UNIVERSITY OF GAZİANTEP
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FEASIBILITY ASSESSMENT OF SMALL HYDROPOWER PROJECTS

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IN
CIVIL ENGINEERING

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MURAT KARAYILAN
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Feasibility Assessment of Small Hydropower Projects

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Supervisor
Assist. Prof. Dr. Mehmet İshak YÜCE

by
Murat KARAYILAN

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ABSTRACT

FEASIBILITY ASSESSMENT OF SMALL HYDROPOWER PROJECTS

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M.Sc. in Civil Engineering
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The most favorable renewable energy production method is small scale hydropower plants. The main parameters needs to be determined in small scale hydropower plants are the installed capacity and cost estimation. Installed capacity and cost estimation are effected by the design flow, gross head, turbines, tunnels, canals, penstocks, and the other variables. All of these variables are analyzed in the feasibility studies to find optimum installed capacity and cost estimation. A computer program named RETScreen, which is generally used in Canada, is capable of evaluating the energy generation, investment and maintenance costs for small scale hydropower projects. In this thesis four different small scale hydropower plants' feasibility studies, which were obtained from State Hydraulic Works (DSI), were compared with the results found by RETScreen. The results achieved by RETScreen were noticed to be very close to the results found in the feasibility studies obtained from DSI. RETScreen was noted to be capable of assessing feasibility studies of small hydropower plants (SHPP) within a relatively short period of time, thus minimizing costs.

Key Words: small scale hydropower plants, RETScreen, feasibility study, installed capacity, cost estimation.

ÖZET

KÜÇÜK HİDROELEKTRİK PROJELERİNİN FİZİBİLİTE ÇALIŞMASI

KARAYILAN, Murat
Yüksek Lisans Tezi, İnşaat Mühendisliği Bölümü
Tez Yöneticisi: Yrd.Doç. Dr. Mehmet İshak YÜCE
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Dünyada yenilenebilir enerji kaynaklarının üretiminde en favori yöntem küçük ölçekli hidroelektrik santralleridir. Küçük ölçekli hidroelektrik santrallerde belirlenmesi gereken ana parametreler kurulu güç ve yaklaşık maliyettir. Kurulu güç ve yaklaşık maliyet; Dizayn debisi, brüt düşü, türbinler, tünel, kanal, cebri boru ve diğer değişkenlerden etkilenir. Bütün bu değişkenlerin, optimum kurulu gücü ve yaklaşık maliyeti bulmak için, fizibilite çalışmasında analizi yapılır. Genel olarak Kanada da kullanılan ismi RETScreen olan bilgisayar programı; Küçük ölçekli hidroelektrik projeleri için enerji üretim, yatırım ve bakım maliyetlerini değerlendirebiliyor. Bu tezde, Devlet Su İşlerinden (DSİ) elde edilen, dört farklı küçük ölçekli hidroelektrik santrallinin fizibilite çalışmaları, RETScreen tarafından bulunan sonuçlar ile karşılaştırıldı. Dsi'den temin edilen fizibilite çalışmalarındaki sonuçlar ile RETScreen ile elde edilen sonuçlar çok yakın olduğu fark edildi. RETScreen, maliyetleri en aza indirerek aynı zamanda kısa bir sürede, küçük ölçekli hidroelektrik santrallerinin fizibilite çalışmaları değerlendirme yeteneğine sahip olduğu gözlendi.

Anahtar kelimeler: küçük ölçekli hidroelektrik santralleri, RETScreen, fizibilite çalışması, kurulu güç, maliyet tahmini.

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LIST OF SYMBOLS/ABBREVIATIONS

A	access road difficulty factor
B	foreign costs civil works factor
C	civil cost factor
C_g	lower cost generation factor
C_v	concrete lining in tunnel (m^3)
d	runner diameter (m)
D	transmission line difficulty factor
d_p	diameter of penstock
e	overall efficiency (%)
E	engineering cost factor
E_{avail}	annual available energy (in kWh/yr)
E_c	equipment costs ratio
E_{dlvd}	renewable energy delivered
e_g	generator efficiency
e_p	turbine peak efficiency
e_q	efficiencies at flows below peak efficiency flow
e_r	drop in efficiency at full load
e_t	turbine efficiency
$e_{t,des}$	turbine efficiency at design flow
f	frost days at site
F	frost days factor
F_c	fuel costs ratio
g	acceleration due to gravity
G	grid connected factor
H_g	gross head (m)

H_{hydr}	hydraulic losses
H_n	net head
H_{tail}	tailrace effect
$H_{tail,max}$	maximum tailwater effect
i	interest rate (%)
J_t	vertical axis turbine factor
k	tunnel headloss (ratio to H_g)
k_1	runner diameter factor
k_2	tunnel speed factor
K	equipment manufacture cost ratio
K_t	small horizontal axis turbine factor
L_a	access road length (km)
l_b	distance to borrow pits (km)
L_c	labour costs ratio
L_{cr}	canal length in rock (m)
l_{cs}	canal length in impervious soil (m)
l_d	dam crest length (m)
l_{dt}	annual downtime losses
$l_{hydr,max}$	maximum hydraulic losses
l_p	penstock length (m)
l_{para}	parasitic electricity losses
l_t	tunnel length (m)
l_T	tranmission line length (km)
L_{trans}	transformer losses
MW	total capacity (MW)
MW_u	capacity per unit (MV)
n	number of turbines
n_p	number of penstocks
n_q	specific speed based on flow
P	transmission line wood or steel factor

Q	flow under consideration (m^3/s)
Q_d	design flow (m^3/s)
Q_{max}	maximum river flow
$Q_{n,used}$	maximum flow that can be used by the turbine
Q_p	peak efficiency flow
Q_r	residual flow
Q_u	flow per unit (m^3/s)
P	power (Watts)
P_{des}	plant capacity
R	rock factor
R_m	turbine manufacture/design coefficient
R_v	tunnel volume of rock excavation (m^3)
S_r	side slope of rock where canal is built (^{o})
S_s	side slope of soil where canal is built (^{o})
T	tote road factor
t_{ave}	average penstock thickness (mm)
t_b	penstock thickness at turbine (mm)
T_c	tunnel lining length ratio
t_t	penstock thickness at intake (mm)
V	transmission line voltage (kV)
W	penstock weight (steel) (kg)
ρ	density of water

CHAPTER I

INTRODUCTION

1.1 General

The socio-economic growth and increased living standards with the fast growing industry has led to a major increase in electricity demand and generation. Being the basic input of all kinds of economic activities, electrical energy has become an indispensable component of social life. As a result of rapid increase in energy consumption and global warming threatening the environment together with the unbalanced and unpredictable increases of the fossil fuel prices has increased the importance of renewable energy sources (Twidell J. and Weir T. 2006, Boyle 2004).

In this respect, small hydropower (SHP) has emerged as an energy source which is accepted as renewable, easily developed, inexpensive and harmless to the environment. These features have increased small hydropower development in value, giving rise to a new trend in renewable energy generation (Adıgüzel et al. 2002).

Moreover, because of the considerable amount of financial requirements and insufficient financial sources of national budgets, together with the strong opposition of environmentalist civil organizations, large scale hydropower projects, generally, cannot be completed in the planned construction period, As a consequence, SHP has been widely used in developing countries with its low investment cost, short construction period and environment friendly nature (IHA 2003, Altınbilek 2005).

Comprising these features, small hydropower has been getting the attention in both developed and developing countries. Europe and North America has already exploited most of their hydropower potential. On the other hand, Africa, Asia and

South America have still substantial unused potential of hydropower (Altınbilek 2005). Small hydro power can be the remedy of the insufficient energy in developing countries. China has developed 43,000 small hydropower plants with a total installed capacity of 265 GW (IHA 2003, Boyle 2004).

In order to increase renewable energy production, it is important to put enormous effort into developing efficient small hydropower plants. European Small Hydro Association has developed a guideline for designing small hydro plants (ESHA, 2004). However, feasibility studies are very important for the correct evaluation and assessment of small hydro power projects. Software called RETScreen has been developed to perform feasibility studies of SHPP projects which can be internationally used. This user friendly software gives a general idea about the feasibility of a SHP project. It can also be used for performing sensitivity analysis or for monitoring the feasibility studies which have already been completed. Furthermore, the software can also be used to investigate the viability of energy production from existing dams which had not been planned as hydropower plants (Boyle 2004).

1.2 Research Objectives and Scope

Although there are several hydro schemes of every scale in Turkey, it is still far behind the full hydropower potential. In recent years, especially after the privatization in energy market, several private companies have engaged in the energy harnessing business. Most of these companies have been involved in developing small hydropower, which shows the importance of SHPPs from economical point of view. Recently, a few studies which pay attention to the importance of small hydropower have been carried out (Derinöz et al., 2005; Yüksel et al., 2005)

The aim of this study is to assess the feasibility studies of Small Scale Hydropower Projects in Turkey. RETScreen software was selected to manage this since it is capable of performing desired computations. Four different feasibility studies, obtained from DSI, have been performed by using RETScreen and these results were compared with the feasibility studies approved by DSI.

In Chapter 1, a brief description of the importance of the problem and the literature review are given. In Chapters 2, hydropower and small hydropower are discussed. Chapter 3 is reserved for the introduction of RETScreen software. Chapters 4 and 5 explain the case studies and the conclusions of the study, respectively.

CHAPTER II

HYDROPOWER

2.1 History of Hydropower

Converting the energy of falling water into mechanical power is an age old tool. Greeks had used to turn water wheels for grinding wheat into flour, more than 2000 years ago. Hydropower was mostly used for milling of lumber and grain and for pumping irrigation water in the 1700's. American and European factories used water wheels to power machines in the early 1800s. The water wheel is an easy machine. The wheel picks up water in buckets located around the wheel. The weight of the water provides energy which turns the wheel. Water wheels convert the energy of flowing water into useful energy to grind grain, drive sawmills or pump water (Andrews et al, 2007, Boyle 2004).

Hydropower was first used to generate electricity in the late 19th century. At the Niagara Falls the first hydroelectric power plant was built in 1879. In the following years a number of hydropower plants were built. Many large dams had been developed in the world at the 1940s (IHA, 2003).

At the same time, fossil fuel power plants began to be popular. These plants could make electricity more cheaply than hydropower plants. It was not until the price of oil skyrocketed in the 1970s that pushed people became interested in hydropower. Nowadays, Hydropower is cheaper than fossil fuel (coal, natural gas, oil) and nuclear power plants, since hydropower’s fuel supply is clean and renewable flowing water (IHA, 2003).

2.2 Hydropower Potential of The World

The hydroelectric power potential of a country is estimated under the assumption that the entire set of natural flows, within the country's borders, will be used with 100% efficiency. This calculation produces the gross theoretical hydroelectric power potential of a country. However, even the latest technologies available today cannot make the use of whole of this potential. Therefore, the maximum potential that can be harnessed with the existing technologies is referred to as the technically viable hydroelectric power potential. Nonetheless, not every technically viable potential is economically viable. Therefore, the part of the technically viable potential that can be utilized under the existing and future local economical conditions is referred to as the economically viable hydroelectric power potential. The gross theoretically viable hydroelectric power potential in the world is 40 billion GWh while the technically viable potential is 14 billion GWh. The economically viable potential, however, is only 8.9 billion GWh (Table 2.1).

Table 2.1 Hydroelectric power potential of the world (DSI, 2009)

	Gross Theoretical HEPP Potential (GWh/year)	**Technically Viable HEPP Potential (GWh/year)**	**Economically Viable HEPP Potential (GWh/year)**	**Economically Viable Percentage (%)**
Europe	3 150 000	1 225 000	800 000	8.98
Asia	12 676 000	5 054 000	4 112 000	46.18
Africa	3 887 000	2 163 000	1 416 000	15.90
America	13 350 000	4 377 000	2 111 000	23.71
Pacific Asia	6 654 000	1 025 000	326 000	3.66
Turkey	**433 000**	**216 000**	**140 000**	**1.57**
World	40 150 000	14 060 000	8 905 000	100.00

Technically viable hydroelectric power potential of a number of countries is given in Table 2.2. USA seems to have developed 86% of the country's technically viable hydroelectric power potential while Japan, Norway, Canada and Turkey harnessed 78%, 68%, 56% and 22% of their technically viable potentials, respectively. The International Energy Agency (IEA) has foreseen 53% increase of the current use of the world's hydroelectric power and other renewable energy sources by 2020, which is a sign that all hydroelectric power potential will be put into operation.

Table 2.2 Hydroelectric power potential development in some countries (DSI, 2009)

Country	**Technical Potential (billion kWh/year)**	**Developed (billion kWh/year)**	**Developed Percentage (%)**
USA	376	322	86
Japan	132	103	78
Norway	171	116	68
Canada	593	332	56
Turkey	216	48	22

2.3 Hydropower Potential of Turkey

Turkey's gross theoretical hydroelectric power potential is 1% of that of the world and 16% of that of Europe. The gross theoretically viable hydroelectric power potential of Turkey is 433 billion kWh and the technically viable potential is 216 billion kWh. The economically viable potential, however, is 140 billion kWh (Table 2.3 and Figure 2.1). Turkey's economically feasible hydropower potential is 30% of that of the gross theoretical potential. The rest of the potential is either technically not feasible (50%) or economically not feasible (20%).

Table 2.3 Hydroelectric power potential of Turkey (DSI, 2009)

	billion kWh	Percentage
Theoretically feasible hydroelectric potential	433	100%
Technically feasible potential	216	50%
Economically feasible potential	140	30%

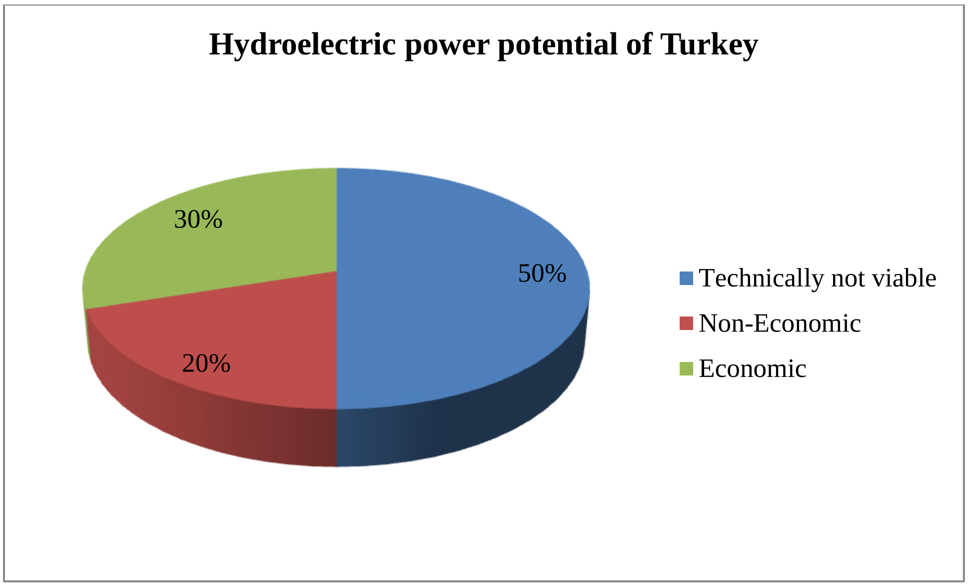

Figure 2.1 Hydroelectric power potential of Turkey

At present Turkey has 172 hydroelectric power plants in operation with a total installed capacity of 13 700 MW, generating an average of 48 000 GWh/year, which is 35% of the economically viable hydroelectric power potential of the country. Currently, there are 148 hydroelectric power plants under construction with 8 600 MW of installed capacity to generate 20 000 GWh annual, representing 14% of the economically viable potential. In the soon future, 1 418 more hydroelectric power plants will be constructed in order to make use of additional 22 700 MW installed capacity. As a result of these works, a total of 1 738 hydroelectric power plants with 45 000 MW installed capacity (Table 2.4) will tame rivers to harness the economically viable hydropower of Turkey (DSI, 2009).

