# FEASIBILITY STUDY OF A HYDROPOWER PROJECT: CASE STUDY OF NİKSAR HEPP, TURKEY

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# FEASIBILITY STUDY OF A HYDROPOWER PROJECT: CASE STUDY OF NİKSAR HEPP, TURKEY

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**I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.**

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# ABSTRACT

## FEASIBILITY STUDY OF A HYDROPOWER PROJECT: CASE STUDY OF NİKSAR HEPP, TURKEY

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Hydropower helps countries meet their energy needs in an economically, environmentally, and socially sustainable way while saving money and increasing energy security and self-reliance. Being one of the fastest developing countries, electricity demand of Turkey has been increasing and is expected to increase in the future. Untapped hydropower potential is among the prospective alternative resources to supply this demand. Developing a hydropower project requires a great deal of expertise in multiple disciplines. RETScreen software developed by CanmetENERGY helps the planners and decision makers to assess the feasibility of renewable energy projects at the pre-feasibility and feasibility stages. This study is an application of RETScreen to assess the feasibility of alternative formulations for Niksar HEPP, a small hydropower project which is under construction in Turkey. Three alternative formulations are generated and their economic performances are evaluated and compared. First, optimum design discharges are calculated and then economical analysis is conducted for various electricity export rates by RETScreen for all the alternatives. This study provides a detailed literature review on hydropower and its economical, social and environmental aspects, and shows how

RETScreen can be used in assessing the economical feasibilities of the current formulation for Niksar HEPP and its alternative schemes.

Keywords: Hydropower, Feasibility, RETScreen

# ÖZ

## BİR HİDROELEKTRİK SANTRALİN YAPILABİLİRLİK ÇALIŞMASI: NİKSAR HES ÖRNEĞİ, TÜRKİYE

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Hidroelektrik enerji, ülkelerin enerji ihtiyaçlarını ekonomik, çevresel ve sosyal açıdan sürdürülebilir bir şekilde karşılamalarına yardım etmekle birlikte enerji güvenliğinin sağlanmasında ve enerjide dışa bağımlılığın azaltılmasında önemli rol oynar. Dünyanın en hızlı gelişen ülkelerden biri olan Türkiye'nin elektrik talebi büyük bir artış göstermiştir ve gelecekte bu talebin daha da artması beklenmektedir. Potansiyelinin büyük bir kısmı henüz kullanılmamış olan hidroelektrik enerji, bu talebi karşılamada kullanılabilecek önemli kaynaklardan biridir. Hidroelektrik enerji projelerinin geliştirilmesi birçok disiplinde uzmanlık gerektirir. CanmetENERGY tarafından geliştirilen RETScreen yazılımı planlamacılara ve karar vericilere ön fizibilite ve fizibilite aşamalarında yenilenebilir enerji projelerinin yapılabilirliklerinin değerlendirilmesinde yardımcı olmaktadır. Bu çalışma, Türkiye'de halihazırda inşaat aşamasında olan Niksar HES'in alternatif formülasyonlarının fizibilitelerinin değerlendirilmesinde RETScreen'in kullanımına bir örnektir. Üç alternatif formülasyon üretilmiş ve bunların ekonomik performansları değerlendirilip karşılaştırılmıştır. Önce optimum dizayn debileri hesaplanmış, sonra değişik elektrik fiyatları için bu alternatiflerin ekonomik analizleri yapılmıştır. Bu çalışma hidroelektrik enerji ve onun ekonomik, sosyal ve çevresel etkileri üzerine detaylı bir literatür çalışması sunmakta ve Niksar HES'in alternatif formülasyonlarının ekonomik fizibilitelerinin incelenmesinde RETScreen'in nasıl kullanılabileceğini anlatmaktadır.

Anahtar Kelimeler: Hidroelektrik Enerji, Fizibilite, RETScreen

To My Family

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| | |
|---|---|
| CAD | Canadian Dollar |
| ÇATOM | Multipurpose Community Center |
| DSİ | General Directorate of State Hydraulic Works |
| EIA | Environmental Impact Assessment |
| EU | European Union |
| EURELECTRIC | The Union of the Electricity Industry |
| GEF | Global Environment Facility |
| GHG | Greenhouse gas |
| HEPP | Hydroelectric Power Plant |
| ICOLD | International Commission of Large Dams |
| IHA | International Hydropower Association |
| Krş | Kuruş (1 Turkish Lira is equal to 100 Kuruş) |
| NASA | National Aeronautics and Space Administration |
| OECD | Organisation for Economic Co-operation and Development |
| REEP | The Renewable Energy & Energy Efficiency Partnership |
| TEİAŞ | Turkish Electricity Transmission Company |
| TL | Turkish Lira |
| UNEP | United Nations Environment Programme |
| USA | The United States of America |
| USD | The United States Dollar |

# CHAPTER 1

# INTRODUCTION

The demand for energy in the world has significantly increased in the last decades as a result of the growing population and the increase in the level of industrialization. Global energy use has risen by 70 % since 1971 [1], and is predicted to increase by 40 % by 2030 [2]. On the other hand, approximately 1.6 billion people have no access to electricity [3].

Fossil fuel-oriented energy sector has been accused of being the main source of global warming. Increased awareness of climate change and international agreements such as Kyoto Protocol has forced the governments to search for alternative energy sources; and increased oil prices accelerated this process.

Within this conjuncture, governments have started to pay more attention on renewable energy technologies. Investors are encouraged to develop renewable energy technologies. Among these technologies, hydropower is the cheapest and the most widely used one. In 2007, 16 % of the world’s total electricity was generated in hydropower plants [4].

Hydropower is the most mature renewable energy technology. Hydropower has been used for more than a century and has become the major source of electricity for 55 countries [3]. Although it is widely used all around the world, only one-third of the economical hydropower potential has been utilized yet [5]. In Asia, Africa and South America a great portion of the economical potential remains to be developed. On the other hand, the developed countries have already utilized much of their economical potential. However, these countries continue investing in renewable resources, especially small hydropower projects.

Hydropower is clean energy technology. It helps to slow down climate change since hydropower plants produces very small amounts of greenhouse gases [3]. Hydropower plants produce no air pollutants. They neither consume nor pollute the water. Moreover, hydropower plants prevent depletion of non-renewable fuel resources thus ensuring the social justice among generations.

There are of course some adverse effects of hydropower plants at the river ecosystem. However these effects can clearly be identified and mitigated. By conducting environmental impact assessment and raising the public awareness, hydropower projects can be developed in an environmentally sound and socially responsible manner.

Although Turkey has been using hydropower since 1902, only 35 % of its economic hydroelectric potential is utilized [6, 7]. Being one of the fastest developing countries, Turkey is in urgent need for additional electricity production capacity. The demand for electricity is expected to increase by 6–7 % every year for the next decade [8]. In order to accelerate the utilization of energy resources, the energy markets were privatized. Companies have been competing to undertake the hydropower projects since then.

In a competitive market, time and money are invaluable for companies. Developing a hydropower project requires a great deal of money and time as well as expertise in engineering. In order to help the developers to make an initial assessment of the economical feasibility of a project before spending considerable amount of money and time, numerous computer tools have been developed.

RETSceen Clean Energy Analysis Software is one of the successful energy project assessment tools developed by CanmetENERGY, a Canadian government organization. It can be used for various types of energy technologies, including hydropower, to evaluate the energy production and savings, costs, emission reductions, and financial viabilities of the projects.

Korkmaz [9] utilized RETScreen for two hydropower projects in Turkey and tested the accuracy of the cost calculations of the software by comparing with the feasibility reports of these projects.

Küçükbeycan [10] also tested the accuracy of RETScreen in Turkish practice studying two case studies from Turkey. In addition, he utilized RETScreen for assessing the feasibility of generating electricity in a dam which is used for flood control and irrigation.

In 1990, DSİ prepared a master plan report for Lower Kelkit Project which comprises five Hydroelectric Power Plants (HEPPs). The subject of this study is Niksar HEPP, which is one of these five HEPPs. Niksar HEPP will be located on Kelkit Stream. A private company has been awarded with the contract and the construction works still continue.

DSİ suggested a formulation of Niksar HEPP. In this study two alternative projects to DSİ formulation are devised by changing the course of the water conveyance system. These three alternatives are evaluated in terms of economical aspects using RETScreen Clean Energy Project Analysis Software (v. 4). Financial parameters of the three alternatives are compared and the best alternative is selected.

One of the most important design parameters in hydropower project planning is the design discharge. In this study, prior to the cost-benefit analysis, the optimum design discharges for each of the three alternatives are determined using an iterative approach.

In addition to design discharge, frequently changing electricity prices in Turkey is another parameter that is considered during the planning phase of the HEPPs. Therefore, while determining the optimum discharges for the alternatives of Niksar HEPP, impact of electricity prices are evaluated as well.

Korkmaz [9] and Küçükbeycan [10] utilized RETScreen for small hydropower projects in Turkey in order to check the suitability of the software to the Turkish practice. The costs obtained from the software are compared with the actual feasibility reports. In this study, however, the cost calculations are assumed correct and several alternatives are investigated in order to obtain the best formulation. Although RETScreen is widely used in many countries, there are not many applications in Turkey. Thus, this study provides another example application of RETScreen for a small hydropower plant in Turkey. It is intended to arouse interest of the project developers to this practical and useful tool.

In Chapter 1, introductory remarks and the scope of the study is given briefly. In Chapter 2, general information about hydropower and hydropower project development are reviewed. Moreover, a concise presentation of RETScreen is given. In Chapter 3, Niksar HEPP project is introduced and the alternatives are explained. Chapter 4 is dedicated to the application of RETScreen for the alternative projects. In Chapter 5, conclusions of the study is given.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Hydropower

### 2.1.1 Definition of Hydropower

Hydropower or ‘water power’ can be defined as the potential energy contained in water at a height. Water constantly moves through a vast global cycle (Figure 1), evaporating from lakes and oceans, forming clouds, precipitating as rain or snow, then falling back to the ocean. The energy of this cycle can be tapped to produce electricity or for mechanical tasks like grinding grain [11]. One third of the solar radiation reaching the Earth is responsible for running of the hydrologic cycle [12]. Therefore, the energy of water never fails to be replenished [13]. Because the hydrologic cycle is a never ending system, hydropower is considered a renewable energy. Indeed, it is the largest renewable resource used for electricity generation [14].

Water may be utilized for power generation if it possesses enough potential energy. As water flows from highlands to lower elevations, its potential energy is reduced by evaporation, drop in elevation, friction, and turbulence. The remaining part can be converted into mechanical energy by turbines and generators convert this mechanical energy into electrical energy.

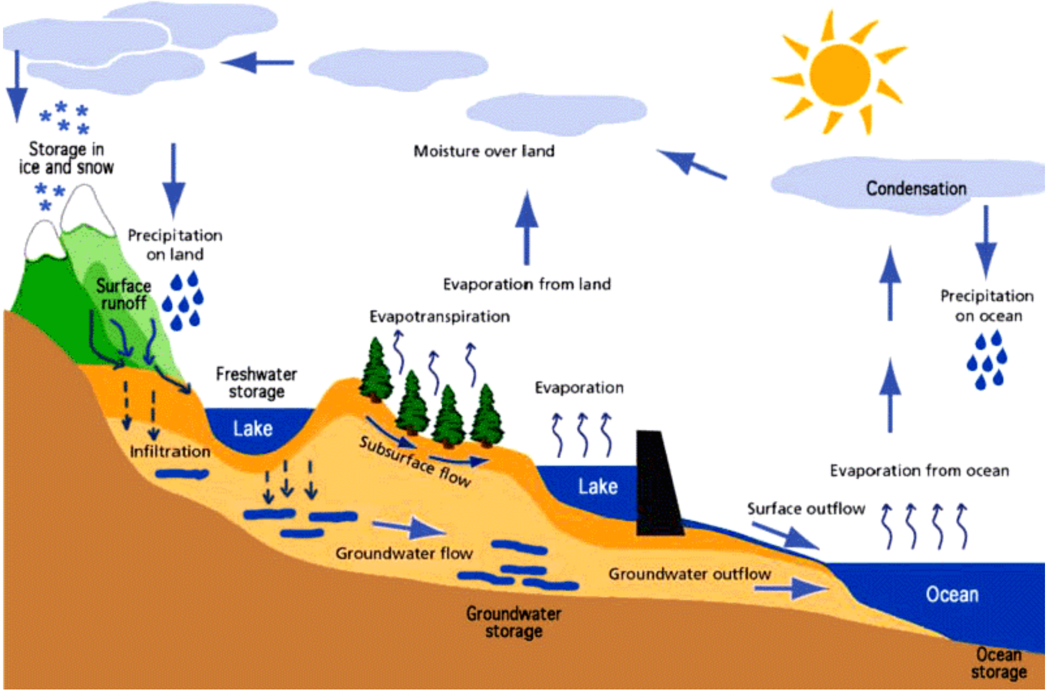


**Figure 1 Hydrologic Cycle [15]**

The amount of water power developed from any stream, river or lake is a function of mainly:

1. The flow rate of water
2. The head that is available

Hydroelectric power and energy that can be generated in a hydropower plant is determined from:

$$P = \gamma Q H_n \eta \quad \text{(Eq.1)}$$

$$E = \gamma Q H_n \eta \Delta t \quad \text{(Eq.2)}$$

where $P$ is the power in kW, $\gamma$ 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, $\eta$ is the overall efficiency (%), $E$ is the hydroelectric energy in kWh and $\Delta t$ is the time interval for power generation in hours.

### 2.1.2 History of Hydropower

Harnessing hydropower dates back over 2000 years. It was used by the Greeks to turn water wheels for grinding wheat into flour more than 2000 years ago [16]. Other tasks that used hydropower included sawing wood, powering textile mills, and later operating manufacturing plants [17].

During the Industrial Revolution, hydropower played an important role in improving the textile, leather and machine industries. Steam engine technology had already been developed. However, coal was scarce and wood was unsatisfactory. Until the middle of the 19th century, when cheap coal became available, hydropower helped to develop early industrial cities in Europe and the United States [16].

The modern turbine has been developed as a result of the improvements of the waterwheel. Most of the developments were achieved by French engineers. Since France lacked rich coal resources, they focused on the water power. Even today the French word *houille blanche*, meaning “white coal” is used for water power [17]. Not surprisingly, a French engineer, Benoit Fourneyron (1802 – 1867), won the prize given by Société d'Encouragement pour l'Industrie Nationale for “applying at large scale, in a satisfactory manner, in mills and factories, the hydraulic turbines or wheels with curved blades” [17, 18]. Therefore, he is credited with developing the first modern turbine in 1833 [17].

In 1849, the Francis turbine was invented and later used in the world’s first hydroelectric power plant on the Fox River in Appleton, Wisconsin in 1882 [17, 19, 20]. With the demonstration of the economic transmission of high-voltage alternating current at the Frankfurt Exhibition in 1891, larger hydropower schemes were accepted as feasible [19].

The golden age of hydropower was the first half of the 20th century. Europe and North America built hydropower plants at a rapid rate and utilized up to 50 % of their technically available potential. Then oil took over as the dominant force in energy provision [21] and the hydropower continued to develop at a slower pace from then on.

### 2.1.3 Types of Hydropower Plants

Hydroelectric power plants can be classified in different ways according to their characteristics.

#### 2.1.3.1 Classification According to Operation Mode

**Impoundment Plants:** Also called ‘storage plants’ or ‘reservoir plants’, is the most common type of hydroelectric power plants [22]. These plants are usually large hydropower schemes and use a dam to store river water in a reservoir. Water is not distributed uniformly in time. These plants store water when the flows are relatively high and this storage compensates for the low-flow seasons. Therefore, a relatively constant supply of energy is maintained throughout a year. The main parts of a typical reservoir type hydropower plant are presented in Figure 2.

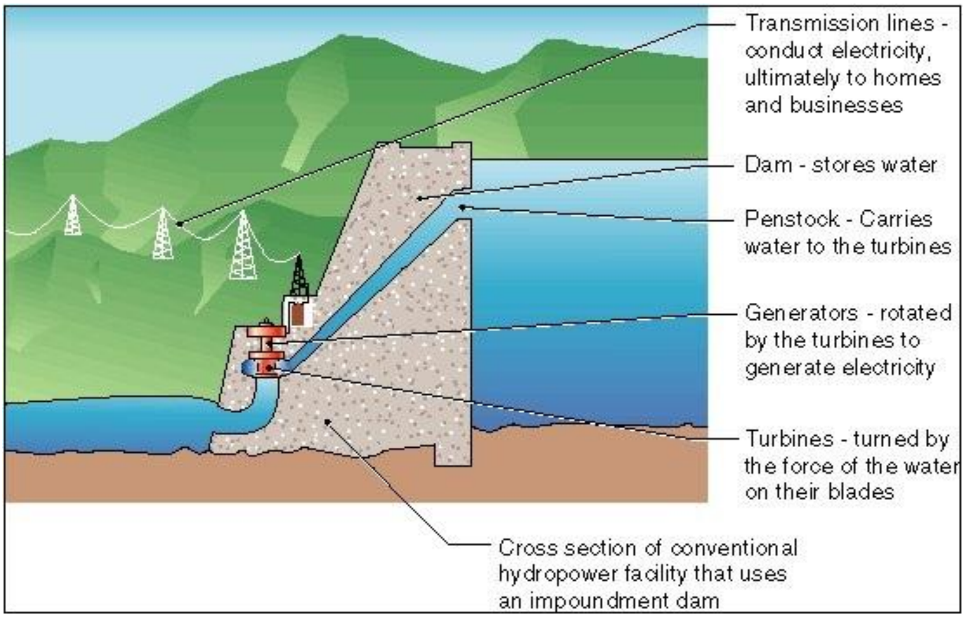


**Figure 2 Main parts of storage type hydropower plants [23]**

**Run-of-river Plants :** This type of plant generally does not have a storage. By means of a diversion weir, water is diverted from the river and given to the transmission canal or sometimes tunnel. At the end of the transmission canal lies a head pond or forebay facilitating a gentle approach to the intake of penstock. Forebays also serve in surge reduction and sediment removal [24]. General layout of run-of-river plants is given in Figure 3. Since these plants do not have storage, energy generation is dependent on the flow in the river. Therefore, run-of river plants can be considered as base load plants [24].

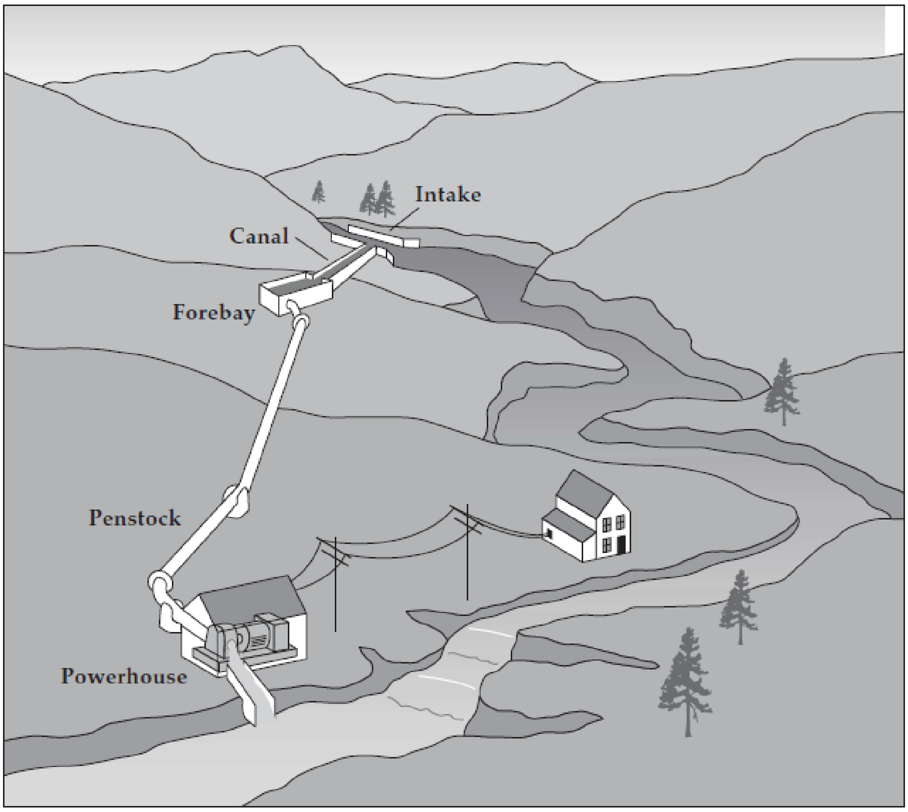


**Figure 3 General layout of a run-of-river plant [25]**

**Pumped-Storage Plants :** When the demand for and the price of electricity is low, a pumped-storage plant stores energy by pumping water from a lower reservoir to an upper one. When the demand for and the price of electricity is high, the water from the upper reservoir is released back from the penstock and passes from the reversible pump-turbine to generate electricity. Therefore, pumped-storage plants function like a large battery [17]. Depending on the electrical and mechanical losses in the system, the overall efficiency is about 70 % [24]. These plants can be regarded as peak load plants and they provide additional peak load capacity to the national electricity system. The combined use of pumped storage facilities with other types of electricity generation creates large cost savings through more efficient utilization of base-load plants. Graphical representation of a pumped-storage plant is given in Figure 4.

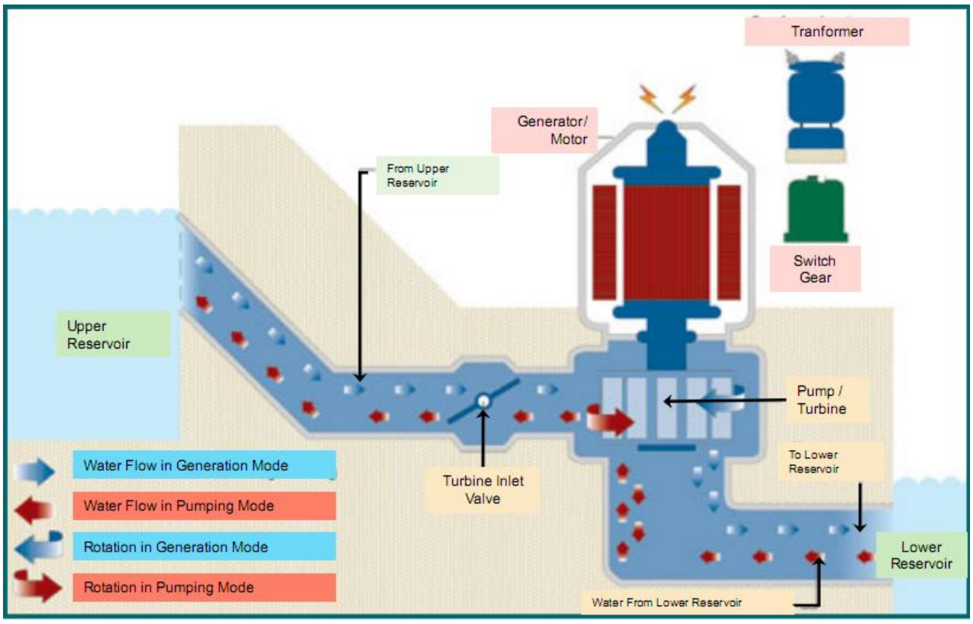


**Figure 4 Pumped Storage Plant [26]**

#### 2.1.3.2 Classification According to the Installed Capacity

There is no consensus in the world on the classification of hydropower plants according to installed capacity. They can be classified as large, small, mini, micro and pico hydropower plants.

