENTS

First of all, I would like to thank profoundly my mother and father for their endless love and faithful support.

Then, I would like to express my special thanks to my dear supervisor, Assist. Prof. Dr. Elçin Kentel for her never ending support, continuous understanding, invaluable patience, and guidance throughout this study. Her guidance made me clarify and realize my goals which I will remember forever.

The author also wishes to express his sincere gratefulness to his co-supervisor Prof. Dr. Doğan Altınbilek for his encouragements, guidance, and comments during this study.

The author wishes to express his deepest gratitude to Reşat Köymen and Nadi Bakır from ERE Group for their financial support throughout this study.

Special thanks go to my colleagues Arzu Soytekin, Reyhan Mutlu and Onur Arı for their guidance and help during this study.

Finally, the author wishes to express his special thanks to his beloved fiancée Bilge Çelik for her endless support and love during this study.

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CHAPTER 1

INTRODUCTION

1.1 General

The demand for energy is increasing day by day with the growing industry and living standards of people. To overcome this demand new energy facilities are under construction all around the world.

Dependence on fossil fuels to generate electricity results in high greenhouse gas emissions, which led to global warming and climate change. Moreover, the cost of electricity is getting higher due to the high fossil fuel prices. Those disadvantages increase the importance of renewable energy.

Hydropower is the most reliable sources of new generation into the future, and its share is more than 92 % among the renewable energy generated (Yemtsa and Steven, 2009). However, there is a great opposition against large scale hydropower projects worldwide. Despite the benefits of large dams, there are social, environmental and economic disadvantages to be concerned (Altınbilek, 2002). Due to these factors small hydropower (SHP) systems gain more importance.

SHP plants combine the advantages of hydropower with those of decentralized power generation, without the disadvantages of large scale installations (Lins et al., 2005). Adigüzel et al., (2002) states that SHP emerged as an energy source which is accepted as renewable, easiliy developed, inexpensive and harmless to the environment.

For the last 10 years, the fastest increase in demand for electricity has been observed in Turkey, among the OECD countries. The dependence of imported sources to generate electricity is more than 70 % in Turkey (MENR, 2010). Turkey has a great untapped SHP potential. Unexploited SHP potential of Turkey is equal to approximately 70 % of unexploited SHP potential of all European Union countries (TNSHP, 2004; Küçükbeycan, 2008).

To use the untapped SHP potential of Turkey, especially after the foundation of Energy Market Regulatory Authority (EMRA) in 2001, many local and foreign investors have entered to the energy market.

1.2 Scope of the Study

Small hydropower has a key role in reducing the greenhouse gas emissions and adverse environmental effects of fossil fuel consumption. However, the design of SHP projects is not an easy task. Each project is site specific and needs detailed and challenging engineering computations to optimize the benefits of the project.

Feasibility study of a project is where initial calculations and optimization studies are made. Depending on these studies, the decision of whether the project is feasible or not is made. Various software's are developed to conduct pre-feasibility studies of SHP projects.

In this study, three consecutive SHP projects located on Baltacı Stream in Trabzon are selected as the case study projects. From upstream to downstream the projects are Kemerçayır, Üçhanlar and Üçharmanlar hydropower projects (Feasibility Report, 2005a). Four different alternative project formulations are developed and pre-feasibility analysis of each alternative is completed using RETScreen. RETScreen Clean Energy Analysis Software developed by Natural Resources Canada is used in this study to compare economical profitability of the alternatives.

Hydropower projects including SHP's have effect on the environment and sustainable development. In order to measure the effect of HEPP's on the environment and sustainable development, Sustainability Assessment Protocol of International Hydropower Association was developed. To evaluate one of the SHP projects in terms of environmental and sustainability aspects this protocol is used in this study. However since the required data for the evaluation is not available, providing a complete sustainability evaluation was not possible so required data and information for completing a sustainability evaluation is identified and provided in this study.

The main motivations of this study are to develop alternative formulations to Kemerçayır, Üçhanlar and Üçharmanlar HEPP's given in the Feasibility Reports (2005a, 2005b, 2005c) and, to compare economical profitability of these alternatives by using RETScreen as a decision support tool. In addition, applicability of Sustainability

Assessment Protocol of International Hydropower Association to HEPPs in Turkey is investigated and necessary information to carry out the sustainability evaluation is identified.

In Chapter 1, general information and objectives of the study are given. Chapter 2 is a literature review of hydropower, small hydropower and computer software for small hydropower. The information about Kemerçayır, Üçhanlar and Üçharmanlar Hydropower Projects are presented in Chapter 3. In Chapter 4, a brief introduction to RETScreen is given and alternative project formulations are described. Evaluation results obtained from RETScreen are provided in Chapter 4 as well. Kemerçayır Hydropower Project is evaluated using the Sustainability Assessment Protocol of International Hydropower Association in Chapter 5. Finally, conclusions are provided in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydropower

2.1.1 History of Hydropower

The power of water has been used by humans for thousands of years. The Greeks used water in wheels where they grind wheat into flour more than 2000 years ago (U.S. Department of Energy, 2008). 19^{th} century was the turning point for the utilization of water power. The improvements in technology and need for electricity replaced the waterwheels with modern day turbines (Korkmaz, 2007). The development of hydroelectricity generation technology is shown in Table 2.1.

Table 2.1 The Development of Hydroelectricity Generation Technology (Raabe, 1985)

Year	Developer	Development
Semi-axial or Francis Turbines		
1827	Fourneyron	Centrifugal reaction-turbine
1837	Howd	Centripetal reaction-turbine
1837	Henschel	Axial reaction turbine and draft tube
1848	Boyden	Diffuser
1848	Francis	Experiments on a Howd turbine
1855	Frink	Adjustable guide-vane
1869	Swain	Reaction runner
1873	Voith	Francis turbine with adjustable gate
Impulse Turbines		
1863	Girard	Axial tangential-action turbine
1880	Peiton	Bucket jet-action turbine
1890	Brener	Needle valve
1900	Abner Doble	Bucket cut-out
Axial Turbines		
1875	Escher Wyss	Straflo Turbine
1913	Kaplan	Adjustable runner vane
1936	Fischer and Escher Wyss	Bulb turbine
1942	Gibrat	Tidal-power turbine
Pumped Storage		
1930	Escher Wyss	Axial pump turbine
1934	Voith	Radial pump turbine
High-Voltage transmission		
1868	Oskar von Miller and Deprez	First İnitiative for high-voltage transmission
1891	Dolivo von Dobrovolsky	Industrial-scale system with an output voltage of 15kV

2.1.2 Definition of Hydropower Energy

The generation of energy from water can be explained by the law of conservation of energy. The potential energy of flowing water is converted to kinetic energy in the penstock. The kinetic energy of the flowing water turns the blades of the turbine, where it is converted to mechanical energy. Finally, the turbine shaft rotates the generator and the final product, electrical energy is generated (Basnyat, 2006).The power generated by using the potential energy of flowing water is given by the following formula:

$$P = \eta \rho g Q H \tag{2.1}$$

Where;

P is the power in Watts,

η is the general efficiency of the plant,

ρ is the density of water in kg/m^3,

g is the gravitational acceleration in m/s^2,

Q is the discharge passing through the turbine in m^3/s,

H is the gross head of the water in m (elevation difference between the forebay and tailwater).

The principal requirements for electricity generation from water are given in ESHA (2005) as;

- Suitable rainfall catchment area

- Hydraulic head
- Means of transporting water form intake to the turbine, such as pipe or millrace
- Turbine house containing the power generation equipment and gate valve
- Tailrace to return the water to its natural course

2.1.2.1 Important Terminology Used in Hydropower

Firm energy is the energy that a plant can generate 95 percent of the time. Firm flow required to generate the firm energy is the minimum flow that a hydroelectricity plant can operate (Linsley et al., 1992). In general, firm power is not guaranteed by a small run-of-river plant. However, a group of small hydro run-of-river plants located in different basins of the country will guarantee a firm power since the low flow seasons of each basin will occur at different times of the year (Penche, 1998).

Secondary energy is all the energy available in excess of firm power. Secondary energy is not guaranteed; therefore the price of secondary energy is lower than the firm energy (Küçükbeycan, 2008).

Gross theoretical hydropower potential of a country is the amount of power that could be generated if all natural flow was turbined with 100 percent efficiency down to the sea level (DSİ, 2009).

Technically available hydropower potential of a country is the gross theoretical hydropower potential that can be changed technically into electrical power (ETH, 2009).

Economic hydropower potential of a country is the amount of technically available potential which can be technically developed and economically competitive with other energy alternatives of same size (ETH, 2009).

In general, the gross theoretical hydropower potential of a country will not change by time. On the contrary, changes in the economic hydropower potential of a country will be expected due to the changes in the world's and countries' economic situation. A plant which is not economic today may become economic in the future (Öztürk et al., 2009).

2.1.3 Hydropower in the World

Hydropower is the most widely used renewable energy source to generate energy. Hydropower is being used by more than 150 countries in the world. 11000 stations with 27000 generation units have an installed capacity of 860 GW and an addition of 120-150 GW capacity is added by the pumped storage plants (IHA, 2010). Hydropower supplies at least 50 % of natural electricity production in 63 countries and at least 90 % in 23 countries (Yüksek et al., 2007). Installed capacity by continent and installed capacity under construction are given in Figure 2.1 and Figure 2.2, respectively.

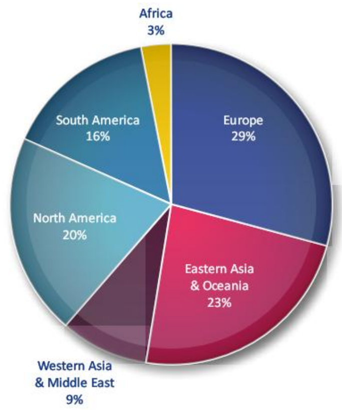

Figure 2.1 Hydropower Generation by Continent (IHA, 2010)

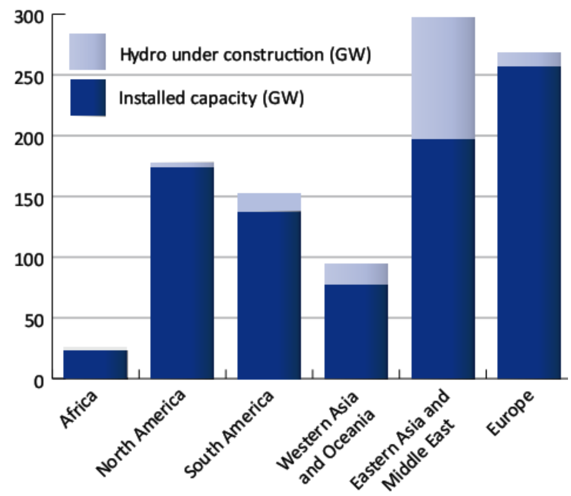

Figure 2.2 Hydropower Under Construction (IHA, 2010)

2.1.4 Hydropower in Turkey

The first hydropower project of Turkey was realized in Tarsus in 1902. It had an installed power of 60 kW. In 1950 the total installed capacity of

Turkey was 408 MW and the share of hydropower was only 4.4 % (Yüksel, 2008).

Today, installed hydropower capacity of Turkey is 14,552 MW, which is 32 % of the total installed capacity of Turkey (DSİ, 2009). Table 2.2 shows the distribution of installed capacity with respect to various sources for 2009.

Turkey has a gross theoretical hydropower potential of 433 TWh/year. The technically available hydropower potential is 216 TWh/year while 140 TWh/year of this potential is the economical hydropower potential of Turkey (DSİ, 2009).

Table 2.2 Installed Power Generated by Each Source (DSİ, 2009)

		CAPACITY		CAPACITY USAGE	
		Installed Power (MW)	Average Generation (GWh)	Actual Generation (GWh)	Percentage (%)
Thermal Power	Coal	10,612	69,576	54,985	79
	Oil	2,310	15,485	6,604	43
	Natural Gas	16,345	121,648	94,396	78
	Others	81	609	255	42
Total Thermal Power		**29,348**	**207,318**	**156,240**	**75**
Reneaweble Energy	Geothermal and Wind	880	3.246	1.940	60
	Hydropower	14,553	52,348	35,880	69
Gross Total		**44,781**	**262,912**	**194,060**	**74**

According to 2009 values (DSİ, 2009), 213 hydropower plants are in operation with an installed capacity of 14,300 MW generating an average of 50,000 GWh per year. 7,286 MW installed capacity and an average yearly generation of 23,770 GWh will be added by the completion of 145 hydropower plants which are currently under construction. In order to generate electricity from the remaining economical hydropower potential of Turkey, 200 hydropower plants which are currently at planning stage will be constructed. Besides 1,100 additional projects will be developed by the private sector using the build-own-transfer (BOT) method (DSİ, 2009). Table 2.3 shows the current status of the hydropower projects in Turkey.

Table 2.3 Current Status of Hydropower Projects in Turkey Including the Projects Developed by Private Sector (DSİ, 2009)

Status	# of plants	Total Installed Capacity (MW)	Average Yearly Generation (GWh/year)	Percentage (%)
Operating	213	14,300	50,000	36
Under Construction	145	7,286	23,770	17
Construction not started*	1300	22,614	66,230	47
Total	**1658**	**44,200**	**140,000**	**100**

*1100 BOT Projects are added

2.2 Small Hydropower

2.2.1 Definition of Small Hydropower

There is no internationally accepted definition for small hydropower. In China, small hydropower can refer to capacities up to 25 MW, in India the limit is 15 MW; whereas the limit in Sweden is 1.5 MW. However, a general agreement of 10 MW capacity is being accepted by European Small Hydropower Association, European Commission and International Union of Producers and Distributors of Electricity (Lins et al., 2005). Moreover, within the range of small hydropower, depending on the installed capacity, the type of the plant is named as; mini, micro, and pico hydropower which have an upper limit for installed capacity as; 1 MW, 100 kW and 5 kW, respectively (Taylor et al., 2006). Table 2.4 shows the upper limits of installed capacity for small hydropower for different countries.

Table 2.4 Upper Limits of Small Hydropower Installed Capacity for Different Countries (TNSHP, 2004)

Country	Upper Limit For Small Hydro (MW)
Portugal, Spain, Greece, Ireland, Belgium	10
Italy	3
Sweeden	1.5
France	12
United Kingdom	20
Turkey	50

Being used more than one hundred years, small hydropower schemes are reliable source of electricity which use a well-understood technology. By this way, they can provide energy to a central grid, an isolated grid or an off-grid load (RETScreen, 2005).

2.2.2 Site Configuration of Small Hydropower Schemes

The working principle of hydropower plants depends on the conversion of the potential energy of flowing water into the electricity energy in the powerhouse. The energy generated is proportional to the head and the flow.

Small Hydropower (SHP) schemes are generally classified according to their heads. Although, there are no rigid limits, the classification given in Table 2.5 can be used (TNSHP, 2004).

Table 2.5 Classification according to head

Type	Limits
High head	100 m and above
Medium head	30 - 100 m
Low head	2 - 30 m

Schemes can also be classified with respect to the type as; Run-of river schemes, schemes with the powerhouse located at the base of a dam and schemes integrated on a canal or in a water supply pipe.

2.2.2.1 Run-of River Schemes

Run-of river schemes use the flowing water of the river to generate electricity. If the flow drops below the minimum design discharge, the generation will stop (TNSHP, 2004). Run-of river type small hydropower plants generate power without flow regulation. Most of the run-of river schemes has no water storage, thus the energy generated will fluctuate with river flow. Jiandong et al., (1996) states that most of the small hydropower plants are run-of river type plants in the world.

Some of the run-of river type plants have a head pond or a forebay which adds a little storage capacity to the scheme. This little storage capacity is used to regulate the peak loads. A weir is used to divert the water from river bed. The diverted water is carried by a combination of channels and tunnels into the forebay (Figure 2.3).

Feasibility studies for alternative project formulations of Kemerçayır, Üçhanlar and Üçharmanlar Hydropower Plants are conducted in this thesis study and these projects are run-of river type hydropower projects.

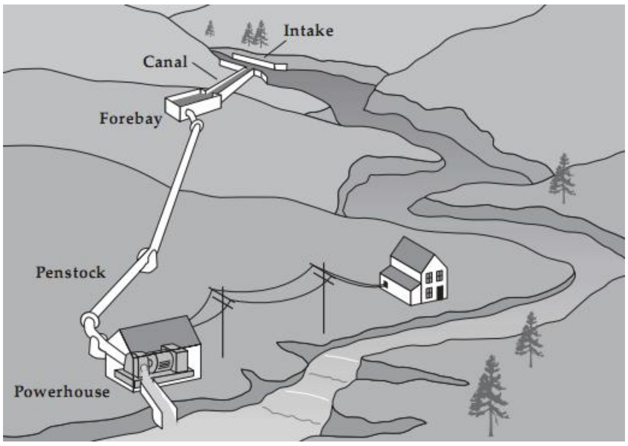

Figure 2.3 A run-of river scheme (National Renewable Energy Laboratory, 2001)

2.2.2.2 Other Types

In some cases, reservoirs are built for other purposes, such as; flood control, supply water for irrigation, municipal or industrial purposes, or recreational use. Some of these reservoirs can also be used for energy generation (TNSHP, 2004). The main problem of this scheme is how to connect the head water with the tail water and where to fit the turbine (TNSHP, 2004). One solution if the dam already has a bottom outlet is construction of a powerhouse at the outlet to generate electricity (Figure 2.4).

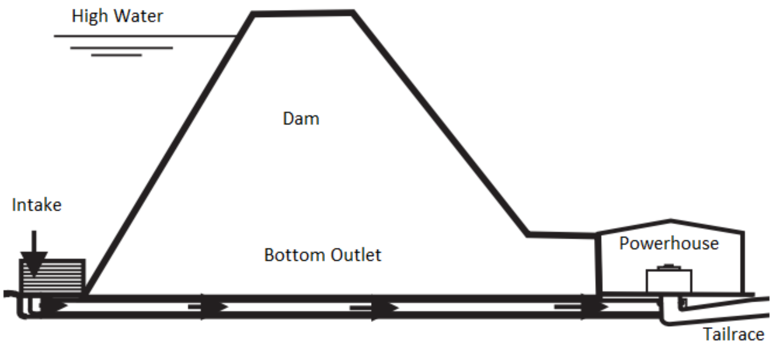

Figure 2.4 Low head scheme using an existing dam (Penche, 1998)

Some of the small hydropower schemes are integrated within the irrigation canals. In these kinds of schemes, the canal is enlarged to accommodate the intake, the power station, the tailrace and the lateral bypass. In case of shutdown of the turbine, to be able to supply the water for irrigation a lateral bypass must be included into this type of scheme (TNSHP, 2004). Figure 2.5 shows a scheme of this kind with a submerged powerhouse.

Schemes integrated into the water abstraction system of a city are another type of SHP scheme (Figure 2.6). Pressured pipes are used to convey the clean water to the city. Normally, special valves are used at the entrance of water treatment plant to dissipate the energy in these pipes. In these types of schemes a turbine is installed at the entrance of the treatment plant to convert the otherwise lost energy to electricity, instead of the valves. Similar to the schemes integrated into within the irrigation canal, a bypass valve must be installed to ensure the water supply all the times (TNSHP, 2004).