Table 2.4 Status of economically viable hydropower potential of Turkey (DSI, 2009)

Status of Economically Viable Potential	Number of Hydroelectric Plants	Total Installed Capacity (MW)	Average Annual Generation (GWh/year)	Ratio (%)
In Operation	172	13,700	48,000	35
Under Construction	148	8 600	20 000	14
Under Investigation	1 418	22 700	72 000	51
Total Potential	1 738	45 000	140 000	100

Annual increase in energy consumption in Turkey is 8 - 10%, except for the recession years. In order to meet this growing demand, Turkey is to invest US$3-4 billion annually in new energy projects. As it can be seen all over the world, energy sources development is a matter of survival, therefore it is important for every country to be self-sufficient in terms of sustainable, trustable and economical energy sources. For that matter, all the energy alternatives are to be thoroughly evaluated starting from hydroelectric power potential running with local energy source, not dependent on the other countries' resources.

2.4. Working Principle of Hydropower Plants

The amount of electrical energy that can be generated from a water source depends primarily on two parameters: the vertical distance the water has to fall from and the amount of flowing water. Hydroelectric power stations are therefore situated, where they can take the advantage of the greatest fall of a large quantity of water, at the bottom of a deep and steep sided valley or gorge, or near the base of a dam (Figure 2.2), (Boyle 2004).

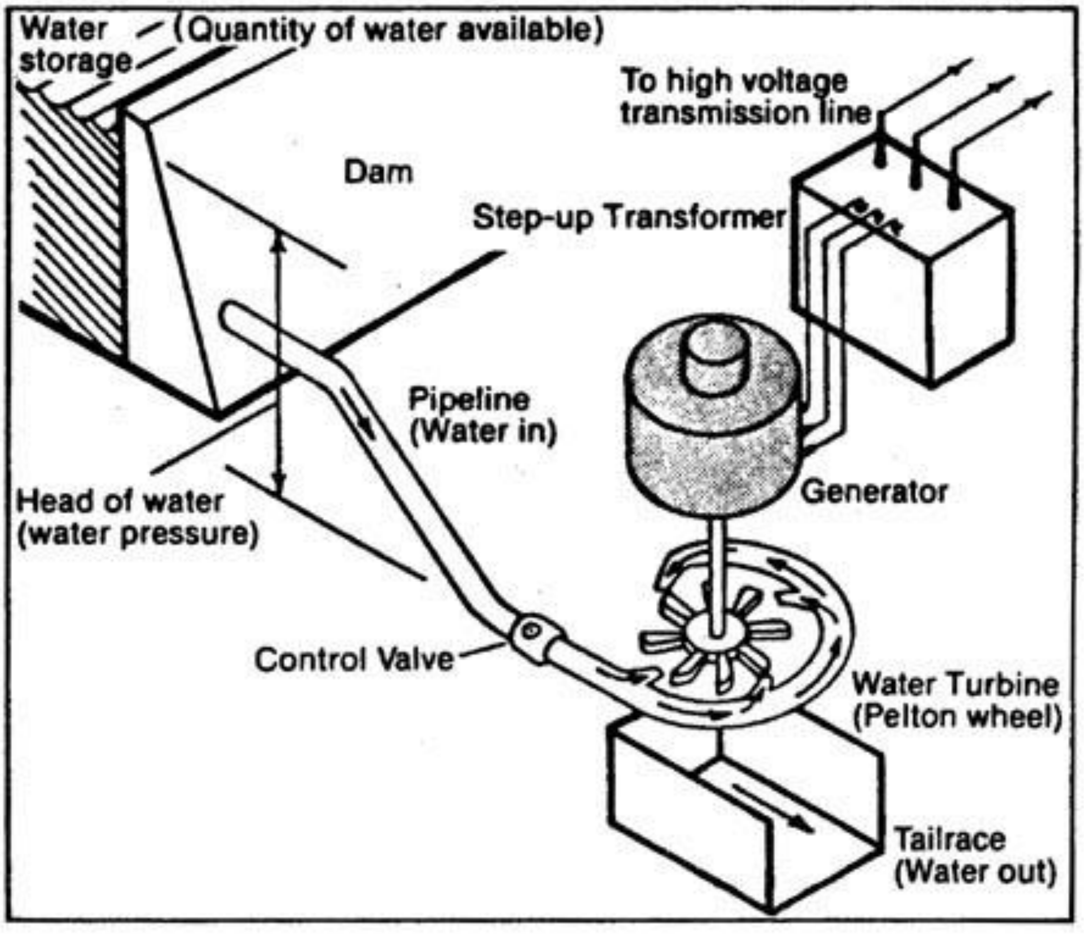

Figure 2.2 Hydropower plant working scheme

Hydroelectric power that can be generated in a hydropower plant is determined by:

$$P_0 = \gamma Q H_n \eta \tag{2.1}$$

where P_0 is the power in kW, γ is the specific weight of water in kN/m^3, Q is the discharge in m^3/s, H_n is the net head (gross head minus hydraulic losses) in meters, η is the overall efficiency of the system (Twidell et al, 2006).

2.5. Discussion over Hydropower

Hydroelectricity enjoys several advantages over most of the other sources of electrical power. These include a high level of reliability, proven technology, high efficiency (>90%), very low operating and maintenance costs, long plant life and the ability to easily adjust to load changes. Since many hydropower plants are located in conjunction with reservoirs, in addition to electricity harnessing, hydropower projects often provide water for irrigation and drinking water, flood control, and recreation benefits. Moreover, hydropower does not generate any toxic waste products that contribute to air pollution problems, acid rains, and greenhouse gases. It is a renewable resource that reduces the use of fossil fuels (oil, gas, and coal) which are subjected to fluctuations in market conditions. Hydropower also provides energy independence for many countries. It is a local source and cannot be transferred from one location to another one in crude form (Andrews et al, 2007).

Disadvantages of hydroelectricity include high initial costs of facilities, dependence on precipitation, changes in stream regimens can affect fish, plants and wildlife, inundation of land by creation of large reservoirs, displacement of people living in the reservoir area and relocation of historical artifact (Andrews et al, 2007).

2.6. Small-Scale Hydropower Plants

2.6.1. Introduction

The development of hydroelectricity in the 20th century was usually associated with the building of large dams. Hundreds of massive barriers of concrete, rock and earth were placed across river valleys world-wide to create huge artificial lakes. While they created a major, reliable power supply, plus irrigation, water supply and flood control benefits, the dams necessarily flooded large areas of fertile land and displaced many thousands of local inhabitants. In many cases, rapid silting up of the dam has since reduced its productivity and lifetime. There are also numerous environmental problems that can result from such major interference with river flows (Paish, 2002).

Small, mini and micro hydropower plants play a key role in many countries for rural electrification. Small-scale hydropower plants (SHPP) are mainly 'run off river,' they do not involve the construction of large dams and reservoirs

SHPP is the main prospect for future hydropower developments in Europe, where the large-scale opportunities have either been exploited already or would now be considered environmentally unacceptable (Kaygusuz, 2004). Small hydropower technology is extremely robust, also has the capacity to make a more immediate impact on the replacement of fossil fuels. Since, unlike other sources of renewable energy, it can generally produce electricity on demand with no need for storage or backup systems. It is also in many cases cost competitive with fossil fuel power stations (Kaygusuz, 2004).

2.6.2. Classification of Small Hydropower World & Turkey

There is no universally accepted classification of the term "small" hydropower, depending on local categorizations, which can range in capacity from a few kilowatts to 50 megawatts or more of rated power output. Internationally, "small" hydropower plant installed capacities typically range in size from 1 MW to 50 MW, with projects in the 100 kW to 1 MW range installed capacity referred to as "mini" hydropower and projects less than 100 kW installed capacity referred to as "micro" hydropower. Installed capacity, however, is not always a good indicator of the size of a project. For example, a 20 MW, low-head small hydropower plant is anything but small as low-head projects generally use much larger volumes of water and require larger turbines as compared with high-head projects. Table 2.5 summarizes the classification of 'small', 'mini' and 'micro' hydro power plants in different countries.

In Turkey, the upper limit for small hydro power plants is accepted to be 50 MW. Norway and Nepal take the upper limit as 10 MW while Brazil, Russia and the United States have set 30 MW as the upper limit for small hydropower plants. In most countries the range of mini hydropower plant size changes from100 kW to 1000 kW as it is the case in Turkey.

Table 2.5 Classification of small hydropower plants (based on capacity)

Country	**Micro (kW)**	**Mini (kW)**	**Small (MW)**
United States	<100	100-1000	1-30
China	-	< 500	0.5-25
Russia	<100	-	0.1-30
France	5- 5 000	-	-
India	< 100	101-1000	1-15
Brazil	< 100	101-1000	1-30
Norway	< 100	101-1000	1-10
Nepal	< 100	101-1000	1-10
Turkey	< 100	101-1000	1- 50

The design flow and the runner diameter are other parameters also used to categorize small hydro. Table 2.6 shows the classification for micro, mini and small hydropower plants used by the RETScreen.

Table 2.6 RETScreen’s classifications of shpp

	Typical Power	**RETScreen Flow (m^3/s)**	**RETScreen Runner Diameter (m)**
Micro	< 100 kW	< 0.4 m^3/s	< 0.3 m
Mini	100 to 1 000 kW	0.4 to 12.8 m^3/s	0.3 to 0.8 m
Small	1 to 50 MW	>12.8 m^3/s	> 0.8 m

2.6.3. Discussion over Small Hydropower Plants

Reliability – This is often cited as the number one advantage of small-scale hydropower plants. Turbine equipment requires relatively little maintenance and has very high efficiency factors and long life spans.

High quality, predictable electricity – Small hydropower plants produce high-quality electricity and generation is as consistent as its water source, allowing for very predictable performance.

Low environmental impact – The low environmental impact of small-scale hydroelectric projects is the other advantage. Since they do not interrupt flows, some projects even result in greater overall in-stream flows.

Can be incorporated into existing systems – Small hydroelectric generation can be incorporated into existing hydraulic systems (for example, a raw water supply system), allowing for a better utilization of infrastructure.

The downsides to small hydroelectric projects are the highly variable capital costs and site-specific conditions. Several factors contribute to the feasibility of the project, and like a fingerprint, no two are identical. Power production is contingent upon head and flow, which is obviously unique in every case. Revenue is contingent upon access to the grid and utility specific policy on decentralized generation such as net metering and power purchase agreements. Capital costs vary considerably based on infrastructure requirements, permitting requirements (local and federal), as well as fluctuations in labor and materials inherent in any construction project. All of these aspects result in a wide range of cost in terms of dollars per kWh, making analysis complicated.

2.6.4. Small Hydropower in the World

Asia, especially China, is set to become a leader in hydroelectric generation. Present developments in Australia and New Zealand are focusing on small hydropower plants. Canada, a country with a long tradition in using hydropower, is developing small hydropower as a replacement for expensive diesel generation in remote off-grid communities. Markets such as South America, the former Soviet Union and Africa also possess great, untapped potential.

The World Energy Council (WEC) estimates that under current policies, installed capacity of small hydro will increase to 55 GW by 2011 with the largest increase coming from China. In the year 2000 the world-installed capacity of small hydropower plants was about 37 GW. All regions of the world are experiencing significant increase in small hydro capacity, with China again showing the greatest increase (ESHA, 2004).

2.6.5. Small Hydropower Development in Turkey

Turkey has a huge untapped potential for SHPPs. The gross theoretical SHP potential of Turkey is 50 000 GWh/year. The technically and economically feasible potential is 30 000 and 20 000 GWh/year, respectively. Only 3.3% of economically feasible potential is developed so far. The hydropower plants in the planning stage, in the country, according to their capacity, are presented in Table 2.7. As it can be seen from the table 33.91% (26.45+7.46) of the hydropower energy produced annual will be generated by SHPPs. There were 80 installed SHPPs in Turkey with a total capacity of 177 MW, 5% of which with medium head and 95 % with high head up to year 2007. Being generally a mountainous country with annual average precipitation of 643 mm, corresponding to a volume of 500 km^3 and 190 km^3 is surface run off. Turkey's SHPP potential is relatively high (ESHA, 2008)

Table 2.7. SHPPs in the planning stage, in Turkey.

Classification	Number of HEPP	Total Installed Capacity (MW)	Average Annual Generation (GWh/y)	Percentage of Total Annual Energy
<10 MW (Small Hydro)	307	1 143	5 163	7.46
10-50 MW (Small Hyrdo)	185	4 558	18 301	26.45
>50 MW (Large Hydro)	97	13 658	45 709	66.07
TOTAL	589	19 359	69 173	100

2.6.6 Types of Small Hydro Plants

Small hydropower plants are sometimes categorized on the basis of the type of grid it is connected to and the regulation of flow, if there is any, by the plant. Small hydropower plants can be connected to a central grid, to an isolated grid or can be connected to a dedicated power load such as a cement factory, lodges, mines etc.

Flow available in the river varies over time, from one season to another and from one year to the other. In run off river schemes and diversion SHPP schemes (Figure 2.3), there is no water storage and the natural flow available in the river is diverted to generate power. Hence, the power generation from a run off river scheme also varies with time and the firm capacity can be quite low. They are normally not suited for isolated grids or off grids unless the minimum power generated in the lowest flow season is sufficient to meet the peak demand.

When they are used to supply a grid, they can be used in conjunction with other power generators to meet the power demand at all times. During high flow season, small hydropower plant can generate more and other reservoir type or thermal generators generate less and vice versa. In some cases, a small pondage is used to store water so that the available flow even in the lowest season can be regulated over a daily period and more power can be generated during some peak demand hours of the day such as the morning and evening. At other times of the day when the demand is low, less power is generated and water is stored. These types of hydropower plants are used for daily hour demands.

When there is a reservoir used to store water, the power generation can be varied according to the load. Hence, the firm capacity is higher and more power can be generated when there is demand. Creating a reservoir to store water however requires damming the river. Dams create environmental problems as they can displace people living there, inundate fertile land or forests, and also change the flow regime impacting the aquatic life downstream. Therefore, unless there is a preexisting lake or dam that can be used, reservoir type small hydropower plants are less likely. Hydropower plants can also use what is known as pumped storage, where energy in off-peak periods can be used to pump water back to the reservoir and the pumped water can later be used to generate power during peak load hours. Again, given the requirements for a reservoir and pumping facilities, they are less likely for a small hydropower plants.