- European Commission and European Small Hydro Association consider the hydropower plants with an installed capacity of 10 MW or less as small hydropower [27]. Plants with higher installed capacity are categorized as large.
- India and China considers the upper value for small hydropower as 25 MW [28] and 50 MW [29], respectively.
- The U. S. Department of Energy defines small hydropower as facilities that have a capacity of 100 kW to 30 MW [22].
- In Turkey, the upper limit for small hydropower is accepted as 50 MW [30].

Mini, micro and pico hydropower plants could be regarded as small hydro power plants; however, they have specific technical characteristics and deserve their own definition. Different countries and organizations have different definitions. An example is the one made by Natural Resources Canada. According to this definition [31];

| | |
|---|---|
| Mini hydropower | 100 kW to 1 MW |
| Micro hydropower | 10 kW to 100 kW |
| Pico hydropower | less than 10 kW |

### 2.1.3.3 Classification According To Operating Conditions

- Base Load Plants: These plants operate continuously at a nearly constant power and provide the power demand at base of the load curve (Figure 5). Storage type and run-of river plants can provide base load service.
- Peak Load Plants: These power plants are designed primarily for the purpose of supplying the peak load of a power system (Figure 5). Pumped-storage plants are good examples of peak load plants. Storage type plants may also provide peak load service. Run-of-river plants can supply peak power only if they have a pond.

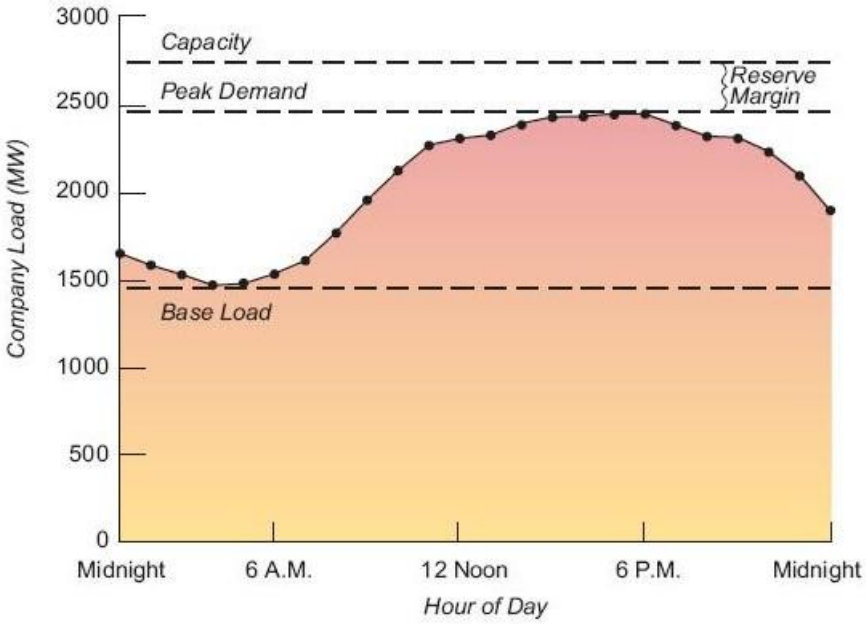


**Figure 5 A typical daily load curve [32]**

#### 2.1.3.4 Classification According to Head

Power that can be generated in a hydroelectric power plant depends on the flow regime in the river and the available head. Since head is an important parameter in describing a power plant, classifying the plants according to the available head would be meaningful. Başeşme classifies the hydropower plants according to available head as follows [33];

| | |
|---|---|
| Low head | $H < 10$ m |
| Medium head | $10 \text{ m} < H < 50$ m |
| High head | $H > 50$ m |

### 2.1.4 Hydropower Potential

Hydropower potential is generally evaluated in three categories, namely theoretical, technical and economical potential.

*Theoretical potential* is defined as the sum of the annual energy potentially available from all natural flows from the largest rivers to the smallest creek, regardless of the losses.

*Technical potential* is the part of theoretical potential which can be utilized with the current technology regardless of economic and other considerations. This definition of potential subtracts friction losses in water ways and efficiencies in the electro-mechanical equipment as well as the extreme low heads which are considered as infeasible. Technical potential is a function of theoretical potential. Since changes in hydropower technology is not rapid and no big changes are expected in the near future, technical potential can be accepted as constant [34]. In other words, it does not vary with time. Öziş [34] estimates the effect of these inevitable losses as 50 %.

*Economic potential* is the part of the technical potential which can be regarded as economic when compared to alternative sources of power like oil and coal. It is dependent on the cost of alternative sources. Therefore, it may change with time and should be updated regularly.

Union of the Electricity Industry (EURELECTRIC) uses a definition called *exploitable hydropower potential* for the portion of the economical potential which can be harnessed considering environmental and other special restrictions [35]. Moreover, International Hydropower Association (IHA) often uses *realistic potential* for 80 % of the economical potential.

### 2.1.5 Hydropower in the World

The demand for energy in the world is continuously increasing with the increase in population and level of industrialization. Global energy use has risen by 70 % since 1971 and continuously increases by approximately 2 % every year [1].

In 2007, hydropower contributed 15.6 % of the world's power generation (Figure 6). When generation from pumped storage plants is added, the total hydropower generation becomes 3162 TWh which is 16 % of the world's electricity generation for the year 2007 [4].

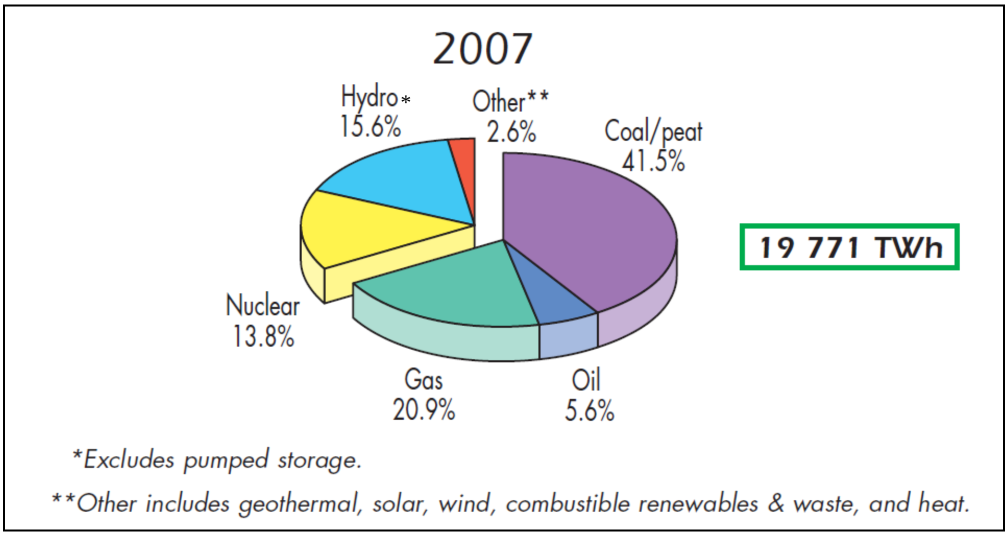
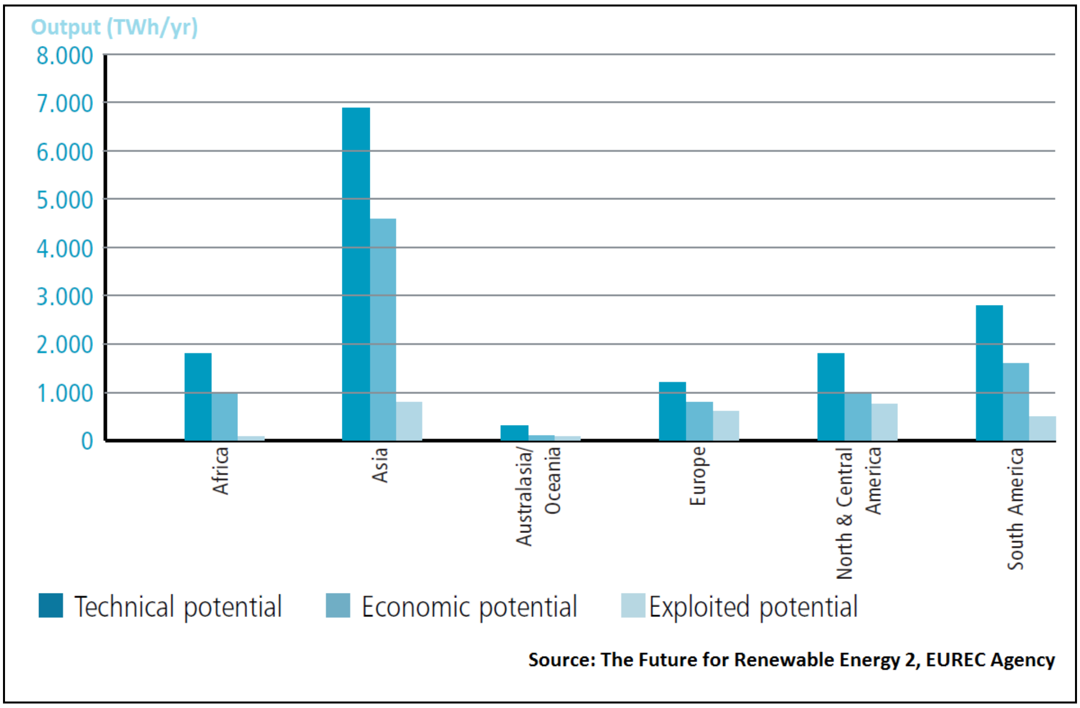


**Figure 6 Fuel share of electricity generation in 2007 [4]**

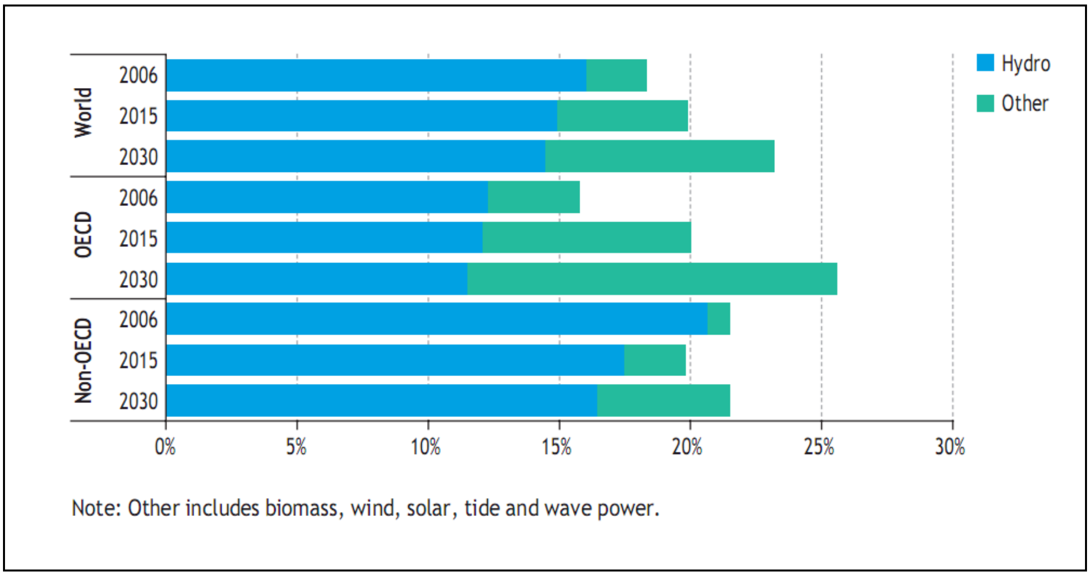
Hydropower provides the majority of supply in 55 countries and for several countries it is the only domestic energy resource [3]. Although hydropower is a mature technology and has been utilized for a long time, much of the potential remain to be developed. World's technical and economical potentials are estimated as 14370 TWh/yr and 8080 TWh/yr, respectively [21, 36]. However, only one-third of the economical potential has been developed yet. Much of the remaining potential exists in Asia, Africa and South America. At the same time, these continents are precisely where the needs for water and energy are the greatest [5]. On the other hand, all Western countries had exploited most of their rivers for hydroelectricity generation by 1975 [37]. Deployment of the hydroelectric potential by continents is given in Figure 7.



Source: The Future for Renewable Energy 2, EUREC Agency

Figure 7 Total hydropower potential by continent [38]

Among the renewable energy sources of electricity, hydropower is in the leading role. International Energy Agency expects this role to remain the same in the future (Figure 8). In the future, hydropower utilization is expected to increase. In non-OECD countries, for instance, hydroelectricity generation is expected to double between 2006 and 2030. However, as can be seen from Figure 8, share of hydropower in total electricity generation is in a decreasing trend. This is because the use of other renewables as well as fossil fuels increases faster than hydropower [39].



Note: Other includes biomass, wind, solar, tide and wave power.

**Figure 8 Share of total electricity generation from renewables by region [39]**

### 2.1.6 Hydropower in Turkey

Turkey’s theoretical hydroelectric potential is 433 TWh/yr, which is 1 % of that of the World and 16 % of Europe’s potential. The technical potential is 216 TWh/yr. DSİ estimates the economical hydroelectric potential as 140 TWh/yr. However it also estimates that the economical potential will reach 150 TWh/yr as a result of projects developed by the private sector [6]. Bakır [40], on the other hand, claims that the economical potential should be much greater. He proposes new criteria for the peak power, firm and secondary energy benefits than those are used by DSİ in feasibility studies. According to these new criteria, which consider some ignored benefits of hydropower plants, and overestimated benefits of thermal power plants, he estimates the economical hydroelectric potential of Turkey as 188 TWh/yr [40].

Although Turkey has a huge hydropower potential, only 35 % of it is currently utilized [6]. Table 1 shows the current situation of hydroelectric power plants (HEPPs) in Turkey.

**Table 1 Status of economical potential of HEPPs as of 2009 [6]**

| Status of Economical Potential | Number of Hydroelectric Power Plants | Total Installed Capacity (MW) | Average Annual Generation GWh/yr | Ratio (%) |
|---|---|---|---|---|
| In Operation | 172 | 13700 | 48000 | 35 |
| Under Construction | 148 | 8600 | 20000 | 14 |
| In Program | 1418 | 22700 | 72000 | 51 |
| Total Potential | 1738 | 45000 | 140000 | 100 |

Turkey has more than a hundred years of hydropower history. The first power generation had been from a hydropower plant in 1902 by the Ottoman Empire. It was a 2 kW dynamo connected to a water-mill in Tarsus, providing electricity only for the lights in Tarsus [7, 41]. However, real increase in hydropower utilization started after the Second World War with the construction of large dams and hydroelectric power plants [42], as can be seen from Figure 9.

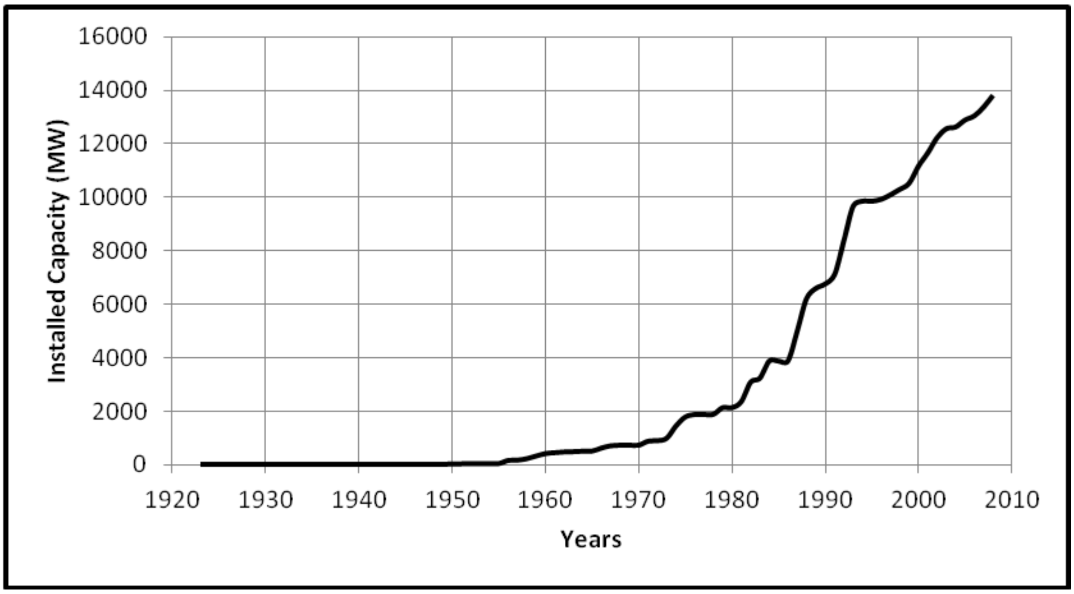


**Figure 9 Development of hydroelectric power plants [43]**

Large dams are defined by ICOLD (International Committee on Large Dams) as the dams having a height of more than 15 m or a reservoir volume of more than 3 $hm^3$. DSİ reports that as of 2009, there are 673 large and 657 small dams according to ICOLD's classification [44]. However, not all of the dams are for energy generation. As seen in Table 1, there are 172 HEPPs in Turkey. Most of the dams serve other purposes like irrigation, water supply and flood control, while some are multi-purpose dams.

Level of energy consumption is an indication of the level of industrialization and prosperity of countries. Annual energy consumption per capita has reached 2900 kWh recently in Turkey. It is slightly above world's average (2500 kWh), but is very low when compared to the average of developed countries (8900 kWh) [44]. Turkey has taken steps to reach the level of developed countries in economic terms for decades. As of 2009, it is the 17th largest economy in the world [45]. Hydroelectric power plants have played an important role in Turkey's development. Share of hydropower in electricity generation reached important levels, even surpassed thermal generation in some years, and reached its maximum with 60.3 % in 1988 (Figure 10) .

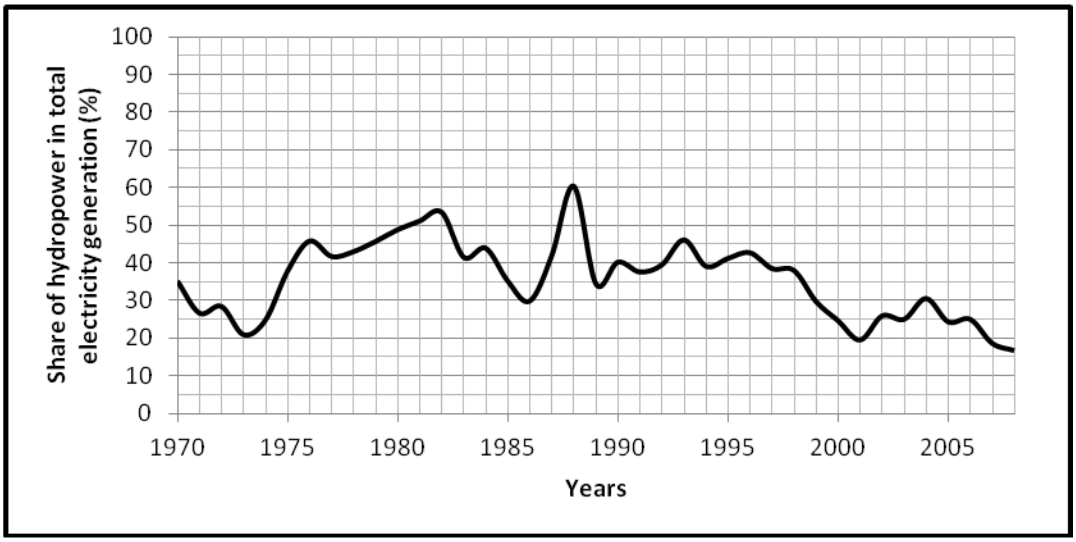


**Figure 10 Share of hydropower in total electricity generation between 1970 and 2008 [43]**

In the last decade, installed capacity of hydropower plants in Turkey increased significantly (Figure 9). However, this trend cannot be observed in the share of hydropower in total electricity generation. Share of hydropower is in a decreasing trend, while the share of thermal generation continuously increases (Figure 11). In 2008, 16.8 % of the total electricity generation is supplied by hydropower plants, while 82.7 % of the electricity is generated by thermal power plants. Geothermal and wind power generation only supplied 0.5 % of the total electricity generation [43]. Küçükali and Barış [46] point a problem arising from this situation: Increasing use of fossil fuels, especially natural gas, led the Turkish electricity market to be highly dependent on thermal plants. As Turkey does not have natural gas and oil sources, increase in utilization of such sources makes Turkey a net energy importing country.

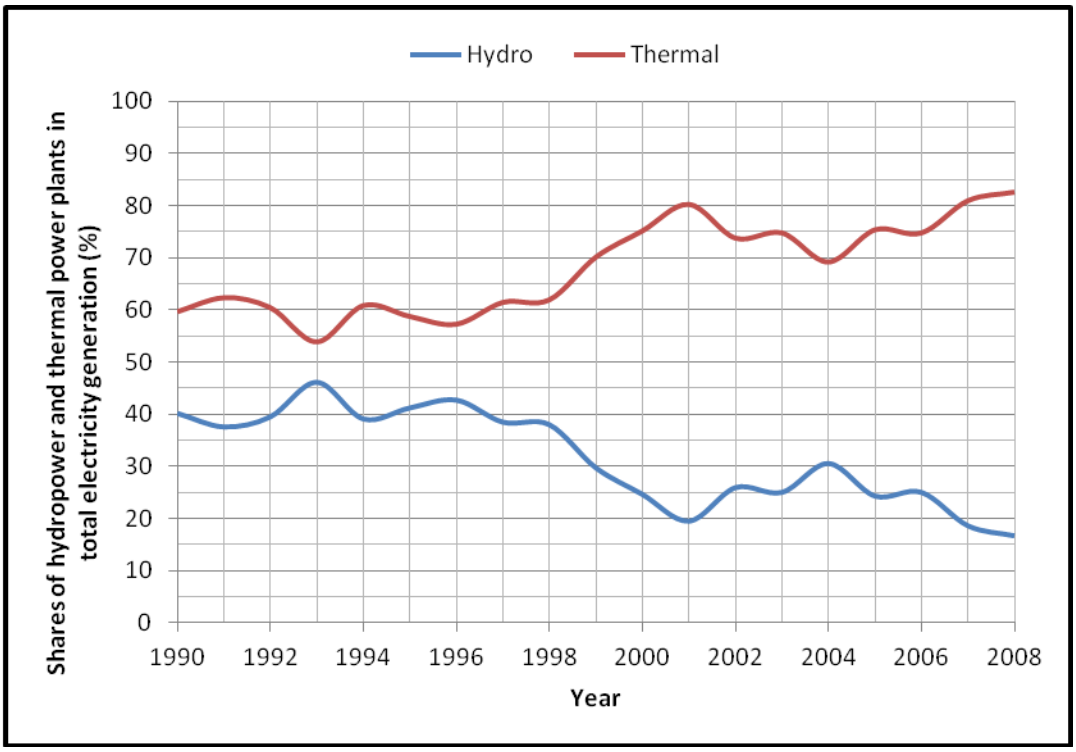


**Figure 11 Turkey's gross electricity generation by share of primary energy sources [43]**

Turkey is a developing country and as it develops, its energy need increases. Annual increase in electricity consumption in Turkey is around 6-9 % except for the recession years (Table 2).