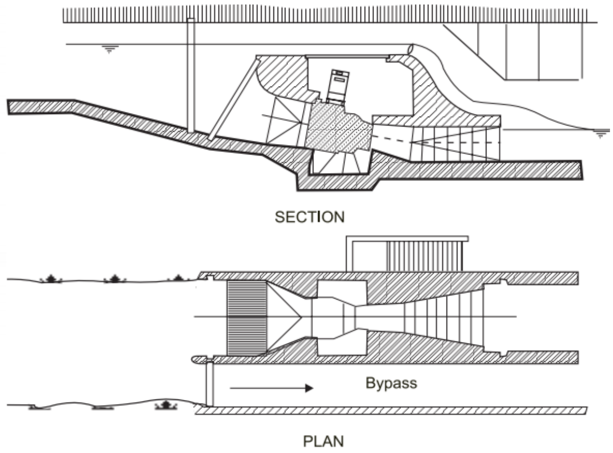

Figure 2.5 A Typical Canal Scheme (Source: TNSHP, 2004)

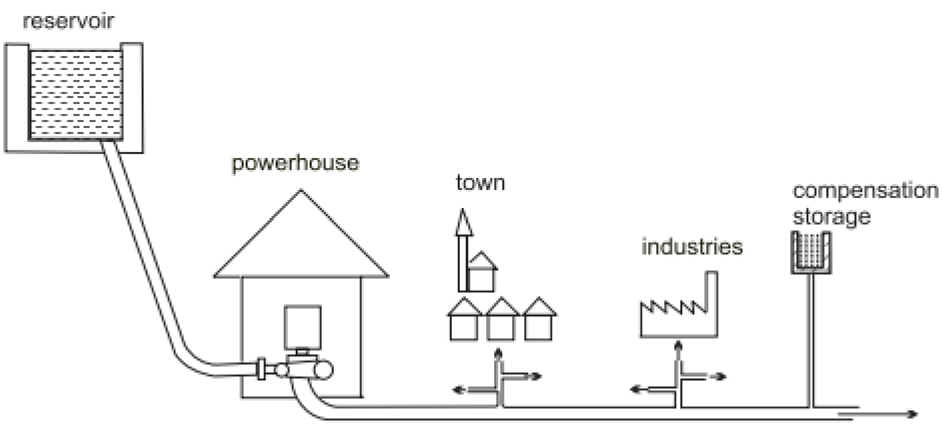

Figure 2.6 Scheme integrated in a water supply system (Penche, 1998)

2.2.3 Components of Small Hydropower Schemes

The main components of run-of river schemes can be divided into two headings; civil works and electromechanical works.

The civil works of a run-of river SHP scheme include water conveyance structures, head pond or forebay, penstock, powerhouse and tailrace structures. Turbine, generator, governor, and regulator are the electromechanical components of a run-of river scheme.

2.2.3.1 Civil Works

An intake structure is required at the entrance to a conduit through which water is withdrawn from a river (Linsley et al., 1992). To prevent the entrance of debris to the system, trash racks are built.

The diverted water is carried by the water conveyance structures. Water conveyance structures are either canal or a tunnel. Depending on the topography and the soil conditions of the construction area, the best alternative to carry water is selected.

Forebay is a small reservoir located at the end of the canal or tunnel which diverts water into the penstock. Forebay always have to store enough water to ensure that the penstock is fully submerged (Yanmaz, 2006).

Penstock is a pressurized water pipe that carries the water to the powerhouse. Steel is the most commonly used material to built penstocks; however, reinforced-concrete and wood-stave pipes are also used (Linsley et al., 1992).

Powerhouse is a building built by conventional building materials. Most of the electromechanical equipment of the hydropower plant is located in the powerhouse that the electricity is generated in the powerhouse.

Tailwater canal connects the turbine with the natural stream bed. The water used in the turbines is diverted into its natural bed by using the tail water canal.

2.2.3.2 Electromechanical Works

Turbine transforms the potential energy of flowing water into rotational energy. The selection of turbine type is dependent on the head and the design discharge of the plant. Table 2.6 shows the turbine classification according to head. Figure 2.7 provides application ranges of different types of turbines depending on the head and the discharge.

Table 2.6 Turbine type According to the Head (Küçükbeycan, 2008; Paish, 2002)

Turbine Type	**Head Classification**		
	High Head	**Medium Head**	**Low Head**
Impulse	Pelton Turgo Multi-jet Pelton	Cross Flow Turgo Multi-jet Pelton	Cross Flow
Reaction		Francis	Francis Propeller Kaplan

Governors are used to control the rotational speed of the turbine within the limits by adjusting the water flow. The range of correct frequency is between 50 to 60 MHz (Paish, 2002).

Generator of the plant transforms the rotational energy of the turbine shaft into electrical energy.

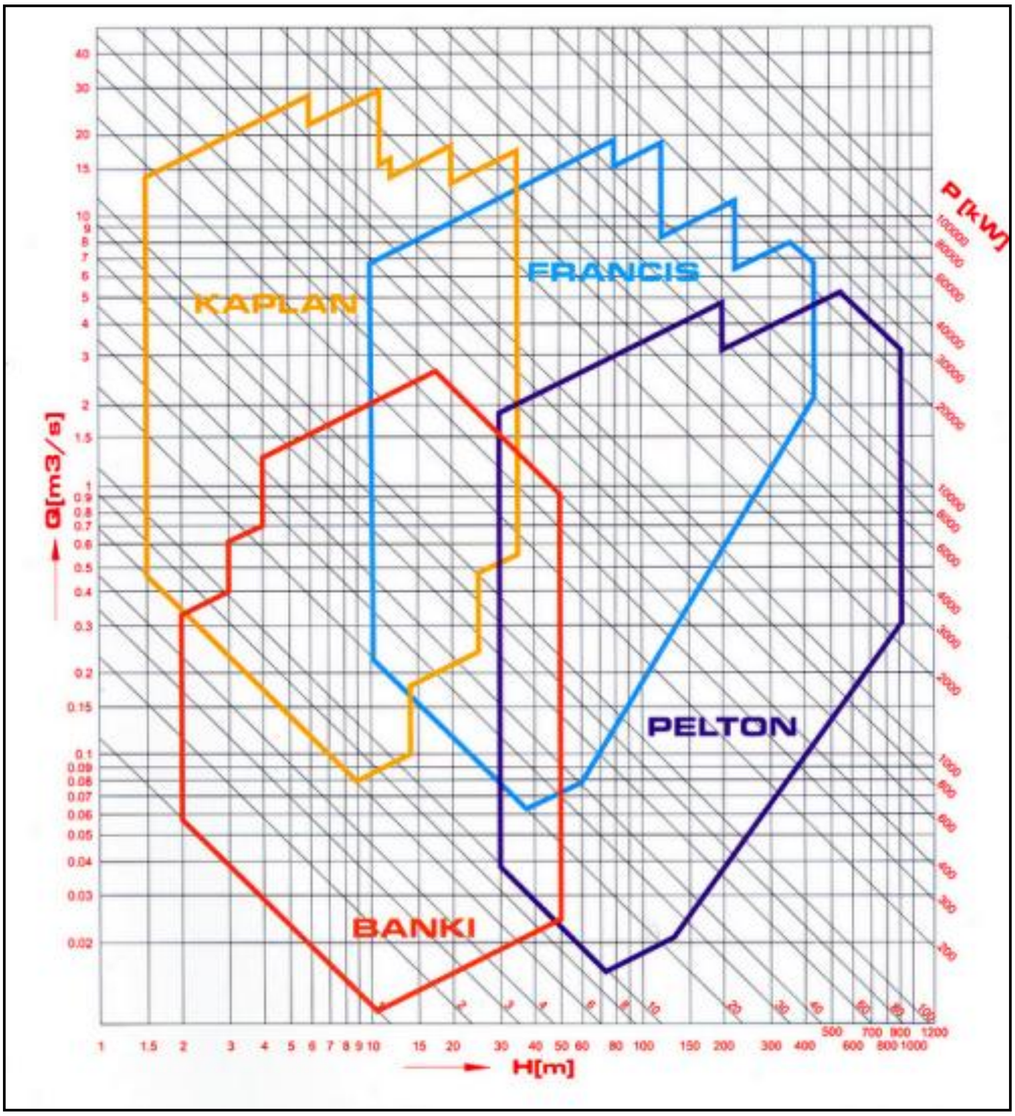

Figure 2.7 Turbine application range (MAVEL, 2009)

2.2.4 Advantages and Disadvantages of Small Hydropower

Small hydropower is a sustainable resource. Lins et al. (2004) states that "SHP meets the needs of the present without compromising the ability of future generations to meet their own needs."

Small hydropower plants are among the cheapest systems to generate electricity. It is a well known technology open to new technological developments. SHP has a high untapped potential especially in developing countries (ESHA, 2005). The main characteristics of small hydropower plants are their flexibility and reliable operation. Moreover, depending on the rapid demand changes, its fast start up and shutdown response is an important advantage (Dragu et al., 2001).

Small hydropower plants are using water to generate electricity therefore the electricity generation is independent from the changes in fuel costs (Dragu et al., 2001). Without any harm or decrease to its resource it can satisfy the energy demand (Lins et al., 2004). Moreover, SHP schemes recovers the waste that flows with the river flow with its trash racks, thus it helps the maintenance of river basins (Pelikan et al., 2006).

Small hydropower is a clean energy source, thus it is environmentally friendly. It does not pollute the environment and does not generate greenhouse gases. Pelikan et al. (2006) states that "one GWh of electricity produced by small hydropower means a reduction of 480 tonnes of emitted carbon dioxide". Moreover, small hydropower schemes have long life span and very limited maintenance is required (Paish, 2002).

Another advantage given by Lins et al. (2004) is that SHP schemes are located within the borders of one country, thus, there will be no disruption by international political events.

On the other hand, there are some disadvantages of small hydropower plants. For example, seasonal variations of the river flow results in variations in energy generation. These low flow seasons limits the firm power of the plant (Paish, 2002).

Dragu et al. (2001) states some adverse effects of small hydropower schemes on fish life. First of all, weir of the plant acts like a barrier which effect the fish movement. Secondly, especially young fish swimming downstream can be killed by the blades of the turbine. Thirdly, the spilled water will be supersaturated with the gas in the air. The gas bubbles in the water will kill the fish if they absorb it. Lastly, warm water will be collected at the surface of the reservoir, while cold water will be present at the bottom. This will result in a decrease in the oxygen level in the cold water in which most species of fish cannot survive.

Another disadvantage is the size and the flow of the river will limit the future site expansions at the demand for power increases (Alternative Energy, 2006).

One problem associated with SHPs in Turkey is public opposition. The critics of SHP in Turkey claim that diversion of most of the water from its natural bed into channels and tunnels causes the water quality and quantity to decrease at the downstream of the diversion. This causes the fish species and various microorganisms living in the river to decrease, and in some cases endangered species to become extinct. Moreover, the critics claim that since the water is carried by canals or tunnels to a downstream location, the groundwater is not fed; therefore, the groundwater water table gets lower. They claim that in the long run this may result in drought (Karadeniz İsyandadır, 2010).

A summary of advantages and disadvantages are given in Table 2.7.

Table 2.7 Summary of Advantages and Disadvantages of SHP (Hydro Tasmania, 2006)

ECONOMIC ASPECTS	
ADVANTAGES	**DISADVANTAGES**
Provides low operating and maintenance costs	Precipitation dependent
Provides long life span (50 to 100 years and more)	Requires long-term planning
Includes proven technology	Requires long-term agreements
Creates employment opportunities	Requires multidisciplinary involvement
Saves fuel	
Can provide energy independence by exploiting national resources	
Optimizes power supply of other generating options (thermal and intermittent renewables)	
SOCIAL ASPECTS	
ADVANTAGES	**DISADVANTAGES**
Leaves water available for other uses	Local land use patterns will be modified
Provides opportunities for construction with a high percentage of local manpower	Waterborne disease vectors may occur

Table 2.7 Continued (Hydro Tasmania, 2006)

ENVIRONMENTAL ASPECTS	
ADVANTAGES	**DISADVANTAGES**
Produces no atmospheric pollutants	Barriers for fish migration, fish entrainment
Neither consumes nor pollutes the water it uses for electricity generation purposes	Modification of hydrological regimes
Produces no waste	Modification of aquatic habitats
Avoids depleting non-renewable fuel resources (i.e., coal, gas, oil)	Water quality needs to be monitored/managed
Can result in increased attention to existing environmental issues in the affected area.	Species activities and populations need to be monitored/managed

2.2.5 Small Hydropower in the World

Among the other renewable energy sources, small hydropower being a cheap and clean energy source has a key role in development. Small hydropower has an important share in worlds' renewable energy budget. Table 2.8 shows global electricity generation by each renewable energy source.

Table 2.8 Global Electricity Generation by Each Renewable Energy Source (Dragu et al., 2001)

Large hydro (>10 MW)	86 %
Small hydro (<10 MW)	8.3 %
Wind and solar	0.6 %
Geothermal	1.6 %
Biomass	3.5 %

In 2004, the total installed capacity of small hydropower (<10 MW) was about 48 GW worldwide as shown in Table 2.9. In 2005, China has reached to a SHP capacity of 31,200 MW which is more than the half of the worlds SHP capacity (Taylor et al., 2006). Canada uses small hydropower to replace expensive diesel generation in remote off-grid regions. Moreover, countries in South America, Africa and former Soviet Union also have great untapped potentials (Lins et al., 2005).

Table 2.9 Installed SHP (<10 MW) Capacity by World Region in 2004 (Taylor et al., 2006)

Region	Capacity (MW)	Percentage (%)
Asia	32,641	68.0
Europe	10,723	22.3
North America	2,929	6.1
South America	1,280	2.7
Africa	228	0.5
Australasia	198	0.4

16,800 SHP are in operation in 25 European Union Countries in 2004. The number of plants in the candidate countries is only 400. Concerning the total hydropower generation, the share of SHP is about 11-13 % in EU25 countries (Marketing Working Group of TNSHP, 2004).

According to Laguna (2006), more than 82 % of the economical potential is developed in the former 15 European Union countries. The development of economical potential in EU10 and candidate countries is less than 40 % and 6 %, respectively. The remaining potential is 20TWh/year in EU15, 4 TWh/year in EU10 and 22 TWh/year in the candidate countries. More than 19500 GWh/year of the latter is located in Turkey.

2.2.6 Small Hydropower in Turkey

As mentioned in the previous section, Turkey has a big untapped small hydropower potential. According to Balat (2007) the gross theoretical small hydropower potential of Turkey is 50,000 GWh/year. 30,000 GWh/year of this potential is technically feasible and only 20,000 GWh/year is the economically feasible SHP potential of Turkey. The SHP potential of Turkey and current situation is given in Table 2.10.

Table 2.10 Turkey's Small Hydropower Potential (Marketing Working Group of TNSHP, 2004; Balat, 2007)

Potential	Generation		Capacity
	GWh/year	%	MW
Gross theoretical	50,000	100	16,500
Technically feasible	30,000	60	10,000
Economically feasible	20,000	40	6,500
Economically feasible potential that has been developed	673	3.3	177.1
Remaining Economically feasible potential	19,336	96.7	6,325

As it is given in previous sections, according to DSİ (2009), total energy generated using thermal power plants was 156,240 GWh in 2009. If remaining 19,336 GWh economically feasible SHP potential of Turkey had been developed and added to the natural grid, the dependence on thermal power would have decreased more than 10 percent for 2009. This would have resulted in a reduction of 9,281,280 tonnes of emitted carbon dioxide. Thus, Turkey may benefit from developing the economically feasible hydroelectricity potential of the country in a timely and environmentally sound manner.

In 2002 there were 71 SHP plants in operation with an installed power of 177.1 MW. The forecast for the year 2015 is 130 SHP plants with a total installed capacity of 335 MW (Marketing Working Group of TNSHP, 2004). The share of installed hydropower capacity in Turkey's total installed capacity is more than 32 % in 2009 (DSİ, 2009). However, the share of small hydropower in Turkey's total energy generation is given in Marketing Working Group of TNSHP (2004) as 0.52 %. If Turkey had used its economically feasible SHP potential in 2009, the share of SHP in total energy generation would have been more than 10 %.

2.3 Computer Software for Small Hydropower Development

Development of a small hydropower scheme is a challenging process which needs great amount of time and money in addition to expertise in various disciplines. The first stages of the development require quick estimations of the energy output of the project. Several computer software programs such as RETScreen, HES, Hydra are developed to make initial economical analysis for a new SHP project. Utilization of such software shortens the time and money spent for conducting the initial economical assessments for the projects.

Table 2.11 summarizes some of the software programs and their main features. Due to some features of these softwares, some of them are applicable only in limited countries or regions. However; as can be seen from Table 2.11 IMP and RETScreen can be used internationally. Both IMP and RETScreen can evaluate energy output of the projects, but RETScreen is one step forward since it is capable of making cost analysis and it can be downloaded free-of charge. Moreover, its user friendly manual helps the user to learn and use the program easily. Due to these advantages RETScreen is used to evaluate the alternative project formulations in this study.

Table 2.11 Small Hydropower Assessment Tools (Wilson, 2000)

Assessment Tool		Features				
Software	Applicable Countries	Hydrology	Power / Energy	Costing	Economic Evaluation	Preliminary Design
ASCE Small Hydro	USA	X				
HES	USA	X				
Hydra	Europe	X	X			
IMP	International	X	X		X	
PEACH	France	X		X		X
PROPHETE	France	X	X		X	
Remote Small Hydro	Canada	X	X		X	
RETScreen	International	X	X	X	X	

2.3.1 RETScreen Clean Energy Analysis Software

RETScreen International Clean Energy Decision Support Centre is managed under the leadership and ongoing financial support of CanmetENERGY which is a research centre of Natural Resources Canada (Natural Resources Canada, 2010). The RETScreen Clean Energy Decision Support Centre seeks the capacity of planners, decision makers and industry to implement renewable energy and energy efficient projects (Leng et al., 2004). This objective is achieved by:

- developing decision-making tools that reduce the cost of pre-feasibility studies (RETScreen Clean Energy Analysis Software);
- disseminating knowledge to help people make better decisions;
- training people to better analyze the technical and financial viability of possible projects.

RETScreen can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs) (Natural Resources Canada, 2010). The usage of RETScreen worldwide has resulted in considerable achievements in different areas. Table 2.12 shows predictions about some of the achievements of RETScreen.

Table 2.12 Predictions for some of the achievements (Leng et al., 2004)

Performance Indicators	Future Impact (1998 to 2012)	
	Canada	World
User Savings	$ 1.8 billion	$ 7.9 billion
Installed Capacity	4.9 GW	24 GW
Installed Value	$10 billion	$41 billion
GHG Reduction	3.6 MT* CO_2/yr	20 MT CO_2/yr

*millions tonnes

As can be seen from Table 2.12, by the end of the 2012, it is estimated that the users will save $ 7.9 billion due to using RETScreen.

RETScreen does not compute any environmental or social costs. The emission analysis sheet allows the user to compare the greenhouse gas emissions of the project with that of a conventional power plant. Moreover, RETScreen does not provide any tool to calculate the costs associated with possible problems such as erosion, sedimentation and earthquake.

RETScreen can be used to evaluate different type of clean energy models. Some of them are; power, heating, cooling, combined heating and power, combined cooling and power and energy efficiency measures. Each model on RETScreen has a common look and follows a standard path to help the decision maker. Moreover, each model has integrated product, cost and weather databases (Leng et al., 2004).

CHAPTER 3

CASE STUDY PROJECTS

3.1 General Information

This thesis study consists of the evaluation of alternative formulations for three consecutive hydropower projects namely; Kemerçayır, Üçhanlar and Üçharmanlar located in Of, Trabzon. This chapter provides general information about the locations of the projects and climate conditions of the project area, as well as the current formulations provided in the Feasibility Reports (2005a, 2005b, 2005c). Due to confidentiality issues the complete references to these feasibility reports are not provided here. From here on these feasibility reports will be referred to as the Feasibility Reports (2005a, 2005b, 2005c).

3.1.1 Project Area

Project area is located in Black Sea region of Turkey in Trabzon. The hydropower projects are situated on Baltacı Stream located in Of. The project area is a mountainous region mostly covered with forests and located in the Of-Baltacı basin. There is no private property in the project area, however; the local people use some parts of the area as grassland.

3.1.2 Earthquake Conditions

The project area is located in the fourth degree earthquake zone (Figure 3.1). Therefore, the project site can be considered as a relatively safe area in terms of earthquakes.

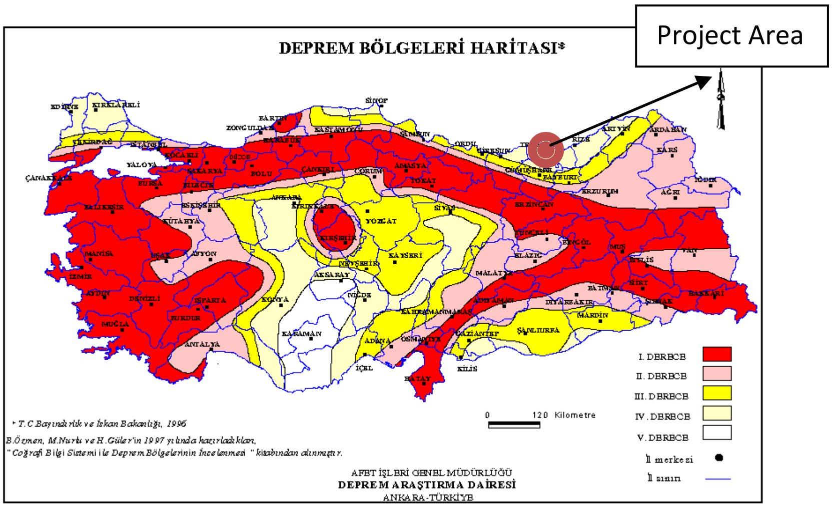

Figure 3.1 Earthquake Regions of Turkey (Disaster and Emergency Management Presidency, 1996)

3.1.3 Climate Conditions

Project area receives rain throughout the year. Using the measurements between the years 1970 and 2009, average rainfall per month is calculated as 68.68 mm, minimum rainfall occurs in July with an average of 37.5 mm and maximum rainfall occurs in October with an average of 118.8 mm in Trabzon (DMİ, 2009). The climate at the project site shows the basic characteristics of the Black Sea climate. The summers are hot and moist, while the winters are warm and very rainy. The records of İkizdere gauging station given in the Feasibility Report (2005a, 2005b, 2005c) show that annual average precipitation reaches 1400 mm in the area.