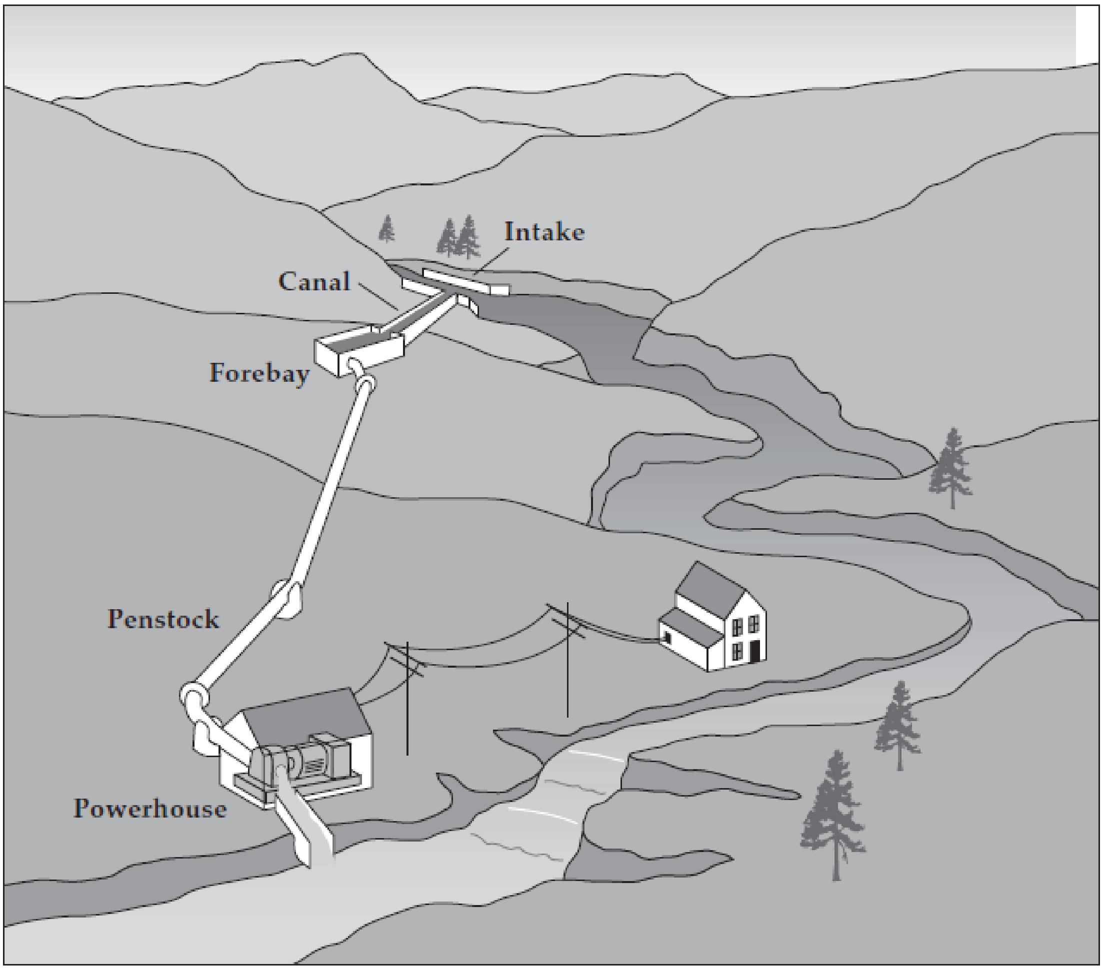

Figure 2.3 Typical layout of diversion small hydropower plant

2.6.7. Main Components of Small Hydropower Plants

The small hydropower plants have three main components. These are civil works, turbines and electromechanical and other equipments

Civil Works

The cost of civil works of a small hydropower plant accounts for about 50-60% of the total project cost. Large dams to store water will be expensive for small hydropower plants. Hence, a low dam or a simple diversion weir is mostly used in small hydropower plants. They divert water through the conveyance system (usually a headrace canal or pipe and sometimes tunnels) to the power house. Intake with the trash racks and gates are provided. Any excess water is discharged downstream over the weir. Fish ladders can also be provided for the fish to upstream. Sometimes the power house is located just below the intake and no water conveyance system is required. Valves and gates at the entrance and at the exit of turbines are used to shut down the system during maintenance.

The settling basins are used to excluding the sediment from entering the turbines. A forebay is also used upstream of the penstock to balance the fluctuations in the water levels during sudden operation and shutdown of the turbines. When a tunnel is used for water conveyance, a surge tank or shaft is used to avoid the impacts of sudden opening and sudden shutting down of power generation. Water from the power house is discharged back to the river through the tail race canal or tunnel.

The power house and other construction involved parts of SHPPs are also part of civil works.

Turbines

In small hydropower plants turbines require to perform well over a highly variable range of flows available. Multiple turbines are thus used so that they can optimally operate in a small range of flow in an optimum manner. Turbines used in small hydropower plants operate at an efficiency level of round 90%.

Turbines can be categorized into two groups: reaction turbines and impulse turbines. In a reaction turbine, the runner or spinning wheel is completely immersed in the flow and they use water pressure and kinetic energy of the flow. They are appropriate for low to medium head applications. On the other hand, in impulse turbines the high pressure flow passes through the nozzle that converts it into a jet of water at atmospheric pressure but high velocity and high kinetic energy. Thus it uses the kinetic energy of a high speed jet of water which exerts an impulsive force on the runner and causing it to spin. Examples of reaction turbines are Francis, fixed pitched propeller turbines and Kaplan and examples of impulse turbines are Pelton, Turgo and cross flow turbines. In order to select the most suitable turbine for a known design discharge and vertical head the chart given in Figure 2.4 is widely used in hydropower projects.

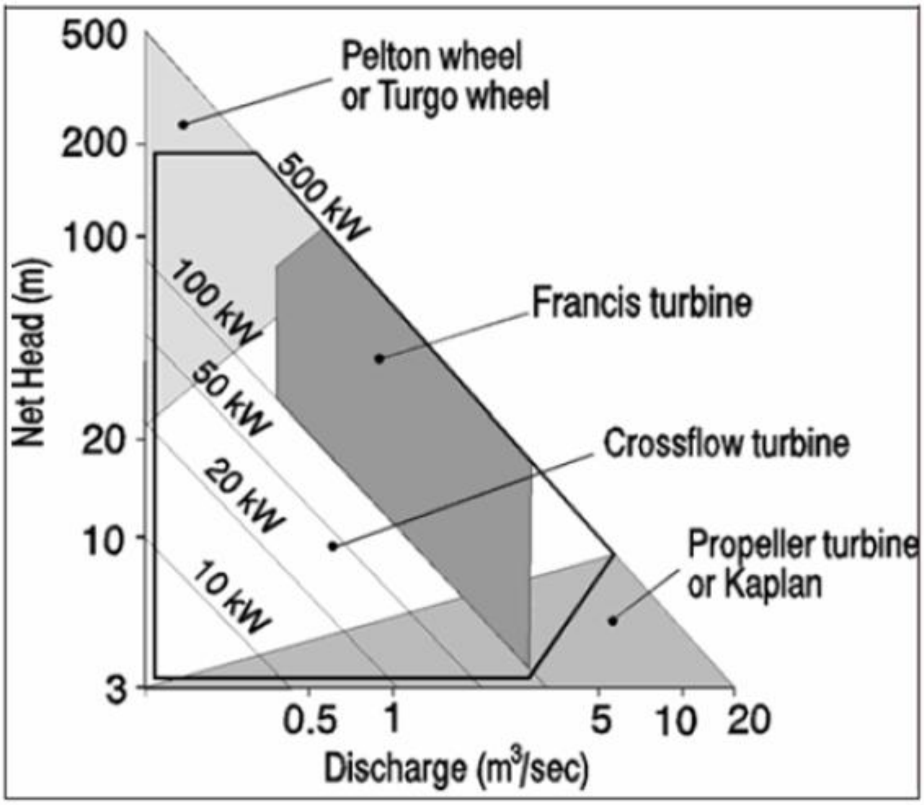

Figure 2.4 Head-Flow Range of Small Hydro Turbines (BHA, 2005)

Electromechanical and Other Equipment

The generator is main electrical component in a small hydropower plant. There are two types of generators: induction generators and synchronous generators. Induction generators are used to supply to large power grids whereas synchronous generators supply energy for stand-alone and isolated-grid applications.

Other electrical and mechanical equipments used in a small hydropower plant are speed increasers, water flow valves, electronic controls and protection devices and transformers. Speed increasers are used to match the rotational speed of the turbine to the speed of the generator, as dictated by the grid frequency. Valves, electronic controls and protection devices are used to protect the equipment from unexpected situations. Transformers are used to increase the voltage of electrical energy produced to reduce transmission losses.

2.6.8. Small Hydro Project Engineering Phases

There are normally four phases for engineering work required to develop a hydro project. However, for small hydropower plants, it is important to note that, the engineering work is generally reduced to three phases in order to decrease costs. Usually, a preliminary investigation is undertaken which combines the work involved in the first two phases explained below. The work, however, is completed to a lower level of detail in order to reduce costs. Reducing the engineering work increases the risk of the project not being financially viable. This can usually be justified due to the lower costs associated with smaller projects. Hydropower projects engineering phases are the reconnaissance survey and hydraulic studies, pre-feasibility studies, feasibility studies and system planning and project engineering (RETScreen, 2004-2, Yanmaz, 2006, Ağıralioğlu 2004)

Reconnaissance surveys and hydraulic studies

This first phase of work generally includes map studies; classification of the drainage basins; preliminary estimates of flow and floods; a short site visit; preliminary layout; cost estimates based on experience and a final ranking of alternatives based on optimization of power potential and initial expected cost (Ağıralioğlu 2004).

Pre-feasibility study

Work on the selected sites would include; site mapping and geological examinations; a reconnaissance for suitable borrow areas; a preliminary layout based on materials known to be available; preliminary selection of the main project characteristics such as installed capacity, type of development, etc.; a cost estimate based on major quantities; the identification of possible environmental impacts; and production of a report on each site (Ağıralioğlu 2004, Yanmaz 2006).

Feasibility study

Work would continue on the selected site with a major foundation investigation program, delineation and testing of all borrow areas; estimation of diversion, design and probable maximum floods, determination of power potential for a range of dam heights and installed capacities for project optimization, determination of the project design earthquake and the maximum credible earthquake, design of all structures in sufficient detail to obtain quantities for all items contributing more than about 10% to the cost of individual structures, determination of the dewatering sequence and project schedule; optimization of the project layout, water levels and components, production of a detailed cost estimate and finally, an economic and financial evaluation of the project including an assessment of the impact on the existing electrical grid along with a comprehensive feasibility report (Ağıralioğlu 2004, Yanmaz, 2006).

System planning and project engineering

This phase of the work would cover studies and final design of the transmission system, integration of the transmission system, integration of the project into the power network to determine precise operating mode, production of tender drawings and specifications, analysis of bids and detailed design of the project, production of detailed construction drawings and review of manufacturer’s equipment drawings. However, the scope of this phase would not include site supervision or project management, since this work would form part of the project application costs (Ağıralioğlu 2004, Yanmaz 2006).

CHAPTER III

METHODOLOGY

3.1. Feasibility Assessment Tools for Small Hydropower Development

Small-scale hydropower development is often seemed to be full of difficulties. Since, in most cases, it involves diversion of water from its natural course. Issues often arise with riparian owners, environment agencies, licensing authorities, fisheries, wildlife protection societies, planning departments, electrical utilities and the general public. The developer has to spend time and money in fixing arguments raised and in finding the optimum solutions to objections made. Regrettably, developers usually have small amount of resource and a prospective source of revenue that is insufficient to hire the necessary engineering and legislation expertise in presenting the case fairly.

In recent years, a number of computer based assessment tools have been developed. These tools address such problems and enable a prospective developer to make an initial assessment of the economic feasibility of a project, before spending substantial amount of money. These range from simple first estimates to quite sophisticated programs.

The objective of these software programs is to find a rapid and reasonably accurate means of predicting the energy output of a particular hydropower scheme. These predictions involve establishing the ‘head’ or vertical distance that water can be dropped from and the incidence in time and magnitude of the quantity of water to be used. The first of these is a relatively simple matter of physical measurement together with some hydraulic loss calculations concerning pipe materials and water velocities, etc. The second is much more difficult and it is this part of the problem that is most intractable. There are two main approaches, the flow duration curve

(FDC) and the simulated stream flow (SSF) methods. Both methods are used in the programs described in this review.

In the FDC method, catchment characteristics such as area, monthly or annual rainfall, evaporation and soil type, are collected. These parameters are then used through a water balance to estimate the mean flow of the catchment and to select a typical FDC for the catchment from a range of dimensionless FDCs. This selection is based on a comparison of certain standardized hydrological statistics. A synthesized FDC is drawn, residual flow superimposed and a value of rated discharge selected. Then the type of turbine is selected in order to calculate the annual energy output.

The SSF approach uses recorded discharge data or a simulated runoff record synthesized by time-series analysis using weather data and topography if recorded discharge data is missing. Based on this continuous discharge record the energy output may be calculated daily or hourly if required.

3.1.1. Integrated Method for Power Analysis (IMP)

IMP is a set of software for evaluating small scale hydropower projects and some other hydrological applications. It is useful to non-specialists exploring possibilities for small hydropower development and to consulting engineers who require preliminary estimates of flood frequency and energy potential. With the relevant meteorological and topographical data in hand an experienced user can evaluate an ungauged hydro site including a power study, powerhouse and penstock optimization, fish habitat analysis and development of a flood frequency curve within one day. The program is particularly designed for and applicable to Canada.

Recorded stream flow data is not essential for IMP, since if uses topographic and daily weather data as input in order to perform flood frequency analysis and to synthesize hourly and daily stream flow and reservoir operations. This data may be obtained from databases imbedded within the program for many sites in North America or could be input directly input by the user. The program contains modules in which proposed power projects are optimized based on the value of energy and the cost of construction.

3.1.2 The Prophete

Another method for the evaluation of small hydropower potential is prophete which is developed for France. Assessing flows are done by two methods; a comparison with neighboring watercourses in the database as a function of catchment area, an automatic calculation of the flows from a hydrologic model based on basin rainfall and predetermined averaged parameters derived from available detailed studies. After the estimation of a series of monthly flows by one of these two methods the database allows the user to simulate automatically a small hydropower station using a prescribed head and the turbine characteristics.

3.1.3 Peach

This is a sophisticated program designed to take the developer through all the necessary procedures in designing, building and commissioning a small hydropower scheme and analyzing the financial returns which may be expected. To do this the user is led through six distinct steps these are site data definition, project creation, project design, plant design, economic and financial analysis, report.

3.1.4 HydrA

HydrA has been aimed at hydropower consultants, electricity utilities, environmental agencies and investors. It incorporates regional flow estimation models, which allow a synthetic flow duration curve (FDC) to be derived at any site in the eight European countries, and methods for determining hydropower potential from the FDC. The regional models are derived from a multi-variate regression analysis of long-term river flow data and key catchment characteristics, as described in International Energy Agency (IEA, 2000). The software is also able to calculate the hydropower potential of sites where gauged river flow data is available.

HydrA comprises four main modules; these are Catchment Characteristics Module, Flow Regime Estimation Module, Turbine Selection Module, and Power Potential Module

The final output from the HydrA software is a single sheet report giving estimates of gross and net annual average energy output (MWh), maximum power output (kW) and rated capacity (kW) for each of the selected turbines. By comparing the performance of each turbine the user is able to make an informed decision on which turbine is appropriate for the site. The output can be written to a file and, if necessary, used in other software for economic assessment. The software is not particularly user-friendly. The various modules do not follow each other without prompting.

3.1.5. RETScreen

The RETScreen (Renewable Energy Technology Screening Software) is a renewable energy analysis tool provided by Natural Resources, Canada. RETScreen is noted to be the most sophisticated tool developed so far for analyzing renewable energy resources. The detailed analysis of the software is given in the sections 3.2.

3.2. The RETScreen Clean Energy Project Analysis Software

3.2.1 General

RETScreen is a Microsoft Excel based analysis tool capable of assessing the feasibility of clean energy projects including, small hydropower plant project from both physical and financial perspectives.

Executing renewable energy and investing in energy efficiency projects can be achieved by developing decision-making software that decrease the duration and cost of pre-feasibility studies. These kinds of tools will help professionals make faster decisions and exercise better analysis of possible projects from the technical and financial viability point of view.

The RETScreen small hydro project model provides the means to assess the available energy at a potential small hydropower plant site that could be provided to a central-grid or isolated grid. The model addresses both run-of-river and reservoir hydropower developments and it incorporates sophisticated formulae for calculating efficiencies of a wide variety of hydropower turbines.

The small hydropower model can be employed to evaluate small hydropower projects typically classified under the following three names:

- Small hydro
- Mini hydro
- Micro hydro

This classification can be expressed in two ways; the first one is manual input by the user and the second one is selection by the model. If the selection is done by the model, the classification is related with the design flow of the project and the runner diameter of the turbine. RETScreen classification of small hydropower plants is given in Table 3.1.

Table 3.1 RETSCreen's project classification

Project classification	**Small**	**Mini**	**Micro**
Design flow (m^3/s)	>12.8	0.4-12.8	<0.4
Turbine runner diameter (m)	>0.8	0.3-0.8	<0.3

The model has been developed primarily to determine whether work on the small hydropower projects should proceed further or be dropped in favour of other alternatives. Each hydro site is unique, since about 75% of the development cost is determined by the location and the site conditions. Only about 25% of the cost is relatively fixed, being the cost of manufacturing the electromechanical equipment.