**Table 2 Peak Load and Electricity Consumption in Turkey in 1999-2008 [8]**

| Year | Peak Load (MW) | Increase (%) | Electricity Consumption (GWh) | Increase (%) |
|---|---|---|---|---|
| 1999 | 18938 | 6.4 | 118485 | 3.9 |
| 2000 | 19390 | 2.4 | 128276 | 8.3 |
| 2001 | 19612 | 1.1 | 126871 | -1.1 |
| 2002 | 21006 | 7.1 | 132553 | 4.5 |
| 2003 | 21729 | 3.4 | 141151 | 6.5 |
| 2004 | 23485 | 8.1 | 150018 | 6.3 |
| 2005 | 25174 | 7.2 | 160794 | 7.2 |
| 2006 | 27594 | 9.6 | 174637 | 8.6 |
| 2007 | 29249 | 6.0 | 190000 | 8.8 |
| 2008 | 30517 | 4.3 | 198085 | 4.2 |

For 2009, the Turkish Electricity Transmission Corporation (TEİAŞ) expects a 2 % decrease in electricity consumption due to economic recession [8]. However, the increasing trend of electricity consumption is expected to continue in the coming years. Several researchers developed models to estimate the future electricity demand of Turkey [47-50]. The most recent demand projection has been made by TEİAŞ in June 2009 considering the effects of economic crisis which has started in 2008. While determining the demand series, it is assumed that the increase in the energy demand will be low in 2010 and 2011 due to the effect of the economical crisis. For the following years, demand series are calculated by using MAED (Model for Analysis of Energy Demand) model and peak load values are calculated by assuming no change in the annual load curve characteristics for the study period [8].The results of this study are presented in Table 3 and Table 4 for low demand and high demand cases respectively.

**Table 3 Demand forecast for low demand case [8]**

| Year | Peak Load | | Electricity Demand | |
|---|---|---|---|---|
| | MW | Increase (%) | GWh | Increase (%) |
| 2009 | 29900 | | 194000 | |
| 2010 | 31246 | 4.5 | 202730 | 4.5 |
| 2011 | 32964 | 5.5 | 213880 | 5.5 |
| 2012 | 35173 | 6.7 | 228210 | 6.7 |
| 2013 | 37529 | 6.7 | 243500 | 6.7 |
| 2014 | 40044 | 6.7 | 259815 | 6.7 |
| 2015 | 42727 | 6.7 | 277222 | 6.7 |
| 2016 | 45546 | 6.6 | 295519 | 6.6 |
| 2017 | 48553 | 6.6 | 315023 | 6.6 |
| 2018 | 51757 | 6.6 | 335815 | 6.6 |

**Table 4 Demand forecast for high demand case [8]**

| Year | Peak Load | | Electricity Demand | |
|---|---|---|---|---|
| | MW | Increase (%) | GWh | Increase (%) |
| 2009 | 29900 | | 194000 | |
| 2010 | 31246 | 4.5 | 202730 | 4.5 |
| 2011 | 33276 | 6.5 | 215907 | 6.5 |
| 2012 | 35772 | 7.5 | 232101 | 7.5 |
| 2013 | 38455 | 7.5 | 249508 | 7.5 |
| 2014 | 41339 | 7.5 | 268221 | 7.5 |
| 2015 | 44440 | 7.5 | 288338 | 7.5 |
| 2016 | 47728 | 7.4 | 309675 | 7.4 |
| 2017 | 51260 | 7.4 | 332591 | 7.4 |
| 2018 | 55053 | 7.4 | 357202 | 7.4 |

As can be seen from Table 3 and Table 4, electricity demand is expected to increase at a considerably high rate between 2009 and 2018. Turkey has to meet this increasing demand. However, TEİAŞ estimates that in this period, the demand will exceed firm electricity generation even in the best case (Table 5 and Figure 12). The best case is the combination of low demand and high supply estimates. TEİAŞ calculates the supply according to two different scenarios (Scenario 1 and Scenario 2). These scenarios use different start times for the planned and under construction facilities. Supply in each year is calculated using these different start times. In Scenario 1, power generation facilities start to operate earlier than in Scenario 2.

**Table 5 Demand and supply forecast for the best case (low demand & scenario 1) in accordance with firm generation capacity [8]**

| Year | Supply (GWh) | Demand (GWh) | Generation from HEPPs (GWh) | Hydropower's share in supply (%) |
|---|---|---|---|---|
| 2009 | 209524 | 194000 | 31625 | 15.1 |
| 2010 | 214700 | 202730 | 34486 | 16.1 |
| 2011 | 223368 | 213880 | 36837 | 16.5 |
| 2012 | 244957 | 228210 | 39890 | 16.3 |
| 2013 | 275002 | 243500 | 41229 | 15.0 |
| 2014 | 276003 | 259815 | 41180 | 14.9 |
| 2015 | 278128 | 277222 | 41141 | 14.8 |
| 2016 | 281477 | 295519 | 43645 | 15.5 |
| 2017 | 280779 | 315023 | 43645 | 15.5 |
| 2018 | 276995 | 335815 | 43645 | 15.8 |

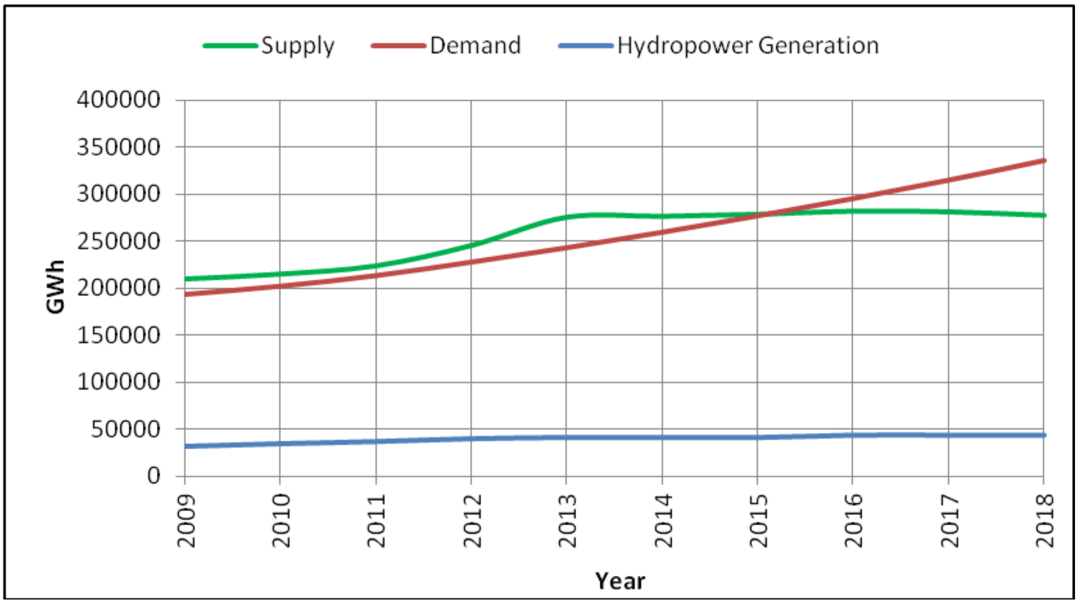


**Figure 12 Demand and supply forecast for the best case [8]**

As can be seen in Table 5 and Figure 12, in the best case, where the demand is low and supply is high, a shortage of electricity is expected in 2016.

For the worst case which is a combination of high demand and low supply (low supply corresponds to Scenario 2 in TEİAŞ's study), a shortage of electricity is expected in 2014 (Table 6 and Figure 13).

**Table 6 Demand and supply forecast for the worst case (high demand & scenario 2) in accordance with firm generation capacity [8]**

| Year | Supply (GWh) | Demand (GWh) | Generation from HEPPs (GWh) | Hydropower's share in supply (%) |
|---|---|---|---|---|
| 2009 | 209278 | 194000 | 31479 | 15.0 |
| 2010 | 213924 | 202730 | 34114 | 15.9 |
| 2011 | 222416 | 215907 | 36340 | 16.3 |
| 2012 | 234119 | 232101 | 39187 | 16.7 |
| 2013 | 258346 | 249508 | 40343 | 15.6 |
| 2014 | 263547 | 268221 | 40294 | 15.3 |
| 2015 | 265672 | 288338 | 40255 | 15.2 |
| 2016 | 269021 | 309675 | 42759 | 15.9 |
| 2017 | 268323 | 332591 | 42759 | 15.9 |
| 2018 | 264539 | 357202 | 42759 | 16.2 |

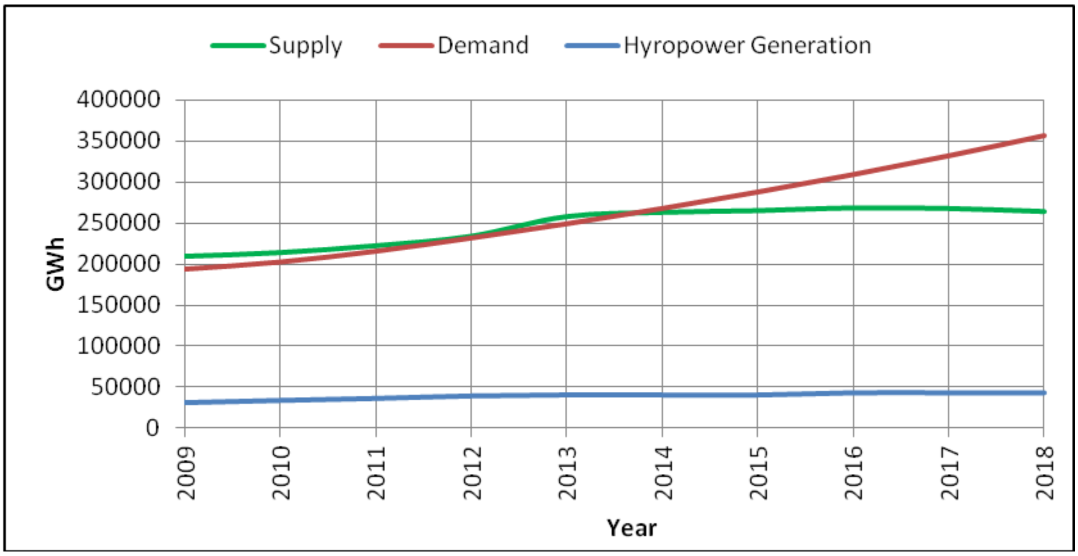


Figure 13 Demand and supply forecast for the worst case [8]

Supply in the best and worst cases above is defined in terms of firm generation capacity. Firm generation capacity is calculated by taking into account maintenance, planned outages, forced outages, hydrologic conditions and rehabilitation schedule or power plants. For example, for hydropower plants, dry hydrologic conditions are assumed when firm generation capacity is calculated.

It is obvious that, even if Turkey develops all of its economical hydropower potential, it will not be sufficient to meet the demand in the future. However, since it is a reliable, domestic, emission-free and renewable resource providing clean, fast and flexible electricity generation, it should be prioritized in the energy policy together with other renewable energy technologies such as wind and solar power.

### 2.1.7 Advantages and Disadvantages of Hydropower

Hydropower is the most widely used renewable energy technology. It is a mature technology and its strengths and weaknesses are equally well understood [3]. Advantages and disadvantages of hydropower schemes can be listed in terms of economic, social and environmental aspects.

#### 2.1.7.1 Economic Aspects

The cost of bringing new power options to the marketplace follows a similar trajectory for most technologies. It increases during research and development and falls off substantially after full scale demonstration. The technology reaches maturity with the deployment of a large number of units [51]. Hydropower is at the end of that trajectory being the most mature technology among other renewable technologies (Figure 14).

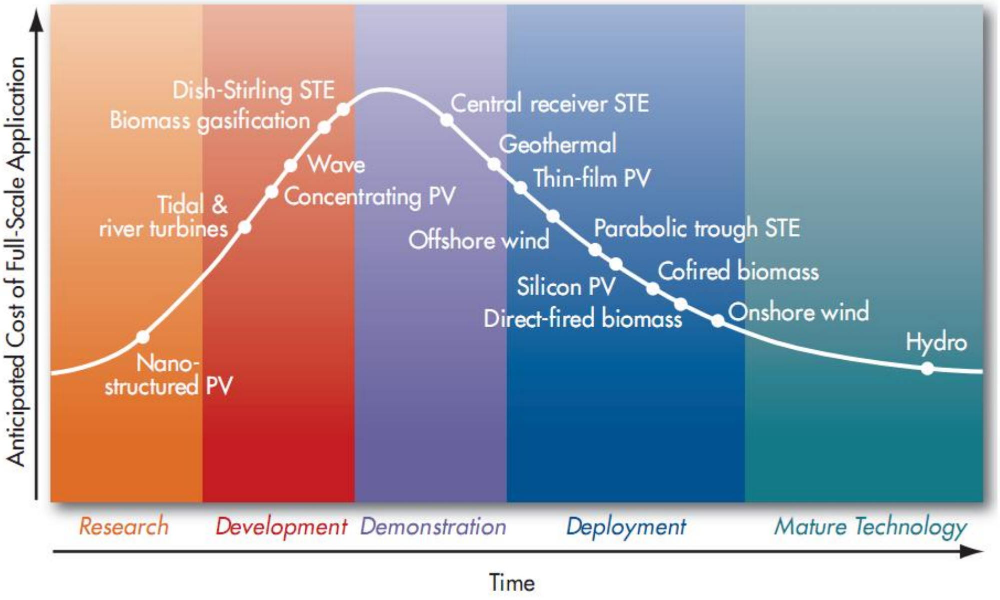


Figure 14 Renewables Technology Development [51]

Hydropower plants can provide peak load service. Their fast response times enable them to meet sudden fluctuations in demand and this improves electricity grid stability and reliability. Production from hydropower plants can start within just a few minutes while the time needed for other turbines are as much as 30 minutes [52]. This feature, when combined with a storage capacity, offers a unique operational flexibility that can assist the development of other less flexible and less reliable renewable energy technologies such as wind and solar power.

Hydropower projects have a long life span of 50 to 100 years or more, unlike thermal plants having a lifetime of 25 to 30 years. Also operation and maintenance costs of hydropower plants are very low when compared to thermal plants [3].

Moreover, hydropower projects have the highest energy payback ratio among other electricity generation options (Figure 15). Energy payback ratio is the ratio of energy produced during the normal life span of a power plant divided by the energy required to build, maintain and operate it. As can be seen from Figure 15, energy payback ratio of hydropower plants with reservoir is around 200 while it is less than 10 for coal and natural gas. The highest energy payback ratio belongs to run-of river plants, which is around 270.

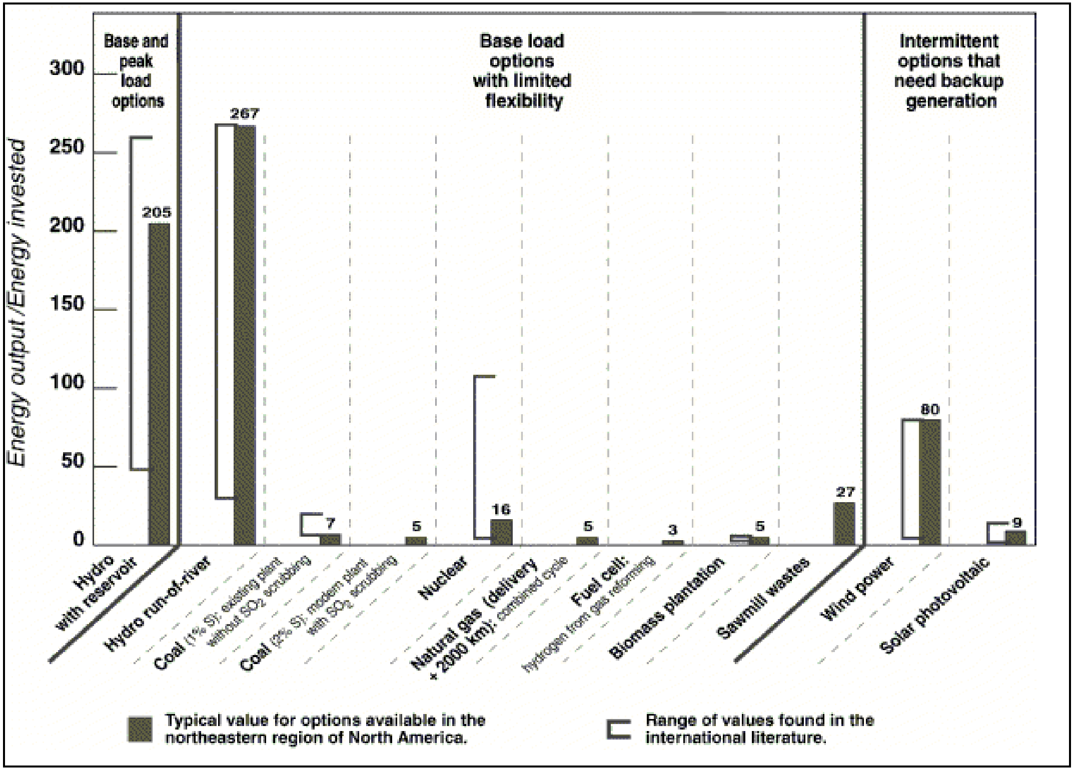


**Figure 15 Energy payback ratio of energy options [53]**

Water is a domestic resource and hydropower uses its energy without depleting it. Actually, this is the definition of “renewable energy”. All hydropower plants, whether a run-of-river or a storage plant, meet this definition. Since water is a domestic resource, hydropower provides independency in terms of energy and fosters energy security and price stability. In Turkey, total electricity generation in 2008 was 200 TWh [43]. Hydropower plants generated 33.3 TWh while thermal plants using natural gas generated 100 TWh [43]. These thermal plants consumed 21.6 x $10^9$ $m^3$ natural gas [43]. If the entire economic hydropower potential (140 TWh) had been utilized, there would have been no need for thermal plants running with natural gas. If the price of 1000 $m^3$ natural gas is assumed to be roughly \$400, the saved import cost would be \$8.6 billion. If all hydropower potential is utilized, 70 % of Turkey’s demand for 2008 can be generated from hydropower. Most of the remaining electricity demand would be met by lignite (42 TWh [43]), which is also a domestic resource. This scenario will result in dependency on foreign resources to decrease significantly.

Another economic benefit of the hydropower plants is that some of the plants with reservoirs are used for water supply and irrigation purposes as well.

There are some disadvantages of hydropower plants in economic terms. For large scale projects the most important economic disadvantage is the need for high upfront investment and long term planning. In this point of view, large hydropower projects are not solely adequate as a complete solution in the short term. However, for small scale projects this disadvantage disappears.

Small hydropower plants, especially run-of river plants without storage are dependent on precipitation. In dry hydrologic seasons, small plants may not be able to generate the expected amount of electricity. This is one of the most important drawbacks of run-of river-plants. For hydropower plants with storage, however, hydrologic conditions do not have a pronounced effect, since these plants can store water in seasons of high flows and use it in dry seasons.

Another problem that may arise during the lifetime of a hydropower plant with storage is the decrease in storage capacity of its reservoir due to sedimentation. Moreover, alteration of sediment transport regimes could result in degradation at the downstream of dams. Magnitude of the degradation can sometimes be significant as in the case of Aswan High Dam on the Nile. The downstream of the dam was reported to be lowered by 2-3 meters in the years following the completion of the dam, leaving irrigation intakes high and dry and bridges being undermined. Further degradation is expected to be around 6-8 meters [54, 55]. However, sedimentation effect can be minimized through sediment management methods such as sediment routing, erosion control, sediment flushing and sediment removal by mechanical dredging or siphoning [56].

### 2.1.7.2 Social Aspects

Hydropower projects can have both positive and negative social impacts. According to IHA [3], hydropower has a huge potential for improving social justice, as long as projects are developed and managed in a way that enhances equity between:

- Present and future generations
- Local and regional communities
- Vulnerable social groups and society at large
- Nations

Equity between present and future generations is enhanced through the use of clean and renewable resources. Therefore, present generations do not deplete natural resources, saving them for future generations and maintaining a cleaner world by minimizing the use of fossil fuels.

Hydropower projects often provide flood control, supply water for domestic and agricultural uses, enhance navigation conditions and accessibility of the territory with access roads and bridges, and provide employment opportunities for the local communities. In many places, hydropower alone facilitated the social and economic development of societies. For example, development of the arid regions of the western USA has only been possible through the construction of dams and in Asia the so-called “Green Revolution”, which has led to large increases in food production over the last 40 years, is to a large extend supported by dams [3].

Hydropower projects may have negative effects on local communities. Negative social impacts of hydropower projects are mainly associated with displacement of people living at and in the close vicinity of the dam and the reservoir area. For large projects, number of people forced to resettle reaches millions. For instance, more than 1.2 million people are relocated due to Three Gorges Dam in China although the reservoir area is typically regarded as a poor mountainous area with little development [57]. Even if the population to be relocated is not very high, serious social conflicts may appear. The San Juan Dam in Mexico was indefinitely postponed when confronted with a tough opposition from the local Indian population. The residents affected by the Chico River project in the Philippines joined the guerillas to stop the project [58]. However, there is a growing awareness about the consequences of resettlement in the world. The countries suffering the most from these consequences in Asia and Latin America have developed comprehensive strategies for compensation and support for the affected people. Successful examples revealed the key concepts in resettlement actions as [52]:

- Timely and continuous communications between developers and those affected
- Adequate compensation, support and long term contact
- Efforts to ensure that the disruption of relocation is balanced by some benefits from the project.

One of the successful examples is Birecik Dam in the Southeastern Anatolia Region of Turkey. 30000 people were affected and 6500 of them were subject to resettlement due to the construction of the dam [59]. In the planning and implementation process of the project, public awareness and participation were sought. Questionnaires and public meetings were arranged and the final shape of the plans was given under the guidance of public opinion. New settlement areas were chosen by the affected people. Besides the funds awarded to the ones affected, new income generating facilities like beekeeping and new crop types suitable to the region were introduced in order to compensate for the losses due to the dam construction. A Multi-Purpose Community Center (ÇATOM) was established in order to facilitate social adaptation to the new settlement area.

Another social impact of hydropower projects arise from the land requirements [3]. Especially large projects with reservoirs can inundate fertile lands, and cultural heritages. For example, Ilısu Dam in Southeastern Anatolia will inundate Hasankeyf, an international heritage which witnessed numerous civilizations for 12000 years [60].

These negative impacts of hydropower projects are mostly related with large hydropower projects with reservoirs. Run-of-river plants do not require large areas. Actually, when compared to other energy options, a run-of river hydropower plant is one of the least land requiring options [53]. As can be seen from Figure 16, run-of river plants need 1 km$^2$/TWh while hydropower plants with reservoir and biomass plantation need 152 km$^2$/TWh and 533 km$^2$/TWh, respectively. Therefore resettlement and land requirement problems are irrelevant for these types of projects.