3.1.4 Water Resources

Rainfall and temperature are recorded at two gauging stations located at İkizdere and Uzungöl. İkizdere station stopped operation after 1996 while the other is still working (Feasibility Report, 2005a).

The main water resource of the project area is Baltacı stream. The discharge of the project area is determined in the Feasibility Report (2005a, 2005b, 2005c) using recordings of 22-68 Baltacı stream Yeniköy discharge gauging station (Feasibility Report, 2005a). This station has been in operation since 1982. The maximum discharge observed in this station was 95.1 m^3/s in 1998 (DSİ, 2009). In this study, the discharges given in the Feasibility Reports (2005a, 2005b, 2005c) are used without any adjustment or correction.

3.2 Current Formulation

This chapter provides information about the current formulations of the Kemerçayır, Üçhanlar and Üçharmanlar Weirs and HEPPs. The Feasibility Reports (2005a, 2005b, 2005c) are used in preparing the following sections. Overview of project formulations generated using Google Earth for Kemerçayır, Üçhanlar and Üçharmanlar HEPP are given in Figures 3.2, 3.3 and 3.4, respectively.

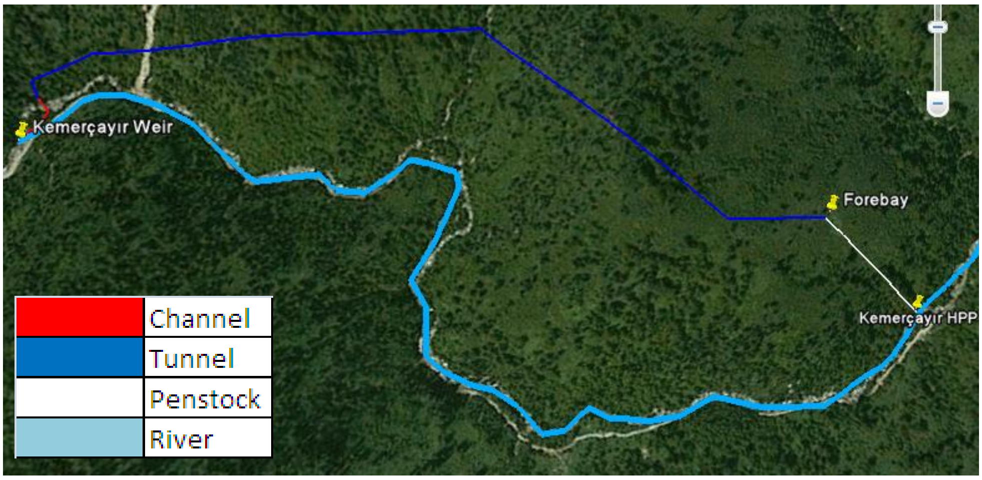

Figure 3.2 Overview of the Kemerçayır Weir and HEPP

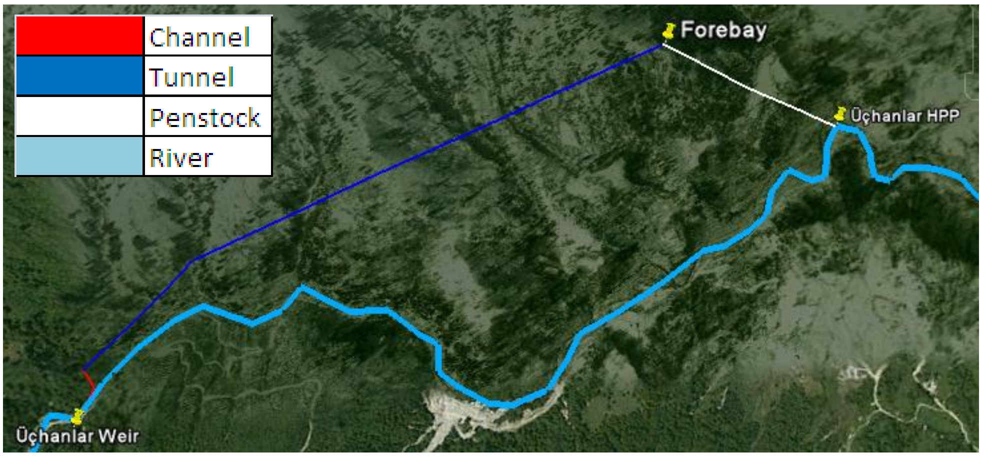

Figure 3.3 Overview of the Üçhanlar Weir and HEPP

Figure 3.4 Overview of the Üçharmanlar Weir and HEPP

As can be seen from Figures 3.2, 3.3 and 3.4, each project has a diversion weir, a water conveyance system, a forebay, a penstock and a powerhouse. Tirol type water intake is used in the projects (2005a).

Flow-duration curves prepared using the discharge measurements given in the Feasibility Reports (2005a, 2005b, 2005c) for Kemerçayır, Üçhanlar and Üçharmanlar projects are provided below in Figures 3.5, 3.6 and 3.7, respectively.

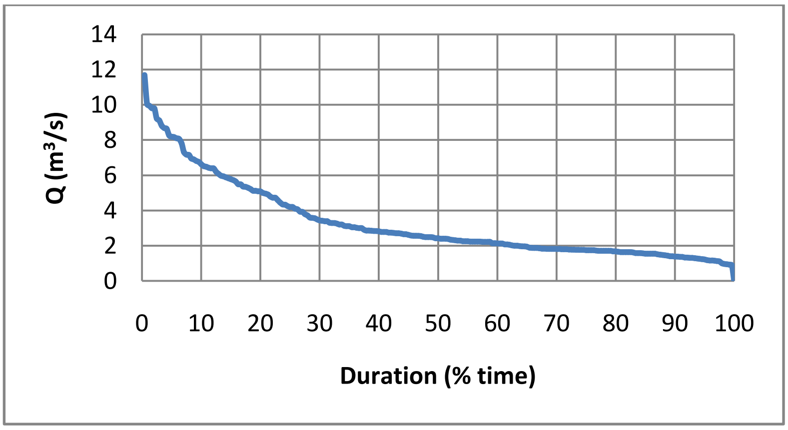

Figure 3.5 Flow-Duration Curve for Kemerçayır Weir

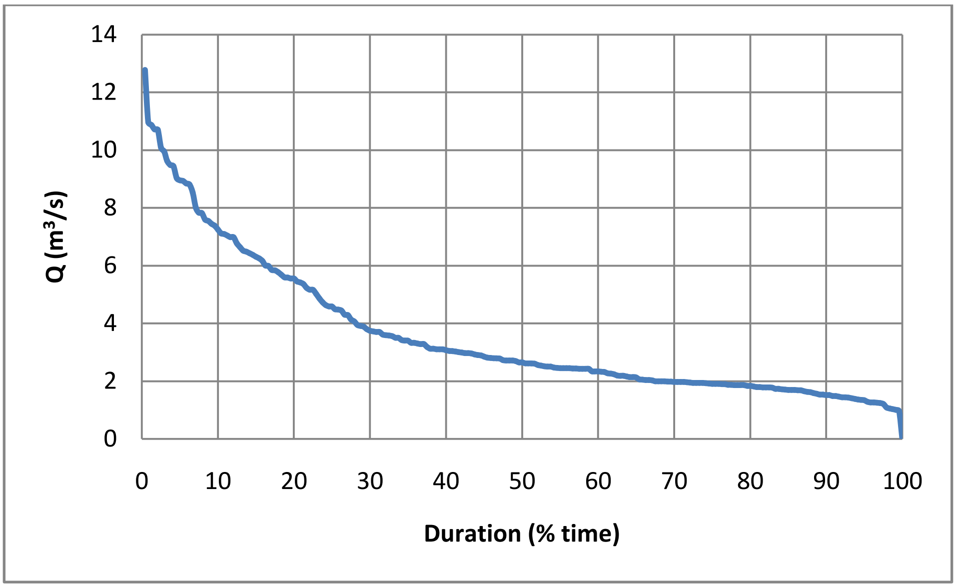

Figure 3.6 Flow-Duration Curve for Üçhanlar Weir

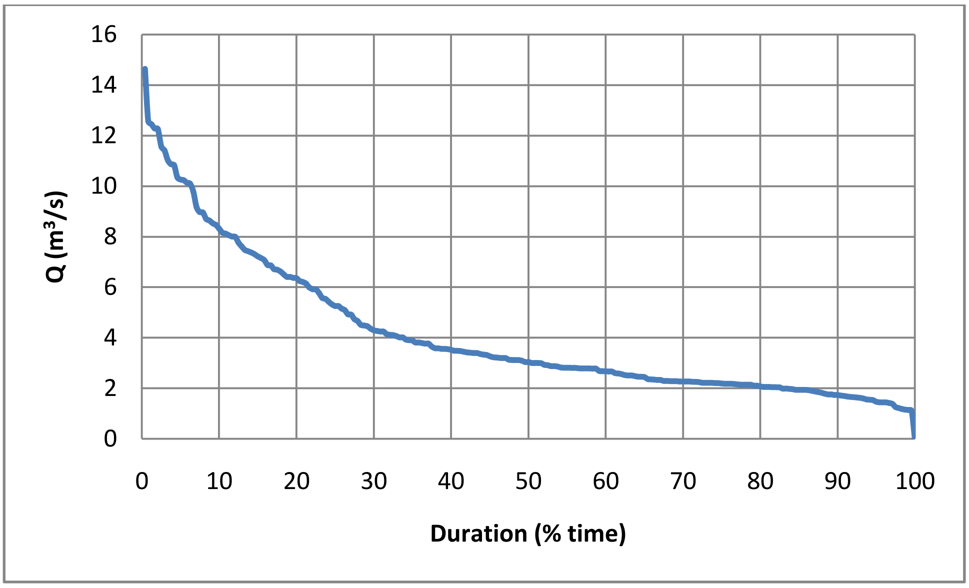

Figure 3.7 Flow-Duration Curve for Üçharmanlar Weir

Design discharges of the projects are calculated using the flow-duration curves through an optimization analysis which is explained in Section 4.2. The main properties of the projects are summarized in Table 3.1.

Table 3.1 Summary of the Main Properties of the Projects

Project Name	Kemerçayır	Üçhanlar	Üçharmanlar
Drainage Area (km^2)	116	126,8	145,3
Gross Head (m)	244.7	207.3	230.8
Design Discharge (m^3/s)	6.8	7.5	10.5
Tunnel Length (m)	1,775.5	1,929.1	2,084.8
Channel Length (m)	40.2	55	736.9
Penstock Length (m)	499.7	505.7	463.1
Number of Turbines & Capacity (MW)	3x4.5	3x4.2	3x6.7
Turbine Type	Francis	Francis	Francis
Total Energy Generation (GWh / yr)	55.29	56.04	67.25

3.2.1 Summary

The general view of the three projects is given in Figure 3.8. Each HEPP is planned as an individual project having separate civil, mechanical and electromechanical costs.

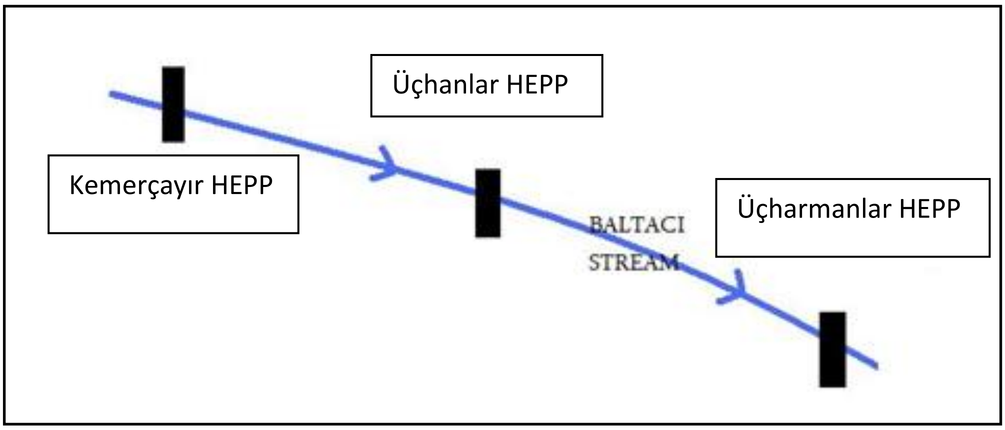

Figure 3.8 General View of the Current Formulation

The head difference between the Kemerçayır weir and Üçharmanlar HEPP is 682.74 meters. Total installed power of the projects is 46.25 MW. Three projects having design discharges of 6.8, 7.5 and 10.5 m^3/s from upstream to downstream is planned to generate a total of 178 GWh/year electricity.

CHAPTER 4

ALTERNATIVE FORMULATIONS

4.1 Alternative Project Formulations

Information about the formulations given in the Feasibility Reports (2005a, 2005b, 2005c) is explained in Chapter 3. In this study, we developed four alternative project formulations and conducted economical evaluation for these alternative projects using RETScreen.

During the project development phases of a SHP project, various characteristics of the project may be revised if the revisions are proven to provide better outputs. The design discharge, gross head, places of main components, intake and tailwater elevations and type and route of water conveyance systems are some of the features that may change during project development. In this study, considering these features of the current formulations (Feasibility Reports, 2005a, 2005b, 2005c), four alternative project formulations are developed.

One alternative for each of the Kemerçayır, Üçhanlar and Üçharmanlar HEPPs provided in the Feasibility Reports (2005a, 2005b, 2005c) are developed by changing the type and route of the water conveyance systems. In these three alternative projects the locations of the weirs, powerhouses and forebays are kept the same. The fourth alternative is generated by connecting the diversion weir of Kemerçayır HEPP and the powerhouse of Üçharmanlar HEPP. A new location is selected for the forebay for the fourth alternative. This last alternative formulation allows utilization of the total head associated with the first two projects in a single setup. The detailed information for each alternative is given in the proceeding sections.

In selection the routes of water conveyance structures for the alternative formulations, topographic maps given in the Feasibility Reports (2005a, 2005b, 2005c) are used. The main objective was to shorten the total length of the water conveyance system. Whenever possible, by following the contour elevations, construction of a channel is preferred instead of a tunnel. In areas where the channel construction considerably lengthens the total length of the system, tunnel is used.

An optimization study is carried to determine the design discharges for each of the four alternatives. Then these design discharges are used in the evaluation of the alternative formulations by RETScreen. The optimization process is discussed in Section 4.2.

4.1.1 Alternative 1

This formulation is an alternative to the Kemerçayır HEPP. Project formulation of Kemerçayır HEPP given in the Feasibility Report (2005a) and Alternative 1 can be seen in Figure 4.1.

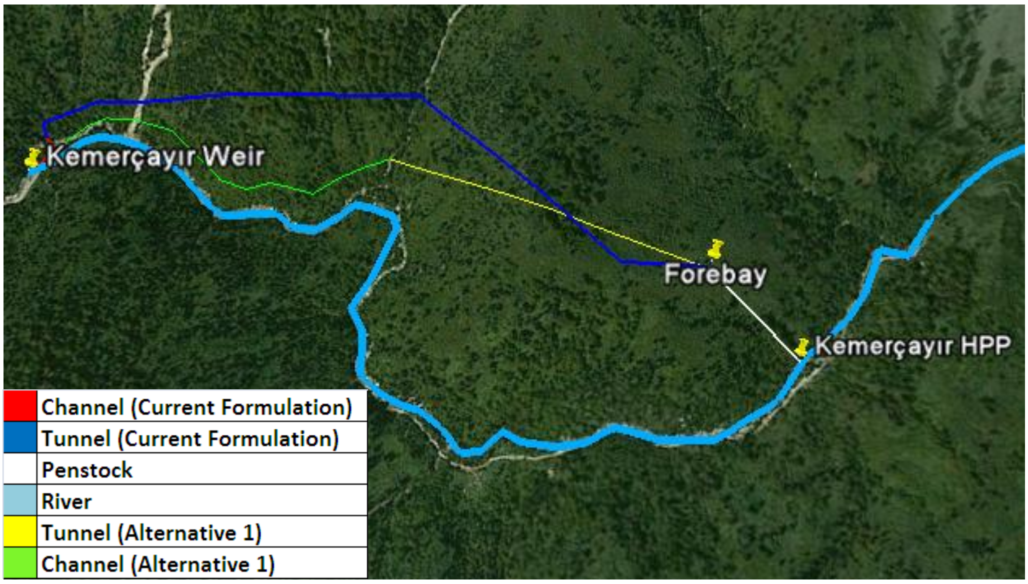

Figure 4.1 Overview of Alternative 1 and Kemerçayır HEPP

Red and blue colours are used to describe the formulation given in the Feasibility Report (2005a), while yellow and green colours are used to describe the alternative formulation. Same legend will be used throughout this study.

In Alternative 1, a longer channel (L = 980 m) is used to connect the Kemerçayır Weir to a shorter tunnel (L = 710 m). This change in the water conveyance systems decreases the tunnel length of Kemerçayır Project from 1,775.46 meters to 710 meters. Tunnel cost is expected to be higher than channel cost, therefore; a lower project cost is expected for this alternative.

4.1.2 Alternative 2

As an alternative to Üçhanlar HEPP, Alternative 2 is developed (Figure 4.2). Similar to Alternative 1, by using a longer channel (L = 730 m), the length of the tunnel decreased from 1929 meters to 1130 meters.

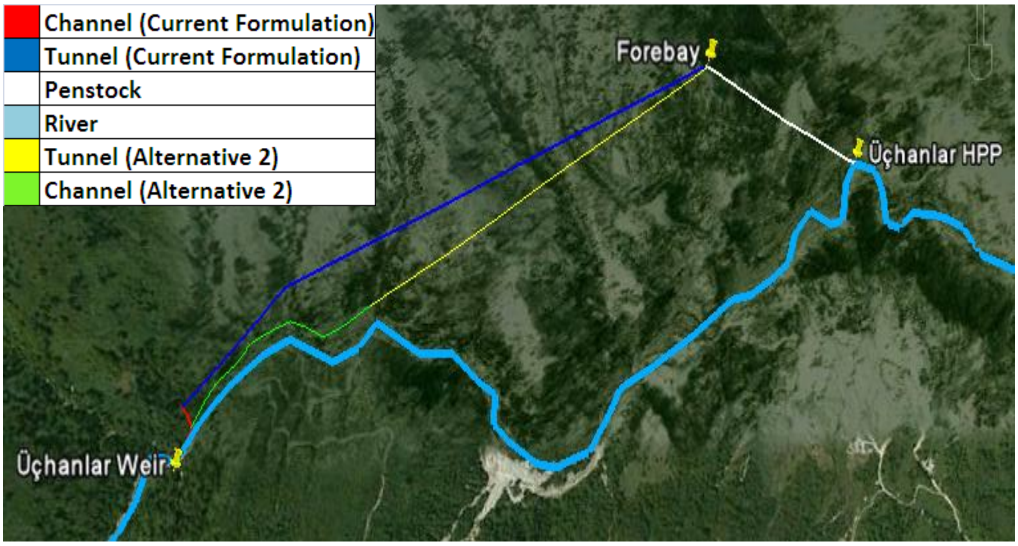

Figure 4.2 Overview of Alternative 2 and Üçhanlar HEPP

The total length of the water conveyance system of Alternative 2 is almost the same as the current Üçhanlar HEPP formulation given in the Feasibility Report (2005b), however, since the tunnel length is shortened the project cost is expected to decrease.