The model is composed of seven worksheets modules namely; Energy Model, Hydrology Analysis and Load Calculation, Equipment Data, Cost Analysis, Greenhouse Gas Emission Reduction Analysis, Financial Summary, Sensitivity and Risk Analysis.

Firstly, the energy model, hydrology & load and equipment data worksheets are completed. The cost analysis worksheet should then be completed, followed by the Financial Summary worksheet. The GHG Analysis and Sensitivity worksheets are optional analyses. The GHG Analysis worksheet is provided to help the user estimate the greenhouse gas (GHG) mitigation potential of the proposed project. The Sensitivity worksheet is provided to help the user estimate the sensitivity of important financial indicators in relation to key technical and financial parameters. In general, the user works from top to down for each of the worksheets. This process can be repeated several times in order to help optimize the design of the project from an energy use and cost standpoint.

The RETScreen has two different methods for estimating small hydropower project cost; these are “Formula” and the “Detailed” costing methods. All of the hydropower cost equations used in the “Formula” costing method is empirical, based on data collected over 20 years for both large and small hydropower plants. The “Formula” costing method will provide a baseline or minimum cost estimate for a proposed project, if used correctly.

The detailed costing method lets the user to asses costs based on calculated quantities and unit cost. In this method the size and the layout of the structures to be build need to be determined by the user. The first method was employed in this study. Since the second method leaves every measurement and calculation to the user to tackle.

3.2.2 Hydrological Data

The flow conditions in the river being studied over the course of an average year are represented in the form of a flow duration curve. At the run off river projects, the required flow-duration curve data can be entered either manually or by using the specific run off method and data contained in the RETScreen online weather database. The model then calculates the firm flow that will be available for electricity production based on the flow-duration curve.

Flow-duration curve

A flow-duration curve is a graph of the historical flow at a site ordered from maximum to minimum flow. It is used to assess the availability of flow over time and thus the power and the energy at a site. The flow-duration curve is specified by twenty-one values Q_0, Q_5…, Q_{100} representing the flows on the flow-duration curve in 5% increments. In other words, Q_n represents the flow that is equaled or exceeded n% of the time. An example of a flow-duration curve is illustrated in Figure 3.1.

Residual flow

Residual flow (Q_r) is the flow that must be left in the river throughout the year for environmental reasons. It is specified by the user and subtracted from all values of the flow-duration curve for the calculation of plant installed capacity, firm capacity and renewable energy available.

Firm flow

The firm flow is the flow being available p% of the time, where p is a percentage specified by the user and usually chosen to be between 90% and 100%. The firm flow is calculated from the available flow-duration curve.

Design flow

The design flow is the maximum flow that can be used by the turbines. The selection of design flow depends on the available flow at the site. For run off river projects, which are connected to a large grid, the optimum design flow is usually close to the flow that is equaled or exceeded about 30% (Q_{30}) of the time.

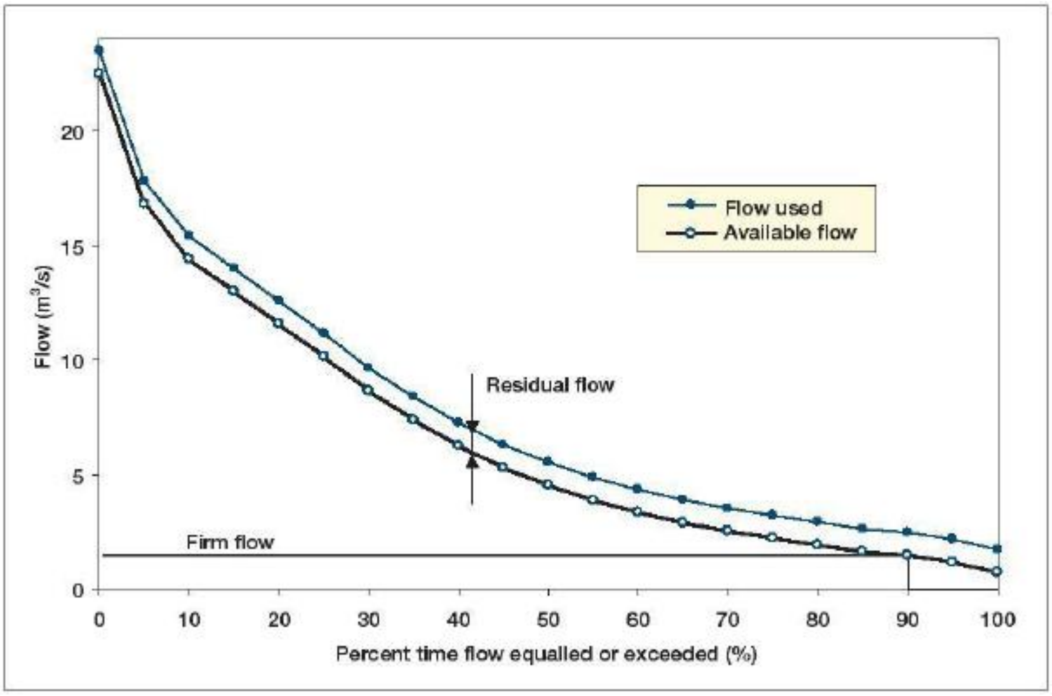

Figure 3.1 An example of flow duration curve.

3.2.3 Load data

The load depends on the type of grid considered. If the small hydropower plant is connected to a central-grid then it is assumed that the grid demands all of the energy production. If on the other hand the system is off-grid or connected to an isolated-grid then the portion of the energy that can be delivered depends on the load. Calculations for off-grid and isolated-grid systems were not taken into account in the present study.

3.2.4 Energy Production

The RETScreen calculates the estimated renewable energy delivered in MWh based on the adjusted flow-duration curve, the design flow, the residual flow, the load (in case of isolated grid), the gross head and the efficiency of the system.

Turbine efficiency curve

Turbine efficiency data can be entered manually or can be calculated by the RETScreen. Standard turbine efficiency curves have been developed and imbedded in the RETScreen for Kaplan, Francis, Propeller, Pelton, Turgo and Crossflow turbine types. The type of turbine is entered by the user based on its suitability to the available head and flow conditions. The turbine efficiency curve calculation is based on net head, runner diameter, turbine specific speed and the turbine design coefficient. The efficiency equations were derived from a large number of obtained from manufactures efficiency curves for different turbine types and head and flow conditions. For multiple turbine applications it is assumed that all turbines are identical and that a single turbine will be used up to its maximum flow and then flow will be divided equally to the number of turbines. Therefore, unidentical turbines used in the small hydropower projects are assumed to be identical by the model. The turbine efficiency equations and the number of turbines are used to calculate plant turbine efficiency from 0% to 100% of design flow at 5% intervals. An example of turbine efficiency curve for 1 and 2 turbines where the gross head and the design flow are 146 m and 1.90 m^3/s, respectively, is shown in Figure 3.2.

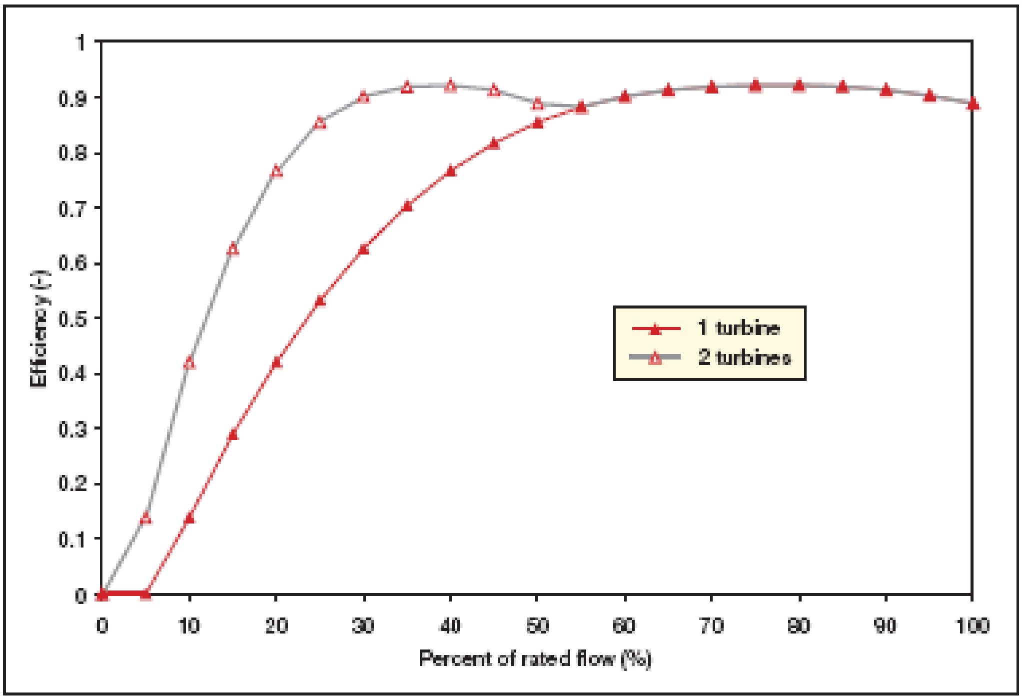

Figure 3.2 One and two turbines efficiency curve

Power available as a function of flow

Actual power P available from the small hydropower plant for any given flow value Q is expressed in Equation 3.1, in which the flow-dependent hydraulic losses and tailrace reduction are taken into account:

$$P = \rho g Q(H_g - (h_{hydr}+h_{tail}))e_t e_g(1-I_{trans})(1-I_{para}) \quad (3.1)$$

where h_{hydr} and h_{tail} are respectively the hydraulic losses and tailrace effect associated with the flow; e_t is the turbine efficiency at flow Q, e_g is the generator efficiency, l_{trans} is the transformer losses, and l_{para} is the parasitic electricity losses. Hydraulic losses are adjusted over the range of available flows based on the following relationship:

$$h_{hydr} = H_g l_{hydr,max} \frac{Q^2}{Q_d^2} \quad (3.2)$$

where $l_{hydr,max}$ is the maximum hydraulic losses specified by the user, and Q_d is the design flow. The maximum tailrace effect is adjusted over the range of available flows with the following relationship:

$$h_{tail} = h_{tail,max} \frac{(Q-Q_{des})^2}{(Q_{max}-Q_{des})^2} \quad (3.3)$$

where $h_{tail,max}$ is the maximum tailwater effect which is the maximum reduction in available gross head that will occur during the times of high flows in the river. Q_{max} is the maximum river flow and Equation 3.3 is applied only to river flows that are greater than the plant design flow (when $Q>Q_{des}$).

Plant capacity

Plant capacity P_{des} is calculated by re-writing Equation 3.1 at the design flow Q_{des};

$$P_{des}=\rho \dot{g} Q_{des} H_g(1-h_{hydr})e_{t,des}e_g(1-l_{trans})(1-l_{para}) \quad (3.4)$$

where P_{des} is the plant capacity and $e_{t,des}$ the turbine efficiency at design flow, calculated from the turbine efficiency curve. The small hydroplant firm capacity is calculated again using Equation 3.4, however this time using the firm flow and corresponding turbine efficiency and hydraulic losses at this flow.

Power-duration curve

Calculation of power available as a function of flow using Equation 3.4 for all 21 values of the available flows Q'_0, Q'_5,…,Q'_{100} used to define the flow-duration curve, leads to 21 values of available power P_0 P_5 ,…, P_{100} defining a power-duration curve. Since the design flow is defined as the maximum flow that can be used by the turbine, the flow values used in Equations 3.1 and 3.2 are actually $Q_{n,used}$ defined as :

$$Q_{n,used} = \min(Q'_0, Q_{des}) \qquad (3.5)$$

An example of power-duration curve is shown in Figure 3.3, with a design flow the to 3 m^3/s.

Renewable energy available

Renewable energy available is the area under the power-duration curve assuming a straight-line between adjacent calculated power output values. Given that the flow-duration curve represents an annual cycle, each 5% interval on the curve is equivalent to 5% of 8 760 hours (number of hours per year). The annual available energy E_{avail} (in kWh/yr) is calculated from the values P (in kW) by:

$$E_{avail} = \sum_{k=1}^{20} \left(\frac{P_{5(k-1)}+P_{5k}}{2}\right) 438(l - l_{dt}) \qquad (3.6)$$

where l_{dt} is the annual downtime losses).

Renewable energy delivered

Equation 3.6 defines the amount of renewable energy available. The amount of energy actually delivered depends on the type of grid. For central-grid applications, it is assumed that the grid is able to absorb all the energy produced by the small hydropower plant. Therefore, all the renewable energy available will be delivered to the central-grid and the renewable energy delivered, E_{dlvd} , is simply:

$$E_{dlyd} = E_{avail} \qquad (3.7)$$

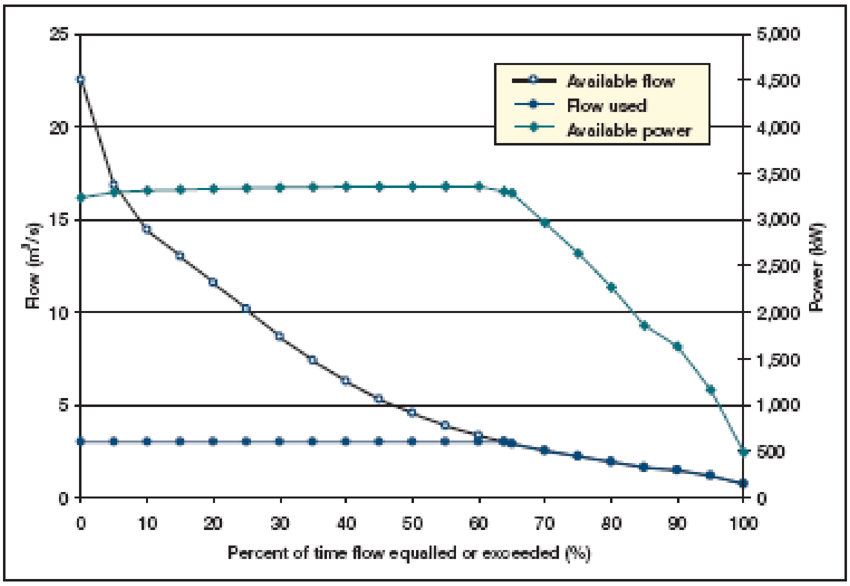

Figure 3.3 An example of power-duration curve

3.2.5 Project Costing

The Model has two methods for project costing; the detailed costing method and the formula costing method. The costing method is selected from the drop-down list in the beginning of Cost Analysis worksheet. The formula costing method was employed in this study. The formula costing method is based on empirical formulae that have been developed to relate project costs to key project parameters. After selecting formula costing method for calculation of project costs, project country should be entered. The formula method uses Canadian projects as a baseline and then allows the user to adjust the results for local conditions. The cost of projects outside Canada compared to the cost of projects in Canada will depend, to a great extent, on the relative cost of equipment, fuel, labour and equipment manufacturing and the currency of the country. For projects outside Canada, costs are adjusted based on the relative costs of these items and the exchange rate. The ratio of the costs of fuel and labour between Turkey and Canada for the year 2009 and currency notes are tabulated in Table 3.2.

Canadian average diesel fuel cost was 0.63 €/liter and Turkish average diesel fuel cost was 1.20 €/liter in 2009. Therefore Turkish versus Canadian fuel costs ratio is calculated as 1.91. Turkish versus Canadian labour costs ratio in January 2009 was calculated to be 0.31, since Canadian minimum labour wage was 7.89 Cad/hour, Turkish minimum labour wage was 3.3TL/hour (tuik.gov.tr 2009).