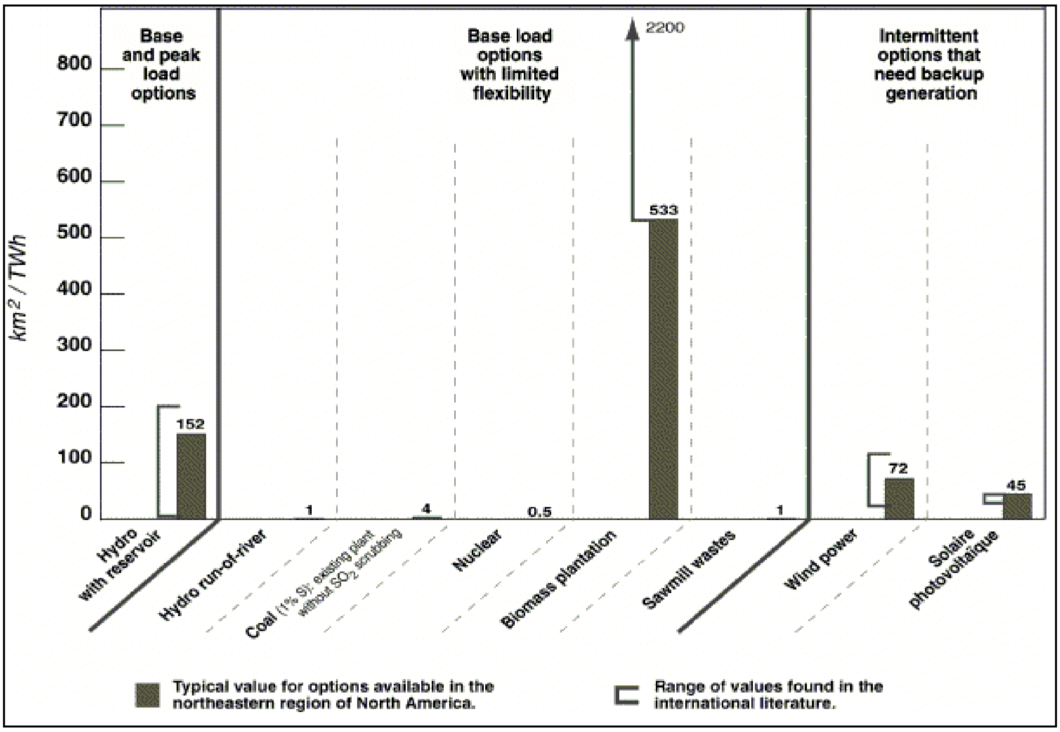


**Figure 16 Land requirements of energy options [53]**

Although run-of-river hydropower plants have relatively small impacts as compared to storage plants, they are also confronted with public opposition. Construction of access road, transmission lines and powerhouse can damage unique ecosystems. Moreover, these plants may negatively impact human activities such as fishing and ecotourism. Since water is diverted from its natural course, the locals who use the water for drinking or irrigation purposes may be affected. Some of them earn their living from the river and they may have to move their house in search of other jobs. Their lifestyle are altered and threatened.

#### 2.1.7.3 Environmental Aspects

United Nations Environment Programme (UNEP) recognizes climate change as a major global challenge that will have significant and long lasting impacts on human well-being and development. The main drivers of climate change are anthropogenic greenhouse gas (GHG) emissions, especially $CO_2$ [61]. GHG emissions are mainly produced by burning of fossil fuels. On the other hand, hydropower plants produce very small amount of GHGs when compared to other energy options (Figure 17). The source of GHG emissions in hydropower plants is the rotting of organic matter from the vegetation and soils flooded when the reservoir is first filled. By offsetting GHG emissions from gas, coal and oil fired power plants, hydropower can help slow down global warming. Studies have shown that development of even half of the world’s economically feasible hydropower potential could reduce GHG emissions by about 13 % [52].

Furthermore, hydropower plants do not emit any air pollutants. A coal-fired plant can emit 1000 times more $SO_2$ (main cause of acid rain) than a hydropower plant when the fuel required to build the hydropower plant is taken into account [52]. Increased utilization of hydropower plants can help reduce emissions of $SO_2$ as well as other air pollutants like nitrous oxides, thus leaving a cleaner air to future generations and minimize life losses which are estimated at 2 million each year [61].

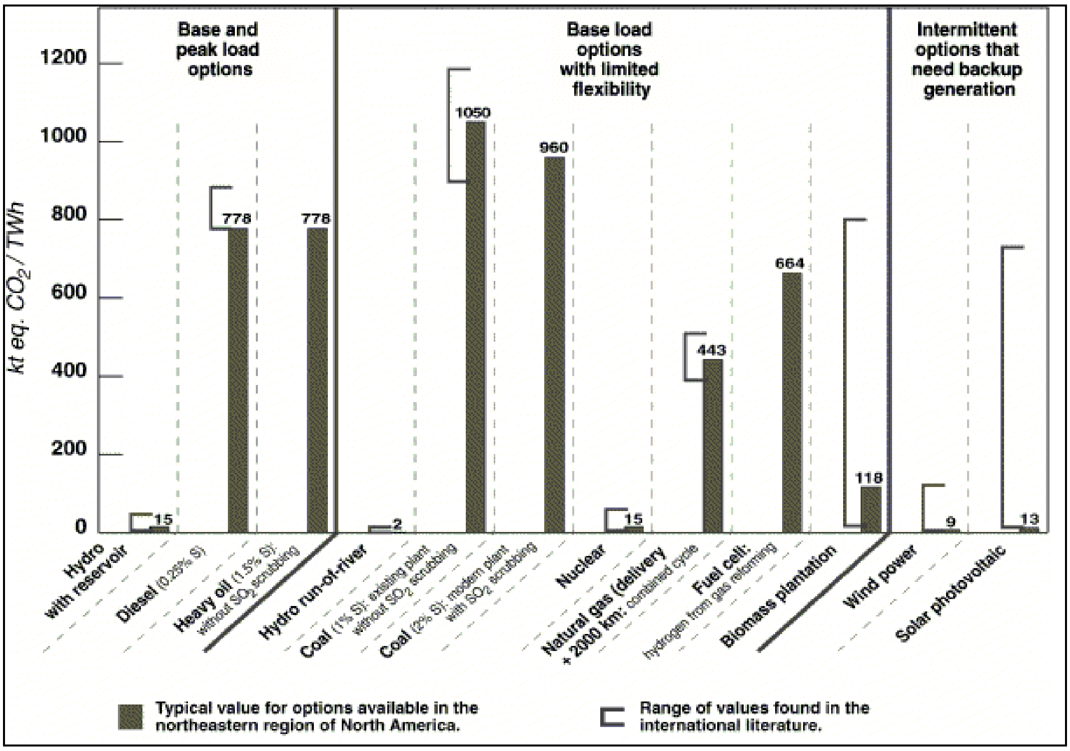


**Figure 17 Greenhouse gas emissions of energy options [53]**

Hydropower projects may also have environmental impacts depending on the project size, especially the reservoir size. The water in the reservoir area increases the humidity and softens the climate around the project area. Increased humidity affects the flora and fauna of the region. Parlak [62] reports that the construction of Atatürk Dam in southeastern Turkey has led to a decrease in the efficiency of peanut and tobacco production in Şanlıurfa and Adıyaman due to increased humidity. However, increase in humidity resulted in an increased production rate for a diverse set of crops. For example, production rate of cotton increased after construction of Atatürk Dam [63].

Dams alter the flow and sediment regime in river channels. As a result, river channels respond to altered sediment transport regimes through geomorphologic changes. When natural sediment content of a river is trapped by a dam, the downstream bed of the dam starts to erode. Since water is stored in the reservoir, the amount of water to be released decreases. The change in flow regime can have detrimental effects on aquatic ecology and habitats [3, 54].

One of the possible negative impacts of dams is the prevention of fish and other aquatic life from traveling upstream. Their reproduction cycle is disturbed. More importantly, the ecology of the entire river basin is at stake since the natural biological interchanges along the river course are disturbed. Nutrient supply to downstream areas will be changed and insect life will be affected. Migration of the living aquatic organisms will be prevented and the existing food webs and biodiversity conditions will be changed [54].

Water temperature is also affected by hydropower projects. In some cases very sensitive ecosystems may suffer from temperature changes [54]. Water quality of the stored water is another issue to be considered regarding the environmental effects of hydropower systems. Decaying organic material and blooms of algae may cause anaerobic processes to be set up in the reservoir, making it impossible for aquatic life to sustain [54].

Besides the aquatic life, terrestrial life can also be affected from hydropower projects. Habitats of some species can be inundated. For example in Balıkesir, Turkey, a colony of more than 20000 bats, were living in the caves which are now under water due to the construction of Havran Dam. However, in this case, DSİ constructed artificial caves and eventually the bat colonies have settled in the artificial caves after the natural caves are inundated [64].

Although environmental impacts of run-of-river hydroelectric plants are smaller as compared to plants with reservoirs, they may also affect the ecosystems. The main problem is that water is diverted from its natural course into channels or tunnels and released back into a downstream section of the river. This results in a decrease in the amount of flowing water between the points where it is diverted and released back. Fish life in these river sections may not survive. Moreover, migration of fish may also be disturbed by run-of-river plants.

In East Blacksea Region of Turkey, people strongly oppose construction of hydroelectric plants. The area has a rich ecosystem with 2300 plant species, 550 of which are endemic [65]. On the other hand, there is a huge hydropower potential in the region. In Çoruh Basin, around 10.5 TWh of electricity can be generated every year, which is one third of the hydroelectricity generated in Turkey in 2008, and this potential is planned to be harnessed by 15 hydropower plants with storage and 22 run-of-river plants [66]. However, local communities are so concerned about the environment that they took most of the projects into court. In Turkey, more than 25 HEPPs are suspended or cancelled by courts [67]. Most of the time, HEPPs are taken to court claiming that these HEPPs damage the environment and destroy the social life at and in the vicinity of the project area.

In Turkey, preparation of an Environmental Impact Assessment (EIA) Report is obligatory for HEPP projects with installed capacities of 25 MW or more [68]. Ministry of Environment and Forestry evaluates the EIA report and issues an “Environmental Impact Assessment is Positive” or “Environmental Impact Assessment is Negative” decision. For “negative” decisions, owners may make a new application after revising the EIA report. Projects failing to get an “EIA is positive” decision cannot be realized. Projects with installed capacities between 0.5 MW and 25 MW are subject to the Selection and Elimination Criteria. The owner prepares a “Project Presentation File” [68]. Ministry of Environment and Forestry decides whether EIA is required or not.

EIA Regulation in Turkey has been changed in 2008 to comply with the EU Directives, and a strong legal infrastructure now exists for EIA procedure [69]. However, there are significant deficiencies in implementation, monitoring and control of EIA procedure. Structure of the EIA report examining commission is specified in the regulation. However, the qualifications and experience of these members are not mentioned. Objectiveness of these commissions is often questioned by the stakeholders. Moreover, there are some issues related to public participation in the EIA Regulation. In the Selection and Elimination Procedure, there is no obligation to consult public opinion. Public participation meetings are mandatory only in the EIA process. However, there is no binding article for the decision makers to reflect the public opinions to the final decision. Therefore, participation in Turkey is generally performed by judicial power [69].

### 2.1.8 Planning and Implementation of Hydropower Projects

Hydropower planning covers a wide range of topics. Professionals from many disciplines take part in the planning and implementation of hydropower projects. Civil engineers, mechanical engineers, electrical engineers, geologists, economists, ecologists, sociologists and many other experts combine their skills in order to develop an optimum design considering technical, financial, environmental and social aspects of hydropower development.

Hydropower project development consists of three main parts:

- Preconstruction
- Implementation
- Operation and Maintenance

#### 2.1.8.1 Preconstruction Phase

The most important part of the project development takes place in the preconstruction phase since the majority of the investigation, planning and design studies are completed in this phase.

There may be several alternative projects to be investigated and each alternative has different properties to be considered. These alternatives are investigated in several consecutive stages with increasing order of detail, importance and reliability. The stages of preconstruction phase are:

- Reconnaissance studies
- Prefeasibility studies
- Feasibility studies

In each of these stages, the alternatives are investigated to the depth necessary for reaching a conclusion on their suitability for the stated purpose. The alternatives failing to meet the requirements of that stage are eliminated, and the remaining ones pass to a new stage where more detailed investigations and evaluations are carried out. This elimination procedure saves money and time since the redundant and less attractive options are eliminated at the early stages.

#### 2.1.8.2 Reconnaissance Studies

These studies are the first step to project planning and the main concern is the identification and investigation of the alternatives. At this early stage of planning, the successful identification and evaluation of the alternatives rely on experienced hydropower planners. The investigations are generally headed by engineers with an extensive experience of planning and construction of hydropower projects. Contractor experience is also needed for costing and scheduling estimations. Contribution of these experienced engineers helps to formulate well balanced project with more practical engineering solutions [70].

For reconnaissance studies, as a first step, all relevant data and information are collected about the power market, hydrology, geology, topography, environment and socio-economy, etc. Using the available data, planners try to establish the main parameters for the project, such as flow, head and environmental constraints. These parameters are not definite but subject to continuous revisions and adjustments throughout the planning process.

With the established tentative parameters, initial planning of the project starts. Several layouts are prepared and with field trips, the suitability of these layouts to the project area is evaluated and unsuitable options are discarded.

Preliminary cost estimates are also prepared using the tentative parameters; and the assessment of the economic viability of the projects is carried out. Alternatives are compared according to the generation capabilities (cost per kWh annual generation).

At the end of the reconnaissance studies, a report is prepared to reflect the planners' opinions about the suitability of the project together with the findings of the study.

#### 2.1.8.3 Prefeasibility Studies

In this stage, the identified projects are brought one step further in the planning process. More detailed investigations are carried out in order to produce more reliable results.

Geological investigations are extended to include drilling, sampling and testing in areas where foundation uncertainties exist since these uncertainties can have a major effect on costs. Moreover, availability of construction materials and suitable borrow pit locations are investigated, preliminary selection of the main project characteristics such as installed capacity and project type (whether run-of river or storage) are realized, possible environmental and social impacts of the alternatives are identified.

With the prefeasibility investigations done and more detailed data obtained, the alternative projects are studied and tested in order to improve project plans. Benefits and costs are estimated based on major quantities and comparison of alternatives is realized.

At the end of prefeasibility studies, a comprehensive report is prepared. Based on this report owners of the project decide whether or not to continue investigations. It also enables the owners to provide a basis for appropriation of funds if they decide to continue investigations.

#### 2.1.8.4 Feasibility Studies

Feasibility study is a comprehensive analysis and detailed study of the proposed project. It is carried out in order to determine whether the potential development is technically, economically and environmentally feasible and justifiable under anticipated economic conditions [70].

Feasibility studies include estimation of diversion, design and probable maximum floods, determination of power potential for a range of dam heights and installed capacities for project optimization, preliminary design of main structures, earthquake effect analysis, optimization of the project layout, water levels and components, detailed cost estimates, development of cash flow tables, production of implementation schedule and development plans, economical and financial analyses and environmental impact assessment [70, 71].

At the end of the feasibility study, a feasibility study report is prepared. This report should provide firm, detailed and reliable information about the project since the owners decide whether or not to go for implementation of the project. Moreover, the report is important for the funding of the project. Lending agencies require these reports in order to determine the desirability of financing the cost of development [70].

The report of the feasibility studies also serves as application documentation for the development license. In Turkey, companies willing to develop a hydropower project prepare a feasibility report and submit it to DSİ in the very early stages of their application to obtain their Independent Power Producer License.

In this study, two alternative projects for Niksar HEPP project, in addition to the one proposed by DSİ, are developed and investigated especially in terms of economical aspects. The analyses carried out in this study are generally performed in pre-feasibility and feasibility phases of the project development cycle in practice.

### 2.1.8.5 Implementation

The implementation phase of the project consists of three stages: 1) definite plan study, 2) tendering and contracting, and 3) construction. Although these stages are presented as separated tasks, most of the parts are carried out simultaneously as the project progresses.

In the definite plan studies, the project is given its final formulation and configuration. The detailed designs of the project components are finalized. Tender drawings are prepared. All of the details of civil engineering, electromechanical and transmission works are determined. Road relocation designs, specifications and bill of quantities, schedules for construction and supply, and financial plans are prepared providing the basis for tendering procedure.

Tendering and contracting procedure starts with prequalification of tenderers, then the tenders are evaluated and eventually contracts are signed after negotiations and bargaining.

After a contractor is awarded with the contract, construction starts. In the construction stage, some of the design works continue. Workshop drawings, as-built drawings, operation and maintenance manuals, training of operation personnel continues along with construction works. The construction works conclude when all of the civil engineering, mechanical, electrical and transmissions works are finished.

#### 2.1.8.6 Operation and Maintenance

Last but not the least is the operation and maintenance stages. The purpose of operation and maintenance is to reduce failure risk and ensure the smooth operation of the facility. In order to achieve this, preventive maintenance schedules should be prepared beforehand. Each component of a hydropower project has an economic life. By careful inspection and repairing, life span of these components can be extended saving considerable amount of money. In some cases, however, renewal of some components can be more feasible. For example, Keban Dam in Turkey will be rehabilitated and turbines will be renewed. This operation will cost €50 million. However, annual increase in the income will be $50 million due to increased efficiency [72]. This means that the cost of the rehabilitation will be compensated in 1-2 years.

Hydropower plant operations are generally automated and remote controlled. Therefore, a small number of employees are necessary. Periodic cleaning and small repair works are carried out by the staff employed in the power plant, whereas, large maintenance tasks, overhaul and repair are usually contracted to manufacturers of electricity generation equipment.

### 2.1.9 Sustainable Development of Hydropower

Sustainable development is defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [73]. The role of hydropower in sustainable development has been recognized by the United Nations. The Beijing Declaration on Hydropower and Sustainable Development adopted at the United Nations Symposium on Hydropower and Sustainable Development, Beijing, China, 29 October 2004 states that [74]:

“*Having considered the social, economic and environmental dimensions of hydropower and its potential contribution to achieving sustainable development goals, we firmly believe that there is a need to develop hydropower that is economically, socially, and environmentally sustainable.”*

Hydropower, large or small, was identified as one of the renewable sources to be developed with a sense of urgency in the Political Declaration signed by Ministers and Government Representatives from 154 countries in the International Conference for Renewable Energies, which is held in Bonn, Germany in 2004 [75]. However, developing the remaining hydropower potential offers many difficulties. Concerns about environmental and social performance of hydropower projects draw the attention of public, in an unprecedented magnitude. In some cases, projects have been cancelled due to public resistance. However, the review of the successful applications in the hydropower sector reveals that the hydropower projects can be truly sustainable when they fully account for their environmental and social costs [76].

In order to guide the projects to be developed in a sustainable way, some national and international organizations have published guidelines. In 1998, Task Committee on Sustainability Criteria, Water Resources planning and Management of American Society of Civil Engineers published a report on Sustainability Criteria for Water Resources Systems. In 2004, the International Federation of Consulting Engineers (FIDIC) published Project Sustainability Management Guidelines [77].

In February 2004, the International Hydropower Association (IHA) published Sustainability Guidelines to “promote greater consideration of environmental, social and economic aspects in the sustainability assessment of new hydro projects and the management and operation of existing power schemes” [78]. The key points of the Sustainability Guidelines are [3]:

- Encouragement for the development of national energy policy plans
- Reducing the carbon intensity of energy production
- A full evaluation of energy alternatives

- A comparison of hydroelectric project alternatives
- The application of environmental impact assessment principles for new projects
- Operational practices which take into account of legal and institutional arrangements, incorporate environmental management systems and safety considerations
- Optimizing environmental outcomes by identifying issues and mitigation strategies
- Consideration of social equity issues at all stages of project implementation through a planned programme of community consultation

IHA Sustainability Guidelines emphasize the importance of planning, implementation and operation based on an open, transparent and effective decision-making process. The guidelines recognize that sustainable development is the collective responsibility of government, business and the community and call for increased cooperation and coordination between these actors.

IHA has also developed a Sustainability Assessment Protocol in order to assist IHA members in assessing performance of new or existing hydropower projects against criteria described in the IHA Sustainability Guidelines. The first section of the assessment protocol describes the selected sustainability aspects and lists key considerations and assessment requirements for each aspect. The second part is used to evaluate and score the hydropower projects against a large number of sustainability aspects [79].

## 2.2 RETScreen Clean Energy Analysis Software

### 2.2.1 Assessment Tools for Small Hydropower Projects

Developing a hydropower project requires a great deal of money and time as well as expertise in engineering. Investors and developers are very meticulous when spending time and money. Any tool that can help to save money and time can easily attract their attention. In order to enable a prospective developer to make an initial assessment of the economic feasibility of a project, numerous computer based assessment tools have been developed. These tools range from very simple programs to quite advanced software packages. The main objective of these tools is to predict the energy output of a particular hydropower scheme. Some of them can perform other tasks such as cost estimation or financial analysis as well. Wilson [80] evaluated available tools that are used for an initial assessment of a small hydropower project. Table 7 shows some of the main features of small hydropower assessment tools.

**Table 7 Assessment methods for small hydro projects [80]**

| **Assessment Tool** | | **Features** | | | | |
|---|---|---|---|---|---|---|
| Product | Applicable Countries | Hydrology | Power & Energy | Costing | Economic Evaluation | Preliminary Design |
| ASCE Small Hydro | USA | ✓ | | | | |
| HES | USA | ✓ | | | | |
| Hydra | Europe | ✓ | ✓ | | | |
| IMP | International | ✓ | ✓ | | | |
| PEACH | France | ✓ | | ✓ | | ✓ |
| PROPHETE | France | ✓ | ✓ | | ✓ | |
| Remote Small Hydro | Canada | ✓ | ✓ | | ✓ | |
| RETScreen | International | ✓ | ✓ | ✓ | ✓ | |

As can be seen in Table 7, only IMP and RETScreen are developed such that they can be applied for projects in different countries around the world. Both can make hydrology and energy calculations. However, RETScreen has also cost estimation and financial analysis features. Since our goal here is to find cost based optimum alternative for Niksar HEPP project, RETScreen is used in this study to evaluate alternatives.

### 2.2.2 RETScreen Clean Energy Project Analysis Software

The RETScreen Clean Energy Project Analysis software (from here on it will be referred to as RETScreen) is developed by CanmetENERGY, Natural Resources Canada [81]. Natural Resources Canada is specialized in the use of natural resources and sustainability. The CanmetENERGY is the Canadian leader in clean energy research and technology development [82]. Support is provided by an international network of experts from industry, government and academia in the development of RETScreen. RETScreen is developed in collaboration with a number of other government and multilateral organizations other than CanmetENERGY. Principle partners include the National Aeronautics and Space Administration (NASA), the Renewable Energy and Energy Efficiency Partnership (REEEP), the United Nations Environment Programme (UNEP) and the Global Environment Facility (GEF) [81].

The RETScreen software can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs) [81]. The software is available in 35 languages including Turkish and provided free of charge. It also includes product, project, hydrology and climate databases, a detailed user manual.

#### 2.2.2.1 RETScreen Objectives

Numerous opportunities for implementing commercially viable energy efficient and renewable energy technologies around the world are currently being missed because planners and decision makers do not routinely consider them [83]. Even when these technologies have proven to be cost effective and reliable, planners and decision makers often fail to appreciate the benefits of these technologies at the critically important initial planning stage. The result then is missed opportunities that could otherwise help countries meet energy needs locally, in a sustainable way, while reducing greenhouse gas emissions, saving money and increasing energy security and self-reliance [84]. This is one of the main reasons why CanmetENERGY developed RETScreen. The software aims to help planners, decision makers and industry to implement renewable energy and energy efficient projects.

The RETScreen software is designed to be used primarily at the pre-feasibility and feasibility levels of project development cycle. It significantly reduces the costs and helps developers to save time while identifying and assessing potential energy projects and alternatives at the critically important initial planning stage [85]. It is a very practical tool to determine whether work on the project should proceed further or to be dropped. According to an independent impact assessment of the RETScreen International, the user savings attributed to the software between 1998 and 2004 are estimated to be $ 600 million worldwide, and expected to reach $ 7.9 billion by 2012 [83].

RETScreen is not a detailed engineering design tool. It provides rough estimations of the project cost. Indeed, in the pre-feasibility and feasibility stages, cost estimations are not expected to be very accurate. Figure 18 shows accuracy of project cost estimates throughout the project completion period. At the prefeasibility stage, project cost accuracy is within ± 40 % to 50 % of the final cost. As the work progresses and more detailed calculations are made, accuracy increases.