4.1.3 Alternative 3

This is the alternative project developed for Üçharmanlar HEPP formulation (Feasibility Report, 2005c). The project area of Alternative 3 is steeper than those of the other alternatives. In some regions the slope exceeds 45 degrees. This limits the construction of channels in the region; therefore, in such areas usually tunnels are used to convey the water. Figure 4.3 shows the overview of this alternative formulation.

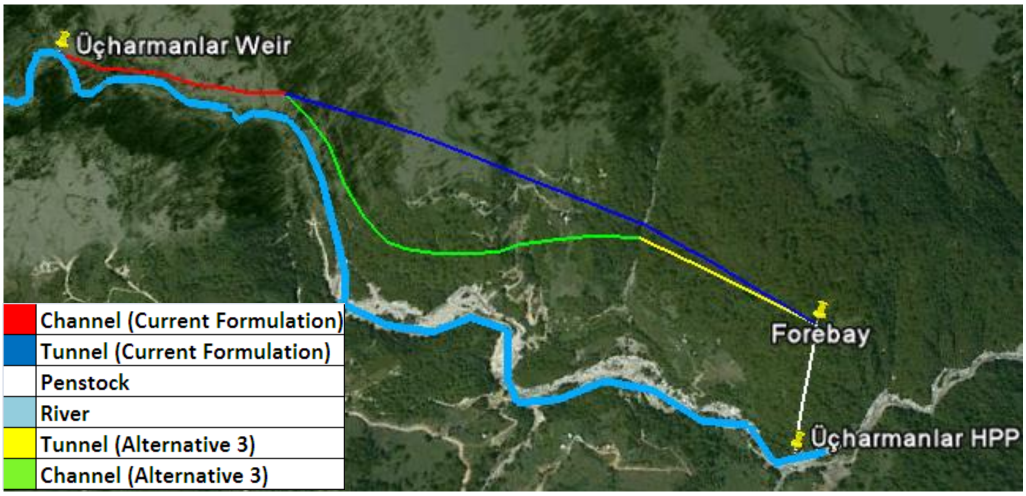

Figure 4.3 Overview of Alternative 3 and Üçharmanlar HEPP

In Alternative 3, most of the water is carried by channels (L = 2440 m). The last part of the system consists of a tunnel (L = 650 m).

4.1.4 Alternative 4

This alternative is more challenging than the other three alternatives. In this alternative first two projects (Kemerçayır and Üçhanlar) are connected and instead of two separate projects, a single SHP is suggested. This system uses the diversion weir of Kemerçayır project and the powerhouse of the Üçhanlar project. Figure 4.4 shows the overview of Alternative 4 together with Kemerçayır and Üçharmanlar HEPP's.

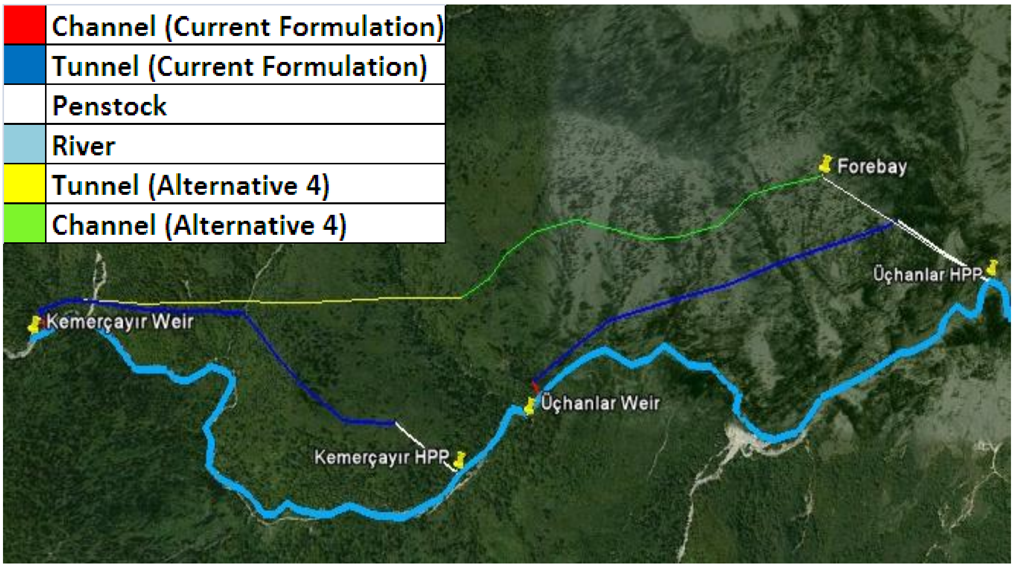

Figure 4.4 Overview of Alternative 4, Kemerçayır and Üçhanlar HEPP

The water conveyance structure of Alternative 4 is composed of a tunnel (L = 2020 m) and a channel (L = 1470 m). The total water conveyance structure length of this alternative is 3490 meters, and this alternative replaces two separate projects having a total water conveyance structure length of 3550 meters.

4.2 Selection of Design Discharges

Design discharge of a project is the most important feature of SHP projects. All the other components of the projects are designed according to the selected design discharge. Therefore, in selection of the design discharge, a detailed cost analysis and an optimization study need to be completed where costs of all the components and benefits of the project are evaluated simultaneously. Thus, an optimization procedure is used in this study to select the design discharges for the proposed alternative formulations. The general steps of the optimization procedure are provided below:

- Identify discharges at the diversion weir location by using a near-by gauging station. These values are taken from the Feasibility Reports (2005a, 2005b, 2005c). As an example the discharges at the Kemerçayır Weir location is provided in Table 4.1.

- Obtain the flow duration curve for the project using the previously identified discharges. As an example, the flow-duration curve for Alternative 1 is given in Figure 4.5.

- Obtain power-duration curve from the flow duration curve and calculate energy generated per year with respect to discharge. As an example, the power-duration curve and energy generated per year with respect to discharge for Alternative 1 are given in Figures 4.6 and 4.7, respectively.

- Calculate the annual benefit of the project for a selected electricity price (7.5 cent/kWh) with respect to discharge using the following formula:

$$AB = E * C \tag{4.1}$$

Where;

AB is the annual benefit of the project in \$/year,

E is the energy generated per year in GWh/year,

C is the electricity price in \$/GWh.

As an example, annual benefit with respect to discharge curve for Alternative 1 is given in Figure 4.8.

- Calculate the annual cost of the project with respect to discharge using the following formula:

$$IC = C_{pow} + C_{elec} + C_{pen} \tag{4.2}$$

$$C_{pow} = 200000 * (InsCap, MW)^{0.699} \tag{4.3}$$

$$C_{elec} = 491300 * (InsCap, Mw)^{0.801} \tag{4.4}$$

$$C_{pen} = M * C_{steel} \tag{4.5}$$

$$AC = IC * 0.11 \tag{4.6}$$

Where;

IC is the initial cost of the project in \$,

C_{pow} is the cost of powerhouse in \$,

C_{elec} is the cost of electromechanical equipments in \$,

C_{pen} is the cost of penstock in \$,

C_{steel} is the cost of steel in \$/kg,

M is the total mass of steel used in the penstock in kg,

$InsCap$ is the installed capacity of the project in MW,

AC is the annual cost of the project in \$/year.

Equations 4.3, 4.4 and 4.6 are equations used by the private companies to make initial estimates of initial cost of a project (personal communication with Turan, 2009). These equations are generated using the past project costs statistics. The multiplier "0.11" in equation 4.6 is the capital recovery factor.

As an example, the annual cost with respect to discharge for Alternative 1 is given in Figure 4.9.

- Calculate the annual net benefit with respect to discharge using the following formula.

$$ANB = AB - AC \qquad (4.7)$$

Where;

ANB is the annual net benefit of the project in \$/year.

As an example, annual net benefit with respect to discharge for Alternative 1 is given in Figure 4.10.

Table 4.1 Discharges at Kemerçayır Weir Location (Feasibility Report)

Year	Discharge (m^3/sec)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1982	1.37	2.24	1.32	0.94	1.15	1.88	5.64	5.29	3.05	1.87	1.16	1.78
1983	2.22	2.14	1.55	1.24	1.16	3.39	6.43	7.15	5.20	3.41	2.39	1.52
1984	3.56	3.73	1.55	1.13	1.81	2.23	3.05	5.77	4.91	3.02	2.50	1.64
1985	2.08	2.24	1.39	1.64	1.59	1.66	6.38	6.75	3.79	2.86	0.97	1.58
1986	3.29	1.87	2.49	1.72	2.34	3.94	5.88	9.11	6.48	3.28	1.49	2.77
1987	2.30	1.77	1.81	1.71	1.62	1.71	3.25	6.08	5.48	3.39	2.58	1.81
1988	1.79	1.83	1.82	2.72	3.13	3.48	6.51	8.09	9.79	5.08	8.26	2.65
1989	2.49	3.20	2.42	1.27	1.81	4.95	8.81	5.83	4.33	1.76	0.89	1.00
1990	2.39	1.45	1.81	1.41	1.71	2.84	4.60	7.16	7.81	4.72	2.14	1.82
1991	3.11	3.01	3.01	2.49	2.84	5.93	9.94	7.32	5.12	2.78	2.12	1.55
1992	1.83	1.76	1.68	1.11	0.92	2.30	9.23	9.80	8.64	5.49	4.19	3.58
1993	2.74	2.86	2.23	1.68	1.54	2.55	5.08	8.17	8.68	5.34	2.72	2.00
1994	1.59	2.43	2.23	1.64	1.74	2.47	5.36	4.99	4.20	2.56	1.74	1.41
1995	1.80	2.01	1.86	1.96	1.48	2.22	3.20	6.63	5.97	3.43	2.22	2.39
1996	3.31	2.84	1.98	1.64	1.57	1.43	2.57	6.95	5.12	3.12	2.24	2.14
1997	2.81	1.89	1.77	1.73	1.55	1.75	4.24	8.19	6.81	3.92	2.25	2.55
1998	2.71	2.25	1.36	1.32	1.77	2.92	10.04	6.90	4.07	2.07	2.61	1.95
1999	2.66	2.00	2.33	1.18	1.34	1.72	4.45	8.06	3.61	2.26	1.71	2.13
2000	1.96	2.39	2.05	1.31	1.39	2.68	11.68	6.20	4.79	1.29	2.79	2.75
2001	4.34	2.29	1.83	1.23	1.25	4.11	5.72	6.39	4.73	1.74	1.63	0.88

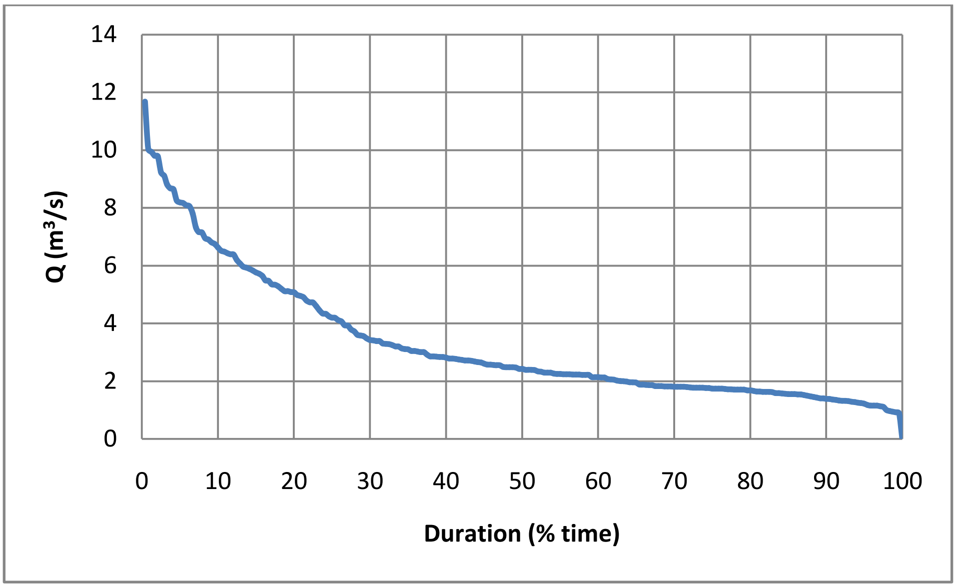

Figure 4.5 Flow-Duration Curve for Alternative 1

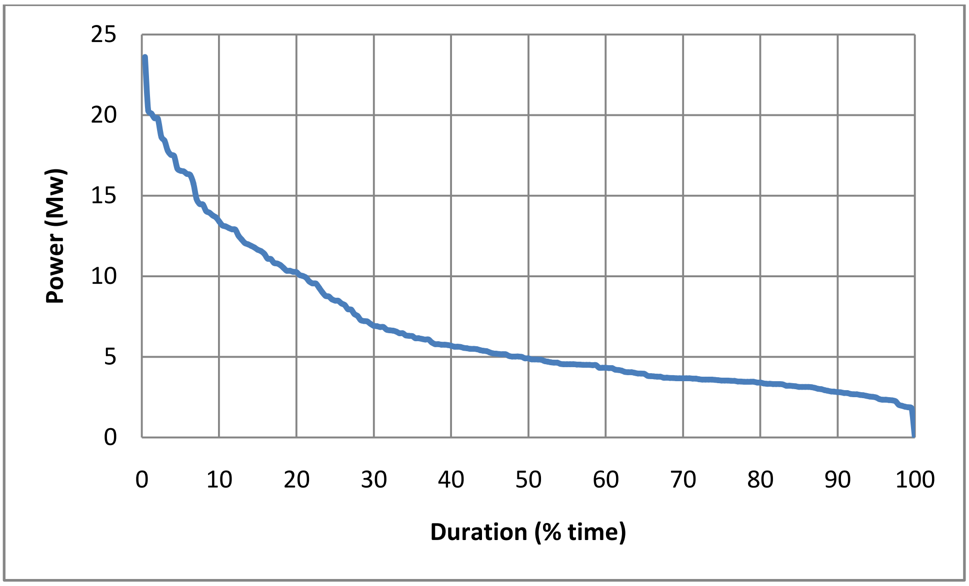

Figure 4.6 Power-Duration Curve for Alternative 1

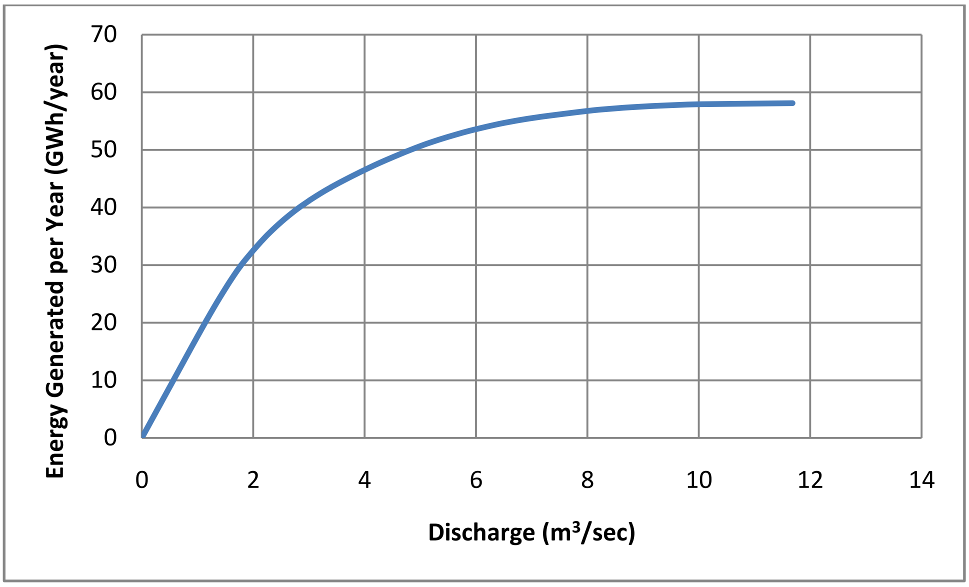

Figure 4.7 Enery Generated per Year with Respect to Discharge for Alternative 1

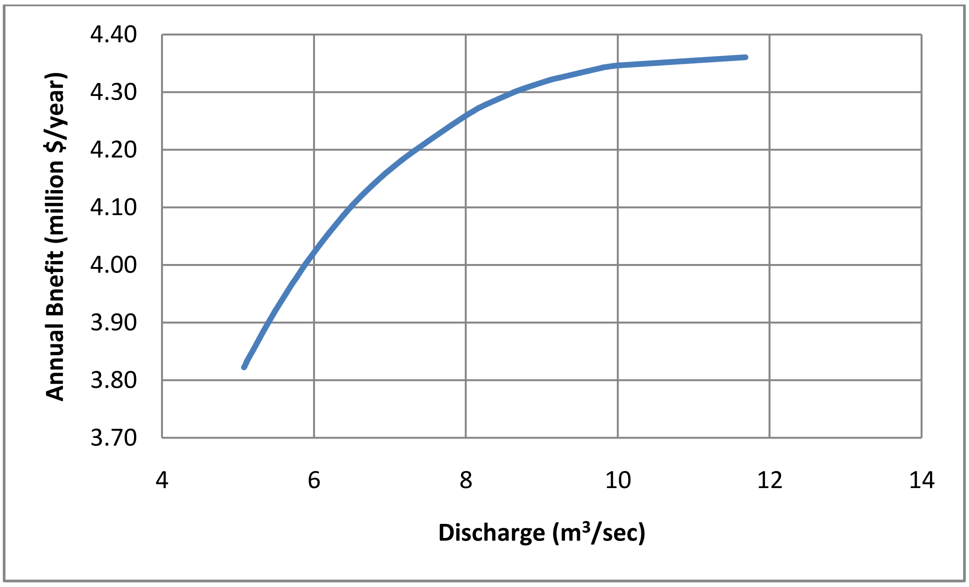

Figure 4.8 Annual Benefit with Respect to Discharge for Alternative 1

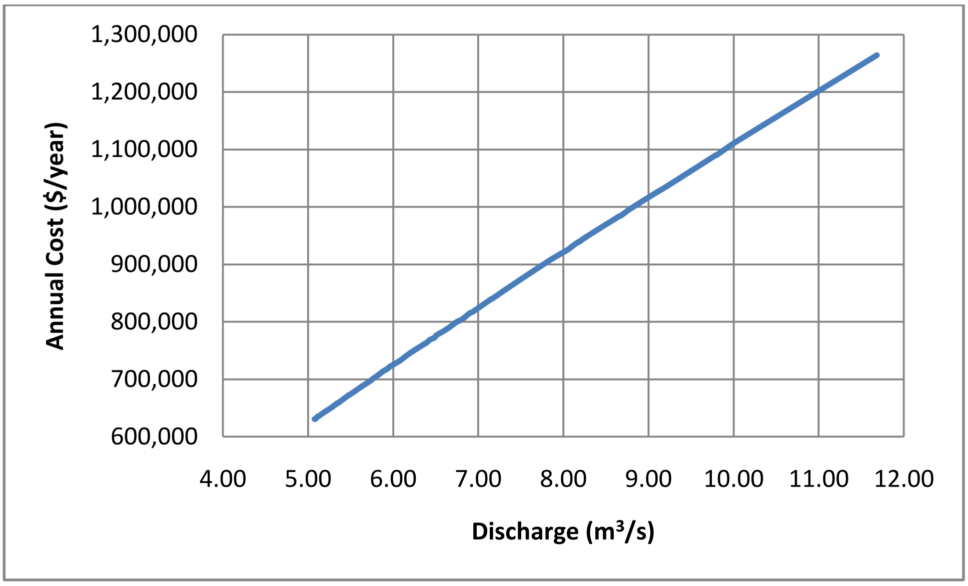

Figure 4.9 Annual Cost with Respect to Discharge for Alternative 1

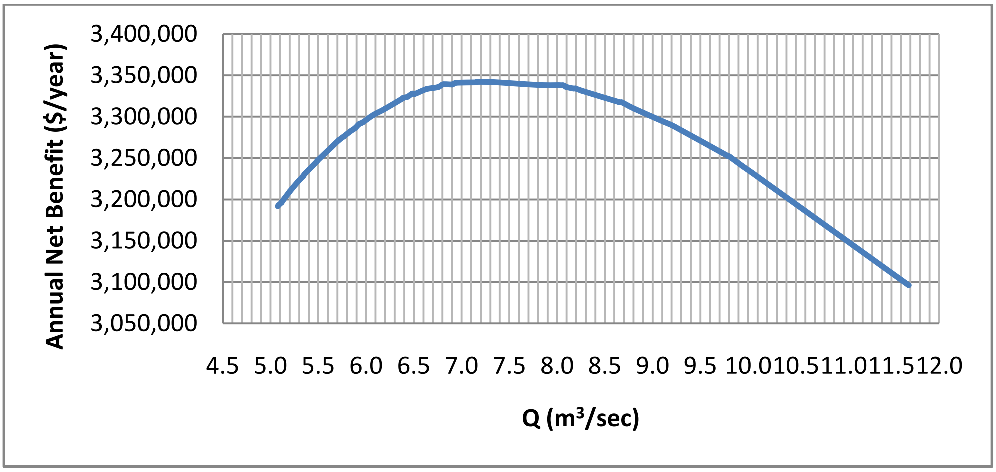

Figure 4.10 Optimization Curve for Alternative 1

As can be seen from Figure 4.10 annual net benefit increases to a maximum value (i.e. 3.35 million $) than decreases with increasing discharge. The optimum discharge for Alternative 1 is 7.16 m^3/s. This discharge corresponds to 8 % of time in flow-duration curve given in Figure 4.5. The discharge used in the Feasibility Report (2005a), is 6.8 m^3/s and it corresponds to 7 % of time in flow duration curve. Normally, discharges corresponding to 25-30 % of time are appropriate as the design discharge. However, by the optimization procedure followed in this study, higher discharges corresponding to lower percent times are obtained as design discharges. Since similar discharges are suggested in the Feasibility Reports (2005a, 2005b, 2005c), the discharges obtained by following this optimization procedure is used in this study.