Table 3.2 Turkish versus Canadian cost ratio

	Cost of fuel (€/L)	**Cost of labour (TL/hour)**	**Currency exchange (TL)**
Turkey	1.20	3,30	1
Canada	0.63	10.65	1.35
TR vs Cad	1.91	0,31	0.74

Turkish versus Canadian equipment and equipment manufacture costs ratio assumed as unity. Since the manufacturing sector for hydropower does not exist in Turkey and significant percentage of the equipment needed is generally imported. The average exchange rate between TL and CAD for the year 2009 was found to be 0.74 (Bank of Canada, 2009). The selection of project classification is an important parameter for the correct evaluation of project costing because of the costs of certain components, particularly the civil works, are affected by this selection. This is due to larger projects requiring more conservative designs with higher associated risks. The variables used in the formula costing method the input data of formulae and the items calculated by the formulae are listed in Tables 3.3, 3.4 and 3.5, respectively.

Table 3.5 shows 15 categorized formulae, which are used in the RETScreen to estimate the initial cost of a small hydropower project. The items and formula were listed in Table 3.5 according to the categorization of the project.

Table 3.3 Variables used in Formula Costing Method

VARIABLES LİSTED ALPHABETICALLY					
A	Access road difficulty factor	**J_t**	Higher cost vertical axis turbine factor	**n_p**	Number of penstocks
B	Foreign costs civil works factor	**k**	Allowable tunnel headloss(ratio to H_g)	**P**	Transmission line wood pole. Steel tower factor
C	Civil cost factor	**K**	User defined equipment manufacture cost coefficient too account for country of manufacture	**Q**	Flow under consideration (m^3/s)
C_g	Lower cost generator factor	**K_t**	Lower cost small horizontal axis turbine factor	**Q_d**	Design flow (m^3/s)
C_v	Tunnel volume of concrete lining (m^3)	**l_a**	Access road length (km)	**Q_u**	Flow per unit (m^3/s)
d	Runner diameter (m)	**l_b**	Distance to borrow pits (km)	**R**	Rock factor
D	Transmission line difficulty factor	**L_c**	Ratio of the cost of local labour costs compared to canadian cost expressed as a decimal	**R_v**	Tunnel volume of rock excavation (m^3)
d_p	Diameter of penstock (m)	**l_{cr}**	Canal length in rock (m)	**S_r**	Side slope of rock terrain (degrees)
E	Engineering cost factor	**l_{cs}**	Canal length in impervious soil (m)	**S_s**	Side slope of soil terrain (degrees)
E_c	Ratio of the cost of local construction equipment costs compared to Canadian costs expressed as decimal	**l_d**	Dam crest length (m)	**T**	Tote road factor
f	Frost day at site	**l_p**	Penstock length (m)	**t_{ave}**	Average penstock thickness (mm)
F	Frost days factor	**l_T**	Transmission line length (km)	**t_b**	Penstock thickness at turbine
F_c	Ratio of cost of local fuel costs compared to Canadian costs expressed as a decimal	**l_t**	Tunnel length (m)	**T_c**	Tunnel lining length ratio
G	Grid connected factor	**MW**	Total capacity (MW)	**t_t**	Penstock thickness at intake
H_g	Gross head (m)	**MW_u**	Capacity per unit (MW)	**V**	Transmission line voltage (kV)
i	Interest rate (%)	**n**	Number of turbines	**W**	Penstock weight (steel) (kg)

Table 3.4 Basic Parameters for Input Data Formula

ITEM	SMALL	MINI	MICRO
Q_d	User-defined value		
Classification	$Q_d > 12.8$	$12.8 \geq Q_d \geq 0.4$	$Q_d \leq 0.4$
n	User-defined value		1
Q_u	$= Q_d/n$		1
d	$=0.428\ Q_u^{0.45}$		
H_g	User-defined value		
MW_u	$=8.22\ Q_u H_g/1000$	$=7.79\ Q_u H_g/1000$	$=7.53 Q_u H_g/1000$
MW	$=MW_u n$		$=MW_u$
E	=0.67 if existing dam, =1.0 if no dam, by yes/no selection		
C_g	$=0.75$ if $MW < 10$, $=1.0$ if $MW \geq 10$		
T	=0.25 if tote road, =1.0 otherwise, by yes/no selection		
A	User-defined factor with recommended range of 1 to 6		
l_a	User-defined value		
D	User-defined factor with recommended range of 1 to 2		
l_t	User-defined value		
V	User defined value		
P	$=0.85$ if $V< 69$, $=1.0$ if $V \geq 69$		
C	=0.44 if existing dam, =1.0 if no dam		
R	= if rack at dam site = 1.05 if no dam		N/A
l_b	User-defined value		
l_d	User-defined value		
n_p	User defined value		
l_p	User defined value		
d_p	$(Q_d/n_p)^{0.43}/H_g^{0.14}$		
W	$24.7 d_p l_p t_{ave}$		
t_{ave}	$0.5(t_t+t_b)$ if $t_b>t_t$, t_t if $t_b<t_t$		
t_t	$d_p^{1.3}+6$		
t_b	$0.0375 d_p H_g$		
S_s	User-defined value		

Table 3.4 Basic Parameters for Input Data Formula (Continued)

ITEM	SMALL	MINI	MICRO
S_r	User-defined value		
l_{cs}	User-defined value		
l_{cr}	User-defined value		
R_v	$0.185 l_t^{1.375}(Q_d^2/(k*H_g))^{0.375}$		N/A
C_v	$0.306 R_v T_c$		N/A
l_t	User-defined value		N/A
k	User-defined value		N/A
T_c	User defined value with recommended range of 15% (excellent rock) to 100% (poor rack)		N/A
i	User-defined value		
f	User-defined value		
F	$= \frac{110}{(365-f)^{0.9}}$		
E_c	User-defined value		
F_c	User-defined value		
L_c	User-defined value		
B	$= 0.3333E_c + 0.3333F_c \text{ x} \frac{1}{(\frac{E_c}{L_c})^{0.5}} + 0.3333(\frac{E_c}{L_c})^{0.5} \text{x} L_c$		
K	User-defined value with recommended range of 0.5 to 1.0		

Table 3.5 Basic Costing Formulae

ITEM	SMALL	MINI	MICRO
Feasibility study (Eq.1)	$= 0.032 \quad \text{Eq. 2 to(Eq. 15)}$		$= 0.032 \quad \text{Eq. 2 to(Eq. 15)}$
Development (Eq.2)	$= 0.04 \quad \text{Eq. 3 to(Eq. 14)}$		
Engineering (Eq.3)	$= 0.37\mathrm{n}^{0.1}\mathrm{E}(\frac{\mathrm{MW}}{\mathrm{H}_\mathrm{g}^{0.3}})^{0.54}\mathrm{x}10^6$		$= 0.04(\frac{MW}{H_g^{0.3}})^{0.54}x10^6$
Energy equipment (Eq.4)	Generator and Control $= 0.82n^{0.96}GC_g(\frac{MW}{H_g^{0.28}})^{0.9}x10^6$		
	Kaplan turbine and governor $= 0.27n^{0.96}J_tK_td^{1.47}\ 1.17H_g^{0.12} + 2\ x10^6$		
	Francis turbine and governor $= 0.17n^{0.96}J_tK_td^{1.47}\ 1.17H_g^{0.12} + 2\ x10^6$		
	Propeller turbine and governor $= 0.125n^{0.96}J_tK_td^{1.47}\ 1.17H_g^{0.12} + 4\ x10^6$		
	Pelton/Turgo turbine and governor $= 3.47n^{0.96}(\frac{MW_u}{H_g^{0.5}})^{0.44}x10^6\ where\ \frac{MW_u}{H_g^{0.5}} > 0.4$ $= 5.34n^{0.96}(\frac{MW_u}{H_g^{0.5}})^{0.91}x10^6\ where\ \frac{MW_u}{H_g^{0.5}} \leq 0.4$		
	Cross flow turbine and governor Cost of Pelton/Turgo x0.5		
Installation of energy equipment (Eq.5)	=0.15 (Eq.4)		
Access road (Eq.6)	$= 0.025\mathrm{TxA}^2\ \mathrm{xl}_a^{0.9}\mathrm{x}10^6$		
Transmission line (Eq.7)	$=0.0011\mathrm{DxPxl}_t^{0.95}\mathrm{xVx}10^6$		
Substation, and transformer (Eq.8)	$= (0.0025n^{0.95} + 0.002\ n + 1\ x\frac{MW}{0.95}^{0.9}\ xV^{0.3}x10^6)$		
Installation of substation and transformer (Eq.9)	=0.15(Eq.8)		

Table 3.5 Basic Costing Formulae (Continued)

ITEM	SMALL	MINI	MICRO
Civil works (Eq.10)	$= 3.54n^{-0.04}CRx \ {\frac{MW}{H_g^{0.3}}}^{0.82} \ x \ 1 + 0.01l_b \ x \ 1 + 0.005\frac{l_d}{H_g} \ x10^6$	$= 1.97n^{-0.04}CRx \ {\frac{MW}{H_g^{0.3}}}^{0.82} \ x \ 1 + 0.01l_b \ x \ 1 + 0.005\frac{l_d}{H_g} \ x10^6$	$= 1.97n^{-0.04}Cx \ {\frac{MW}{H_g^{0.3}}}^{0.82} \ x \ 1 + 0.01l_b \ x \ 1 + 0.005\frac{l_d}{H_g} \ x10^6$
Penstock (Eq.11)	$=20 \ n_p^{0.95} W^{0.88}$, where: $W=(24.7d_p l_p t_{ave})$, where: $d_p = \frac{(\frac{Q_d}{H_g})^{0.43}}{H_g^{0.14}}$ $t_t=d_p^{1.3}+6$ $t_b=0.0375d_p H_g$ $t_{ave}=0.5(t_t+t_b)$ if $t_b \geq t_t$ $t_{ave}=t_t$ if $t_b<t_t$		
Installation of penstock (Eq.12)	$=5xW^{0.88}$		
Canal (Eq.13)	$=20x[(1.5+0.01S_s^{1.5})Q_d l_{cs}]^{0.9}$ (for soil conditions) $=20x[(1.5+0.01S_r^{2})Q_d l_{cs}]^{0.9}$ (for rock conditions)		
Tunnel (Eq.14)	$=400 \ R_v^{0.88}+4000 \ C_v^{0.88}$ Where : $R_v=0.185l_t^{1.375}(Q_d^2/kH_g)^{0.375}$ $C_v=0.306 \ R_v \ T_c$		N/A
Miscellaneous (Eq.15)	$=0.25Q_d^{0.35}$x1.1∑(Eq.2) to (Eq.14)+0.1∑(Eq.2) to(Eq.14)		0.17i x 1.1∑(Eq.2) to (Eq.14)+0.1∑(Eq.2) to (Eq.14)
Initial Costs –Total (Formula Method)	=∑ (Eq.1) to (Eq.15)		

3.2.6 Project Financing

RETScreen provides a financial analysis feature which allows the user to see pre-tax, after-tax and cumulative cash flows over the project life. This feature helps the developer to consider various financial parameters with relative ease with its financial input parameters and feasibility output items.

There are six sections in the Financial Analysis worksheet; Project Costs and Savings, Annual Energy Balance, Financial Parameters, Financial Feasibility, Yearly Cash Flows and Cumulative Cash Flow Graph. The Annual Energy Balance and the Project Costs and Savings sections supply a summary of the Energy Model, Cost Analysis and GHG Analysis worksheets associated with each project studied. In addition to this summary information, the Financial Feasibility section supplies financial indicators of the project analyzed based on the data entered by the user in the Financial Parameters section. The Yearly Cash Flows part allows the user to visualize the stream of pre-tax, after-tax and cumulative cash flows over the project life.

3.2.7 Cell Color Coding

In RETScreen software data are entered into "shaded" worksheet cells. All other cells that do not require input data are protected to prevent the user from mistakenly deleting a formula or reference cell and the software reports error if the user does so. The RETScreen cell color coding chart for input and output cells is presented below in Table 3.5

Table 3.6 RETScreen software color coding system

Input and Output Cells	
White	Model Output – calculated by the model
Yellow	User input – required to run the model
Blue	User input – required to run the model’s online databases if necessary
Grey	User input – for reference purposes only

CHAPTER IV

SMALL HYDROPOWER PLANT FEASIBILITY STUDIES

4.1 General

In this chapter, the feasibility studies endorsed by DSI (State's water works) for Gökgedik, Torlar, Kale and Damlasu SHPPs are compared with the feasibility works performed by employing the RETScreen. In order to comprehend the way the RETScreen performs the feasibility study for Kale small hydropower plant was re-assessed step by step.

4.2. Description of Kale SHPP Project

KALE small hydropower plant is located on Körsulu River at the countryside of Andırın, Kahramanmaraş, Turkey. The project summary information and the location which are demonstrated in Table 4.1 and Figures 4.1, 4.2, 4.3 were obtained from the feasibility report endorsed by DSI. The cost estimation presented in Table 4.2 has been approved by DSI as well.

Table 4.1 Kale SHPP project information

No	Introduction	
1	Project Name	KALE HES
2	1/25.000 Maps Name	Gaziantep M36-c3
3	Regulatör 6^0 Coordinates	567 742.77 ~4 167 748.11
4	Plant 6^0 coordinates	546 638.43~4 167 627.36
5	City	Gaziantep M36-c3
6	Township	Andırın
7	River basin	20- Ceyhan Basin
8	DSI territory	XX
9	River Name	Körsulu Çayı
10	Used AGI No	20-36
11	Drainage area (km^2)	334.20
12	Design Flow (m^3/sn)	16
13	Gross Head (m)	257.20
14	Net Gross Head (m)	252
15	Number of Turbines	3
16	Turbine Type	Pelton
17	Facility Type	Small
18	Dam Crest Lenght (m)	30
19	Maksimum Hydraulic Loses (m)	5,2
20	Tunnel (m)	4203
21	Penstcok Lenght (m)	478.52
22	Diameter (m)	1,10
23	Transmision Line Lenght(km)	11
24	Hydroplant Voltage (kV)	33
25	Residual flow (m^3/s)	0.1
26	Initial Power (MW)	35.33