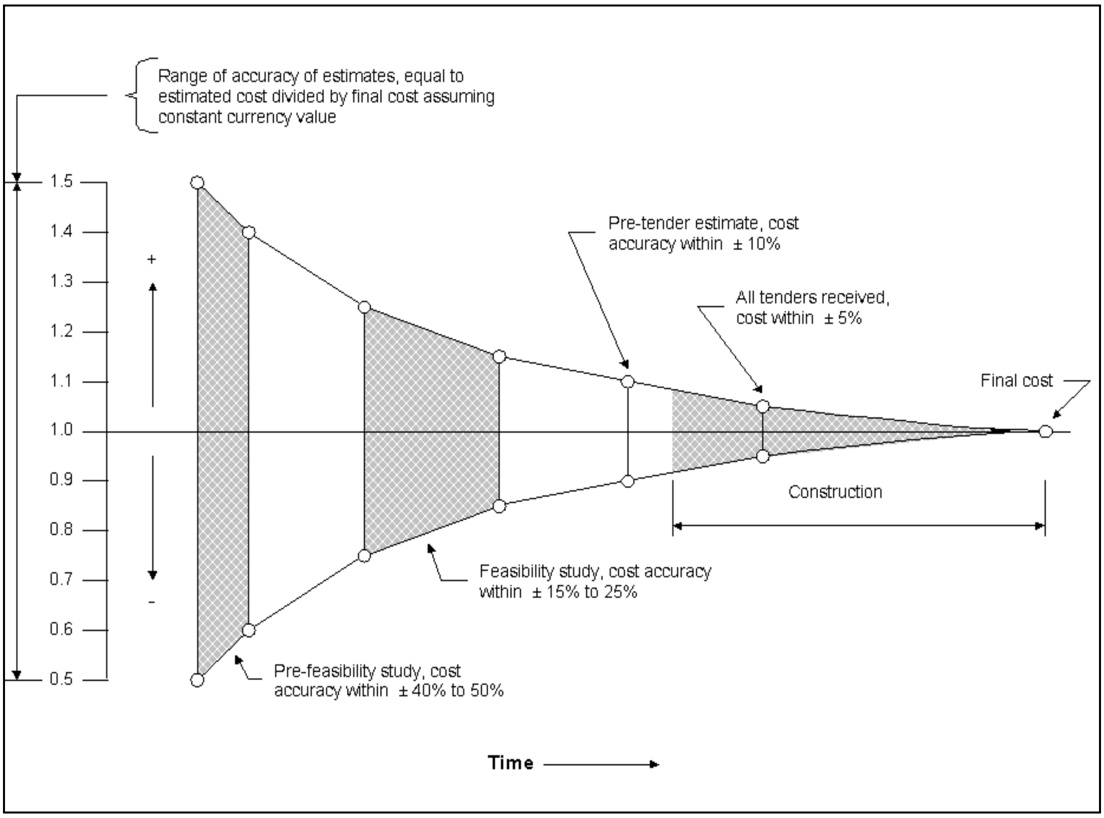


**Figure 18 Accuracy of the project cost estimates [86]**

### 2.2.2.2 Software and Data

The RETScreen software can be used to evaluate a wide range of conventional and renewable energy technologies. Some of the models integrated into the software are:

- Hydropower
- Wind Energy
- Photovoltaic
- Ocean Current
- Fuel Cell
- Gas Turbine
- Biomass Heating
- Solar Air Heating

- Wave
- Geothermal
- Combined Heat & Power (CHP)
- Energy Efficiency Measures, etc.

The software runs on Microsoft® Excel workbooks. On the start sheet the project type and the technology used in the system is selected. For each technology, there are integrated meteorological and equipment performance data used by the software. Some additional data regarding the costs and financial parameters are also needed to evaluate the financial aspects of the project. Since gathering these data may be very expensive and time consuming the software integrates a series of databases to overcome this problem. However, the user can enter data manually at any time.

Although each technology has its own analysis model, a five step standard analysis procedure is common for all of these technologies. Figure 19 shows the five step standard analysis procedure.

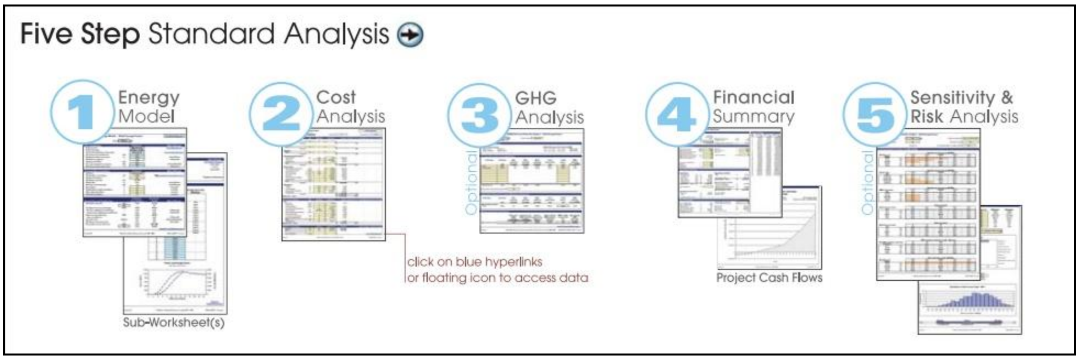


Figure 19 Five step standard analysis used by the RETScreen software [87]

**Step 1 – Energy Model:** In this worksheet, some parameters describing the project layout, equipment and technology to be used and load(s) or resource(s) (hydrology in the hydropower case) are entered by the user. The software then calculates some other values such as the annual energy production and power capacity of the plant.

**Step 2 – Cost Analysis:** There are two alternatives to carry out cost analysis. In the cost analysis worksheet, the software allows the user to enter the initial, annual and periodic costs. In cost analysis sheet, all of the costs are entered by the user. The second alternative for cost analysis is called the “hydro formula costing method”. This method is based on empirical cost formulas and is described in more detail in Section 4.1.3.

**Step 3 – Emission Analysis or Greenhouse Gas (GHG) Analysis:** This is an optional worksheet. It can be used to determine reduction in the emission of greenhouse gases as a result of using a renewable or clean technology instead of conventional technologies.

**Step 4 – Financial Analysis:** In this worksheet, the user enters the financial parameters needed for a financial analysis. These parameters include inflation, discount rate, debts, taxes, etc. Using these parameters together with the costs and electricity price, RETScreen calculates some financial indicators to evaluate the viability of the proposed project. Some of these indicators are internal rate of return (IRR), net present value and benefit-cost ratio. Yearly cash flows together with a cumulative cash flow diagram are also presented in the financial analysis worksheet.

**Step 5 – Sensitivity & Risk Analysis:** This is another optional worksheet. It helps user determine how uncertainty in some input parameters may affect the overall financial viability of the project.

# CHAPTER 3

# A CASE STUDY FROM TURKEY: NiKSAR HEPP

Niksar HEPP is a part of Lower Kelkit Project Master Plan Report, which is prepared by State Hydraulic Works (DSİ) in 1990.

## 3.1 Lower Kelkit Project Master Plan Report

Project area is located in Black Sea Region of Turkey. It is at the downstream of Kelkit Stream, within the boundaries of Tokat and Sivas.

The master plan report [88] aims to utilize the hydroelectric potential in Yeşilırmak Basin. The project area is bounded by Çamlıgöze Dam on Kelkit Stream at the upstream and Hasan Uğurlu Dam on Yeşilırmak at the downstream. There is 535 m of gross head available. This much of head is planned to be converted into energy by means of five consecutive run-of-river hydropower plants:

1. Koyulhisar HEPP
2. Reşadiye HEPP
3. Akıncı HEPP
4. Niksar HEPP
5. Erbaa HEPP

Koyulhisar HEPP has been completed in 2009 [89]. Reşadiye, Akıncı and Niksar HEPPs are under construction [90-92]. Erbaa HEPP project has been suspended due to “stay of execution” decision of the Council of State in December, 2009 [93]. Some of the basic characteristics of hydropower plants in Lower Kelkit Project are shown in Table 8.

**Table 8 Characteristics of hydropower plants in Lower Kelkit Project [88]**

| | Design Discharge ($m^3/s$) | Available Head (m) | Installed Power (MW) | Annual Electricity Generation (GWh) |
|---|---|---|---|---|
| **Kılıçkaya Dam** | 166 | 86.2 | 120 | 309.55 |
| **Çamlıgöze Dam** | 83 | 23.25 | 16 | 79.4 |
| **Koyulhisar HEPP** | 50 | 102.25 | 38.2 | 311.24 |
| **Reşadiye HEPP** | 50 | 139 | 52.7 | 443.61 |
| **Akıncı HEPP** | 50 | 119 | 45.9 | 391.4 |
| **Niksar HEPP** | 60 | 64.4 | 29.9 | 234.32 |
| **Erbaa HEPP** | 80 | 104.87 | 60.6 | 464.81 |

Kelkit Stream flows along Kelkit Valley. Kelkit Valley stretches along North Anatolian Fault Zone, which is one of the most active fault zones in the world. Therefore, only run-of river plants are considered, avoiding reservoirs for safety reasons. Moreover, there is a serious erosion problem in the valley. Therefore, in order to prevent eroded material from mixing with water, water from Çamlıgöze Dam is directly given to the conveyance systems of subsequent plants without releasing it back to the river. Water drained from the area between two HEPPs is collected by diversion weirs. These weirs are also intended to collect water from upstream HEPP in case the upstream HEPP is out of order for maintenance, breakdown, etc. General Layout of the Lower Kelkit Project is given in Figure 20.

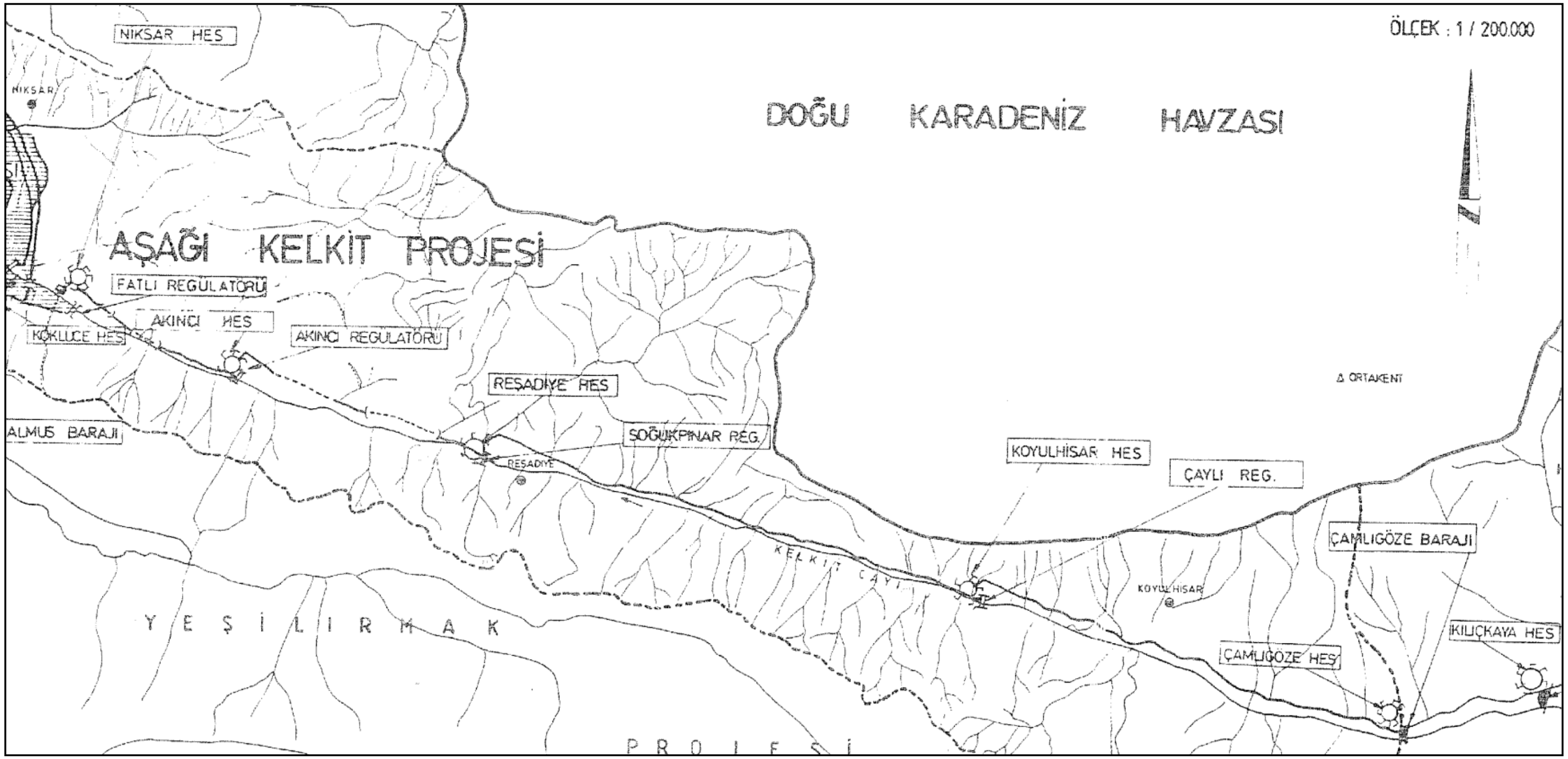


Figure 20 General Layout of Lower Kelkit Project [88]

## 3.2 Niksar HEPP

**Location :** The project area is located in Tokat. It is on Kelkit Stream, which is one of the main branches of Yeşilırmak River. Kelkit constitutes 55 % of Yeşilırmak's total flow [88]. It joins with Yeşilırmak River near Erbaa and flows into Hasan Uğurlu Dam reservoir.

**Mountains :** The project area is mountainous, while the downstream part of Kelkit Stream is flatter. Erbaa Plateau and Niksar Plateau lie in the flatter part. Main mountains are Karaömer Mountain (1959 m), Köse Mountains (1820 m), and Sakarat Mountain (1956 m).

**Earthquake condition :** The area is classified as 1st degree earthquake zone [94]. In the last fifty years, three major earthquakes were recorded with magnitudes larger than 7 on the Richter scale [88]. A detailed earthquake zoning map is given in Figure 21.

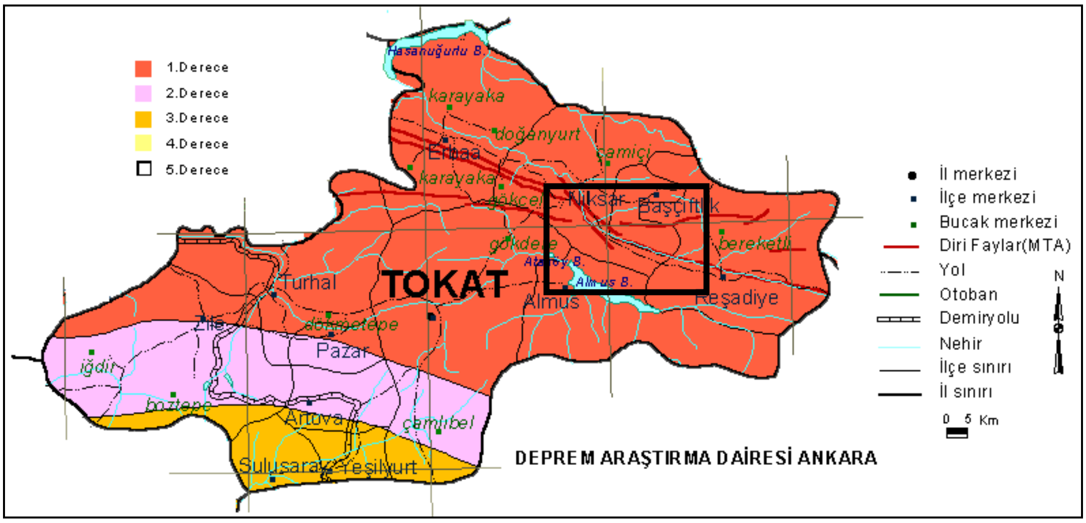


Figure 21 Earthquake zoning map of Tokat [95]

**Water resources :** Kelkit Stream is formed by small creeks arising from Pülür, Otlükbeli, Sarhan, and Bolaban Mountains in Erzincan. Kelkit's mean source elevation is 1500 m. It is 245.5 km long, and has a drainage area of 11445 km$^2$ [88]. Niksar HEPP area shows transitional characteristics between Black Sea and Central Anatolian climates. Rainfall is concentrated in spring. In December-March period, the area is mostly under snow cover. This cover is thicker on the northern and eastern parts of the region. In spring, when snow melts, discharge in Kelkit Stream significantly increases. The discharges at the location of diversion weir of Niksar HEPP between 1966 and 2001 are given in Table 9. These discharges include the effects of upstream plants. The values given in Table 9 are taken from the feasibility report prepared for Niksar HEPP. Due to confidentiality reasons we will refer to this report as The Feasibility Report [96] throughout the thesis.

A flow duration curve gives the percentage of time a given flow has been equaled or exceeded for the period of record [17]. This curve provides information about the future regime of the river and is used to estimate the electricity generation potential of a power scheme at a given location. Flow duration curve can be computed from mean monthly flows or daily flows. It is preferable to use daily flows since there may be significant variation in flow within a month. These variations cannot be seen in monthly flow duration curves. However, daily measurements might not be available for each project. In such cases, mean monthly curves can be used, ignoring the errors involved. These errors usually range from 5 % to 15 % depending on the characteristics of the stream [97]. In order the curve to represent the flow with sufficient accuracy, it is necessary to have a record length of at least 30 years [24, 98]. The flow duration curve is derived from the past flow data, and it is accepted to be time-invariant. In other words, possible changes in future hydrologic regime cannot be accounted for. Therefore, this procedure includes some uncertainties, but it is acceptable for feasibility studies.

For the Niksar HEPP, mean monthly discharges are available for a period of 36 years (1966-2001). Using these discharges, the flow duration curve is obtained and given in Figure 22.

**Table 9 Discharge at Akıncı Diversion Weir [96]**

| Year | Discharge ($m^3$/s) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
| 1966 | 50.1 | 49.5 | 53.5 | 60.3 | 52.8 | 106.5 | 236.6 | 191.2 | 69.9 | 43.6 | 41.2 | 45.2 |
| 1967 | 49.6 | 51.2 | 55.4 | 56.9 | 52.7 | 64.3 | 88.2 | 125.8 | 82.2 | 45.8 | 41.6 | 45.3 |
| 1968 | 51.3 | 51.6 | 58.7 | 57.2 | 53.1 | 74.4 | 460.9 | 313.2 | 97.9 | 44.1 | 42.5 | 46.0 |
| 1969 | 51.6 | 52.7 | 56.2 | 55.1 | 52.9 | 65.3 | 99.4 | 248.4 | 68.9 | 43.0 | 40.3 | 44.3 |
| 1970 | 52.1 | 49.7 | 53.7 | 55.8 | 60.0 | 66.0 | 53.1 | 60.9 | 41.9 | 43.0 | 40.6 | 46.6 |
| 1971 | 54.2 | 55.9 | 62.9 | 65.7 | 59.4 | 77.7 | 86.9 | 63.7 | 57.9 | 48.1 | 48.3 | 54.3 |
| 1972 | 62.5 | 65.8 | 53.3 | 30.9 | 33.8 | 79.4 | 120.5 | 76.9 | 64.6 | 46.9 | 46.8 | 50.6 |
| 1973 | 58.1 | 60.5 | 65.7 | 64.9 | 30.7 | 44.4 | 91.1 | 77.5 | 60.5 | 57.1 | 26.9 | 1.6 |
| 1974 | 11.2 | 22.9 | 23.9 | 14.7 | 16.0 | 65.4 | 84.4 | 73.5 | 55.9 | 44.1 | 45.0 | 53.2 |
| 1975 | 60.0 | 56.9 | 28.1 | 18.2 | 20.1 | 85.0 | 107.9 | 70.6 | 60.2 | 47.3 | 42.9 | 49.4 |
| 1976 | 57.4 | 59.4 | 66.4 | 55.3 | 26.3 | 78.8 | 82.6 | 81.8 | 59.4 | 41.7 | 39.3 | 43.9 |
| 1977 | 53.0 | 50.3 | 52.8 | 54.4 | 58.0 | 65.4 | 79.0 | 90.1 | 69.3 | 41.3 | 40.6 | 44.7 |
| 1978 | 55.0 | 56.8 | 58.3 | 60.8 | 65.5 | 96.5 | 137.1 | 183.2 | 67.2 | 40.8 | 40.9 | 46.8 |
| 1979 | 51.1 | 53.2 | 57.3 | 75.2 | 63.1 | 70.4 | 76.2 | 66.8 | 49.0 | 41.8 | 41.6 | 47.7 |
| 1980 | 54.1 | 60.4 | 58.6 | 59.2 | 56.6 | 87.1 | 82.8 | 195.2 | 51.0 | 42.2 | 39.6 | 43.5 |
| 1981 | 49.5 | 52.3 | 57.6 | 57.9 | 56.8 | 106.7 | 74.1 | 83.4 | 61.0 | 41.2 | 39.8 | 42.9 |
| 1982 | 50.7 | 53.2 | 59.1 | 57.6 | 53.8 | 63.8 | 115.9 | 169.2 | 74.9 | 43.1 | 42.9 | 45.8 |
| 1983 | 48.0 | 51.0 | 53.9 | 56.9 | 52.7 | 76.3 | 93.8 | 124.2 | 44.5 | 43.4 | 42.5 | 48.6 |
| 1984 | 52.5 | 60.2 | 62.4 | 62.7 | 57.1 | 71.2 | 75.0 | 61.6 | 46.6 | 38.9 | 42.1 | 46.4 |
| 1985 | 51.6 | 52.5 | 55.0 | 57.7 | 57.6 | 71.2 | 94.4 | 67.3 | 50.2 | 43.5 | 43.5 | 49.1 |
| 1986 | 58.7 | 64.2 | 69.2 | 69.6 | 67.8 | 71.8 | 80.7 | 104.5 | 75.5 | 47.8 | 44.5 | 47.8 |
| 1987 | 57.5 | 63.4 | 70.2 | 72.1 | 77.8 | 64.1 | 110.6 | 101.1 | 130.1 | 43.1 | 42.2 | 46.5 |
| 1988 | 50.0 | 56.0 | 66.1 | 54.7 | 54.9 | 89.6 | 224.6 | 343.4 | 170.0 | 50.7 | 41.6 | 45.2 |
| 1989 | 59.5 | 197.0 | 210.9 | 149.2 | 123.8 | 185.8 | 220.8 | 74.5 | 44.6 | 40.7 | 41.0 | 46.8 |
| 1990 | 50.8 | 61.7 | 65.2 | 55.5 | 50.4 | 68.8 | 129.4 | 313.1 | 107.8 | 46.2 | 60.7 | 46.4 |
| 1991 | 94.0 | 50.7 | 70.4 | 52.6 | 54.4 | 95.8 | 108.9 | 166.9 | 65.1 | 39.7 | 44.2 | 48.0 |
| 1992 | 55.7 | 60.0 | 78.6 | 57.8 | 53.7 | 73.8 | 114.2 | 139.6 | 91.4 | 51.9 | 53.2 | 62.4 |
| 1993 | 53.9 | 61.5 | 82.2 | 75.0 | 70.1 | 97.1 | 119.0 | 365.6 | 189.4 | 55.3 | 46.9 | 46.5 |
| 1994 | 60.3 | 61.2 | 60.0 | 65.3 | 61.2 | 69.4 | 68.3 | 64.8 | 45.7 | 47.2 | 48.3 | 52.0 |
| 1995 | 60.6 | 57.1 | 64.5 | 99.9 | 83.9 | 92.1 | 102.6 | 84.5 | 54.8 | 43.2 | 46.6 | 53.8 |
| 1996 | 58.6 | 66.3 | 70.6 | 65.1 | 56.7 | 71.0 | 87.9 | 333.4 | 64.0 | 45.0 | 45.5 | 54.5 |
| 1997 | 63.4 | 71.3 | 65.0 | 58.4 | 55.4 | 64.5 | 125.5 | 230.8 | 73.9 | 50.1 | 53.5 | 54.6 |
| 1998 | 57.7 | 53.6 | 59.9 | 60.4 | 57.2 | 71.4 | 249.2 | 291.0 | 155.7 | 47.6 | 48.6 | 46.2 |
| 1999 | 54.2 | 60.1 | 61.7 | 57.0 | 47.6 | 58.0 | 205.1 | 249.7 | 83.7 | 45.2 | 41.7 | 43.2 |
| 2000 | 49.2 | 57.1 | 49.3 | 55.2 | 52.9 | 64.6 | 164.5 | 182.0 | 59.6 | 49.2 | 44.0 | 49.6 |
| 2001 | 53.3 | 54.1 | 61.0 | 63.1 | 61.2 | 71.0 | 65.5 | 72.7 | 53.0 | 53.8 | 58.0 | 60.3 |