By following the procedure given above, design discharges for each of the alternatives are calculated. The summary of the optimization procedure for Alternative 2, Alternative 3 and Alternative 4 are given in Figures 4.11-4.13, 4.14-4.16 and 4.17-4.19, respectively.

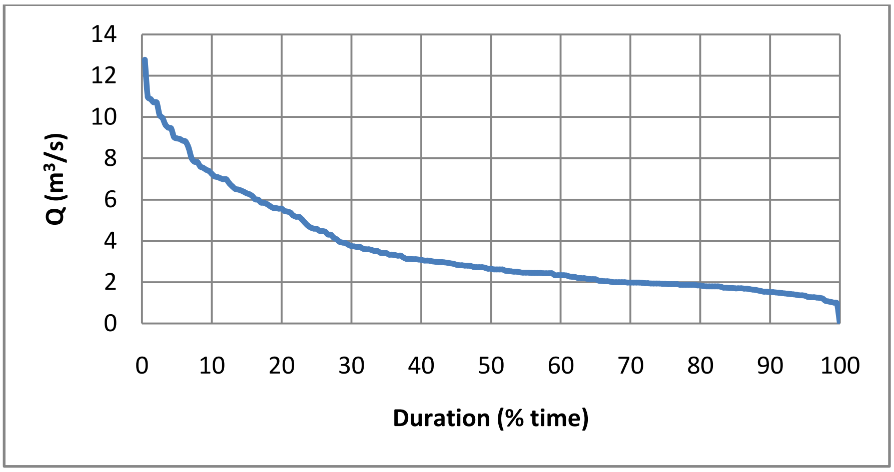

Figure 4.11 Flow-Duration Curve for Alternative 2

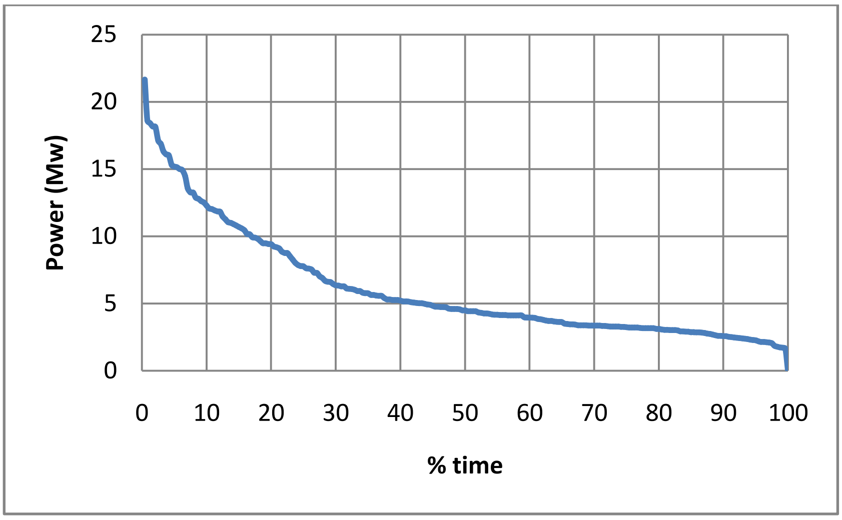

Figure 4.12 Power-Duration Curve for Alternative 2

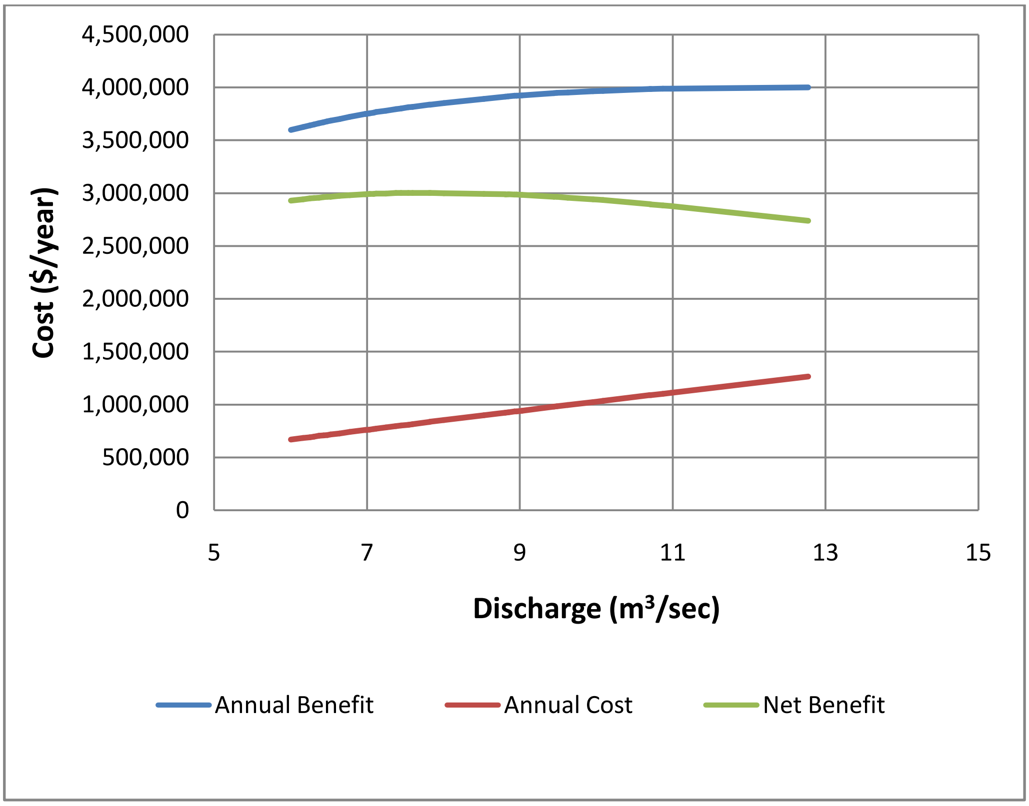

Figure 4.13 Annual Income, Cost and Net Benefit with Respect to Discharge for Alternative 2

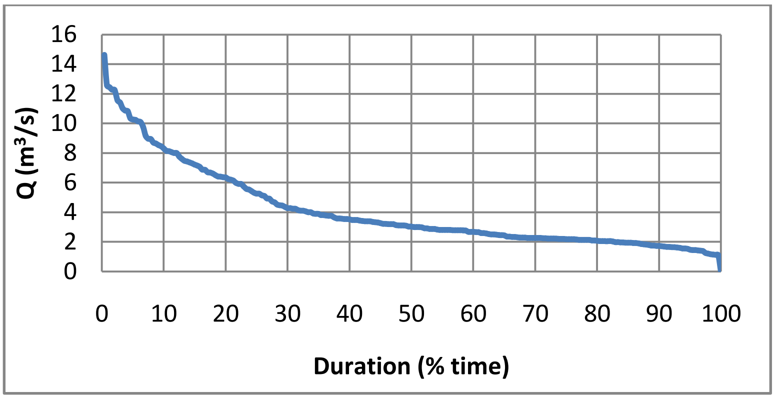

Figure 4.14 Flow-Duration Curve for Alternative 3

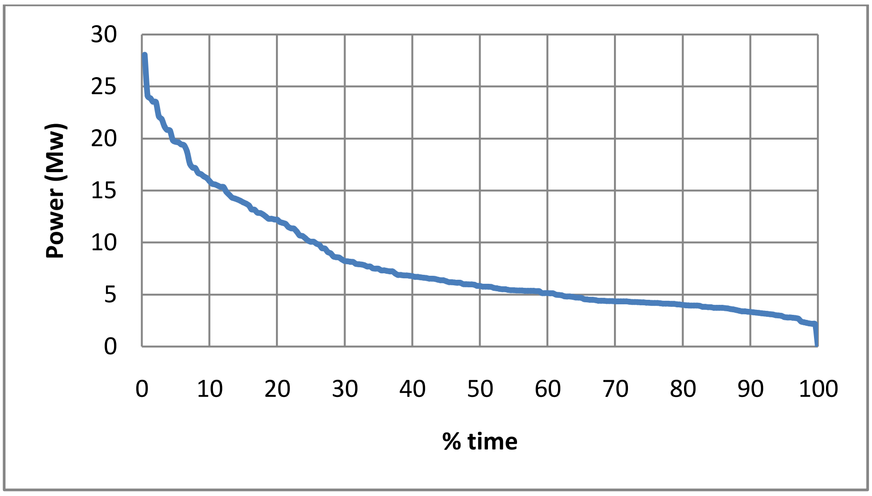

Figure 4.15 Power-Duration Curve for Alternative 3

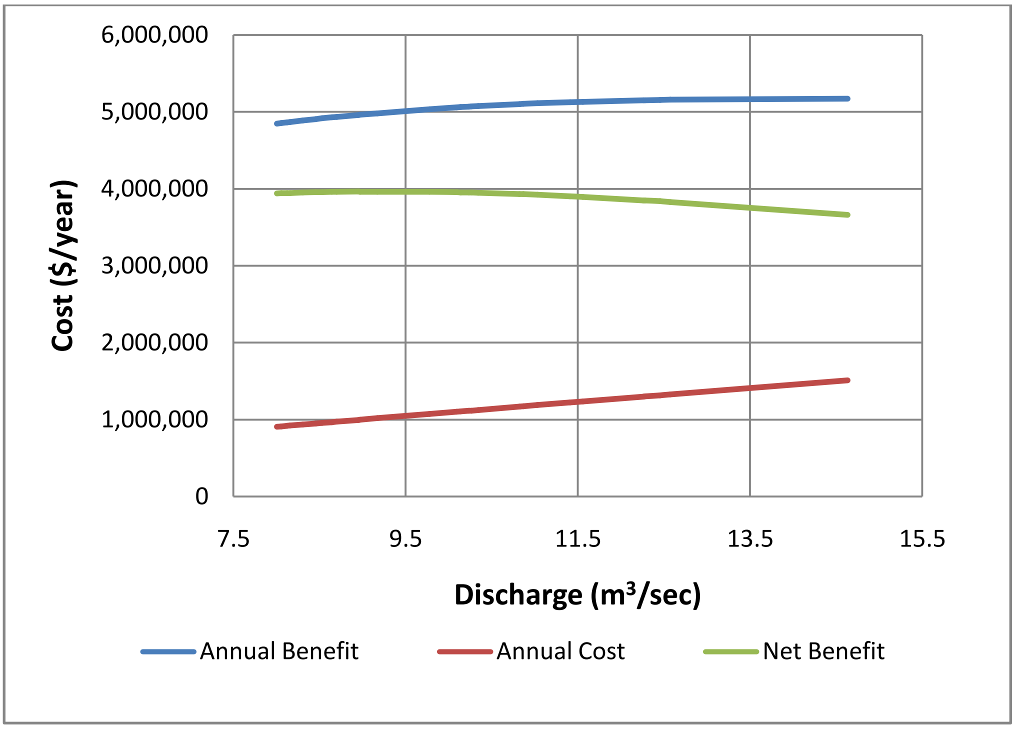

Figure 4.16 Annual Income, Cost and Net Benefit with Respect to Discharge for Alternative 3

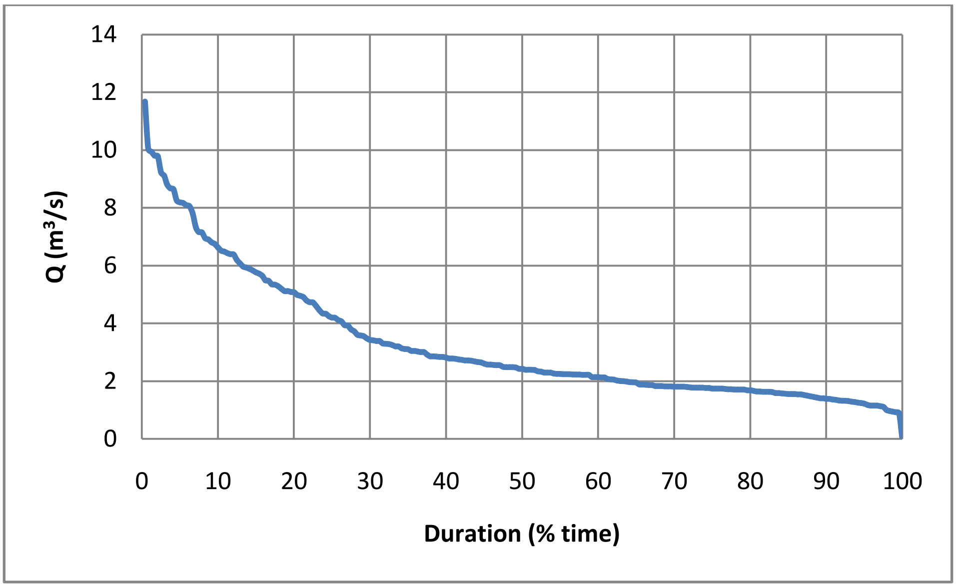

Figure 4.17 Flow-Duration Curve for Alternative 4

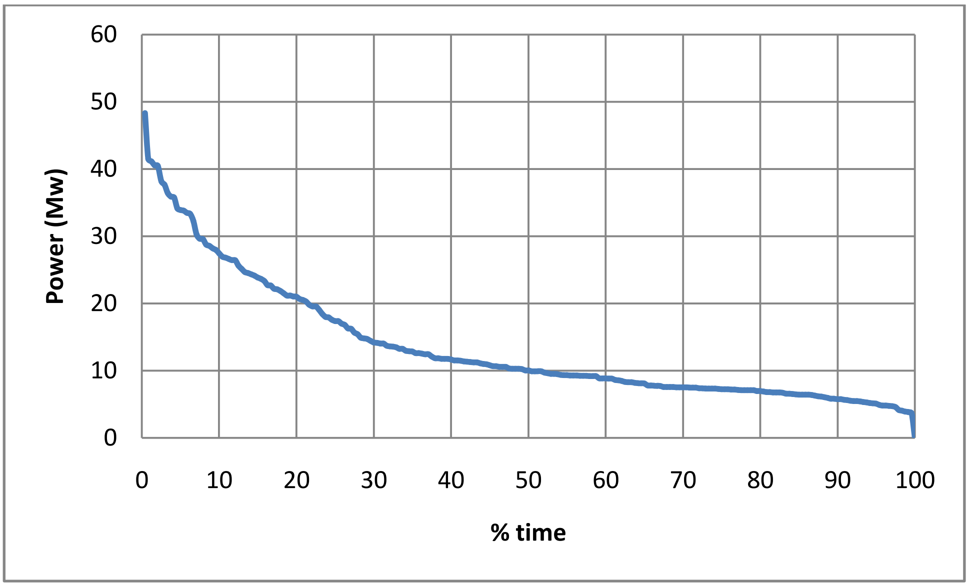

Figure 4.18 Power-Duration Curve for Alternative 4

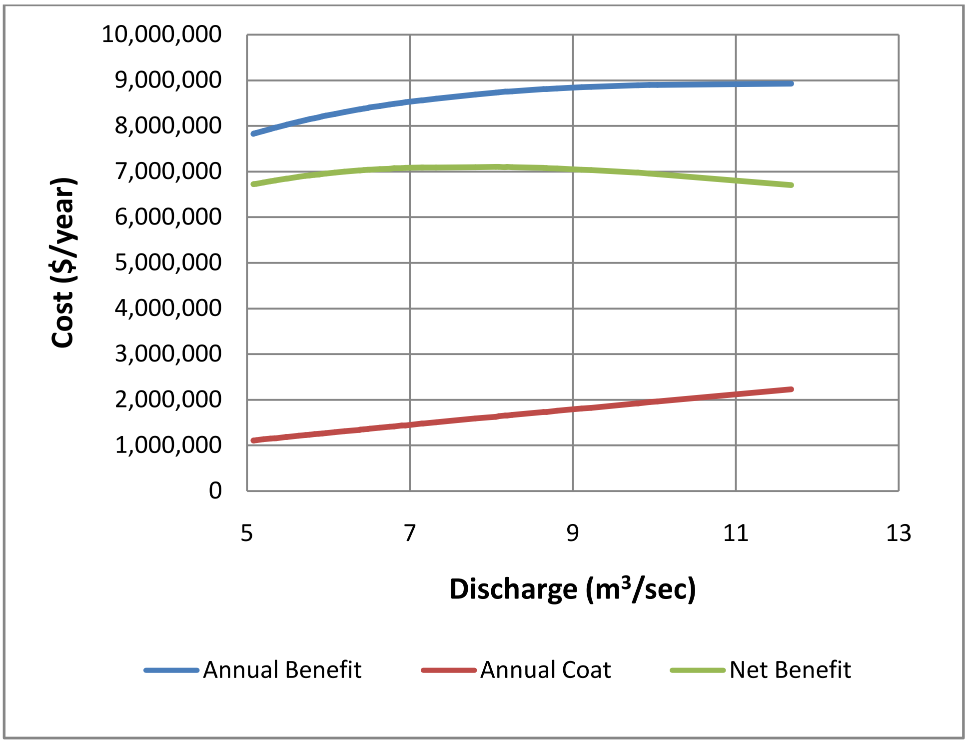

Figure 4.19 Annual Income, Cost and Net Benefit with Respect to Discharge for Alternative 4

The design discharges obtained for each alternative is given in Table 4.2.

Table 4.2 Results of the Optimization Procedure

Project Name	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Design Discharge (m^3/sec)	7.15	7.59	8.95	8.06

4.3 Evaluation of the Project Formulations Using RETScreen

Three project formulations given in the Feasibility Reports (2005a, 2005b, 2005c) and four alternative projects formulations are evaluated using RETScreen. The values such as discharge, elevations, tunnel and channel lengths used in the evaluation of the alternatives are taken from the Feasibility Reports (2005a, 2005b, 2005c). A brief explanation about the data requirements is provided here. Detailed information about the input requirements of RETScreen and how to use this software is provided in Korkmaz (2007) and Küçükbeycan (2008). Moreover, the software has a built-in user manual. Interested reader may refer to these references for further details.

RETScreen runs on Microsoft Excel platform and uses empirical equations to calculate the energy output and costs of the projects. Figure 4.20 shows the general layout of the program. As can be seen in Figure 4.20, the program has; "Start, Energy Model, Cost Analysis, Emission Analysis, Financial Analysis, Risk Analysis and Tools" sheets. In this study, emission and risk analysis sheets are not used.

In the evaluation of the alternatives, first Start and Energy Model sheets are completed with the required data. After that the "Hydro Formula Costing Method" given in the Tools sheet is used to calculate the total initial costs of the project. In the next step the Cost Analysis sheet is completed. Finally, Financial Analysis sheet is filled and as a result benefit-cost ratio of the project is obtained.