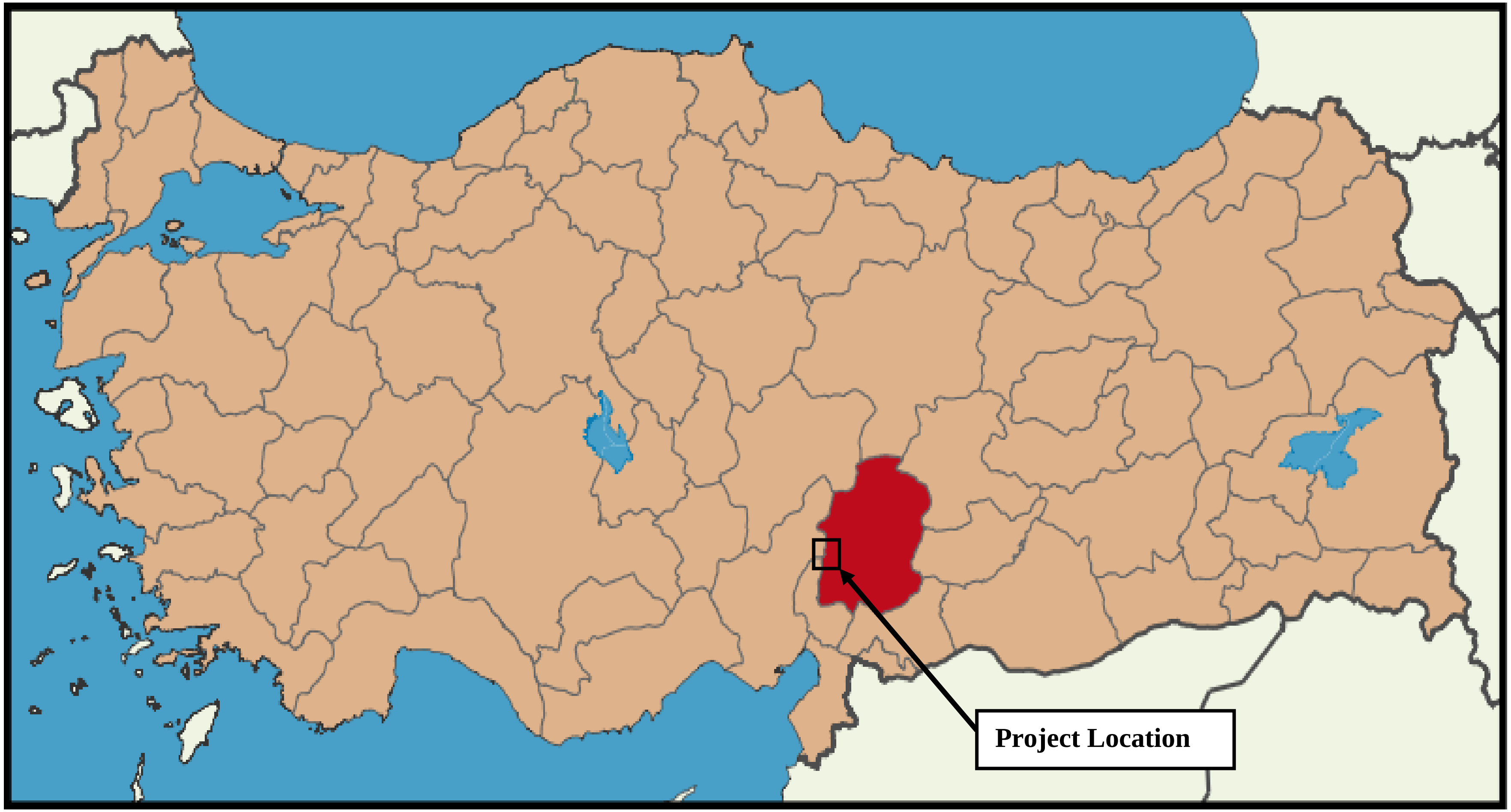

Figure 4.1 General location of Kale SHPP

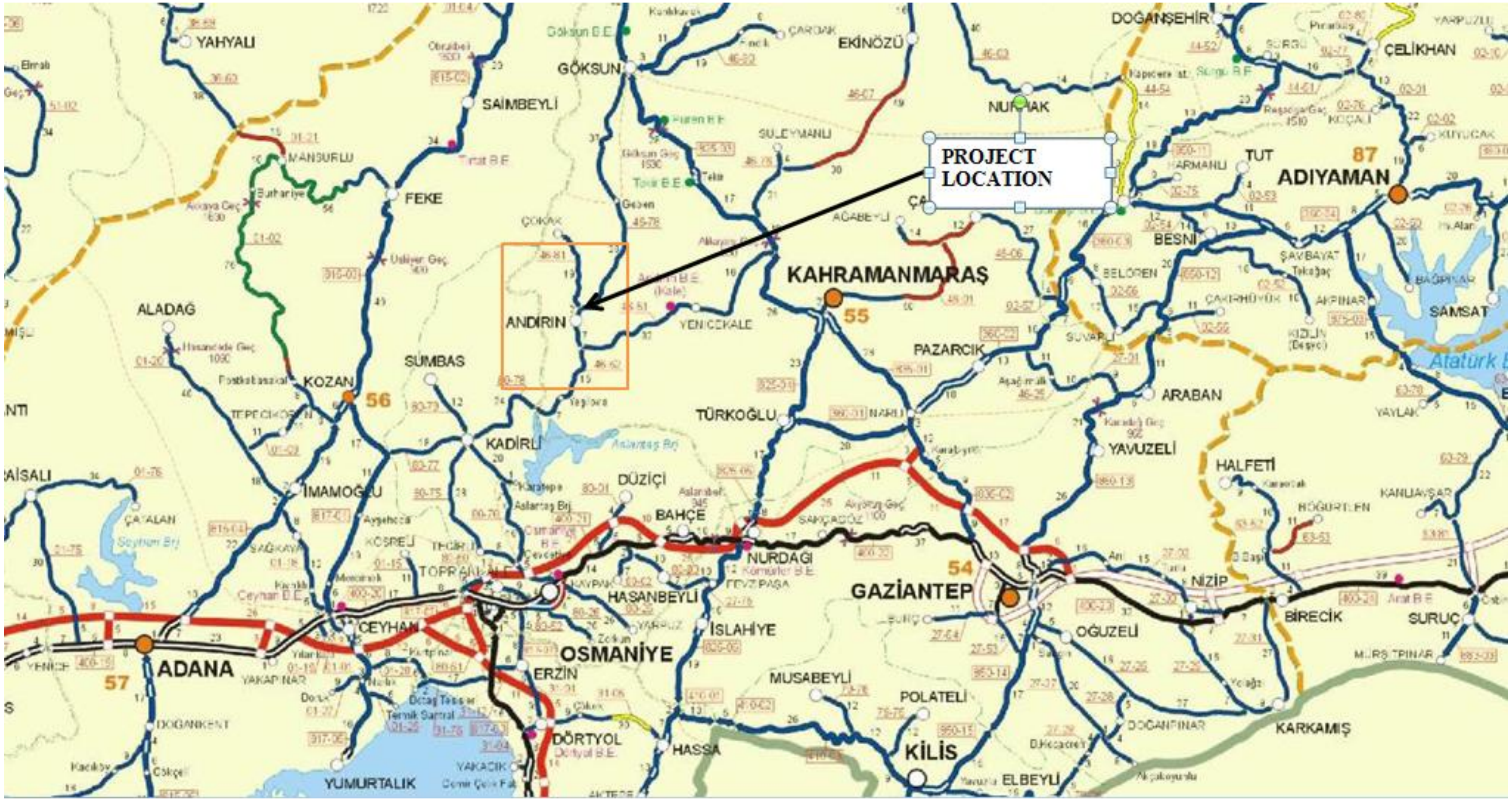

Figure 4.2 Detailed location of Kale SHPP

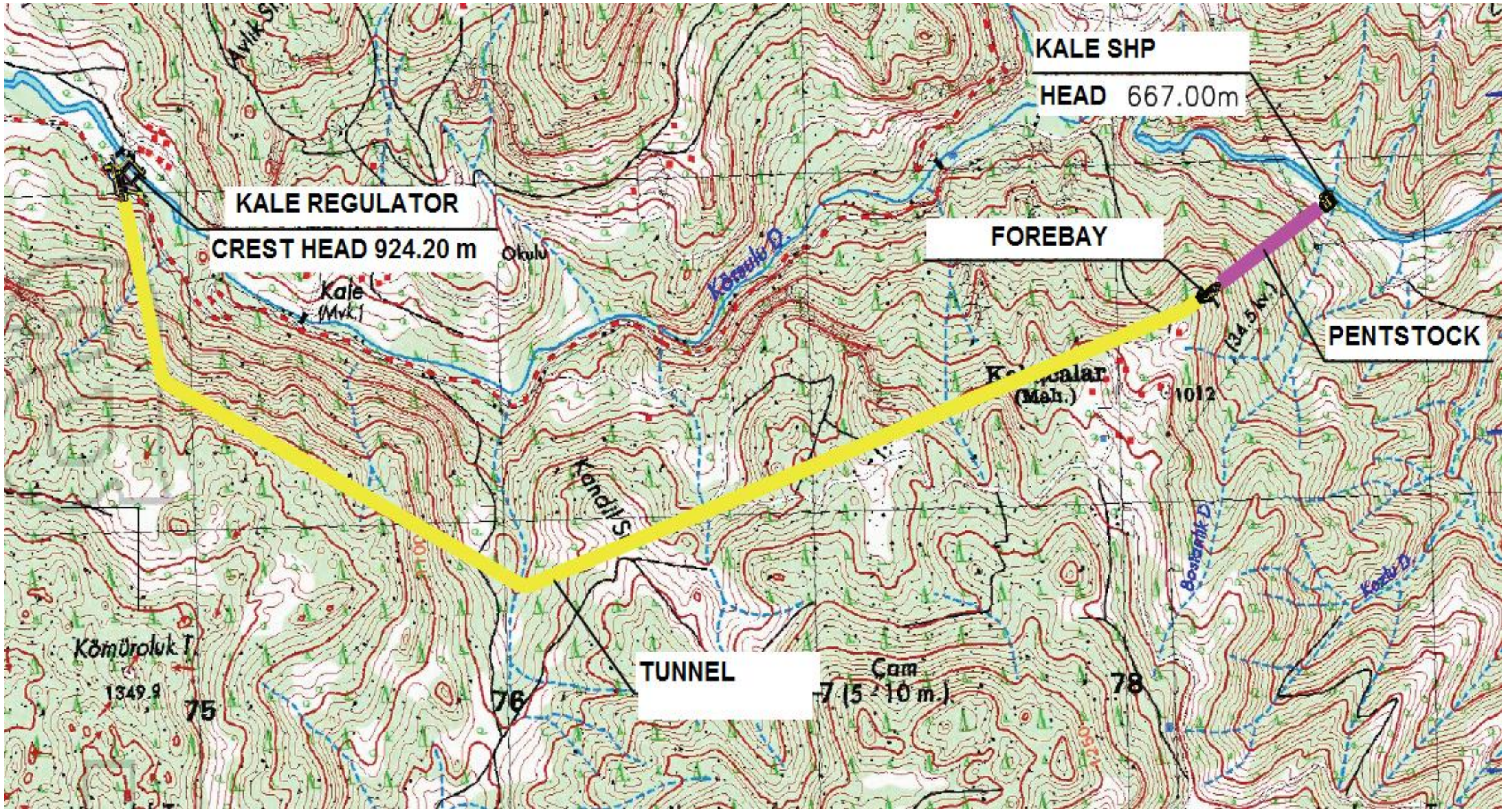

Figure 4.3 General plan of Kale SHPP project

Table 4.2 Cost estimation of Kale SHPP (From the feasibility report approved by DSI)

No	Cost ITEM	COST	
		TL	**US($)**
1	Settling Basin	200.000,00 TL	$145.985,40
2	Access Road	250.000,00 TL	$182.481,75
3	Regulator	8.382.974,50 TL	$6.118.959,49
4	Transmision Tunnel	15.763.583,40 TL	$11.506.265,26
5	Forebay	4.979.241,26 TL	$3.634.482,67
6	Powerhouse	4.842.016,60 TL	$3.534.318,69
7	Penstcok	8.336.650,00 TL	$6.085.145,99
Construction Works Subtotal		42.754.465,76 TL	$31.207.639,24
8	Turbine and Generators	9.654.269,10 TL	$7.046.911,75
9	Other Equipment	7.898.947,50 TL	$5.765.655,11
10	Transformer	100.000,00 TL	$72.992,70
11	Transmision Line	582.250,00 TL	$425.000,00
Energy Equipment Subtotal		18.235.466,60 TL	$13.310.559,56
12	Miscellaneus %10	6.413.169,90 TL	$4.681.145,91
Plant Subtotal		67.403.102,26 TL	$49.199.344,72
13	Feasibility+Engineering+Development	1.113.099,10 TL	$812.481,09
TOTAL PROJECT COST		**68.516.201,36 TL**	**$50.011.825,81**

4.3. Assessing Feasibility Report of Kale SHPP Project by RETScreen

4.3.1. Start Worksheet

RETScreen small hydropower plants model working sheets (Figure 4.4) include energy model, cost analysis, emission analysis, financial analysis, risk analysis and tools.

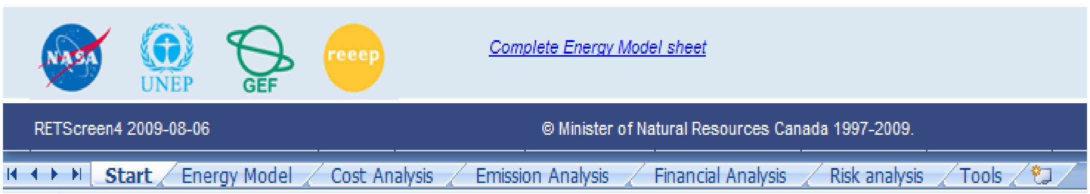

Figure 4.4 RETScreen small hydropower model working sheets

The first section gives information about the hydropower plant and selected project type, technology, grid type and analysis type. These are show in Figure 4.5

Project information — *See project database*

Project name	KALE SHPP
Project location	Kahramanmaraş, Andırın
Prepared for	
Prepared by	Murat KARAYILAN
Project type	Power
Technology	Hydro turbine
Grid type	Central-grid
Analysis type	Method 2

Figure 4.5 Project information sheet

As the project location is entered, Kahramanmaraş in this case, the climatic data is automatically taken from NASA by RETScreen (Figure 4.6).

Site reference conditions — *Select climate data location*

Climate data location: Kahramanmaraş

Show data ☑

	Unit	Climate data location	Project location
Latitude	˚N	37,6	37,6
Longitude	˚E	36,9	36,9
Elevation	m	937	937
Heating design temperature	°C	-2,7	
Cooling design temperature	°C	30,7	
Earth temperature amplitude	°C	23,9	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		1,7	77,9%	2,30	91,1	3,8	1,9	505	0
February		2,6	72,3%	3,14	90,9	4,3	3,0	432	0
March		6,6	65,0%	4,16	90,8	4,0	7,8	355	0
April		12,3	57,6%	4,90	90,7	3,8	14,6	170	70
May		17,5	50,5%	6,08	90,7	3,5	20,6	16	232
June		22,1	41,9%	7,27	90,5	3,5	26,2	0	363
July		25,8	36,1%	7,46	90,4	3,8	30,3	0	488
August		25,4	37,7%	6,60	90,5	3,7	29,6	0	478
September		21,7	39,5%	5,41	90,8	3,4	24,9	0	350
October		16,0	50,7%	3,87	91,1	3,6	17,7	64	184
November		8,5	65,9%	2,56	91,2	3,4	9,1	285	0
December		3,3	76,2%	2,01	91,2	3,7	3,3	457	0
Annual		13,7	55,8%	4,65	90,8	3,7	15,8	2.284	2.165
Measured at	m					10,0	0,0		

Figure 4.6 Kahramanmaraş climatic data taken from NASA.

4.3.2 Energy Model Worksheet

The inputs and outputs of the energy model worksheet are shown in Figures 4.7 and 4.8. Proposed project type was selected as run off river. The user selects the hydrology method from the two options in the drop-down list: "Specific runoff" and "User-defined." When "User-defined" is selected the flow-duration curve data is entered directly by the user. The Specific run-off method is used in conjunction with the RETScreen online weather database. To be in compliance with the feasibility report authorized by DSI, the “User-defined” was selected at the hydrology method. Tailwater effect was assumed to be zero, because there is no information on this value in the report. Gross head was entered to be 257.2 m. residual flow was 0.1 m^3/s, however the input into the program was 0.00, since during the process of the calculation of the flow duration curve this value was taken into account. Percentage time firm flow available was selected to be 95%. and the firm flow was 0.07 m^3/s.

Resource assessment		
Proposed project		Run-of-river
Hydrology method		User-defined
Gross head	m	257,2
Maximum tailwater effect	m	0,00
Residual flow	m³/s	0,000
Percent time firm flow available	%	95,0%
Firm flow	m³/s	0,07

Figure 4.7 Resource assessment of energy model

Design flow was entered as 16 m^3/s, turbine type was selected to be Pelton, turbine efficiency was selected as standard, the number of jets can vary from 1 to 6 and has an impact on the turbine efficiency. A value of 2 can be used as a default. Number of turbines used in this project was three and the design coefficient was selected as the default value, 4.5. Efficiency adjustment factor was chosen to be “0”, the values lay in the range of -5 to +5%

The turbine peak efficiency was calculated to be 91.8%, while flow at peak efficiency was found to be 10,6 m^3/s and the turbine efficiency at design flow was noted to be 90,2%.