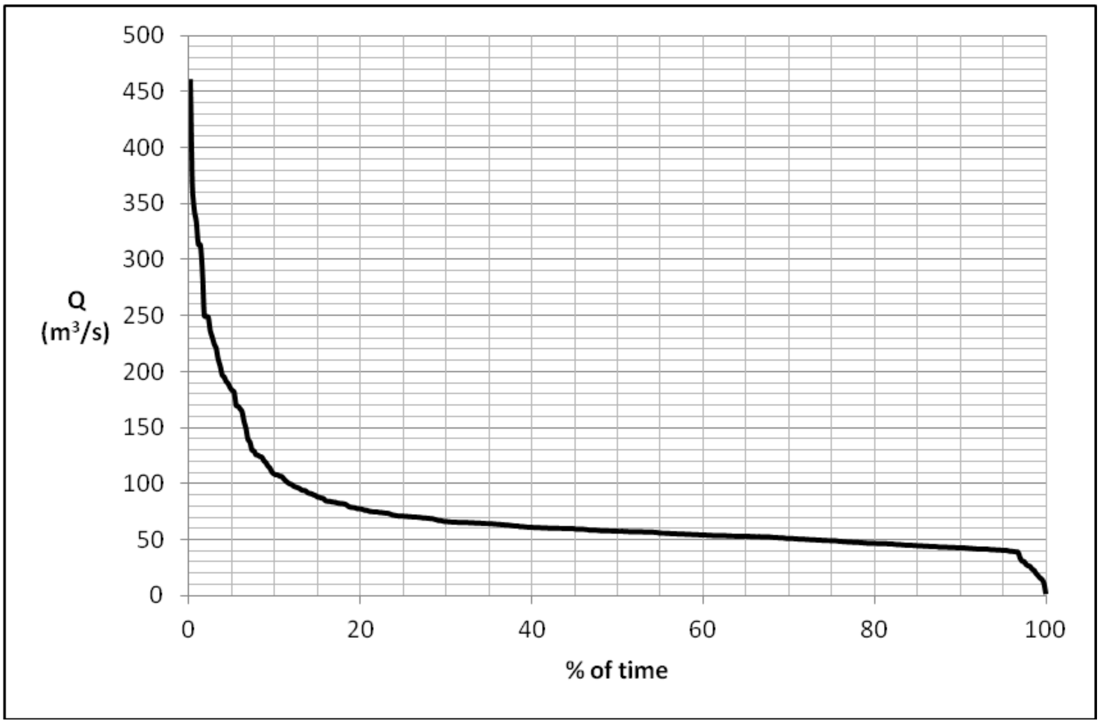


**Figure 22 Flow duration curve of Niksar HEPP**

DSİ defines firm energy as the energy that can be delivered 95 % of the time [99]. As can be seen in Figure 22, the discharge which is exceeded 95 % of the time is approximately 40 $m^3/s$. Figure 22 also shows that the design discharge of Niksar HEPP used in DSİ formulation (60 $m^3/s$) is exceeded about 40 % of the time. As a rule of thumb discharges corresponding to 20-30 % of time are often identified as design discharges for small HEPPs in Turkey.

For energy calculations, the flow duration curve adopted from the Feasibility Report [96] (Figure 22) is used in this study. These data covers the monthly average discharges between 1966 and 2001. However, in order to observe the changes in the flow regime in the recent years, monthly average discharges for 2002-2004 are also collected from another feasibility report [100]. These discharges are presented in Table 10.

**Table 10 Monthly average discharges between 2002-2004 [100]**

| Year | Discharge (m$^3$/s) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
| 2002 | 71.4 | 32.2 | 11.6 | 24.7 | 10.0 | 21.1 | 48.1 | 24.5 | 14.0 | 58.3 | 41.0 | 53.2 |
| 2003 | 48.9 | 56.6 | 31.5 | 16.4 | 11.0 | 14.2 | 86.2 | 89.5 | 71.6 | 53.2 | 33.2 | 30.5 |
| 2004 | 25.7 | 18.1 | 21.5 | 35.4 | 27.1 | 87.6 | 77.9 | 67.7 | 62.3 | 43.8 | 43.4 | 52.4 |

Using the discharges given in Table 9 and Table 10, a new flow duration curve is obtained and it is presented Figure 23.

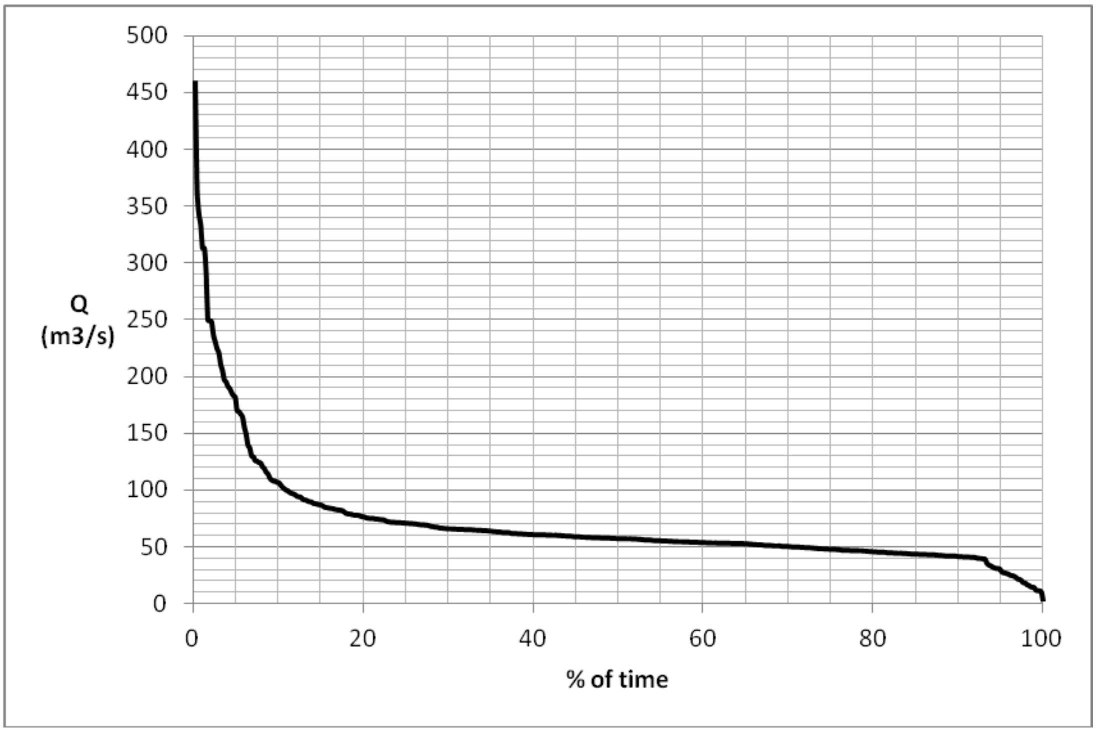


**Figure 23 Flow duration curve of Niksar HEPP, with the addition of the flow data between 2002-2004**

When the two flow duration curves given in Figure 22 and Figure 23 are compared, it can be seen that when the flow data between 2002-2004 is added, the discharge values in the flow duration curve slightly decreases. This means, in the practice, that the expected annual energy generation will decrease. This effect can be seen in Table 11.

**Table 11 Energy production for two different flow duration curves**

| | Energy Production (MWh) | | |
|---|---|---|---|
| **Q ($m^3/s$)** | **with data of 1966-2001** | **with data of 1966-2004** | **Difference %** |
| 50 | 204366 | 200901 | -1.7 |
| 60 | 232626 | 228133 | -1.9 |
| 70 | 250874 | 245619 | -2.1 |
| 80 | 262945 | 256992 | -2.3 |
| 90 | 271871 | 265608 | -2.3 |
| 100 | 279144 | 272892 | -2.2 |

As can be seen in Table 11, when the flow data of 2002-2004 are added, the expected energy production decreases by around 2 % which is not a major decrease. However, it should be realized that flow rate decreased in the river in recent years. This decrease may be due to climate change or changes in upstream river management policy. This effect is observed by including the flow data of only three more years (i.e. 2002-2004). Since more recent flow data is not available to us, the analysis is not complete (i.e. does not involve flow data between 2005-2009). If all the flow data until 2009 were included in the analysis, the change in energy production could have been more pronounced. Therefore, the past flow data is important in estimating the energy production of a system, but the recent trend in the flow regime should be considered carefully as well.

## 3.3 DSİ Formulation for Niksar HEPP

In Lower Kelkit Project Master Plan Report, DSİ proposed a formulation for the layout of Niksar HEPP. In this formulation, water from upstream HEPP (Akıncı HEPP) is directly given to the conveyance system of Niksar HEPP. In addition, Akıncı Diversion Weir is constructed 300 m upstream of Akıncı HEPP in order to collect the natural flow between Soğukpınar and Akıncı Diversion Weirs. The proposed conveyance system of Niksar HEPP is a hybrid one consisting of two tunnels (3320 m in total) and three channels (11080 m in total). At the end of the conveyance system lies a forebay. Water is then released from the forebay through penstock to the powerhouse. The general layout of Niksar HEPP according to DSİ formulation is shown in Figure 24.

Figure 24 General Layout of Niksar HEPP (DSİ formulation)

The available gross head for Niksar HEPP is 64 m and the selected discharge is 60 $m^3/s$. DSİ converts the flow duration curve into the power duration curve and calculates associated net benefits for various power levels. Then these results are used in selecting the design discharge. For this formulation, two Francis turbines with a total capacity of 29.9 MW are found suitable. This power system can generate 234.32 GWh of electricity each year.

## 3.4 Possible Alternatives to DSİ formulation of Niksar HEPP

This study intends to investigate if there are other ways to formulate the Niksar HEPP project such that more energy can be generated with less cost.

Various alterations to DSİ formulation can be implemented. These alterations include changing the following items:

1. Locations of the main components such as diversion weir, forebay and power house,
2. The course of water conveyance system,
3. The design discharge.

Implementation of these alterations will result in various alternatives to DSİ formulation. Each of these alterations is investigated in detail in the following paragraphs.

Locations of the main components

Locations of the major project components are very important for energy production since the gross head is determined from these locations. In order to make changes on the locations of main components of hydropower plants, the topography of the area should be carefully investigated. For preliminary assessment of locations, 1:25000 scale topographic maps are sufficient [70]. However, supplementary field investigations are always useful for a sound conception of the project. The topography of the area may sometimes make it impossible, or infeasible to develop a hydropower project. If it is too flat, for example, available head will be small and this may make the project infeasible.

Another consideration that should be taken into account when deciding the locations of project components is the presence of upstream or downstream power plants. If an upstream hydropower plant exists, the maximum elevation at which water can be taken will be the tailwater elevation of the upstream plant.

For Niksar HEPP, topography of the area and presence of upstream power plant limits the selection of locations of the powerhouse and the diversion weir. In DSİ formulation, the power house is located at a point where the mountainous terrain ends and Niksar Plateau begins. If the powerhouse is moved to a downstream location, increase in the gross head will be negligible because of the level ground of the plateau. If it is moved to an upstream location, decrease in the gross head will be significant since the upstream terrain is mountainous. Therefore, the location of the power house remained unchanged in the alternative projects suggested in this study.

In DSİ formulation, tailwater of the upstream Akıncı HEPP is taken to the conveyance system of Niksar HEPP just after the Akıncı HEPP. If the diversion weir and water intake structure of Niksar HEPP is located at a higher elevation, tailwater of Akıncı HEPP will be missed. On the other hand, if these structures are constructed at a downstream part, the available gross head will decrease. Therefore, like power house, diversion weir and water intake are kept in their original locations suggested by DSİ.

Since the option to change locations of powerhouse and diversion weir is eliminated, the alternative projects are generated by changing the course of the water conveyance system and the design discharge.

The course of the water conveyance system

By the help of 1:25000 scale topographic map and satellite images, two alternative paths for water conveyance were found suitable and worthy for further investigation. The plan view of these alternatives is shown in Figure 25.

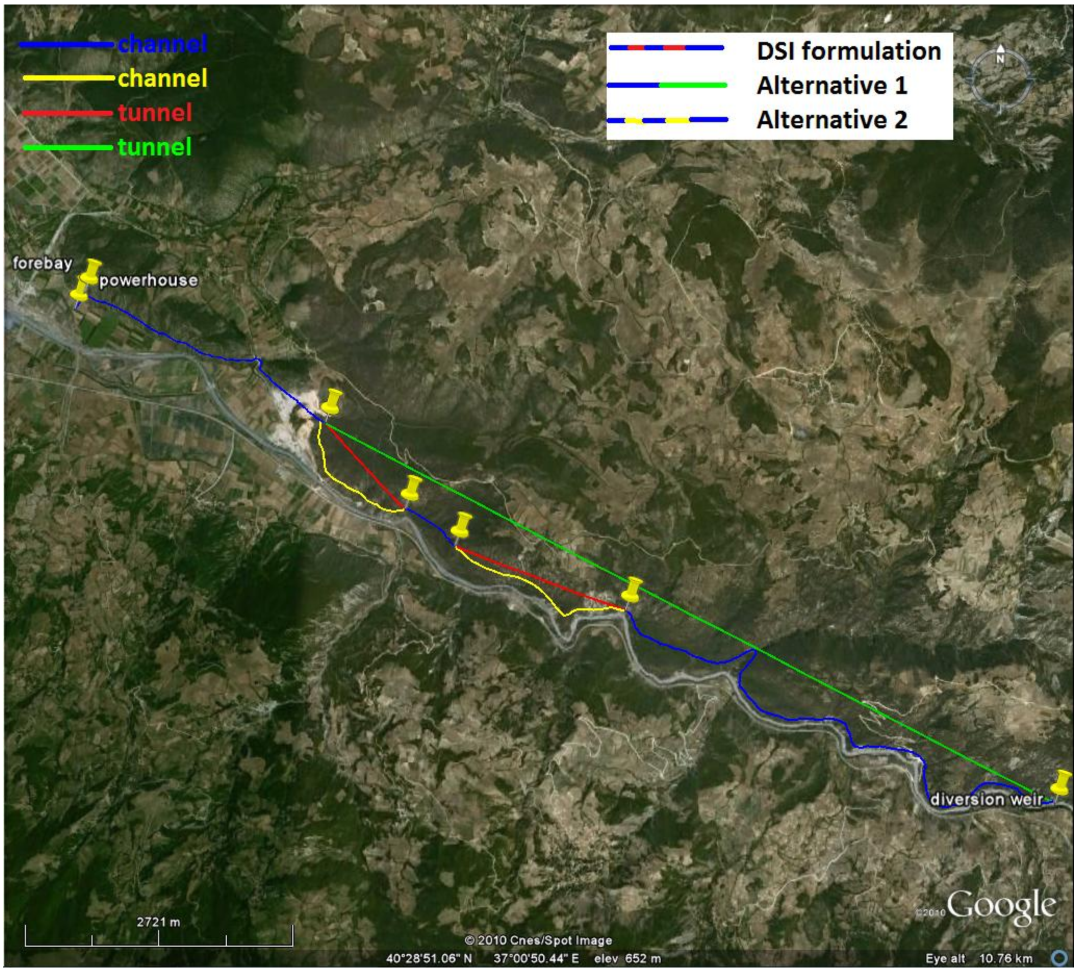


**Figure 25 DSİ formulation and the alternatives**

The topographic conditions at the site can be observed better in Figure 26. When selecting the alternative routes for water conveyance system, the topographic conditions in the project site are considered. In Alternative 1, the mountainous part of the project area is by-passed with a tunnel. In Alternative 2, the path that is suggested by DSİ is followed except for the tunnel sections. In this alternative tunnels are replaced by channel sections around the two hills as can be seen in Figure 26. The earthquake conditions and erosion problems are not taken into account while selecting the alternatives. Moreover, environmental aspects of these alternatives are not studied. The two alternative projects and the formulation proposed by DSİ are compared only in economic terms.

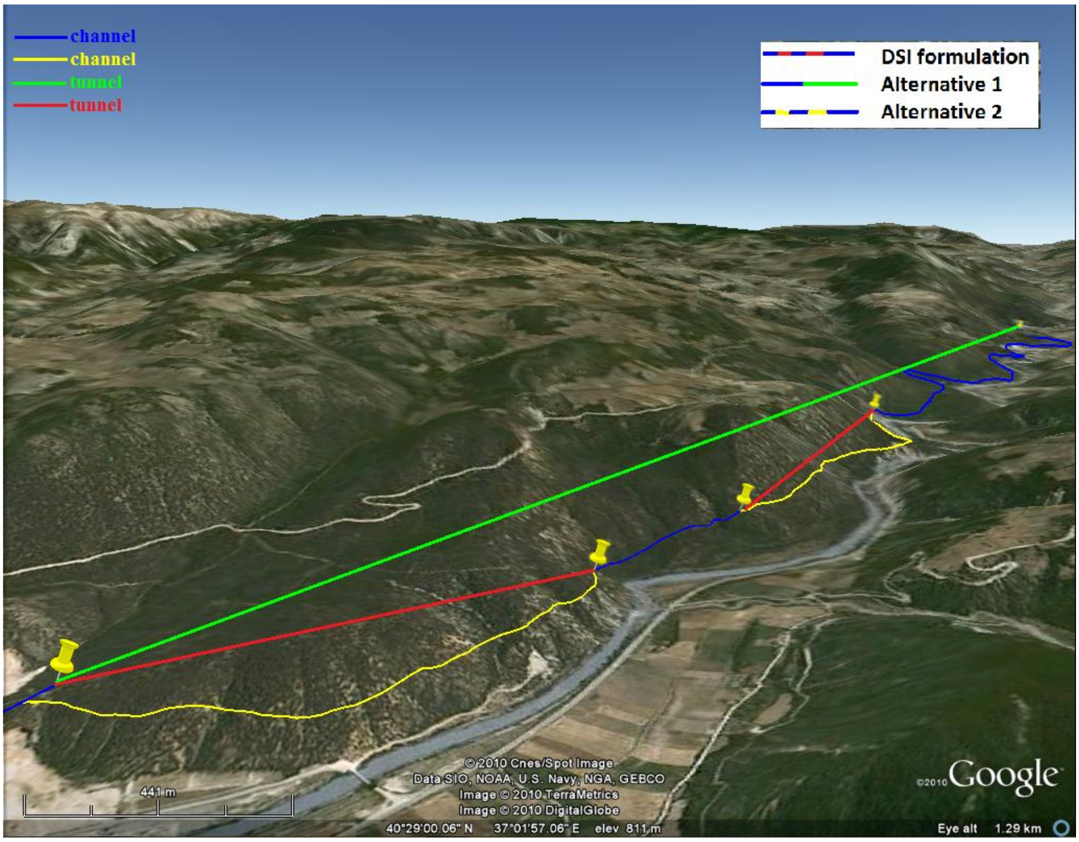


**Figure 26 Topographic view of the project site**

In the first alternative (Alternative 1), the two short tunnels and the channel section are by-passed with a 9000 m long tunnel. The remaining part of the conveyance system is composed of a 3800 m long open channel. This alternative decreases the total length of the conveyance system from 14400 m to 12800 m. However, tunnel construction is more expensive than channel construction. In addition, the tunnel is on the North Anatolian Fault Zone. Therefore, it should be earthquake-resistant, which makes it more expensive.

In the second alternative (Alternative 2), the entire conveyance system is composed of open channels. This alternative increases the total length of the conveyance system. However, since tunnels are avoided, the total cost may still be feasible.

### The design discharge

Design discharge impacts selection of the installed capacity as well. Thus, it is one of the key parameters used in the planning of hydropower projects. Selected discharge dictates the amount of electricity that can be generated in a hydropower plant. If a high design discharge is selected, the amount of electricity that can be generated in a year will be more. However, as the design discharge increases, dimensions of the project components such as hydro turbines or water conveyance systems also increase, resulting in increased costs in addition to higher risk of not having the required discharge in the river. Therefore, a cost-benefit analysis has to be carried out. The discharge giving the maximum net benefit should be selected as the design discharge of the project.

DSİ formulation and two alternatives (i.e. Alternative 1 and Alternative 2) created by changing the course of the water conveyance system are evaluated for various design discharges and electricity prices (RETScreen uses the term “electricity export rate” for “electricity price”. These terms will be used interchangeably from here on) in this study. A trial-and-error methodology is used to identify the optimum design discharge for each of these alternatives.

Frequently changing electricity prices in Turkey is another parameter that needs to be considered during the planning phases of HEPPs. Thus while selecting the optimum discharge of various alternatives for Niksar HEPP, impact of electricity prices are investigated as well. The procedure for determining optimum design discharge for various possible electricity price alternatives are explained in detail in Section 4.1.5.

# CHAPTER 4

# APPLICATION OF RETSCREEN TO NİKSAR HEPP

## 4.1 Application of RETScreen to DSİ formulation of Niksar HEPP

RETScreen software runs on Microsoft Excel environment. The software uses colored cells to guide the user when entering data. The color coding system of RETScreen is shown in Table 12.

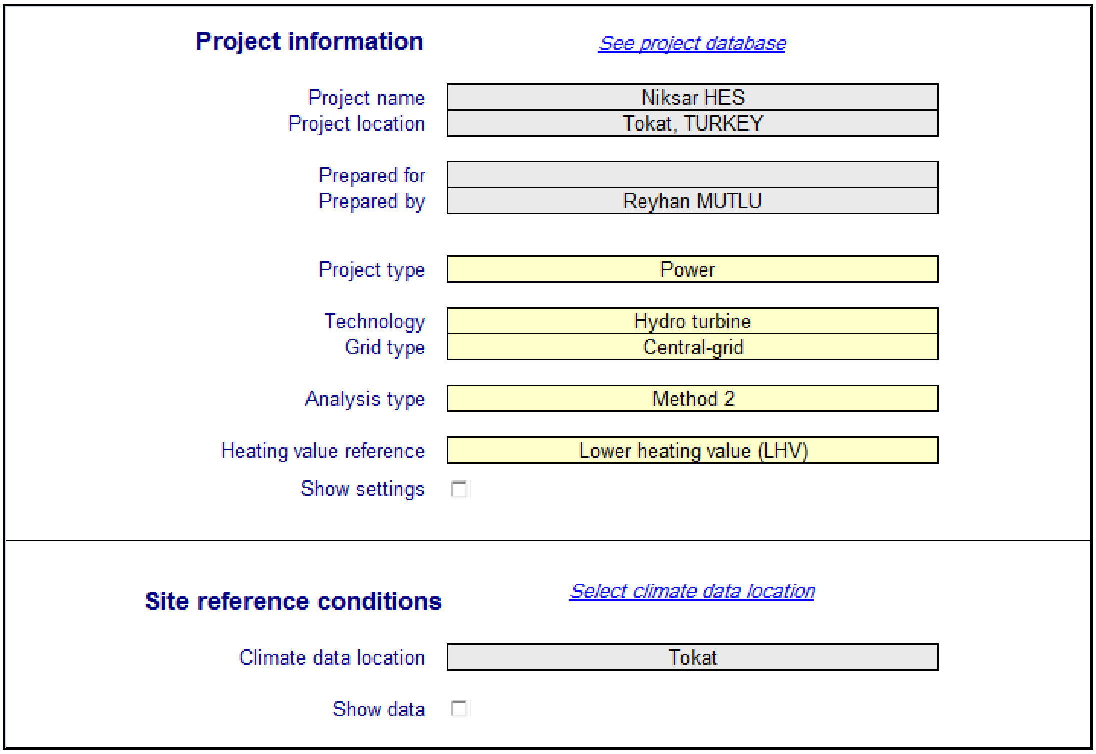
**Table 12 Cell color coding system of RETScreen**

| **Input & 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 and online databases available |
| Grey | User input – for reference purposes only. Not required to run the model |

Evaluation of a small hydropower scheme in RETScreen involves completion of many input data provided in a number of worksheets. Within the scope of this thesis, these sheets are completed for various alternatives of Niksar HEPP. Each of these sheets is explained briefly in the following paragraphs.