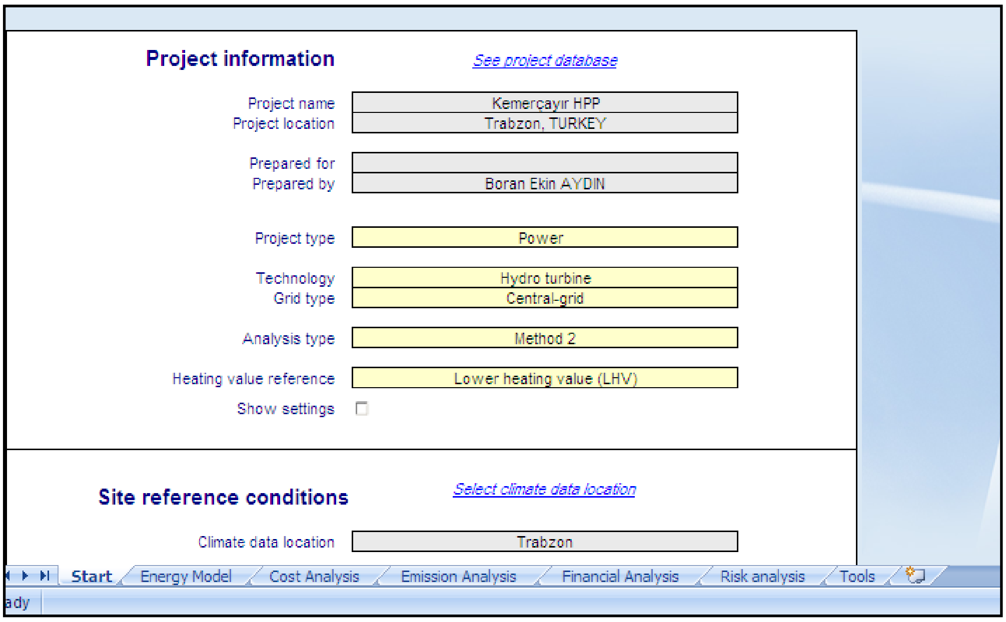

Figure 4.20 General Layout of RETScreen

Each sheet used in this analysis and the data entered at each sheet is explained briefly in the following sections.

4.3.1 Explanation of Input Data for RETScreen

Input requirements of RETScreen are explained in the following sections. The sheets that are completed for Kemerçayır HEPP are provided as examples.

4.3.1.1 The Start Sheet

General information about the project is entered to the Start Sheet of the program. The Start Sheet of Kemerçayır HEPP is given in Figure 4.21.

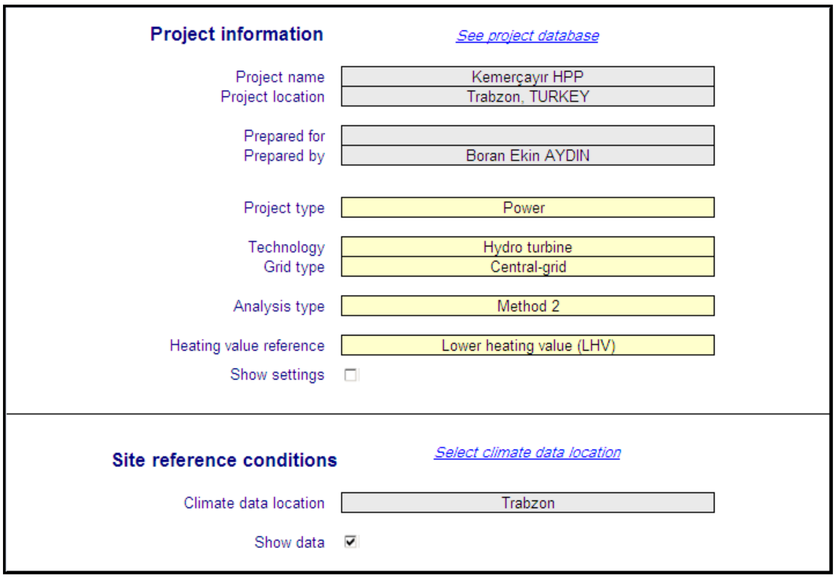

Figure 4.21 The Start Sheet

Project type and **technology** is selected depending on the type of the project. Since all three projects given in the Feasibility Reports (2005a, 2005b, 2005c) are connected to the natural grid, "central-grid" is selected as the **grid type**. If the projects were planed to provide electricity to a local area, then "isolated grid" will be selected for the grid type. **Heating value reference** is required for emission analysis which is not conducted in this study therefore it is not completed.

4.3.1.2 The Energy Model Sheet

The data entered to the energy model sheet is used to calculate the energy output of the project. As an example, the energy sheet prepared for the Kemerçayır HEPP is shown in Figure 4.22.

Project type, gross head, residual flow, percent time firm flow available, design flow, turbine type and numbers, maximum hydraulic losses, generator efficiency and electricity export rate are filled using the information given in the Feasibility Reports (2005a, 2005b, 2005c).

If the user has the flow-duration curve of the project, by selecting the **hydrology method** as “user-defined” he/she is allowed to input the flow-duration curve to the program. In this study, since the flow-duration curves of the projects are known, “user defined” hydrology method is used.

There is no information about the **turbine efficiencies** of the projects. Therefore, “standard” is selected as the turbine efficiency and built in efficiency curves in turbine database of RETScreen are used.

Design coefficient is a dimensionless factor used to adjust the turbine efficiency by taking into account varying manufacturing techniques (RETScreen, 2010). In this study, software default value is used since there is no information about the manufacturing techniques of the turbines.

Efficiency adjustment factor is used to adjust the turbine efficiency curves (RETScreen, 2010). As mentioned above, in this study, standard turbine efficiency is used; so there is no need for efficiency adjustment.

Miscellaneous losses includes parasitic electricity losses and transformer losses. Since a value of 2 % is identified as appropriate for most hydro plants in RETScreen Manual (RETScreen, 2010) we used 2 % in this study for miscellaneous losses.

96 % availability is suggested by RETScreen Manual if the plant will have 15 days downtime in a year. 100 % **availability** is selected since all the projects in this study has multiple turbines and faiure of all three turbines at the same time is not possible. Therefore, even in the low flow seasons the projects continue generating electricity.

Technology		Hydro turbine	
Analysis type		Method 1 Method 2	
Resource assessment			
Proposed project		Run-of-river	
Hydrology method		User-defined	
Gross head	m	244,7	
Maximum tailwater effect	m	0,00	
Residual flow	m³/s	0,050	
Percent time firm flow available	%	95,0%	
Firm flow	m³/s	1,18	
Hydro turbine			
Design flow	m³/s	6,800	
Type		Francis	
Turbine efficiency		Standard	
Number of turbines		3	
Manufacturer		Alstom	
Model		Francis	
Design coefficient		4,5	
Efficiency adjustment	%	0,0%	
Turbine peak efficiency	%	92,8%	
Flow at peak efficiency	m³/s	5,3	
Turbine efficiency at design flow	%	89,8%	

%	Flow m³/s	Turbine efficiency	Number of turbines	Combined efficiency
0%	11,68	0,00	0	0,00
5%	8,19	0,00	1	0,33
10%	6,63	0,17	1	0,67
15%	5,77	0,33	1	0,85
20%	5,08	0,46	1	0,91
25%	4,20	0,58	1	0,93
30%	3,43	0,67	1	0,92
35%	3,11	0,74	2	0,89
40%	2,81	0,80	2	0,91
45%	2,61	0,85	2	0,92
50%	2,42	0,88	2	0,93
55%	2,25	0,90	2	0,93
60%	2,14	0,91	2	0,92
65%	1,95	0,92	2	0,90
70%	1,81	0,93	3	0,93
75%	1,75	0,93	3	0,93
80%	1,68	0,93	3	0,93
85%	1,55	0,92	3	0,92
90%	1,39	0,92	3	0,92
95%	1,23	0,91	3	0,91
100%	0,88	0,90	3	0,90

Maximum hydraulic losses	%	4,7%	
Miscellaneous losses	%	2,0%	
Generator efficiency	%	97,0%	
Availability	%	100,0%	
Summary			Firm
Power capacity	kW	13.275	2.349
Available flow adjustment factor		1,00	
Capacity factor	%	47,2%	
Electricity exported to grid	MWh	54.899	
Electricity export rate	$/MWh	75,00	

Figure 4.22 The Energy Sheet

As mentioned above, installed capacity of the project is calculated in the energy model sheet. Figure 4.23 shows the flow and power duration curves for Kemerçayır HEPP generated in the energy model sheet.

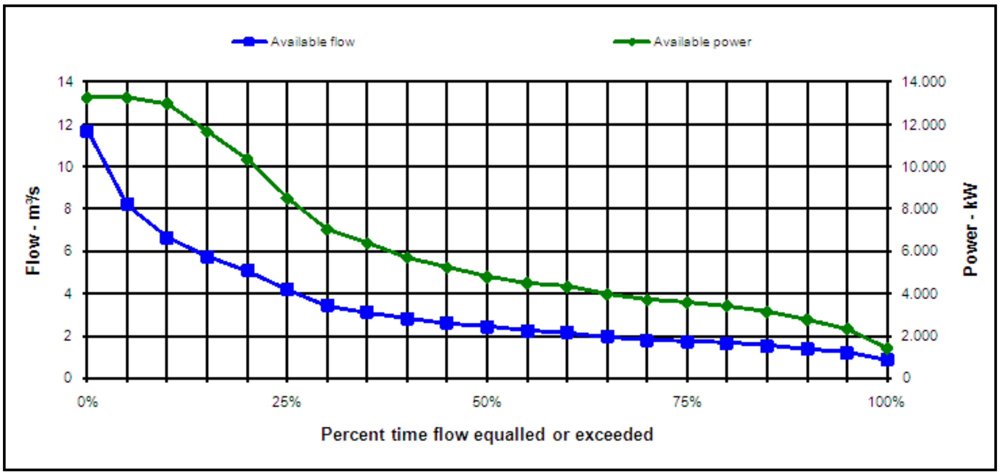

Figure 4.23 Flow and Power Duration Curves for Kemerçayır HEPP

4.3.1.3 The Tools Sheet and Hydro Formula Costing Method

In the tools sheet the user is free to select any settings given in Figure 4.24 depending on the project under evaluation.

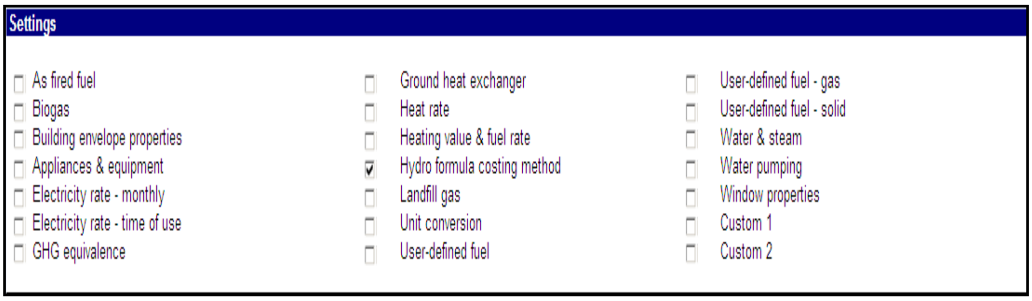

Figure 4.24 Setting Lists given in the Tools Sheet

The Hydro formula costing method tool is used to estimate small hydro project costs using formulae derived from the costs of numerous completed small hydro projects (RETScreen, 2010). Figure 4.25 shows the hydro formula costing method sheet prepeared for Kemercayır HEPP.

After completing hydro formula costing method, the user should return back to the Cost Analysis Sheet and enter the major costs items calculated by the hydro formula costing method tool.

Local vs. Canadian equipment cost ratio and the **equipment manufacture cost coefficient** is taken from Korkmaz (2007) as unity.

In 2008, the average diesel price for Turkey was 163 US Cent/liter, while it was 90 US Cents/liter in Canada (GTZ, 2009). Therefore, **Local vs. Canadian fuel cost ratio** is calculated as 1.81.

The average yearly labour cost in Canada for 2008 was 53345.68 CAD (OECD, 2010), while the average monthly labour cost in Turkey was 1055 TL (TÜİK, 2009). Using these values, **Local vs. Canadian labour cost ratio** is calculated as 0.17.

Exchange rate ($/CAD) is taken as 0.97 (Bank of Canada, 2010).

Terrain side slope in rock is calculated using the topographic maps given in the Feasibility Reports (2005a, 2005b, 2005c). For Kemerçayır, Üçhanlar and Üçharmanlar projects the terrain side slope in rock values are estimated as 24, 26, and, 22 degrees, respectively.

Hydro formula costing method

Country		Turkey	
Local vs. Canadian equipment cost ratio		1,00	
Local vs. Canadian fuel cost ratio		1,81	
Local vs. Canadian labour cost ratio		0,17	
Equipment manufacture cost coefficient		1,00	
Exchange rate	$/CAD	0,97	
Cold climate	yes/no	No	
Design flow	m³/s	6,8	6,8
Gross head	m	244,7	244,7
Number of turbines	turbine	3	3
Type		Francis	Francis
Flow per turbine	m³/s	2,27	
Turbine runner diameter per unit	m	0,70	
Facility type		Mini	Mini
Existing dam	yes/no	No	
New dam crest length	m	15	
Rock at dam site	yes/no	Yes	
Maximum hydraulic losses	%	4,7%	4,7%
Miscellaneous losses	%	2,0%	
☑ **Road construction**			
Length	km	1,5	
Tote road only	yes/no	Yes	
Difficulty of terrain		3,0	
☑ **Tunnel**			
Length	m	1.775	
Allowable tunnel headloss factor	%	5,0%	
Percent length of tunnel that is lined	%	100%	
Excavation method		Mechanised	
Diameter	m	2,47	
☑ **Canal**			
Length in rock	m	40	
Terrain side slope in rock (average)	°	26	
Length in impervious soil	m	0	
Terrain side slope in soil (average)	°	26	
Total canal headloss	m	0,0	
☑ **Penstock**			
Length	m	499,7	
Number	penstock	1	
Allowable penstock headloss factor	%	2,5%	
Diameter	m	1,36	
Average pipe wall thickness	mm	10,46	
Distance to borrow pits	km	8,0	
Transmission line			
Grid type		Central-grid	Central-grid
Length	km	14,0	
Difficulty of terrain		1,5	
Voltage	kV	154,0	

Initial costs (credits)	**Amount $**	**Adjustment factor**	**Amount $**
Feasibility study	724.000		0
Development	870.000		0
Engineering	787.000		0
Power system			
Hydro turbine	8.622.000		0
Road construction	49.000		0
Transmission line	2.939.000		0
Substation	837.000		0
Balance of system & miscellaneous			
Penstock	962.000		0
Canal	91.000		0
Tunnel	3.604.000		0
Other	3.851.000		0
Sub-total:	8.508.000		0
Total initial costs	**23.336.000**		**0**

Figure 4.25 The Hydro Formula Costing Method Sheet for Kemerçayır HEPP

Allowable tunnel headloss factor is a ratio between the allowable headloss in the tunnel and the available gross head (RETScreen, 2010). A ratio between 4 % and 7 % is suggested by the software. In this study, 5 % is used as the allowable tunnel headloss factor. The tunnel diameters obtained in RETScreen is similar to the diameter calculated in the Feasibility Reports (2005a, 2005b, 2005c). As an example, the diameter of the tunnel of Kemerçayır HEPP is given as 2.40 m (Feasibility Report, 2005a) while RETScreen calculated the diameter of the tunnel for this project as 2.47 m. In Turkey, minimum diameter used in tunnel construction is 3.0 m. Although, smaller tunnel diameters are obtained in design stage, due to the restrictions of the equipments used a diameter of 3 m is used for the tunnel.

4.3.1.4 The Cost Analysis Sheet

If the quantity and unit cost of the main items calculated in the hydro formula costing method are known, the user should enter all of them into the cost analysis sheet. However, in this study, since the quantity and unit costs of the items are not known the total initial cost obtained in the hydro formula costing method sheet is directly entered to the cost analysis sheet. Figure 4.26 shows the cost analysis sheet prepared for Kemerçayır HEPP.

Initial costs (credits)	Unit	Quantity	Unit cost	Amount
Feasibility study				
Feasibility study	cost			$ -
Sub-total:				$ -
Development				
Development	cost			$ -
Sub-total:				$ -
Engineering				
Engineering	cost			$ -
Sub-total:				$ -
Power system				
Hydro turbine	kW	13.274,55		$ -
Road construction	km	1	$ 23.336.000	$ 23.336.000
Transmission line	km			$ -
Substation	project			$ -
Energy efficiency measures	project			$ -
User-defined	cost			$ -
				$ -
Sub-total:				$ 23.336.000
Balance of system & miscellaneous				
Spare parts	%			$ -
Transportation	project			$ -
Training & commissioning	p-d			$ -
User-defined	cost			$ -
Contingencies	%	0,0%	$ 23.336.000	$ -
Interest during construction			$ 23.336.000	$ -
Sub-total:		Enter number of months		$ -
Total initial costs				$ 23.336.000
Annual costs (credits)	**Unit**	**Quantity**	**Unit cost**	**Amount**
O&M				
Parts & labour	project	1	$ 46.672	$ 46.672
User-defined	cost			$ -
Contingencies	%		$ 46.672	$ -
Sub-total:				$ 46.672
Periodic costs (credits)	**Unit**	**Year**	**Unit cost**	**Amount**
User-defined	cost	35	$ 4.311.000	$ 4.311.000
				$ -
End of project life	cost			$ -

Figure 4.26 The Cost Analysis Sheet for Kemerçayır HEPP

Küçükbeycan (2008) suggests using 0.2 % of total initial cost as **annual cost**. **Periodic costs** are the costs which are paid at regular intervals to maintain the project in working condition (RETScreen, 2010). As the periodic costs Küçükbeycan (2008) suggests using 50 % of initial electromechanical equipment cost in the 35th year of the projects life time. In this study, annual and periodic costs of the projects are calculated using these ratios suggested by Küçükbeycan (2008).

4.3.1.5 The Financial Analysis Sheet

Parameters related with financial analysis of the project are entered into the financial analysis sheet. Figure 4.27 shows the financial parameters entered for Kemerçayır HEPP.

Financial parameters		
General		
Fuel cost escalation rate	%	0,0%
Inflation rate	%	5,0%
Discount rate	%	9,5%
Project life	yr	50
Finance		
Incentives and grants	$	
Debt ratio	%	65,0%
Debt	$	15.168.400
Equity	$	8.167.600
Debt interest rate	%	8,00%
Debt term	yr	8
Debt payments	$/yr	2.639.525
Income tax analysis		
Effective income tax rate	%	20,0%
Loss carryforward?		Yes
Depreciation method		Straight-line
Depreciation tax basis	%	95,0%
Depreciation period	yr	50
Tax holiday available?	yes/no	No

Figure 4.27 Financial Parameter entered for Kemerçayır HEPP

Hydropower projects do not consume any fuel; therefore, **fuel cost escalation rate** is taken as 0 %.

Inflation rate and **effective income tax rate** are suggested by Korkmaz (2007) as 5 % and 20 %, respectively; and these values are used in this study.

Discount rate and **project life** is taken from the Feasibility Reports (2005a, 2005b, 2005c) as 9.5 % and 50 years, respectively.

Debt ratio, **debt interest rate** and **debt term** as 65 %, 8 % and 8 year, respectively (personal communication with Küçükbeycan, 2009).

Depreciation method is selected as “straight line” and **depreciation tax basis** is used as 95 % as suggested by Korkmaz (2007). **Depreciation period** is used as the project life of the project.

After entering these values to the financial analysis sheet, project costs and savings/income summary (Figure 4.28), yearly cash flows (Figure 4.29), financial viability (Figure 4.30) and cumulative cash flows graph (Figure 4.31) are calculated by RETScreen.