Hydro turbine		
Design flow	m³/s	16,000
Type		Pelton
Turbine efficiency		Standard
Number of jets for impulse turbine	jet	2
Number of turbines		3
Manufacturer		Canyon Hydro
Model		Pelton
Efficiency adjustment	%	0,0%
Turbine peak efficiency	%	91,8%
Flow at peak efficiency	m³/s	10,6
Turbine efficiency at design flow	%	90,2%

Figure 4.8 Hydropower turbine inputs and outputs

Maximum hydraulic losses were chosen as 2%, miscellaneous losses were 0.0%, the generator efficiency was 95% and availability was 100% (Figure 4.8), which were taken from the DSI endorsed feasibility report.

Maximum hydraulic losses	%	2,0%
Miscellaneous losses	%	0,0%
Generator efficiency	%	95,0%
Availability	%	100,0%

Figure 4.8 Hydropower turbine inputs (Continued)

Flow-duration-curve data manually entered directly into the program by the user (Figure 4.9). Figures 4.10 and 4.11 show the output of flow-duration-curve and turbine efficiency curve

%	Flow m³/s	Turbine efficiency	Number of turbines	Combined efficiency
0%	287,67	0,00	0	0,00
5%	34,43	0,16	1	0,68
10%	23,11	0,48	1	0,89
15%	16,78	0,68	1	0,92
20%	12,75	0,79	1	0,92
25%	9,74	0,86	1	0,92
30%	7,78	0,89	1	0,92
35%	6,64	0,91	2	0,92
40%	5,08	0,91	2	0,92
45%	3,93	0,92	2	0,92
50%	3,52	0,92	2	0,92
55%	2,92	0,92	2	0,92
60%	2,39	0,92	2	0,92
65%	1,82	0,92	2	0,91
70%	1,36	0,92	3	0,92
75%	0,90	0,92	3	0,92
80%	0,63	0,92	3	0,92
85%	0,44	0,92	3	0,92
90%	0,28	0,92	3	0,92
95%	0,07	0,91	3	0,91
100%	0,00	0,90	3	0,90

Figure 4.9 Flow-duration-curve and turbine efficiency inputs

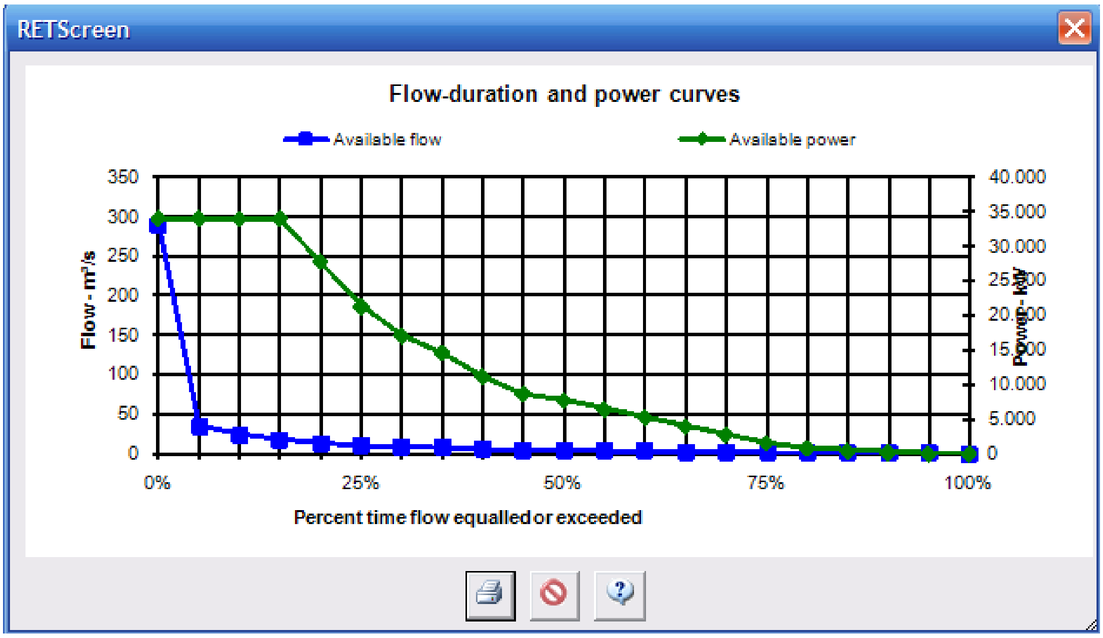

Figure 4.10 Flow duration and power curve

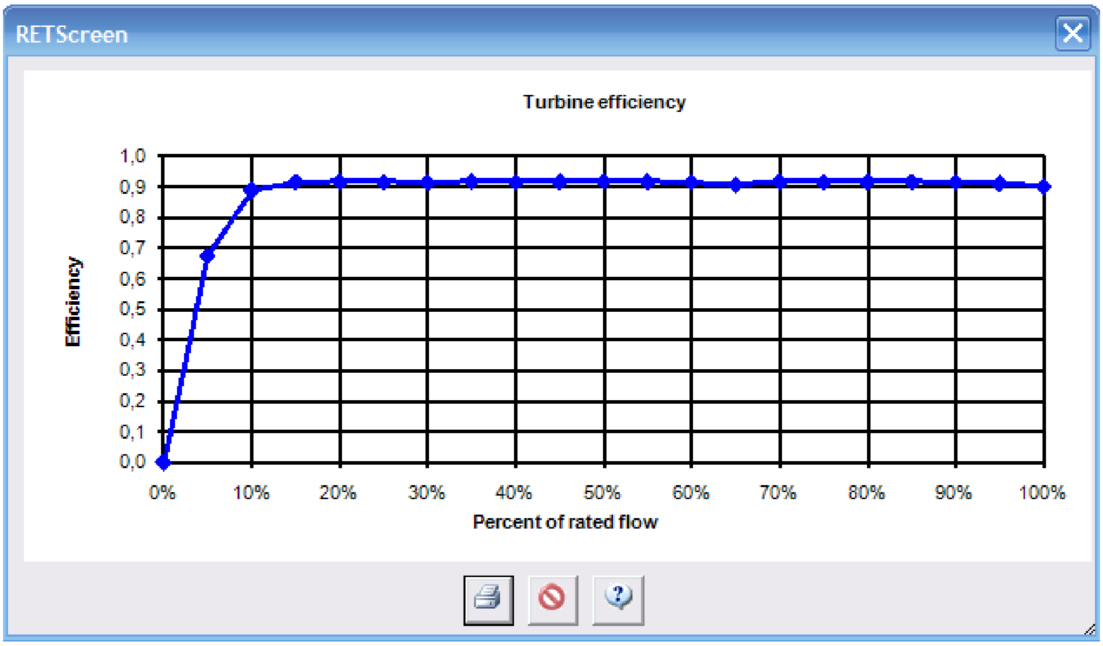

Figure 4.11 Turbine efficiency curve

The installed capacity and the renewable energy delivered by Kale SHPP was calculated to be 33.908 kW and 108.831 MWh, respectively, by the RETScreen (Figure 4.12).

Summary			Firm
Power capacity	kW	33.908	11
Available flow adjustment factor		1,00	
Capacity factor	%	36,6%	
Electricity exported to grid	MWh	108.831	
Electricity export rate	TRL/MWh	82,00	

Figure 4.12 Summary of Kale SHPP

4.3.3. Cost Analysis.

The inputs and outputs of the cost analysis worksheet are shown in Figures 4.13, 4.14 and 4.15. The source of the inputs listed below is the feasibility report of Kale small hydropower plant project except for the project classification selection.

- The climate was selected as not cold.
- Project classification was selected as small as the model suggests.
- New dam crest length was chosen as 30 m.
- Access road length was defined as 8 km and the terrain difficulty was selected as 3 since the terrain is hilly. The road will be used only as a tote road and will not be used after construction ends.
- Length of the tunnel was determined as 4.203 m and the head loss in tunnel was selected as 2%. The lined portion of the tunnel was 100%
- The total length of the penstock was 478,5 m, and the head loss in penstock was selected as 2%.
- Distance to borrow pits was found as 8 km.
- Length of transmission line was determined as 11 km and transmission line voltage defined as 33 kV. The difficulty of terrain over which transmission line is constructed, was selected as 1.5 because of the hilly terrain.

Country	Turkey		
Local vs. Canadian equipment cost ratio		1,00	
Local vs. Canadian fuel cost ratio		1,91	
Local vs. Canadian labour cost ratio		0,31	
Equipment manufacture cost coefficient		1,00	
Exchange rate	TRL/CAD	0,74	
Cold climate	yes/no	No	
Design flow	m³/s	16	16
Gross head	m	257,2	257,2
Number of turbines	turbine	3	3
Type		Pelton	Pelton
Flow per turbine	m³/s	5,33	
Turbine runner diameter per unit	m	1,02	
Facility type		Small	Small
Existing dam	yes/no	No	
New dam crest length	m	30	
Rock at dam site	yes/no	Yes	
Maximum hydraulic losses	%	2,0%	2,0%
Miscellaneous losses	%	0,0%	
Road construction			
Length	km	8,0	
Tote road only	yes/no	Yes	
Difficulty of terrain		3,0	
Tunnel			
Length	m	4.203	
Allowable tunnel headloss factor	%	2,0%	
Percent length of tunnel that is lined	%	100%	
Excavation method		Mechanised	
Diameter	m	4,71	
Canal			
Penstock			
Length	m	478,5	
Number	penstock	1	
Allowable penstock headloss factor	%	2,0%	
Diameter	m	1,93	
Average pipe wall thickness	mm	14,07	
Distance to borrow pits	km	8,0	
Transmission line			
Grid type		Central-grid	Central-grid
Length	km	11,0	
Difficulty of terrain		1,5	
Voltage	kV	33,0	

Figure 4.13. Cost analysis worksheet

Initial costs (credits)	Amount TRL	Adjustment factor	Amount TRL	Relative costs
Feasibility study	2.029.000	1,00	2.029.000	3,1%
Development	2.439.000	1,00	2.439.000	3,7%
Engineering	998.000	1,00	998.000	1,5%
Power system				
Hydro turbine	19.824.000	1,00	19.824.000	30,3%
Road construction	235.000	1,00	235.000	0,4%
Transmission line	334.000	1,00	334.000	0,5%
Substation	952.000	1,00	952.000	1,5%
Balance of system & miscellaneous				
Penstock	1.245.000	1,00	1.245.000	1,9%
Canal	0	1,00	0	0,0%
Tunnel	23.488.000	1,00	23.488.000	35,9%
Other	13.891.000	1,00	13.891.000	21,2%
Sub-total:	38.624.000		38.624.000	
Total initial costs	**65.435.000**		**65.435.000**	**100,0%**

Figure 4.14 Total initial cost of Kale SHPP

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
O&M (savings) costs	project			TRL -
Land lease & resource rental	project	1		TRL -
Property taxes	project	0	TRL 65.435.000	TRL -
Insurance premium	%	0,40%	TRL 65.435.000	TRL 261.740
Parts & labour	%	0,40%	TRL 65.435.000	TRL 261.740
GHG monitoring & verification	project	0		TRL -
Community benefits	project	0		TRL -
General & administrative	%	10,0%	TRL 523.480	TRL 52.348
User-defined	cost			TRL -
Contingencies	%	10,0%	TRL 575.828	TRL 57.583
Sub-total:				**TRL 633.411**

Figure 4.15 Annual costs of the Kale SHPP

The total initial and annual costs of the Kale SHPP Project were calculated as 65.435.000 TL and 633.411 TL, respectively, by RETScreen.

.

4.3.4. Financial Analysis

The inputs and outputs of the financial analysis worksheet are shown in Figures 4.16a, 4.16b. The following information was used; The cost of energy was entered as 0.075 US$/kWh which was the average value in the market in the year 2009 (DSI, 2009). Energy cost escalation rate was assumed as 0% because there is no guarantee that the cost of energy will increase every year. The inflation was predicted as 4% for the project life of the Kale SHPP. The discount rate was entered as 9.5% (DSI, 2009). The debt ratio was selected as 0% which means all of the initial costs will be paid by the investor. The project is feasible according to RETScreen as the net present value and internal rate of return are positive and the benefit cost ratio is 1,25 which is shown in Figure 4.16b. The simple payback is after 7.9 years. The yearly cash flows and the cumulative cash flow are shown in Figures 4.17 and 4.18. Cumulative cost starts at -65.435.000 TL, while 7.9 years later annual and initial cost pays back.

Annual income		
Electricity export income		
Electricity exported to grid	MWh	108.831
Electricity export rate	TRL/MWh	82,00
Electricity export income	TRL	8.924.108
Electricity export escalation rate	%	

Financial parameters		
General		
Fuel cost escalation rate	%	0,0%
Inflation rate	%	4,0%
Discount rate	%	9,5%
Project life	yr	50
Finance		
Incentives and grants	TRL	0
Debt ratio	%	0,0%

Financial viability		
Simple payback	yr	7,9
Net Present Value (NPV)	TRL	16.431.402
Benefit-Cost (B-C) ratio		1,25
Debt service coverage		No debt
GHG reduction cost	TRL/tCO2	No reduction

Figure 4.16a Financial analysis worksheet of Kale SHPP

Project costs and savings/income summary			
Initial costs			
Feasibility study	3,1%	TRL	2.029.000
Development	3,7%	TRL	2.439.000
Engineering	1,5%	TRL	998.000
Power system	32,6%	TRL	21.345.000
Balance of system & misc.	59,0%	TRL	38.624.000
Total initial costs	**100,0%**	**TRL**	**65.435.000**
Annual costs and debt payments			
O&M		TRL	633.411
Fuel cost - proposed case		TRL	0
Total annual costs		**TRL**	**633.411**
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		TRL	0
Electricity export income		TRL	8.924.108
Total annual savings and income		**TRL**	**8.924.108**

Figure 4.16b Financial analysis worksheet of Kale SHPP (Continued)

Yearly cash flows			
Year	Pre-tax	After-tax	Cumulative
#	TRL	TRL	TRL
0	-65.435.000	-65.435.000	-65.435.000
1	8.265.360	8.265.360	-57.169.640
2	8.239.010	8.239.010	-48.930.629
3	8.211.607	8.211.607	-40.719.022
4	8.183.107	8.183.107	-32.535.916
5	8.153.467	8.153.467	-24.382.449
6	8.122.641	8.122.641	-16.259.809
7	8.090.582	8.090.582	-8.169.226
8	8.057.241	8.057.241	-111.985
9	8.022.567	8.022.567	7.910.581
10	7.986.505	7.986.505	15.897.086
11	7.949.001	7.949.001	23.846.087
12	7.909.997	7.909.997	31.756.084
13	7.869.432	7.869.432	39.625.516
14	7.827.245	7.827.245	47.452.761
15	7.783.371	7.783.371	55.236.131
16	7.737.741	7.737.741	62.973.872
17	7.690.286	7.690.286	70.664.159
18	7.640.934	7.640.934	78.305.092
19	7.589.607	7.589.607	85.894.699
20	7.536.227	7.536.227	93.430.925
21	7.480.711	7.480.711	100.911.637
22	7.422.975	7.422.975	108.334.612
23	7.362.930	7.362.930	115.697.542
24	7.300.483	7.300.483	122.998.025
25	7.235.538	7.235.538	130.233.563
26	7.167.995	7.167.995	137.401.559
27	7.097.751	7.097.751	144.499.309
28	7.024.697	7.024.697	151.524.006
29	6.948.720	6.948.720	158.472.726
30	6.869.705	6.869.705	165.342.431
31	6.787.528	6.787.528	172.129.959
32	6.702.065	6.702.065	178.832.024
33	6.613.184	6.613.184	185.445.208
34	6.520.747	6.520.747	191.965.955
35	6.424.612	6.424.612	198.390.567
36	6.324.632	6.324.632	204.715.199
37	6.220.653	6.220.653	210.935.853
38	6.112.515	6.112.515	217.048.368
39	6.000.052	6.000.052	223.048.419
40	5.883.089	5.883.089	228.931.509
41	5.761.449	5.761.449	234.692.957
42	5.634.942	5.634.942	240.327.899
43	5.503.376	5.503.376	245.831.275
44	5.366.546	5.366.546	251.197.821
45	5.224.244	5.224.244	256.422.065
46	5.076.249	5.076.249	261.498.314
47	4.922.335	4.922.335	266.420.649
48	4.762.264	4.762.264	271.182.913
49	4.595.790	4.595.790	275.778.704
50	4.422.658	4.422.658	280.201.361