### 4.1.1 Start Sheet

The start sheet of the RETScreen for the application of Niksar HEPP project is presented in Figure 27.



**Project information**

| | |
|---|---|
| Project name | Niksar HES |
| Project location | Tokat, TURKEY |
| Prepared for | |
| Prepared by | Reyhan MUTLU |
| Project type | Power |
| Technology | Hydro turbine |
| Grid type | Central-grid |
| Analysis type | Method 2 |
| Heating value reference | Lower heating value (LHV) |
| Show settings | ☐ |

**Site reference conditions**

| | |
|---|---|
| Climate data location | Tokat |
| Show data | ☐ |

**Figure 27 Start Sheet of RETScreen**

**Grid type** can be central grid, isolated grid or off-grid. Since the electricity generated in Niksar HEPP is given to the Turkish Interconnected Network, central grid is selected.

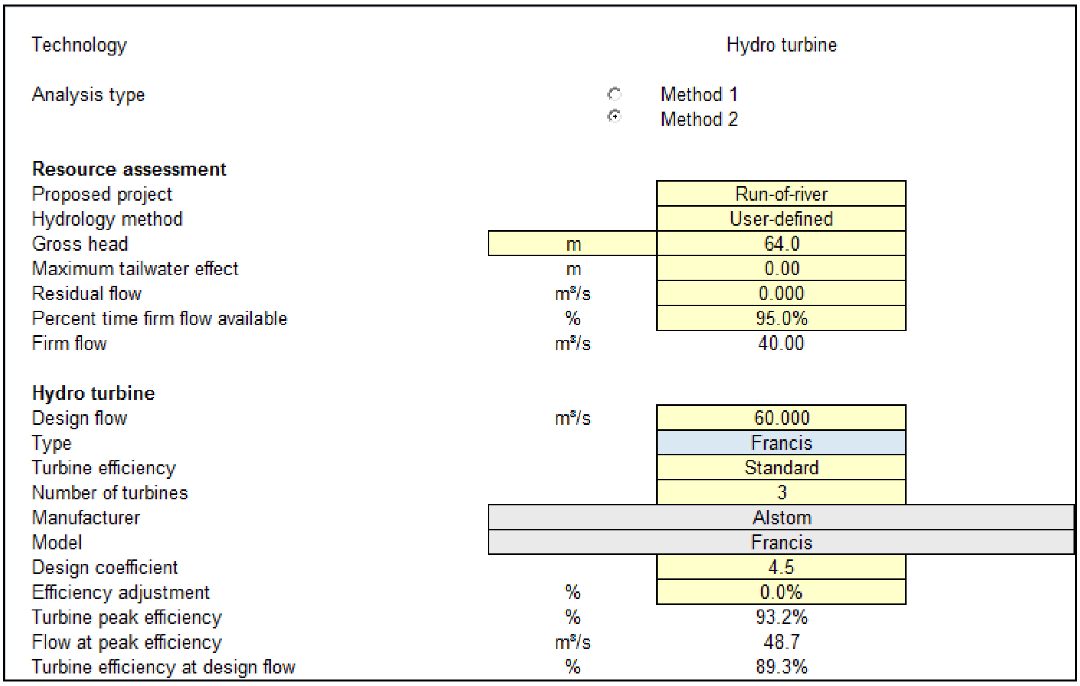
There are two **analysis types**. It is selected according to the extent of the available information. Method 2 requires more detailed information than Method 1 and it is preferable to use Method 2 if sufficient amount of information is available. If not, Method 1 can be selected but in this case cost analysis, emission analysis, financial and risk analyses become unavailable. For Niksar HEPP case, Method 2 is selected.

**Heating value** is a measure of energy released when fuel is completely burned. For hydropower projects, this value is important only if emission analysis will be carried out. In this study, emission analysis is not carried out.

In the **site reference conditions** section of the start sheet, the user enters the climatic data (such as air temperature, relative humidity, wind speed, etc.) of the project area or copy them from the RETScreen’s climate database. These data are displayed when “Show data” is ticked. The climate data are essential for solar or wind power projects, but not necessary for hydropower projects. Thus, in this study climate data are not entered.

### 4.1.2 Energy Model Sheet

The first part of the energy model sheet of RETScreen for the application of Niksar HEPP project is presented in Figure 28.



| | | |
|---|---|---|
| Technology | | Hydro turbine |
| Analysis type | | ○ Method 1<br>● Method 2 |
| **Resource assessment** | | |
| Proposed project | | Run-of-river |
| Hydrology method | | User-defined |
| Gross head | m | 64.0 |
| Maximum tailwater effect | m | 0.00 |
| Residual flow | m³/s | 0.000 |
| Percent time firm flow available | % | 95.0% |
| Firm flow | m³/s | 40.00 |
| **Hydro turbine** | | |
| Design flow | m³/s | 60.000 |
| Type | | Francis |
| Turbine efficiency | | Standard |
| Number of turbines | | 3 |
| Manufacturer | | Alstom |
| Model | | Francis |
| Design coefficient | | 4.5 |
| Efficiency adjustment | % | 0.0% |
| Turbine peak efficiency | % | 93.2% |
| Flow at peak efficiency | m³/s | 48.7 |
| Turbine efficiency at design flow | % | 89.3% |

**Figure 28 Niksar HEPP DSİ formulation, Energy Model**

For the **analysis type** in the energy model sheet, if Method 1 is selected, a simplified analysis based on hydro turbine power capacity and capacity factor is performed. If Method 2 is selected, a more detailed analysis can be performed with the addition of hydrology and equipment parameters. For Niksar HEPP project, Method 2 is selected.

The **hydrology method** depends on whether the flow duration curve for the subject river is available. If it is available, **user-defined** should be selected. If it is not, **specific run-off** can be selected and this will result in the hydrology data to be taken from RETScreen hydrology database. However, only Canada is covered in this database. Since the flow duration curve was developed for Niksar HEPP, the user-defined option is selected.

During high flows, the tailwater level may rise resulting in the decrease in gross head and thus reducing the energy production. However, this is significant for low-head sites [87]. Since no information is available for Niksar HEPP, **maximum tailwater effect** is entered as zero.

**Residual flow** is the amount of water that should be released to the river for environmental reasons. This can be entered in the allocated cell. However, if the flow duration curve is prepared after subtracting the residual flow, this cell should be left zero. In Niksar HEPP’s flow duration curve, residual flow has already been subtracted, thus residual flow cell is left zero. **Percent time firm flow available** is taken as 95 % by DSİ [99]. RETScreen suggests a value between 90 % and 100 % [87]. In this study, 95 % is used.

**Turbine efficiency** can be entered manually if the turbine efficiency curve is available. However, RETScreen has integrated efficiency curves for selected turbine types. Also with the **efficiency adjustment**, these efficiency curves can be adjusted and can be used in the sensitivity analysis. For Niksar HEPP’s Francis turbines, standard efficiency curves of RETScreen are utilized without adjustment. The combined turbine efficiency curve generated by RETScreen is shown in Figure 29.

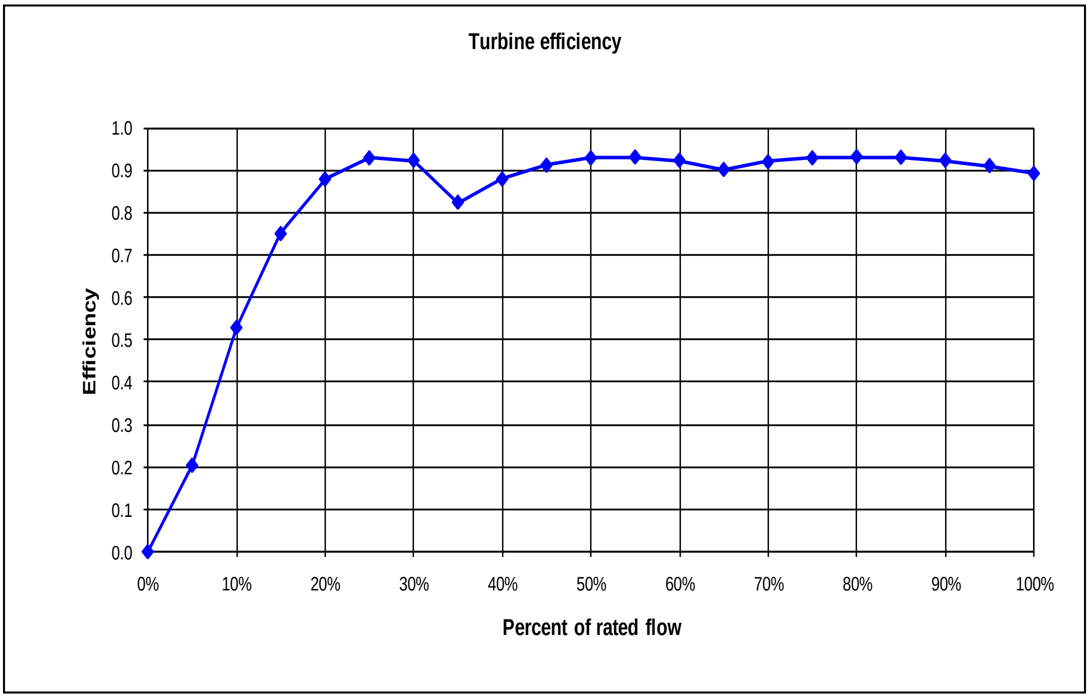


**Figure 29 Combined turbine efficiency, Niksar HEPP**

Figure 29 shows the combined efficiency curve for three turbines which are used in Niksar HEPP. These turbines are assumed to be identical. A single turbine is used up to its maximum flow and then the second turbine starts to operate. As can be seen in Figure 29, the second turbine and the third turbine start to operate approximately at 35 % and 65 % of the rated flow, respectively. The advantage of using three turbines is that for lower discharge values, high efficiencies can be obtained. If only one turbine was selected for Niksar HEPP, the efficiency curve for the turbine would be a smoother curve. The efficiency curve for a single turbine is given in Figure 30.

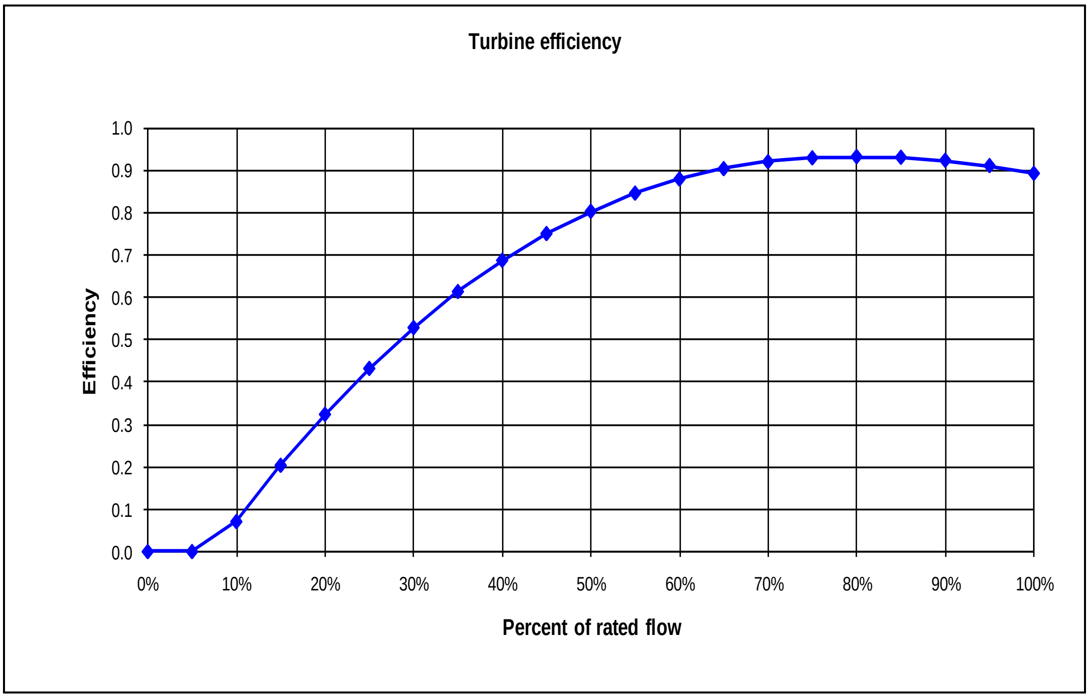
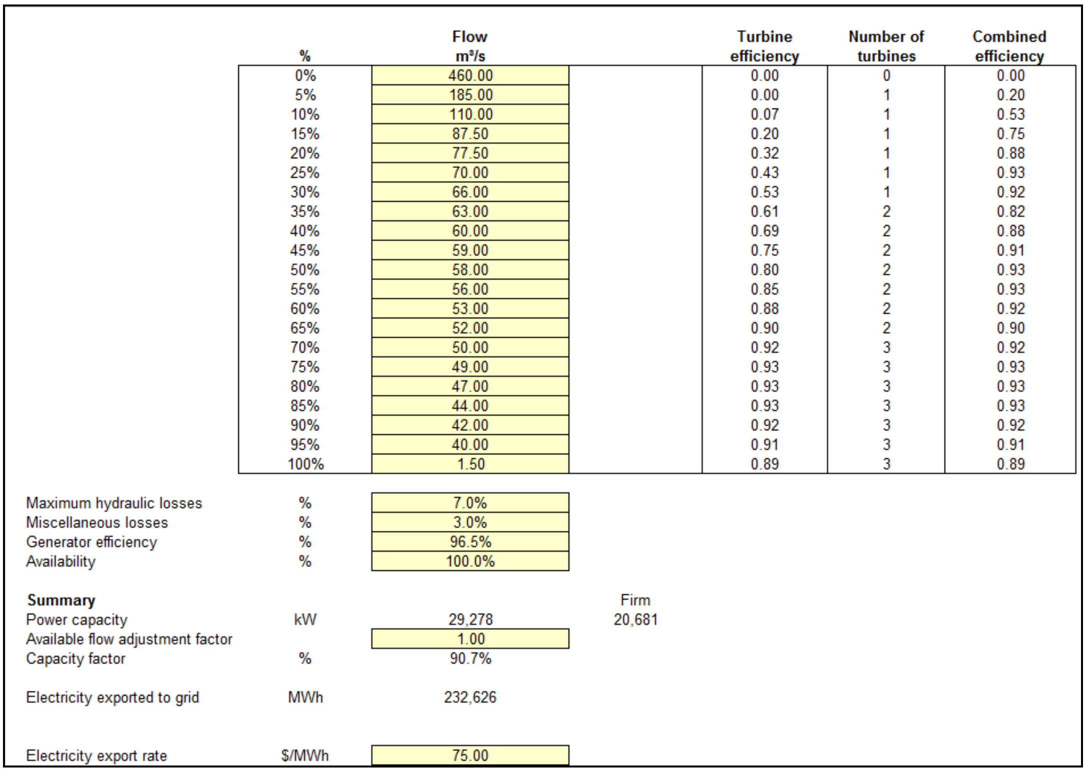


**Figure 30 Turbine efficiency for one turbine, Niksar HEPP**

When Figure 29 and Figure 30 are compared, it can be seen that for low discharges, single turbine system operates with smaller efficiency. For example, at 20 % of rated flow, efficiency in the system with three turbines is about 90 %, while that of the single turbine system is around 35 %. Optimization of the number of turbines and the types of them are also possible. However, in this study, the number and the type of turbines are taken the same as used in the Feasibility Report [96].

**Design coefficient** is a dimensionless factor in order to adjust the turbine efficiency by taking into account varying manufacturing techniques [87]. Typical values range from 2.8 to 6.1 and the default value is 4.5. Since no information is available for the manufacturing technique of the turbines, the default value is used in this study.

The second part of the energy model sheet of RETScreen for the application of Niksar HEPP is shown in Figure 31.



| % | Flow m³/s | Turbine efficiency | Number of turbines | Combined efficiency |
|---|---|---|---|---|
| 0% | 460.00 | 0.00 | 0 | 0.00 |
| 5% | 185.00 | 0.00 | 1 | 0.20 |
| 10% | 110.00 | 0.07 | 1 | 0.53 |
| 15% | 87.50 | 0.20 | 1 | 0.75 |
| 20% | 77.50 | 0.32 | 1 | 0.88 |
| 25% | 70.00 | 0.43 | 1 | 0.93 |
| 30% | 66.00 | 0.53 | 1 | 0.92 |
| 35% | 63.00 | 0.61 | 2 | 0.82 |
| 40% | 60.00 | 0.69 | 2 | 0.88 |
| 45% | 59.00 | 0.75 | 2 | 0.91 |
| 50% | 58.00 | 0.80 | 2 | 0.93 |
| 55% | 56.00 | 0.85 | 2 | 0.93 |
| 60% | 53.00 | 0.88 | 2 | 0.92 |
| 65% | 52.00 | 0.90 | 2 | 0.90 |
| 70% | 50.00 | 0.92 | 3 | 0.92 |
| 75% | 49.00 | 0.93 | 3 | 0.93 |
| 80% | 47.00 | 0.93 | 3 | 0.93 |
| 85% | 44.00 | 0.93 | 3 | 0.93 |
| 90% | 42.00 | 0.92 | 3 | 0.92 |
| 95% | 40.00 | 0.91 | 3 | 0.91 |
| 100% | 1.50 | 0.89 | 3 | 0.89 |

| | | | |
|---|---|---|---|
| Maximum hydraulic losses | % | 7.0% | |
| Miscellaneous losses | % | 3.0% | |
| Generator efficiency | % | 96.5% | |
| Availability | % | 100.0% | |
| **Summary** | | | Firm |
| Power capacity | kW | 29,278 | 20,681 |
| Available flow adjustment factor | | 1.00 | |
| Capacity factor | % | 90.7% | |
| Electricity exported to grid | MWh | 232,626 | |
| Electricity export rate | $/MWh | 75.00 | |

Figure 31 Niksar HEPP DSİ formulation, Energy Model

In Figure 31, the “Flow” column is where the flow duration curve is entered. RETScreen used these data together with the gross head, losses and turbine characteristics in order to calculate power capacity and electricity generated.

For **maximum hydraulic losses**, RETScreen suggests a value 5 % to be used for most hydropower plants [101]. The hydraulic losses occur due to friction and intakes along the conveyance system. If the conveyance system is long, hydraulic losses will be higher. RETScreen suggests 2 % for short water passages and 7 % for long water passages. The conveyance system of Niksar HEPP is 14 km long. Therefore it is considered as a long water passage and 7 % for the maximum hydraulic losses was selected.

**Miscellaneous losses** include the transformer losses and parasitic losses. Transformers are used to match the voltages of the generator and the transmission line. Transformer losses are typically minor and can be selected as 1 % for most hydropower projects [101]. Parasitic losses account for the portion of electricity generated that is used for auxiliary equipment, lighting, heating, etc. A value of 2 % is appropriate for most hydropower plants. Therefore, miscellaneous losses are taken as 3 % in total for Niksar HEPP.

**Availability** of the power plant can also be entered by the user. The power plants can sometimes be out of order for several reasons such as maintenance or turbine failure. RETScreen suggests 96 % availability for a typical plant [101]. However, if there are two or more turbines in a power plant, maintenances can be scheduled to low flow seasons where the flows are not enough to run all of the turbines. The idle turbines then can be taken to maintenance and the energy production continues without interruption. Since there are three turbines in Niksar HEPP, availability was taken as 100 %.

**Available flow adjustment factor** is intended to allow the user to adjust the capacity factor and electricity exported to the grid. This factor is primarily used for sensitivity analysis in order to observe the effects of capacity factor and electricity generated on the financial summary. This factor was entered as unity in this study, meaning that the flow values were not changed. If 1.1 was entered, for example, each value in the flow duration curve would increase by 10 %.

Another input to be entered by the user in the energy model sheet is the **electricity export rate**, which is used by the software to calculate the income from electricity sale. In this study, economical feasibility of the project is investigated for three different selling prices which are explained in Section 4.1.5. Upon entering the values as in Figure 31, the software calculates the installed capacity and electricity generated. The user can also plot the flow duration and power curves as can be seen in Figure 32.

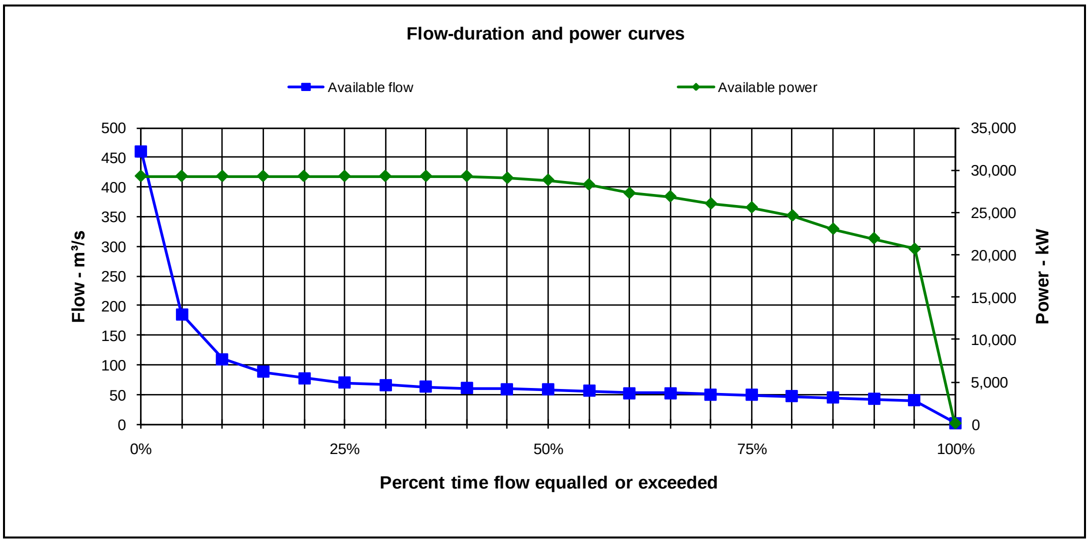


**Figure 32 Flow duration and power curves, Niksar HEPP**

As can be seen in Figure 32, the firm power, which corresponds to 95 % of time the flow is equaled or exceeded, is approximately 21 MW and the maximum power is around 29 MW. The exact values of firm power and maximum power (or power capacity) can be seen in Figure 31.