Project costs and savings/income summary			
Initial costs			
Power system	100,0%	$	23.336.000
Balance of system & misc.	0,0%	$	0
Total initial costs	**100,0%**	**$**	**23.336.000**
Annual costs and debt payments			
O&M		$	46.672
Fuel cost - proposed case		$	0
Debt payments - 8 yrs		$	2.639.525
Total annual costs		**$**	**2.686.197**
Periodic costs (credits)			
User-defined - 35 yrs		$	4.311.000
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	4.117.443
Total annual savings and income		**$**	**4.117.443**

Figure 4.28 Project Costs and Savings/ Income Summary prepared for Kemerçayır HEPP

Yearly cash flows			
Year	Pre-tax	After-tax	Cumulative
#	$	$	$
0	-8.167.600	-8.167.600	-8.167.600
1	1.634.784	1.344.653	-6.822.947
2	1.848.500	1.259.449	-5.563.498
3	2.072.901	1.414.328	-4.149.170
4	2.308.522	1.576.211	-2.572.959
5	2.555.925	1.745.390	-827.568
6	2.815.697	1.922.166	1.094.598
7	3.088.458	2.106.850	3.201.448
8	3.374.857	2.299.762	5.501.210
9	6.315.102	5.140.758	10.641.969
10	6.630.857	5.393.363	16.035.331
11	6.962.400	5.658.597	21.693.928
12	7.310.520	5.937.093	27.631.021
13	7.676.046	6.229.514	33.860.534
14	8.059.848	6.536.556	40.397.090
15	8.462.841	6.858.949	47.256.039
16	8.885.983	7.197.463	54.453.502
17	9.330.282	7.552.902	62.006.405
18	9.796.796	7.926.114	69.932.518
19	10.286.636	8.317.986	78.250.504
20	10.800.968	8.729.451	86.979.955
21	11.341.016	9.161.490	96.141.445
22	11.908.067	9.615.130	105.756.575
23	12.503.470	10.091.453	115.848.028
24	13.128.644	10.591.592	126.439.620
25	13.785.076	11.116.738	137.556.357
26	14.474.330	11.668.141	149.224.498
27	15.198.046	12.247.114	161.471.611
28	15.957.948	12.855.036	174.326.647
29	16.755.846	13.493.354	187.820.001
30	17.593.638	14.163.587	201.983.588
31	18.473.320	14.867.333	216.850.921
32	19.396.986	15.606.266	232.457.187
33	20.366.835	16.382.145	248.839.332
34	21.385.177	17.196.819	266.036.150
35	-1.325.106	-1.325.106	264.711.044
36	23.577.158	19.304.101	284.015.145
37	24.756.016	19.893.489	303.908.635
38	25.993.817	20.883.730	324.792.365
39	27.293.507	21.923.483	346.715.847
40	28.658.183	23.015.223	369.731.070
41	30.091.092	24.161.550	393.892.621
42	31.595.646	25.365.194	419.257.815
43	33.175.429	26.629.020	445.886.834
44	34.834.200	27.956.037	473.842.871
45	36.575.910	29.349.405	503.192.276
46	38.404.706	30.812.441	534.004.718
47	40.324.941	32.348.630	566.353.348
48	42.341.188	33.961.627	600.314.975
49	44.458.248	35.655.275	635.970.250
50	46.681.160	37.433.605	673.403.854

Figure 4.29 Yearly Cash Flows prepared for Kemerçayır HEPP

Financial viability		
Pre-tax IRR - equity	%	32,8%
Pre-tax IRR - assets	%	17,4%
After-tax IRR - equity	%	27,2%
After-tax IRR - assets	%	15,0%
Simple payback	yr	5,7
Equity payback	yr	5,4
Net Present Value (NPV)	$	45.379.726
Annual life cycle savings	$/yr	4.357.692
Benefit-Cost (B-C) ratio		6,56
Debt service coverage		1,62
Energy production cost	$/MWh	24,64
GHG reduction cost	$/tCO2	(404)

Figure 4.30 Financial Viability for Kemerçayır HEPP

The benefit-cost ratio of a project is one of the most important factors in assessing the feasibility of a project. A benefit-cost ratio greater than 1 is an indicator of a profitable project (RETScreen, 2010). As it is given in Figure 4.30, benefit cost ratio for Kemerçayır HEPP is calculated as 6.56 which indicate that the project is feasible. However, it should be recognized that, RETScreen does not consider any environmental and social costs associated with the projects.

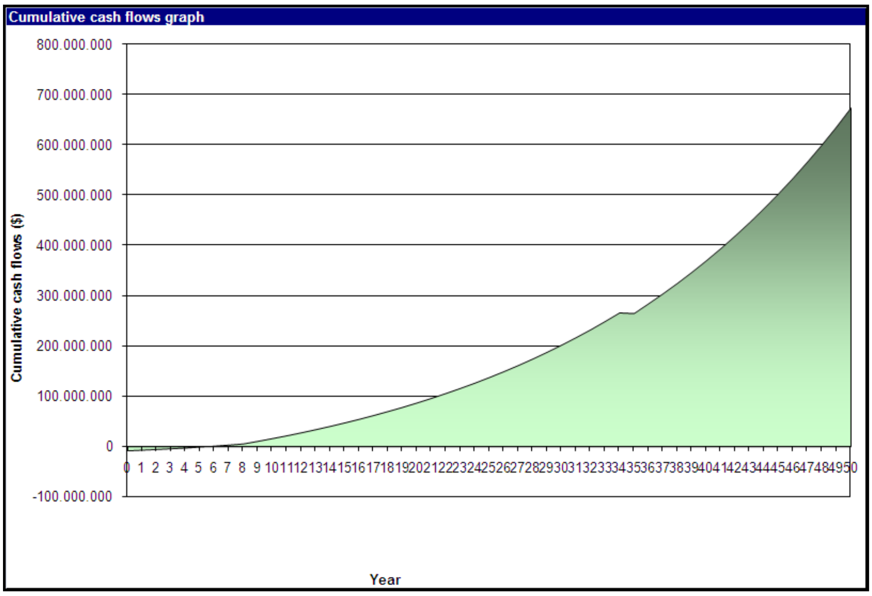

Figure 4.31 Cumulative Cash Flows Graph for Kemerçayır HEPP

As it is seen in Figure 4.29, after 6th year the project starts to generate benefits. The same thing is observed in Figure 4.31. Until 6th year the cumulative cash flows is negative. Starting from 6th year, cumulative cash flow continues to increase up to the 35th year. As it is mentioned in section 4.3.1.4, at 35th year, periodic cost is paid. The effect of this payment can be seen in Figure 4.31 as a levelling of in the plot. After year 36, the cumulative cash flow continues to increase.

4.3.2 Summary of the Evaluations for all Alternatives

In this study, three alternatives for three formulations provided in the Feasibility Reports (2005a, 2005b, 2005c) are developed. In addition to these three alternative formulations, an additional alternative which combines Kemerçayır and Üçharmanlar projects is suggested. A summary of the existing formulations and the alternatives suggested in this study is provided in Table 4.3.

Table 4.3 Summary of the Current and Alternative Formulations

	Current Formulation	**Alternative Formulation**
Kemerçayır	Feasibility Report (2005a)	Alternative 1
Üçhanlar	Feasibility Report (2005b)	Alternative 2
Üçharmanlar	Feasibility Report (2005c)	Alternative 3
Kemerçayır + Üçhanlar		Alternative 4

As explained before, design discharges are calculated for Kemerçayır, Üçhanlar and Üçharmanlar HEPPs in the Feasibility Reports (2005a, 2005b, 2005c). However, the details of these calculations are not provided in the Feasibility Reports (2005a, 2005b, 2005c). In this study, design discharges for all the suggested alternative formulations (i.e. Alternative 1, Alternative 2, Alternative 3 and Alternative 4) are calculated through an optimization procedure as explained in Section 4.2. Therefore, there are two different design discharges associated with each of the HEPPs (i.e. Kemerçayır, Üçhanlar, Üçharmanlar) and a single design discharge value for Alternative 4 (i.e. Kemerçayır+Üçhanlar).

An economical analysis is conducted for each of the three HEPPs (i.e. Kemerçayır, Üçhanlar, Üçharmanlar) for three different cases:

- Case 1: Project formulation given in the Feasibility Report (2005a, 2005b, 2005c),
- Case 2: Alternative formulation using the discharge given in the Feasibility Report (2005a, 2005b, 2005c),
- Case 3: Alternative formulation using the discharge obtained from optimization procedure conducted in this study.

Finally, the economical analysis for Alternative 4 is conducted using the design discharge obtained from the optimization procedure conducted in this study.

The inputs and some of the important outputs of Kemerçayır, Üçhanlar and Üçharmanlar HEPP and their alternatives are given in Table 4.4, Table 4.5 and Table 4.6, respectively.

Table 4.4 Kemerçayır HEPP and Alternative 1

		Case 1 Kemerçayır Q_d =6.8 m^3/s	Case 2 Alternative 1 Q_d = 6.8 m^3/s	Case 3 Alternative 1 Q_d = 7.16 m^3/s
Inputs	Gross Head (m)	244.7	244.7	244.7
	Tunnel Length (m)	1,775	710	710
	Channel Length (m)	40	980	980
	Penstock Length (m)	499.7	499.7	499.7
Outputs	Power Capacity (kW)	13,275	13,275	13,982
	Total Initial Costs ($)	23,337,000	22,744,000	23,517,000
	Annual Costs ($)	46,674	45,488	47,034
	Periodic Costs ($)	4,311,000	4,311,000	4,505,000
	Total annual savings and income ($)	4,117,443	4,117,443	4,116,005
	Simple Payback (year)	5.7	5.6	5.7
	Benefit-Cost Ratio	6.56	6.77	6.59

As can be seen from Table 4.4, for Kemerçayır Project, Case 2 (i.e. Alternative 1 with the discharge given in the Feasibility Study (2005a)) gives better benefit-cost ratios than the others. Although, Case 3 has a higher installed capacity (power capacity is used instead of installed capacity in RETScreen), its total annual savings and benefit-cost ratio is smaller than Case 2.

Table 4.5 Üçhanlar HEPP and Alternative 2

		Case 1 **Üçhanlar** **Q_d =7.5 m^3/s**	**Case 2** **Alternative 2** **Q_d = 7.5 m^3/s**	**Case 3** **Alternative 2** **Q_d = 7.59 m^3/s**
Inputs	Gross Head (m)	207.25	207.25	207.25
	Tunnel Length (m)	1,929	1,130	1,130
	Channel Length (m)	55	730	730
	Penstock Length (m)	505.7	505.7	505.7
Outputs	Power Capacity (kW)	12,302	12,302	12,455
	Total Initial Costs ($)	24,128,000	23,145,000	23,341,000
	Annual Costs ($)	48,256	46,290	46,682
	Periodic Costs ($)	4,291,000	4,291,000	4,291,000
	Total annual savings and income ($)	3,812,784	3,812,784	3,824,233
	Simple Payback (year)	6.4	6.1	6.2
	Benefit-Cost Ratio	5.7	6.01	5.97

When Table 4.5 is investigated, it can be seen that Case 2 and 3 give better benefits-cost ratios than current formulation (i.e. Case 1) given in the Feasibility Report (2005b). However, like in the previous case, the calculated design discharge did not give a better result. The total initial cost of Case 2 is smaller than Case 3.

For Kemerçayır and Üçhanlar HEPP's, the benefit cost ratios of three cases are quite similar to each other. Since there are uncertainties in some of the parameters used in the evaluations, it is not possible to select the best project formulation.

Table 4.6 Üçharmanlar HEPP and Alternative 3

		Case 1 Üçharmanlar Q_d =10.5 m^3/s	Case 2 Alternative 3 Q_d = 10,5 m^3/s	Case 3 Alternative 3 Q_d = 8.95 m^3/s
Inputs	Gross Head (m)	230.78	230.78	230.78
	Tunnel Length (m)	2084.82	650	650
	Channel Length (m)	736.93	2,436	2,436
	Penstock Length (m)	463.06	463.06	463.06
Outputs	Power Capacity (kW)	19,501	19,501	16,612
	Total Initial Costs ($)	30,972,000	35,607,000	31,497,000
	Annual Costs ($)	61,944	71,214	62,994
	Periodic Costs ($)	6,043,500	6,043,500	5,274,500
	Total annual savings and income ($)	5,074,351	5,074,351	4,948,001
	Simple Payback (year)	6.6	7.6	6.9
	Benefit-Cost Ratio	5.62	4.71	5.33

Case 2 and Case 3 have a higher total initial cost and a lower benefit-cost ratio than Case 1. In Alternative 3, a longer channel is used instead of the tunnel offered in the Feasibility Report (2005c). In the previous alternatives replacement of tunnel with channel resulted in cheaper solutions. However, in Üçharmanlar project the project area is steeper than the others (Feasibility Report, 2005c). Thus, channel constructions requires high amount of excavations which is the reason of the higher total initial cost of Case 2and Case 3.

Benefit-cost ratios of the three cases are quite different than each other. Since Case 1 has the best benefit-cost ratio, it can be concluded that Case 1 is the best option for Üçharmanlar project.

As explained before, Alternative 4 is a combination of Kemerçayır and Üçhanlar HEPPs. The results obtained from RETScreen runs for Alternative 4 are shown in Table 4.7.

Table 4.7 Evaluation Results for Alternative 4 (Q_d = 8.06 m^3/s)

Inputs	Gross Head (m)	477.5
	Tunnel Length (m)	2,020
	Channel Length (m)	1,470
	Penstock Length (m)	940
Outputs	Power Capacity (kW)	30,685
	Total Initial Costs ($)	38,762,000
	Annual Costs ($)	77,524
	Periodic Costs ($)	7,174,500
	Total annual savings and income ($)	8,277,883
	Simple Payback (year)	4.7
	Benefit-Cost Ratio	8.33

A discharge of 8.06 m^3/s is used in Alternative 4, which has a gross head of 477.5 meters. This alternative has the best benefit-cost ratio among all the other alternatives evaluated. A summary table providing comparison of the best formulations for Kemerçayır and Üçhanlar project with Alternative 4 is shown in Table 4.8.

Table 4.8 Results of Comparision

	Kemerçayır + Üçhanlar	Alternative 4
Power Capacity (kW)	25,577	30,685
Total Initial Costs ($)	45,889,000	38,762,000
Benefit-Cost Ratios	6.77 & 6.01	8.33

As it can be seen from Table 4.8, if Alternative 4 is used to generate electricity the installed capacity inceases from 25.6 MW to 30.6 MW and the total initial cost decreases approximately 7 million dollars. The benefit-cost ratio of Alternative 4 is 8.33 which is higher than the benefit-cost ratios of best formulations of Kemerçayır and Üçhanlar projects. Therefore, it is reasonable to select Alternative 4 instead of building two separate projects.

4.3.3 Effect of Electricity Export Rate

The electricity export rate used in the above mentioned evaluations is taken from Feasibility Reports (2005a, 2005b, 2005c) as 75 $/MWh. In this section, the effect of changing electricity export rate on the alternatives is studied.

The average electricity export rate for 2009 is announced as 13.32 krş/kWh in Turkey (Energy Market Regulatory Authority, 2009). This is equal to 87.41 $/MWh. The above mentioned steps starting from the optimization procedure for Alternative 4 is repeated using this electricity export rate.

Using the optimization procedure given in Section 4.2, the optimum discharge for Alternative 4 is obtained as 8.06 m^3/s same as the previous case. A change of 12.41 \$/MWh electricity export rate did not effect the optimum discharge. Figure 4.32 shows the optimization curve calculated using electricity export rate as 87.41 \$/MWh for Alternative 4.

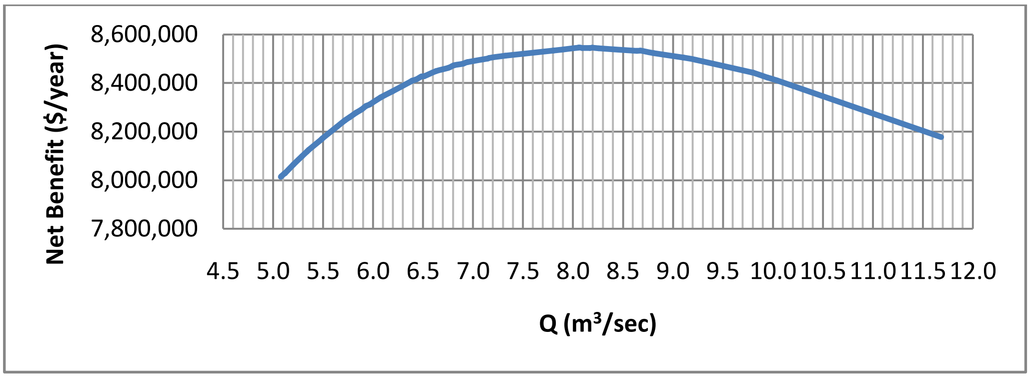

Figure 4.32 Optimization Curve for Alternative 4 (Electricity Export Rate = 87.41 \$/MWh)

Since the design discharge did not change for this electricity export rate, a higher electricity export rate is assumed as 130 \$/MWh and analysis has been repeated for this case.

By following the optimization procedure for 130 \$/MWh electricity export rate case, the optimum discharge for Alternative 4 is obtained as 8.68 m^3/s. The optimization curve for this case is shown in Figure 4.33.

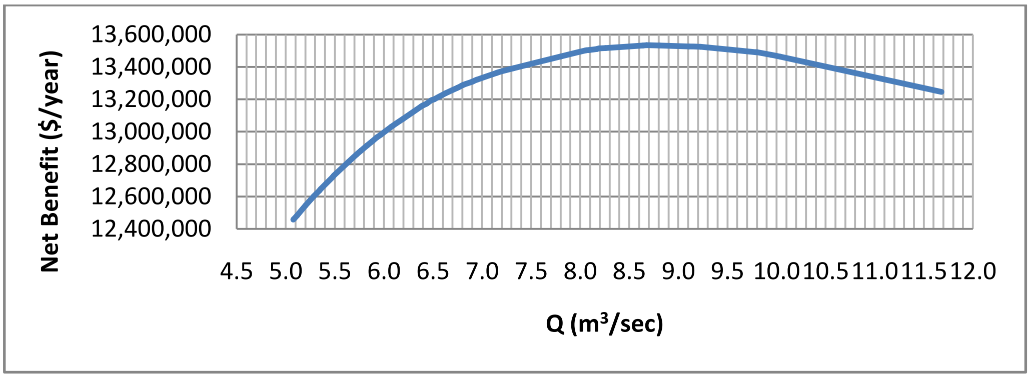

Figure 4.33 Optimization Curve for Alternative 4 (Electricity Export Rate = 130 $/MWh)

The results of the evaluations for three cases are shown in Table 4.9.

Table 4.9 Effect of Electricity Export Rate on the Results

	Case 1 Alternative 4 C_e* = 75 $/MWh	Case 2 Alternative 4 C_e = 87.41 $/MWh	Case 3 Alternative 4 C_e = 130 $/MWh
Power Capacity (kW)	30,685	30,685	33,062
Total Initial Costs ($)	38,762,000	38,762,001	40,884,000
Annual Costs ($)	77,524	77,524	81,768
Periodic Costs ($)	7,174,500	7,174,501	7,651,000
Total annual savings and income ($)	8,277,883	9,647,594	14,478,056
Simple Payback (year)	4.7	4.1	2.8
Benefit-Cost Ratio	8.33	9.95	14.87

*Ce = Electricity export rate

As it is seen in Table 4.9, as the electricity export rate increases, higher discharges become feasible which will produce more electricity. Although, the total initial cost for Case 3 is higher than Case 1 and Case 2, its benefit-cost ratio is almost twice as the other.

CHAPTER 5

INTERNATIONAL HYDROPOWER ASSOCIATION'S SUSTAINABILITY ASSESMENT PROTOCOL

5.1 General Information

The International Hydropower Association (IHA) regards sustainability as a component of social responsibility, sound business practice, and natural resources management (IHA, 2006).

Sustainable development is defined in the Report of the World Commission on Environment and Development as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nations, 1987). Economic development, social development and environmental protection are the three essential components of sustainability (IHA, 2006). Moreover, sustainable development requires (IHA, 2006):

- eradicating poverty;
- changing unsustainable patters of production and consumption;
- protecting and managing the natural resource base that underpins economic and social development.

Hydropower has a major role in enabling the countries around the world to meet their sustainability objectives. Therefore, IHA has published the Sustainability Guidelines 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 (IHA, 2004).

To support the sustainability guidelines, IHA has published the "Sustainability Assessment Protocol". The protocol is divided into three sections. The first section, Section A, provides general information about the sustainability issues that should be checked during the evaluation of new energy projects. In addition, it describes each of the twenty sustainability aspects, and lists key considerations and assessment requirements for each aspect. Second section, Section B, covers the sustainability issues of new hydro projects, and lastly the third section, Section C, evaluates the sustainability aspects of operating hydropower facilities. Section B and Section C rely on objective evidence to support a sustainability score for twenty sustainability aspects. Since new hydropower projects (i.e. Kemerçayır, Üçhanlar, Üçharmanlar HEPPs) are evaluated in this study, only Section B of the Sustainability Assessment Protocol is considered here.

For collecting objective evidence, three methods were given by Karki (2008):

- Document review –Examining plans, procedures and records can be included in document review.