Figure 4.17 Annual cash flows

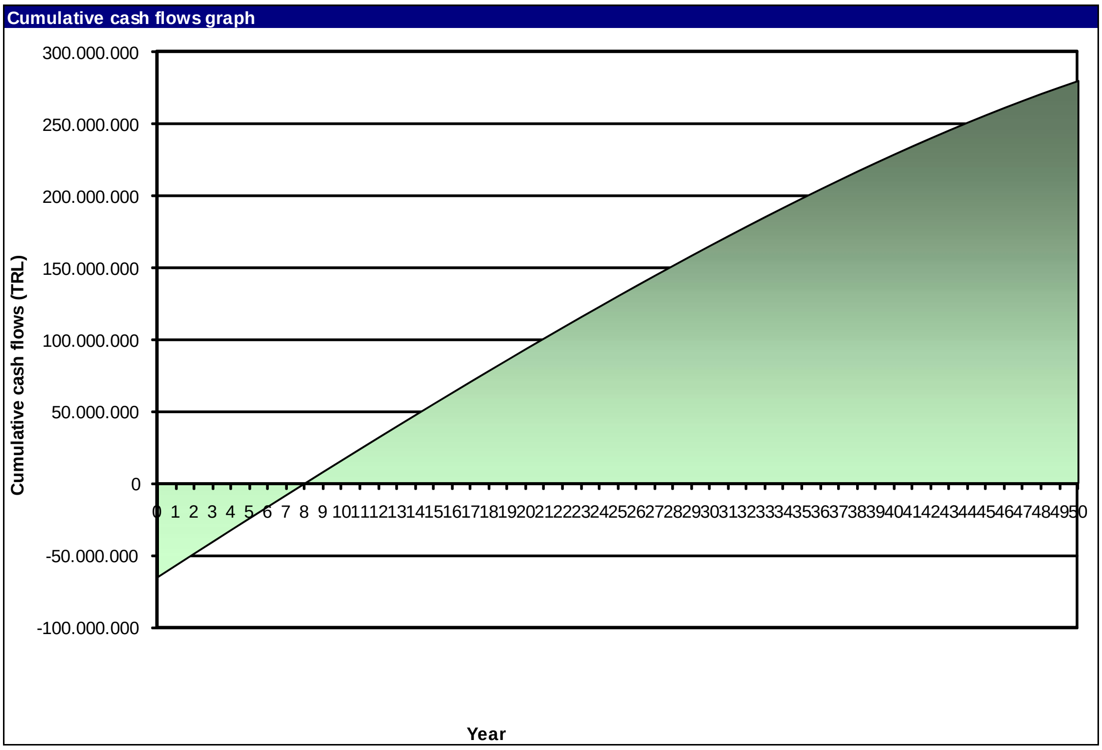

Figure 4.18 Cumulative cash flow of Kale SHPP

4.4. Comparison of the Feasibility Reports

4.4.1. Kale SHPP Installed Power and Delivered Energy

The results of the feasibility approved by DSI and feasibility study performed by employing RETScreen are illustrated in Table 4.3. A deviation of 4% was noted in the result found for installed power capacities. The deviation for delivered energy was found to be only 1.4%.

Table 4.3 Installed power and delivered energy

Parameter	**RETScreen' Results**	**DSI' Results**	**Deviation(%)**
Installed Power	33,91 MW	35,33 MW	4%
Delivered Energy	108,83 GWh	107,28 GWh	1.4%

4.4.2 Cost of the Project

In the feasibility study approved by DSI, the total project cost includes the total cost of constructions works, the cost of energy equipments, the cost of power plant, etc. Nevertheless, RETScreen calculates the initial costs, cost of power system, cost of system balance and miscellaneous costs. In order to make a reliable comparison and avoid from any miscalculations the formulae specified in Table 3.4, where all of the costs related with the work categories, were employed. The comparison between these two ways of calculations is shown in Table 4.4. To be able to compare the cost of each component of the project the costs of each item and total cost of the project found by RETScreen and in the DSI approved feasibility reports are presented in Table 4.4.

Table 4.4 Comparison of the feasibility studies approved by DSI and conducted by RETScreen for Kale SHPP

Cost Item	DSI Costs (TL)	DSI Total Cost (TL)	RETScreen Costs (TL)	RETScreen Total Cost (TL)	Ratio: RETScreen/DSI
Feasibility study	-	1.113.099,10	2.029.000,00	5.466.000,00	4.91
Development	-		2.439.000,00		
Engineering	-		998.000,00		
Hydro turbine	-	22.695.233,20	19.824.000,00	20.776.000,00	0.91
Substation	-		952.000,00		
Settling Basin	200.000,00		-		
Powerhouse	4.842.016,60		-		
Turbine and Generators	9.654.269,10		-		
Other Equipment	7.898.947,50		-		
Transformer	100.000,00		-		
Transmission line	582.250,00	582.250,00	334.000,00	334.000,00	0.57
Road construction	250.000,00	250.000,00	235.000,00	235.000,00	0.94
Penstock	8.336.650,00	8.336.650,00	1.245.000,00	1.245.000,00	0.14
Tunnel	-	29.125.799,16	23.488.000,00	23.488.000,00	0.80
Regulator	8.382.974,50		-		
Transmision Tunnel	15.763.583,40		-		
Forebay	4.979.241,26		-		
Other (Civil Works)	6.413.169,90	6.413.169,90	13.891.000,00	13.891.000,00	2.16
Total Project Cost		68.516.201,36		65.435.000,00	0.96

The total project cost of Kale SHPP was calculated by employing RETScreen and the results found were compared with the feasibility study approved by DSI. The total project cost estimated by RETScreen was noted to be lower than the cost estimated in the DSI endorsed feasibility report. The ratio of costs found by RETScreen to DSI approved costs was found to be 0.96, which is a tolerable error if it could be seen as an error (Table 4.4). The costs of a number items (feasibility study, development, engineering and civil works) calculated by RETScreen were found to be higher than the corresponding costs in the DSI endorsed feasibility study, while costs of several other items (penstock, transmission line) were noted to be lower than the corresponding costs in the same report. RETScreen does not allow the user to enter a value for the diameter of the penstock; instead, this value is calculated by the software using the value entered for the head loss in the penstock. The calculated value of the diameter by the software and the value given in the feasibility report differ from one another.

4.4.3. Financial summary

In the feasibility study of Kale SHPP approved by the State Hydraulic Works (DSI), the method of financial analysis is based on criteria of DSI. The method used by RETScreen in the financial summary worksheet was described in the section 3.2.6. The initial cost of the project is assumed to be spent at the beginning of the construction. Therefore, the cumulative cash flow starts with the negative value of the total initial cost in the year zero. The project is feasible according to RETScreen as the net present value and internal rate of return are positive and the benefit cost ratio is above 1. The simple payback is after 7.9 years and cash-flow turns to positive after the year 7.9

4.4.4. Comparison of the other three SHPP

In order to be able to generalize the results, 3 more SHPP projects were performed by RETScreen. These projects are Gökgedik, Torlar and Damlasu SHPPs. The feasibility of these three projects also has been approved by DSI. The results are tabulated in Tables 4.5, 4.6 and 4.7. The total project costs found for Gökgedik, Torlar and Damlasu SHPPs by RETScreen were 70.171.000 TL, 40.245.000 TL and

18.336.000 respectively. The feasibility reports endorsed by DSI calculated the total projects costs for the three projects, with the same order, as 69.565.233 TL, 44.956.723 TL and 16.670.006 TL. The deviations of the total cost found by RETScreen from the total cost in the feasibility report approved by DSI were noted to be 0.8%, 11% and 9% for Gokgedik,Torlar and Damlasu, respectively.

Table 4.5 Comparison of the feasibility studies approved by DSI and conducted by RETScreen for Gökgedik SHPP

Cost Item	DSI Costs (TL)	DSI Total Cost (TL)	RETScreen Costs (TL)	RETScreen Total Cost (TL)	Ratio: RETScreen/DSI
Feasibility study	-	1.318.660,00	2.176.000,00	5.392.000,00	4.08
Development	-		2.615.000,00		
Engineering	-		601.000,00		
Hydro turbine	-	11.993.550,00	12.776.000,00	13.437.000,00	1.12
Substation	-		661.000,00		
Settling Basin	500.000,00		-		
Powerhouse	2.693.407,00		-		
Turbine and Generators	8.701.560,00		-		
Other Equipment	98.583,00		-		
Transformer	-		-		
Transmission line	525.000,00	525.000,00	744.000,00	744.000,00	1.41
Road construction	350.000,00	350.000,00	128.000,00	128.000,00	0.36
Penstock	4.578.091,00	4.578.091,00	1.436.000,00	1.436.000,00	0.31
Tunnel	-	43.101.661,00	43.042.000,00	43.042.000,00	0.99
Regulator	7.305.585,00		-		
Transmision Tunnel	30.428.081,00		-		
Forebay	5.367.995,00		-		
Other (Civil Works)	7.698.261,00	7.698.261,00	5.992.000,00	5.992.000,00	0.77
Total Project Cost		69.565.223,00		70.171.000,00	1.008

Table 4.6 Comparison of the feasibility studies approved by DSI and conducted by RETScreen for Tolar SHPP

Cost Item	DSI Costs (TL)	DSI Total Cost (TL)	RETScreen Costs (TL)	RETScreen Total Cost (TL)	Ratio: RETScreen/DSI
Feasibility study	-	2.555.759,00	1.248.000,00	3.380.000,00	1.32
Development	-		1.500.000,00		
Engineering	-		632.000,00		
Hydro turbine	-	7.875.395,00	13.350.000,00	13.879.000,00	1.76
Substation	-		529.000,00		
Settling Basin	500.000,00		-		
Powerhouse	2.016.607,00		-		
Turbine and Generators	5.358.788,00		-		
Other Equipment	-		-		
Transformer	-		-		
Transmission line	525.000,00	525.000,00	874.000,00	874.000,00	1.66
Road construction	350.000,00	350.000,00	811.000,00	811.000,00	2.31
Penstock	1.123.035,00	1.123.035,00	1.109.000,00	1.109.000,00	0.98
Tunnel	-	27.764.424,00	10.519.000,00	10.519.000,00	0.37
Regulator	9.131.763,00		-		
Transmision Tunnel	12.941.174,00		-		
Forebay	5.691.487,00		-		
Other (Civil Works)	4.763.110,00	4.763.110,00	9.673.000,00	9.673.000,00	2.03
Total Project Cost		**44.956.723,00**		**40.245.000,00**	**0.89**

Table 4.7 Comparison of the feasibility studies approved by DSI and conducted by RETScreen for Damlasu SHPP

Cost Item	DSI Costs (TL)	DSI Total Cost (TL)	RETScreen Costs (TL)	RETScreen Total Cost (TL)	Ratio: RETScreen/DSI
Feasibility study	-	1.176.760,00	569.000,00	1.737.000,00	1.47
Development	-		683.000,00		
Engineering	-		485.000,00		
Hydro turbine	-	4.020.576,00	6.753.000,00	6.953.000,00	1.72
Substation	-		200.000,00		
Settling Basin	186.000,00		-		
Powerhouse	1.089.960,00		-		
Turbine and Generators	2.744.616,00		-		
Other Equipment	-		-		
Transformer	-		-		
Transmission line	843.200,00	843.200,00	608.000,00	608.000,00	0.72
Road construction	1.695.080,00	1.695.080,00	262.000,00	262.000,00	0.15
Penstock	739.230,00	739.230,00	701.000,00	701.000,00	0.94
Canal	-	6.987.400,00	2.624.000,00	2.624.000,00	0.37
Regulator	3.535.240,00		-		
Transmision Canal	3.025.600,00		-		
Forebay	426.560,00		-		
Other (Civil Works)	1.207.760,00	1.207.760,00	5.451.000,00	5.451.000,00	4.51
Total Project Cost		**16.670.006,00**		**18.336.000,00**	**1.09**

Table 4.8 Comparison of the result found by RETScreen and in DSI approved feasibility reports.

SHPP	Installed Power (MW)		Renewable Energy Delivered (GWh)		Total Initial Cost (TL)		Benefit Cost Ratio	
	DSI	RETScreen	DSI	RETScreen	DSI	RETScreen	DSI	RETScreen
Gökgedik	24,29	22,45	58,90	57,04	69,565,225	70,170,000	0,68	0,64
Kale	35,33	33,91	107,28	108,83	68,516,201	65,435,000	1,24	1,25
Torlar	15,01	13,75	34,38	32,99	44,956,722	40,245,000	0,62	0,51
Damlasu	6,32	5,69	17,91	15,56	16,670,006	18,336,000	0,97	0,83

The installed power capacity, renewable energy delivered, total initial cost and benefit cost ratio of the SHPPs in question are compared with one another. Gökgedik, Torlar and Damlasu SHPPs were found not feasible, since their benefit cost ratios were noted to be under unity (Table 4.8) On the other hand the benefit cost ratio for Kale SHPP project was estimated to be more than unity, 1.25, thus it is a feasible project. Taking the results tabulated in Table 4.8 into account one can say that RETScreen can be used in assessment of feasibility studies of SHPP in Turkey. Since the installed power capacities, energy delivered and total initial costs estimated by RETScreen were found to be very close to these found in DSI approved reports.

CHAPTER V

CONCLUSION

Small hydropower projects should categorically be dealt with dissimilar approach large scale hydropower projects, because of the differences between the ways they operate. Rather than optimization of the system, maximization of delivered energy and cost effectiveness should be the primary objective.

The RETScreen is a decision support tool which is widely used in Canada to assess the energy production and savings, life-cycle costs, emission reductions, financial viability and risk for various types of energy efficient and renewable energy technologies (RETs) such as small hydropower plants. RETScreen is capable of making optimizations to maximize the delivered energy and minimize the initial cost of a SHP project within a short period of time, without detailed study. For reservoir and run-off river type of projects, a pre-feasibility report can be prepared in a short period of time compared to the traditional feasibility studies. In addition, the report can be revised every time by altering a number of variables and therefore, different alternatives can be compared with ease without extensive calculations which will help designers save time and money.

Kale, Gökgedik, Torlar and Damlasu small hydropower projects all located in Andırın. Kahramanmaraş, are selected as case studies. Data available from the feasibility studies approved by DSI were the inputs for RETScreen. The outputs were analyzed in details.

The outcomes of this study show that RETScreen Software can easily be used for SHPPs Projects in Turkey. The Labour Costs can be adjusted to give more accurate results according to the data bank about the construction sector in Turkey announced by State Institute of Statistics published every year. This survey report can be very helpful to calculate the exact ratio for labour and equipment costs.

Diesel fuel costs in Turkey are more than 1.9 times of the diesel fuel costs in Canada and this fuel cost ratio is increasing year by year because of the unstable prices of oil around the world. Energy, when it is renewable, is a key element for development. Energy generated from fossil fuels has been continuously consumed and it is expected to be finished in the future; however renewable sources together with hydropower are expected to always be available. Countries generating green energy such as small hydropower plants will be self-dependent and their industries will be more competitive than the fossil fuel exporting countries. Among these countries, Turkey has an opportunity with its high economical hydropower potential which is insurance for the unpredictable future of the world.

RETScreen employs Canadian hydrological and meteorological databases, when it is used in other countries, it may cause deviations in assessment of the cost of components of small hydropower plants and thus, the total cost of the project. In addition local labour costs, fuel costs, equipment manufacture costs, etc, could also influence the total cost of the project from one country to another. In order to achieve accurate prefeasibility assessment results for any small hydropower project to be build in Turkey a new software could be developed to be utilized in the country, which makes use of the local economical, hydrological and meteorological databases.

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