- Interviews – Interviews conducted with responsible stuff, management, and contractors can be used as evidence.
- Direct observations – This could involve looking at physical locations and at other activities related to the management of an activity or process.

Section B has 20 sustainability aspects covering economic, social and environmental issues. As mentioned above depending on the objective evidence listed in the protocol, each aspect is scored using a scoring system given in Table 5.1. The average score of 20 sustainability aspects gives the overall score of the project where a score of 3 is considered as satisfactory.

In Turkey, there is no legal system to evaluate the sustainability of hydropower projects. For river type power plants with an installed capacity of 25 MW or more Environmental Impact Assessment (EIA) reports need to be prepared and submitted to the Ministry of Environment and Forestry. If the project has an installed capacity between 0.5 MW-25 MW, selection and elimination criteria given in the By-Law on Environmental Impact Assessment is applied. Selection and elimination criteria require preparation of a project presentation file for the project which is examined by The Ministry of Environment and Forestry. Depending on the examination of the project presentation file, the decision of “Environmental Impact Assessment is Required/Not Required” is given (The Ministry of Enviroment and Forestry, 2008).

Table 5.1 Description of the Scoring System Used in the Protocol (IHA, 2006)

Score	Performance	Description
5	Outstanding / Strong / Comprehensive	• At or very near international best practice. • Suitable, adequate, and effective planning and management systems. • Meets or exceeds objectives and measurable targets.
4	Good to Very Good	• High standard performance. • Generally suitable adequate, and effective (minor gaps only) planning and management systems. • Meets most objectives and measurable targets including all critical ones.
3	Satisfactory	• Essentially meets the requirements of the Sustainability Guidelines (no major gaps) • Generally compliant with regulations and commitments (minor exceptions only) • Some non-critical gaps in planning and management systems. • Some non-critical gaps in meeting objectives and measurable targets
2	Less than satisfactory	• Gaps in meeting the requirements of the Sustainability Guidelines • Some gaps in compliance with regulations and commitments. • Gaps in planning and management systems • Gaps in meeting objectives and measurable targets.
1	Poor / Very Limited	• Poor performance. • Major gaps in compliance with regulations and commitments. • Major gaps in planning and management systems. • Major gaps in meeting objectives and measurable targets.
0	Very Poor	• No evidence of meeting the requirements of the Sustainability Guidelines. • Very poor performance or failure to address fundamental issues. • Little or no compliance with regulations and commitments. • Ineffective or absent planning or management systems. • Fails to meet objectives and measurable targets.

Kemerçayır, Üçhanlar and Üçharmanlar HEPP's have an installed capacity in the range between 0.5 MW-25 MW. Therefore, for each of the projects, only project presentation file have been prepared and the decision of "Environmental Impact Assessment is Not Required" is obtained from the Ministry of Environment and Forestry. However, project presentation files prepared for Kemerçayır, Üçhanlar and Üçharmanlar projects are not available to us since the engineering firm who prepared these files was not willing to share these documents.

5.2 Scoring for New Hydro Projects: Kemerçayır HEPP as an example

Sustainability aspects provided in Section B of the Sustainability Assessment Protocol are given in Table 5.2. The details of these aspects together with scoring guidelines and examples of evidence provided in the Protocol (IHA, 2006) are studied carefully. With the available data and information only some of aspects can be scored thus instead of assigning scores with incomplete information, we tried to identify the necessary data and knowledge to be able to conduct a sustainability assessment study. Thus, this chapter instead of providing an example sustainability assessment for a SHP, it identifies type and extent of missing knowledge and information that is necessary to conduct the sustainability assessment for a SHP. Considering the available information, data and knowledge that exist for new small hydropower schemes in Turkey, the applicability of the IHA's Sustainability Assessment Protocol (IHA, 2006) is evaluated.

Each of the 20 aspects is evaluated in terms of Kemerçayır HEPP. However, as explained before the goal here is not to conduct a sustainability assessment study for Kemerçayır HEPP, but rather to identify what type of information and data is missing to be able to conduct the sustainability assessment.

Table 5.2 List of Sustainability Aspects for New Hydro Projects

NO	ASPECT
B1	Political risk and regulatory approval
B2	Economic viability
B3	Additional benefits
B4	Planned operational efficiency and reliability
B5	Project management plan
B6	Site selection and design optimisation
B7	Community and stakeholder consultation and support
B8	Social impact assessment and management plan
B9	Predicted extent and severity of economic and social impacts on directly affected stakeholders
B10	Enhancement of public health and minimisation of public health risks
B11	Safety
B12	Cultural heritage
B13	Environmental impact assessment and management plan
B14	Threshold and cumulative environmental or social impacts
B15	Construction and associated infrastructure impacts
B16	Land management and rehabilitation
B17	Aquatic biodiversity
B18	Environmental flows and reservoir management
B19	Reservoir and downstream sedimentation and erosion risks
B20	Water quality

B1 Political risk and regulatory approval

Political instability and/or sovereign risk issues always exist in Turkey. However, it is unlikely that these issues will pose a threat to small hydropower projects. It is expected for small HEPPs to obtain regulatory approval but this may involve some uncertainty in timing and conditions. Moreover, it is clearly stated in the 9th Development Plan of State Planning Organization that "The share of domestic and renewable energy resources in the production system will be raised to maximum extent and it is fundamental to complete the hydroelectricity power plants" (DPT, 2006).

B2 Economic viability

Detailed benefit-cost analysis is completed for Kemerçayır project. As a result of this analysis it is calculated that the project has a benefit-cost ratio of 6.56 which is much greater than one. In addition to benefit-cost analysis, the Protocol (IHA, 2006) requires a suitable and adequate plan for future auditing/monitoring program to exist for the new hydro power project to attain a high score from this criterion. Since Kemerçayır project is going to be a privately owned project it is reasonable to assume that the owner will have a suitable and adequate plan for future auditing/monitoring program.

B3 Additional Economic benefits

The protocol (IHA, 2006) identifies the additional benefits as follows: 1) direct and indirect employment; 2) education, transfer of knowledge, and capacity building; 3) improved health care; 4) national development and additional economic activity; and 5) additional amenity. Since

Kemerçayır is a small HEPP, most of these additional economic benefits do not exist. It is for sure that especially during the construction period there will be employment opportunities. The project may as well provide positive impact on national development by decreasing Turkey's dependency on foreign resources for energy generation and increase knowledge transfer and contribute to capacity building through utilization of various softwares such as RETScreen.

B4 Planned operational efficiency and reliability

The Protocol (IHA, 2006) assesses the planned operational efficiency of the project through evaluation of three specific areas: 1) planned management of the hydrological resources; 2) design efficiency of the power station assets; and 3) planned and/or existing efficiency of the network assets. Flow duration curve and optimum design discharge are calculated for Kemerçayır HEPP, thus in terms of planned management of the hydrological resources the project can be regarded as satisfactory. However, no long-term resource availability analysis is conducted. To our knowledge, no emergency/unusual event plans are prepared for Kemerçayır HEPP either.

B5 Project management plan

Large and small hydropower projects have been realized in Turkey for a long time; thus necessary knowledge and skills for design and construction of these structures have been accumulated. There are areas in which international assistance is required and these areas are known and necessary guidance is taken from foreign experts when needed. Moreover, Kemerçayır Project is a privately owned project and it is reasonable to assume that the owner will have a good project management plan in order to increase its profit.

B6 Site selection and design optimisation

According to the Protocol (IHA, 2006) a high score is granted to the projects which 1) avoid exceptional environmental and cultural heritage sites; 2) minimize disturbances to existing features and activities; and 3) maximize economic, social, and environmental opportunities. Most of these requirements are mainly applicable for large hydropower schemes with reservoirs. Flooded areas may cause disturbances to existing features and activities. Thus major environmental and cultural impacts are usually associated with large hydropower plants. As explained in Section 2.2, SHP's may as well have some negative impacts on the environment thus proper site selection and implementation of mitigation measures and enhancement strategies may be necessary. In short, since the area impacted by a SHP is relatively negligible with respect to that of a large HEPP with reservoir, this aspect is more applicable for larger projects.

Kemerçayır project is not located within an exceptional environmental or cultural heritage site (2005a). Since it is a small hydropower plant, its disturbance to the environment is minimal. However, the project area is located in a region which is covered with forests, thus construction of the tunnels and channels may result in destruction of some forest land. It is reasonable to assume that the owner of Kemerçayır project will try to maximize its economic benefits. However the same maximization may not take place in terms of social and environmental benefits.

B7 Community and stakeholder consultation and support

Community consulting and support is a critical issue for hydropower projects. Public opposition sometimes become very important and causes the projects to be delayed or even dismissed. To avoid such situations, the community need to be informed and their involvement in the projects need to be supported. The owner of the project together with officers from the government and local authorities should hear the needs and demands of the community and take required mitigation measures and implement necessary revisions.

Public meetings are generally realized for projects that require Environmental Impact Assessment (EIA) reports in Turkey. As explained before, an EIA study is required for river type hydropower plants if it has an installed capacity of 25 MW or larger. Thus, for SHPs EIA studies and public meetings are not required. Thus, it is not likely for SHP owners to conduct public hearings and try to raise support from the community.

To assess stakeholder consulting and support, first the stakeholders of the project need to be identified. Stakeholders are people who are involved in or affected by an action. The best way to determine stakeholders of a project which involves utilization of a river is to identify the whole associated catchment and all the users located inside the catchment. Then the optimum utilization of the water resource (i.e. the river) can be determined by considering the needs of all the users together with environmental, social and political constraints. This is termed integrated basin management. Integrated basin management is a new concept and attempts to apply it to practical problems have very recently started in Turkey. Thus, integrated basin management strategies for basins and sub-basins have not been developed yet.

If the project area encompasses private property or involves various activities such as fishing, transportation or recreational utilization then property owners and people conducting these activities are identified as stakeholders without any effort. However, if these activities are conducted at some downstream location as well then it is not as straightforward to identify these additional stakeholders unless the government has conducted some studies and prepared integrated basin management plans.

Since Kemerçayır project does not require an EIA study, a formal requirement for public hearings does not exist. However, the consulter of Kemerçayır project stated that public meetings were held. In addition, we have not found any community opposition news on the internet. In terms of stakeholder consultation and support, no study has been conducted. Downstream users have not been identified and impacts on these users have not been assessed. It is likely that the downstream users are not aware of the project thus have not raised any opposition yet.

B8 Social impact assessment and management plan

Social impact assessment studies are conducted only for large water resources projects in Turkey. Generally for SHP social impact assessment studies are not conducted. Mitigation, compensation, and/or enhancement strategies can only be identified and acceptability of these strategies can be evaluated if there exists an affected group of people (i.e. stakeholders).

For Kemerçayır project no study is conducted to identify the directly affected group of people to our knowledge. Thus, stakeholders for this project are not determined. However, the project site does not include any privately owned land, thus it is not likely that the project will directly impact anybody at the project site. However, the situation with downstream users is uncertain and the project may have some social impacts on downstream users (if they exist). Thus, although no directly affected stakeholders exist at the project site, all the stakeholders (i.e. possible downstream users) are not known.

B9 Predicted extent and severity of economic and social impacts on directly affected stakeholders

As explained in the previous paragraph, the project area does not include any private property thus it is reasonable to assume that there will not be any directly affected stakeholders who live within the project area. However, it is not known if the river is used for other purposes at the downstream of Kemerçayır project. The downstream users may be impacted from the change in the quality of the water in the river or their activities might be impacted. However, the extent of change in the quality of the water due to Kemerçayır HEPP is not studied in detail. Since it is not known if there are any downstream users and what type of activities are conducted, it is not possible to evaluate if anybody will be economically, socially or culturally impacted by the project.

B10 Enhancement of public health and minimisation of public health risks

Generally public health risk assessment studies are not conducted for small HEPPs in Turkey. Thus health risks associated with hydropower schemes are not known. The hydropower projects will provide employment opportunities thus may have an indirect positive impact on public health benefits. However, the extents of these benefits are not known.

The impact of Kemerçayır HEPP on the quality of water is not investigated, thus is unknown and a monitoring program has not been planned. Since the future water quality of the rivers is not predicted it is not possible to conduct a public health risk assessment study. Since possible heath risks are not identified and studied in detail the impact of Kemerçayır HEPP on public health benefits is not known.

B11 Safety

The project is constructed by IC İÇTAŞ company. The company implements Health Safety and Environmental policy as an important company strategy (IC İÇTAŞ, 2010). Moreover, the project presentation file covers information about the risk of accidents which may arise due to technology and materials to be used in the project (The Ministry of Enviroment and Forestry, 2008). Therefore, a good safety performance is predicted for Kemerçayır HEPP.

B12 Cultural heritage

The project area has no cultural heritage values (2005a). Moreover, selection and elimination criteria which are the basis of project presentation file have a part covering information about the sensitive areas in the project area (The Ministry of Enviroment and Forestry, 2008).

B13 Environmental impact assessment and management plan

As mentioned above, Environmental Impact Assessment is prepared for river type hydropower projects with an installed capacity higher or equal to 25 MW (The Ministry of Enviroment and Forestry, 2008). Kemerçayır HEPP has an installed capacity of approximately 13 MW. Therefore, for this project, project presentation file has been prepared and accepted by the Ministry of Environment and Forestry. As a result of this evaluation "No environmental impact assessment is required" decision is made for Kemerçayır HEPP. However, there are some gaps about the stakeholder support to the project as explained in sustainability aspect B7.

B14 Threshold and cumulative environmental or social impacts

Threshold impacts and cumulative impacts are given in the protocol as the actions that cause a large step change to environmental or social conditions and the sum of total of impacts resulting from a series of changes to environmental or social conditions, respectively (IHA, 2006). The project presentation file covers information about the measures to be taken against the possible environmental impacts of the project. As mentioned before, project presentation file is prepared for Kemerçayır

HEPP and accepted. Moreover, no information is given about the negative impacts of Kemerçayır HEPP in the Feasibility Report (2005a). However, this aspect requires an option assessment in relation to regulated and unregulated rivers in the region which for this project did not prepared.

B15 Construction and associated infrastructure impacts

As mentioned in aspect B6, since the project area is a forestry area, the construction of tunnels and channel as well as roads requires destruction of some of the forest lands. During construction of Kemerçayır HEPP, excavation material will be disposed to a storage area such that no environmental hazard will occur (2005a). However, there is no information about an emergency response plan or program.

B16 Land management and rehabilitation

The project presentation file has a part giving information about the existing land use and quality and as mentioned before the project area is a forestry area. Moreover, it is clearly stated in the Feasibility Report (2005a) that whenever necessary expropriation of the lands used by local people will be completed. However, there is no design plans for land restoration and rehabilitation mentioned in the Feasibility Report (2005a).

B17 Aquatic biodiversity

No information is given about the endangered specimens, fish passages or any ecosystem values in the Feasibility Report (2005a). On the other hand, Feasibility Report (2005a) states that the water required for the specimens and fishes living in the river will be released. However, this aspect requires detailed research about the threatened specimens on the project area and fish passages which could not be obtained.

B18 Environmental flows and reservoir management

As mentioned in Section 2.2.2, run-of river type of small hydropower schemes does not have a reservoir. Since Kemerçayır HEPP is a run-of river scheme, it has no reservoir. Therefore, no reservoir management is required for Kemerçayır HEPP.

B19 Reservoir and downstream sedimentation and erosion risks

Kemerçayır HEPP has no reservoir. Thus, sedimentation problem in the reservoir is not possible. However, there is no information about the downstream sedimentation and erosion risks. The evaluation of this aspect requires sedimentation and erosion risk management plan and investigations about sedimentation and erosion issues.

B20 Water quality

The waste to be produced and the water surface quality are mentioned in the project presentation file. Since the project presentation file is accepted by the officials it could be concluded that no harmful wastes will be produced. However, no information is provided about the water quality management plan of the project and plans of water quality investigations which are required to score this aspect.

5.2.1 Summary of Section B – New Hydro Projects

This evaluation has been completed with a very limited source of evidence. Therefore, it was not possible to assign scores to sustainability aspect. In order to complete a detailed scoring of a hydropower project using the Sustainability Assessment Protocol, the help of all the parties involved in the planning, design, and construction of the project as well as the stakeholders of the projects are needed.

Each sustainability aspect is given with a detailed list of evidence to support the scoring of the criterion. Therefore, all of the types of objective evidence types mentioned in Section 5.1 must be used to complete a detailed scoring of a project. Moreover, most of the sustainability aspects require different types of management plans. The list of plans to be prepared and examined to evaluate the sustainability aspects is given below.

- Auditing and monitoring plans to score sustainability aspect B2,
- Emergency/Unusual event plans to score sustainability aspect B4,
- Written agreements with stakeholders or plans of agreements to score sustainability aspect B7,
- Social impact assessment and management plan to score sustainability aspect B8,
- Mitigation, compensation and enhancement plans or programs to score sustainability aspect B9,

- Public health management plans and planned monitoring programs to score sustainability aspect B10,
- Construction management plans, emergency response program or plans and land rehabilitation and restoration plans to score sustainability aspects B15 and B16,
- Sedimentation and erosion risk management planning to score sustainability aspect B19
- Lastly, water quality management planning and water quality investigations to score sustainability aspect B20.

In addition to these plans and/or programs, whenever necessary, interviews with directly affected stakeholders and regulators must be completed.

CHAPTER 6

CONCLUSION

To overcome the increasing demand for electricity, new energy facilities are under construction all around the world. Fossil fuel fired power plants are the main source of greenhouse gas emissions which increase the threat of climate change. The countries all around the world are trying to supply their increasing demands for electricity with clean energy technologies. Hydropower as a sustainable and renewable resource is a major energy source for Turkey.

A significant portion of the economically viable hydropower potential of Turkey has not been utilized yet. Thus, many small HEPPs are under construction and in program to harness this economically viable potential. Developing a hydropower project requires time and money as well as engineering experience. In order to assist engineers in conducting feasibility analysis of hydropower projects many computer tools have been developed. One such software is RETScreen.

RETScreen International Clean Energy Analysis Software is a decision support tool which could be applied internationally. RETScreen is useful software which may be utilized in comparing various alternative project formulations. The main advantage provided by RETScreen is the capability to conduct benefit-cost analysis in a timely manner.

In this study, a number of alternative formulations are developed for three consecutive hydropower projects, namely; Kemerçayır, Üçhanlar and Üçharmanlar HEPP located in Of, Trabzon and their profitabilities are compared by using benefit-cost analysis of RETScreen. Alternatives with longer channels instead of tunnels resulted in higher net benefits. However, for Kemerçayır and Üçhanlar HEPP's the benefit cost ratios for three cases were very similar to each other. Therefore, for these projects, it was not possible to identify a best alternative. Only for Üçharmanlar project the alternative with longer tunnel is found to be better than the one with longer channel. The cost of channel construction is cheaper than cost of tunnel construction, if the topography of the project area is not too steep. Üçharmanlar project site is composed of an area with high side slopes thus utilization of channels is not feasible.

Within the scope of this study, best design discharges are identified and benefit-cost analysis is carried for various electricity prices for a number of alternatives. Realization of many runs required for this analysis is conducted by RETScreen in a timely manner. It can be concluded that especially at the pre-feasibility stage, RETScreen is a useful tool which can be used to compare the possible project alternatives. Its user friendly environment, ease of utilization and timely calculations can decrease the cost of pre-feasibility studies. The analysis results will provide additional information for the decision makers and design engineers.

In addition to economical feasibility of hydropower plants, their impacts on the environment and contribution to sustainable development need to be evaluated. IHA has published the Sustainability Guidelines (IHA, 2004) and the Sustainability Assessment Protocol (IHA, 2006) 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. As an example application, Kemerçayır HEPP is evaluated using the Sustainability Assessment Protocol.

The Sustainability Assessment Protocol for new hydro projects is composed of 20 aspects to be scored. When these aspects are studied in detail it is realized that it is not possible to evaluate SHPs in Turkey with respect to these aspects. Thus, in this study instead of conduct a sustainability assessment for Kemerçayır HEPP, we tried to identify what type of information and data is missing to be able to conduct the sustainability assessment. As a result of this analysis, the following data, knowledge and applications are identified as missing for SHPs in Turkey:

- All the stakeholders of the projects,
- The extent of change in the quality of the water due to the projects,
- Potential social, environmental and cultural impacts associated with the projects,
- A monitoring program for both the quantity and quality of river water at the upstream and downstream of the HEPP,
- An integrated basin management plan.

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