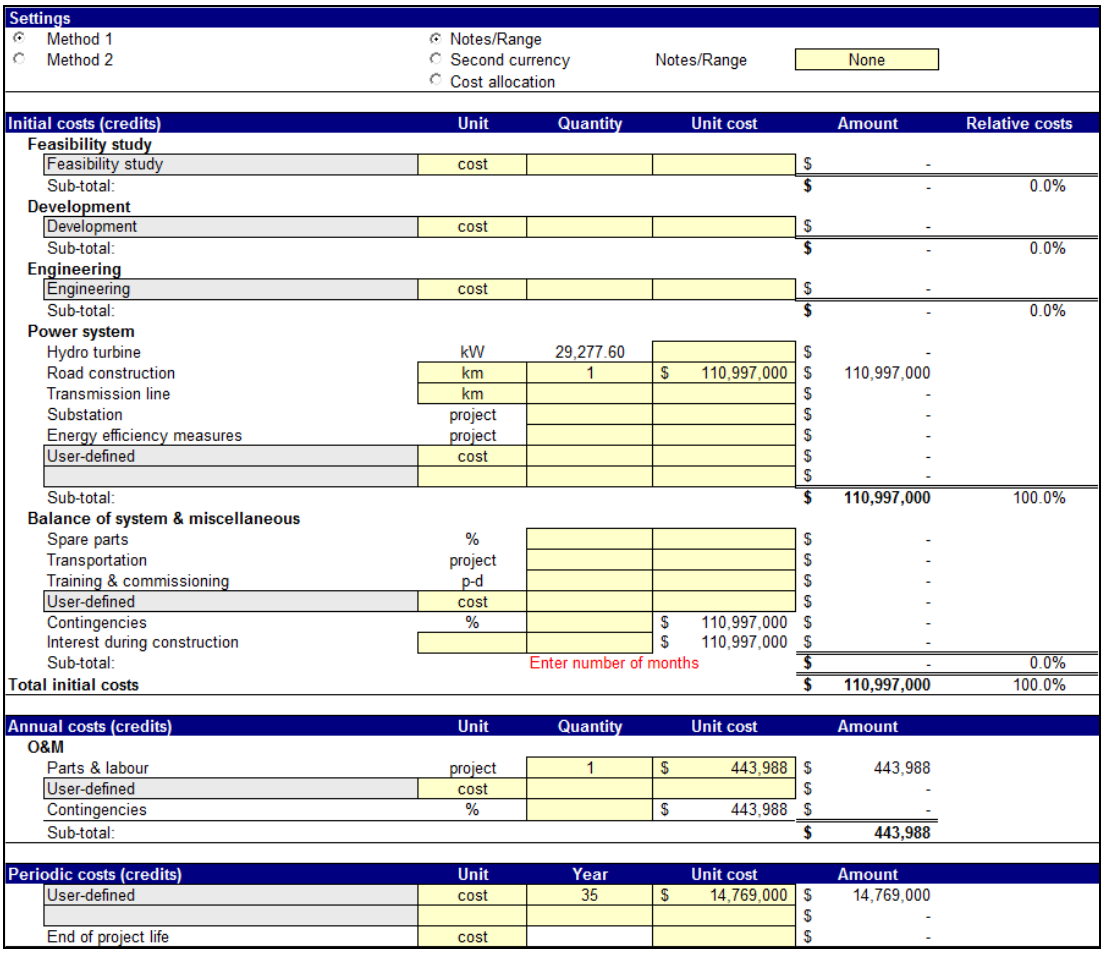
### 4.1.3 Cost Analysis Sheet and Hydro Formula Costing Method Tool

After filling the energy model sheet, the software directs the user to complete the cost analysis sheet. RETScreen offers two types of cost estimations. The first one is a detailed cost estimation based on estimated quantities and unit costs. This cost estimation method is carried out in the cost analysis sheet. The user can enter the pre-calculated quantities and unit costs for specific items such as engineering or turbine costs. This estimation method has two other sub methods in itself. The user can select one of them considering the level of detail available for cost calculation. More detailed cost estimations can be made with the second sub method. The sub method to be used is selected at the beginning of the cost analysis sheet.

The second cost estimation method offered by RETScreen is “hydro formula costing method”. This method is available in the “tools sheet”. The hydro formula costing method tool estimates the project costs using the empirical formulae derived from the costs of numerous completed small hydro projects. Since costs associated with various construction items, engineering and development works are not available for Niksar HEPP project, hydro formula costing method is used to estimate total initial costs. However, RETScreen cannot automatically use this calculated total initial costs in financial analysis and requires the user to externally input this value into the cost analysis worksheet. Thus, the total initial costs calculated by hydro formula costing method should be entered into one of the cost item listed in the cost analysis sheet. For example, the total initial cost of the Niksar HEPP project calculated by the costing formula method tool is entered as “Road construction” cost into the cost analysis sheet as can be seen in Figure 33.

The total initial cost is found to be $ 110997000. This value is calculated by the hydro formula costing method tool. The user can use referencing to the cell rather than entering the total cost by hand so that it will be automatically updated when the costs in the formula costing tool change.

There are also annual costs. Annual costs include operation and maintenance costs, land lease and resource rental, property taxes, insurance premium, parts and labor, GHG monitoring and verification, community benefits, and general and administrative expenses [101]. Küçükbeycan [10] suggests 0.2 % of the total investment cost can be allocated as operation and maintenance costs. Considering the other sources of annual costs such as labor cost or insurance premium, 0.4 % of the total investment cost is used for total annual costs in this study. It should be noted that interest and depreciation costs are not accepted as annual costs by RETScreen.



**Settings**

● Method 1
○ Method 2

● Notes/Range
○ Second currency
○ Cost allocation

Notes/Range: None

| Initial costs (credits) | Unit | Quantity | Unit cost | Amount | Relative costs |
|---|---|---|---|---|---|
| **Feasibility study** | | | | | |
| Feasibility study | cost | | | $ - | |
| Sub-total: | | | | **$** - | 0.0% |
| **Development** | | | | | |
| Development | cost | | | $ - | |
| Sub-total: | | | | **$** - | 0.0% |
| **Engineering** | | | | | |
| Engineering | cost | | | $ - | |
| Sub-total: | | | | **$** - | 0.0% |
| **Power system** | | | | | |
| Hydro turbine | kW | 29,277.60 | | $ - | |
| Road construction | km | 1 | $ 110,997,000 | $ 110,997,000 | |
| Transmission line | km | | | $ - | |
| Substation | project | | | $ - | |
| Energy efficiency measures | project | | | $ - | |
| User-defined | cost | | | $ - | |
| | | | | $ - | |
| Sub-total: | | | | **$ 110,997,000** | 100.0% |
| **Balance of system & miscellaneous** | | | | | |
| Spare parts | % | | | $ - | |
| Transportation | project | | | $ - | |
| Training & commissioning | p-d | | | $ - | |
| User-defined | cost | | | $ - | |
| Contingencies | % | | $ 110,997,000 | $ - | |
| Interest during construction | | | $ 110,997,000 | $ - | |
| Sub-total: | | Enter number of months | | **$** - | 0.0% |
| **Total initial costs** | | | | **$ 110,997,000** | 100.0% |

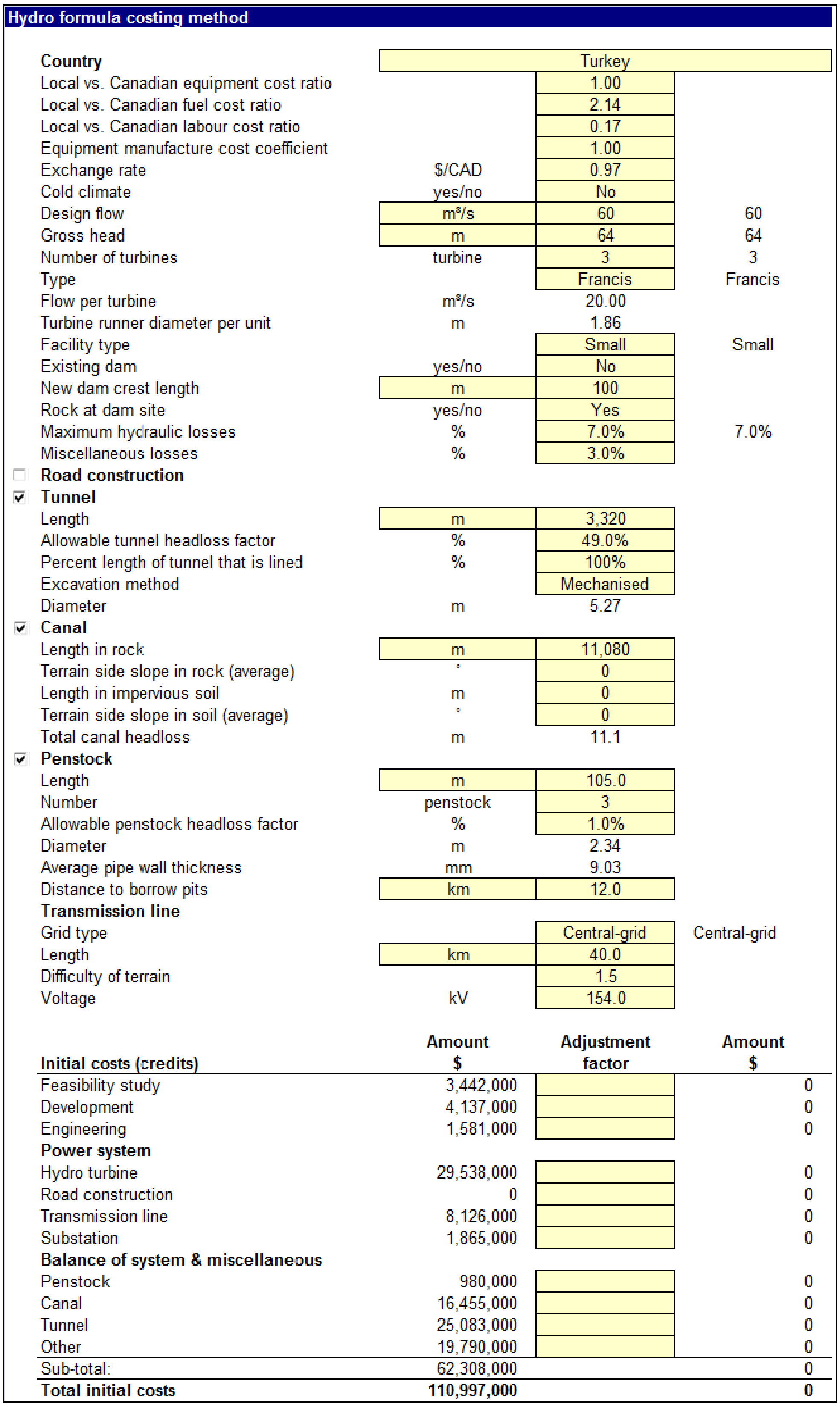
| Annual costs (credits) | Unit | Quantity | Unit cost | Amount |
|---|---|---|---|---|
| **O&M** | | | | |
| Parts & labour | project | 1 | $ 443,988 | $ 443,988 |
| User-defined | cost | | | $ - |
| Contingencies | % | | $ 443,988 | $ - |
| Sub-total: | | | | **$ 443,988** |

| Periodic costs (credits) | Unit | Year | Unit cost | Amount |
|---|---|---|---|---|
| User-defined | cost | 35 | $ 14,769,000 | $ 14,769,000 |
| | | | | $ - |
| End of project life | cost | | | $ - |

**Figure 33 Cost analysis sheet, Niksar HEPP, DSİ formulation**

Periodic cost of a power plant is the renewal costs of electromechanical equipment. The total renewal cost for Niksar HEPP is taken as 50 % of the electromechanical equipment cost in the 35th year as suggested by Küçükbeycan [10].

All of the aforementioned costs depend on the values entered to the formula costing method tool. The formula costing method tool sheet can be seen in Figure 34, and the items are explained in the proceeding paragraphs.



**Hydro formula costing method**

| | | | |
|---|---|---|---|
| **Country** | Turkey | | |
| Local vs. Canadian equipment cost ratio | | 1.00 | |
| Local vs. Canadian fuel cost ratio | | 2.14 | |
| Local vs. Canadian labour cost ratio | | 0.17 | |
| Equipment manufacture cost coefficient | | 1.00 | |
| Exchange rate | $/CAD | 0.97 | |
| Cold climate | yes/no | No | |
| Design flow | m³/s | 60 | 60 |
| Gross head | m | 64 | 64 |
| Number of turbines | turbine | 3 | 3 |
| Type | | Francis | Francis |
| Flow per turbine | m³/s | 20.00 | |
| Turbine runner diameter per unit | m | 1.86 | |
| Facility type | | Small | Small |
| Existing dam | yes/no | No | |
| New dam crest length | m | 100 | |
| Rock at dam site | yes/no | Yes | |
| Maximum hydraulic losses | % | 7.0% | 7.0% |
| Miscellaneous losses | % | 3.0% | |
| ☐ **Road construction** | | | |
| ☑ **Tunnel** | | | |
| Length | m | 3,320 | |
| Allowable tunnel headloss factor | % | 49.0% | |
| Percent length of tunnel that is lined | % | 100% | |
| Excavation method | | Mechanised | |
| Diameter | m | 5.27 | |
| ☑ **Canal** | | | |
| Length in rock | m | 11,080 | |
| Terrain side slope in rock (average) | ° | 0 | |
| Length in impervious soil | m | 0 | |
| Terrain side slope in soil (average) | ° | 0 | |
| Total canal headloss | m | 11.1 | |
| ☑ **Penstock** | | | |
| Length | m | 105.0 | |
| Number | penstock | 3 | |
| Allowable penstock headloss factor | % | 1.0% | |
| Diameter | m | 2.34 | |
| Average pipe wall thickness | mm | 9.03 | |
| Distance to borrow pits | km | 12.0 | |
| **Transmission line** | | | |
| Grid type | | Central-grid | Central-grid |
| Length | km | 40.0 | |
| Difficulty of terrain | | 1.5 | |
| Voltage | kV | 154.0 | |

| **Initial costs (credits)** | **Amount $** | **Adjustment factor** | **Amount $** |
|---|---|---|---|
| Feasibility study | 3,442,000 | | 0 |
| Development | 4,137,000 | | 0 |
| Engineering | 1,581,000 | | 0 |
| **Power system** | | | |
| Hydro turbine | 29,538,000 | | 0 |
| Road construction | 0 | | 0 |
| Transmission line | 8,126,000 | | 0 |
| Substation | 1,865,000 | | 0 |
| **Balance of system & miscellaneous** | | | |
| Penstock | 980,000 | | 0 |
| Canal | 16,455,000 | | 0 |
| Tunnel | 25,083,000 | | 0 |
| Other | 19,790,000 | | 0 |
| Sub-total: | 62,308,000 | | 0 |
| **Total initial costs** | **110,997,000** | | **0** |

Figure 34 Hydro costing formula method, Niksar HEPP, DSİ formulation

Hydro formula costing method uses the projects completed in Canada as the source for empirical formulae. Therefore, the cost estimations are applicable for Canada. However, RETScreen enables the user to enter the local conditions through cost ratios. These ratios should carefully be calculated since the cost estimations could vary greatly with different cost ratios.

**Turkish versus Canadian equipment cost ratio** and **equipment manufacture cost coefficient** requires a detailed study which is out of the scope of this thesis. As suggested by Korkmaz [9] and Küçükbeycan [10] these ratios are taken as one in this study. These ratios contain uncertainties. Detailed studies must be carried out in determining these ratios for comprehensive feasibility studies.

**Turkish versus Canadian fuel cost ratio** is calculated by using the diesel fuel prices and exchange rates in Canada and Turkey on January 14th, 2010. The conversion rates used for calculating fuel cost ratio is given in Table 13. Using these conversion rates, Turkish versus Canadian fuel cost ratio is calculated as 2.14. Fuel costs does not differ significantly from place to place in a country, but may change in time. Therefore, this value should be updated every time with the current fuel prices.

**Table 13 Fuel prices and exchange rates in Turkey and Canada**

| | Canada | Turkey |
|---|---|---|
| Price of 1 l diesel fuel | 1.003 CAD [102] | 3.04 TL [103] |
| 1 USD equivalent in local currency | 1.03 CAD [104] | 1.46 TL [105] |

**Turkish versus Canadian labor cost ratio** is calculated as 0.167 using the information given in Table 14. It should be noted that the unit labor costs are average costs. These may change from project to project or from place to place. However, for feasibility studies, using these average unit labor costs is reasonable.

**Table 14 Estimation of Turkish versus Canadian labor cost ratio**

| | |
|---|---|
| Annual average labor cost in Canada for construction sector in 2006 | 46550.92 CAD [9] |
| Unit labor cost growth in Canada in 2007 | 7.3 % [106] |
| Unit labor cost growth in Canada in 2008 | 6.8 % [106] |
| Annual average labor cost in Canada for construction sector in 2008 | = 46550.92* 1.073* 1.068<br>= 53345.68 CAD |
| Monthly average labor cost in Turkey for construction sector in 2008 | = 1055 TL (744.28 CAD) [107] |
| Turkish versus Canadian labor cost ratio | = 744.28 CAD* 12 month/53345.68 CAD<br>= 0.167 |

**Facility type** is suggested by the software according to the design discharge. The criteria that RETScreen used in the classification of the projects are shown in Table 15. According to this classification the facility type is selected as “small” for Niksar HEPP.

**Table 15 RETScreen's project classification [108]**

| | **Facility Type** | | |
|---|---|---|---|
| | **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 |
| Typical power | 1 – 50 MW | 100 – 1000 kW | < 100 kW |

Tunnel construction is an important item of the overall cost of the project. The diameter of a tunnel is very critical for cost calculations since a slightly large diameter can increase the tunnel costs by millions of dollars. However, RETScren does not require the user to enter the diameter of the tunnel. It automatically calculates the diameters. For the Niksar HEPP, the automatically calculated diameter and the diameter used in the master plan report are very different. The tunnel diameter in the master plan report is taken as 5.75 m, but RETScreen calculates it as 8.08 m. The same problem was addressed by Küçükbeycan [10] as well. This problem can be overcome by increasing **allowable tunnel headloss factor**. RETScreen suggests a value between 4 % -7 % for allowable tunnel headloss factor. However, in order to adjust the automatically calculated diameter to the one used in the master plan for Niksar HEPP, the headloss factor needs to be increased to around 30 %. When a 30 % allowable tunnel headloss factor is used for Niksar HEPP the tunnel diameter is automatically calculated as 5.78 m and the tunnel cost is estimated as $ 29492000. If the allowable tunnel headloss factor is chosen as 5 % as suggested by RETScreen, the tunnel diameter is automatically calculated as 8.08 m and the tunnel cost is calculated as $ 53271000. Changing the allowable tunnel headloss factor to 30 % or more is not realistic in terms of hydraulic requirements. However, in this study, the economic feasibility analysis which is carried out using RETScreen produced unreasonable economic parameters when headloss is chosen in the allowable range. Since RETScreen does not allow modification of hydraulic parameters, the headloss factors are modified to obtain reasonable economical analysis results. This is a major weakness of the software.

The tunnel diameter given in the master plan report is 5.75 m [88]. However, it is calculated for a horse shoe shaped tunnel. The diameter calculations for such tunnels are time consuming. These diameters are generally read from tables prepared beforehand. For the sake of simplicity, the tunnels are assumed to be circular in this study. By assuming 85 % fullness of tunnel, the diameter of tunnel for each discharge value is found using the following equations [109]:

$$A = \frac{D^2}{4}(\alpha - \sin\alpha\cos\alpha) \qquad \text{(Eq. 3)}$$

$$P = \alpha D \qquad \text{(Eq. 4)}$$

$$\alpha = \cos^{-1}(1 - 2\frac{y}{D}) \qquad \textbf{(}\text{Eq. 5)}$$

$$Q = \frac{1}{n} A R^{2/3} \sqrt{S_0} \qquad \textbf{(}\text{Eq. 6)}$$

where $A$ is the flow area in m$^2$, $D$ is the tunnel diameter in m, $P$ is the wetted perimeter in m, $y$ is the water depth in m, $Q$ is the discharge in m$^3$/s, $n$ is Manning's roughness coefficient, $R$ is the hydraulic radius in m (equal to $A/P$), $S_0$ is the slope of the bed. The angle $\alpha$ is defined in Figure 35.

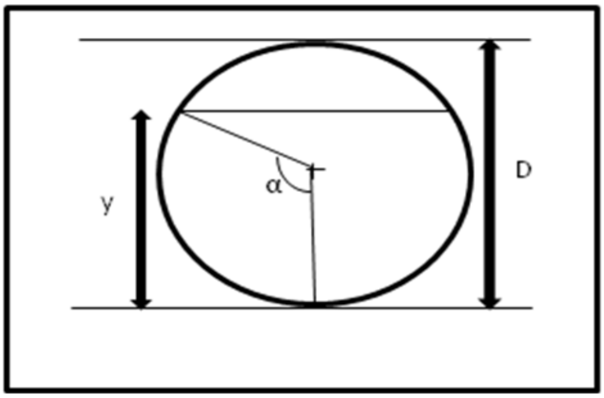


**Figure 35 Representative cross section of a tunnel**

$\frac{y}{D}$ is defined as percent fullness and assumed to be 0.85. Manning's roughness coefficient for closed, straight, free of debris conduits flowing partially full, made of concrete is taken as 0.011 [110]. The tunnel slope is calculated from the topographic map of Niksar HEPP as 0.0006 for DSİ formulation.

If the discharge is selected as 60 m$^3$/s, the information given in Table 16 is obtained for DSİ formulation.

**Table 16 Tunnel parameters for a discharge of 60 m$^3$/s, DSİ formulation**

| **Parameter** | **Value** |
|---|---|
| percent fullness ( $y/D$ ) | 0.85 |
| $D$ (diameter) (m) | 5.265 |
| $n$ (Manning roughness coeff.) | 0.011 |
| $S_0$ (slope) | 0.0006 |
| $\alpha$ (radian) | 2.346 |
| $P$ (wetted perimeter) (m) | 12.353 |
| $A$ (flow area) (m$^2$) | 19.724 |
| $R$ (hydraulic radius) (m) | 1.597 |
| $Q$ (discharge) (m$^3$/s) | 60.000 |
| $u$ (velocity) (m/s) | 3.042 |
| $y$ (water depth) (m) | 4.475 |

As can be seen in Table 16, the tunnel diameter is calculated as 5.265 m which is close to the one used in DSİ formulation (i.e. 5.75 m). Using the same procedure, the diameters corresponding to different discharges are calculated. Results of these calculations are presented in Table 17.

The allowable tunnel headloss factor that is to be selected in order to obtain the same diameters in RETScreen is found by trial-and-error. For DSİ formulation this factor is determined to be 49 %. If 49 % is selected, the tunnel diameters calculated by RETScreen are equal to the diameters given in Table 17 for all the discharges. However, 49 % is suitable only for this formulation. If any of the parameters such as the length of the tunnel, percent fullness, bed slope or Manning's roughness coefficient changes, a new value for allowable tunnel headloss factor has to be found by trial-and-error.

**Table 17 Diameters for different discharges**

| SUMMARY (y/D=0.85, S=0.0006) | |
|---|---|
| **Q ($m^3/s$)** | **D (m)** |
| 50 | 4.917 |
| 55 | 5.096 |
| 60 | 5.265 |
| 65 | 5.425 |
| 70 | 5.578 |
| 75 | 5.725 |
| 80 | 5.865 |
| 85 | 6.000 |
| 90 | 6.130 |
| 95 | 6.255 |
| 100 | 6.377 |

For the penstock, another allowable headloss factor is available. RETScreen suggests a value between 1 - 4 % [101]. For Niksar HEPP, 1 % is used and the software returned reasonable dimensions for diameter and pipe thickness.

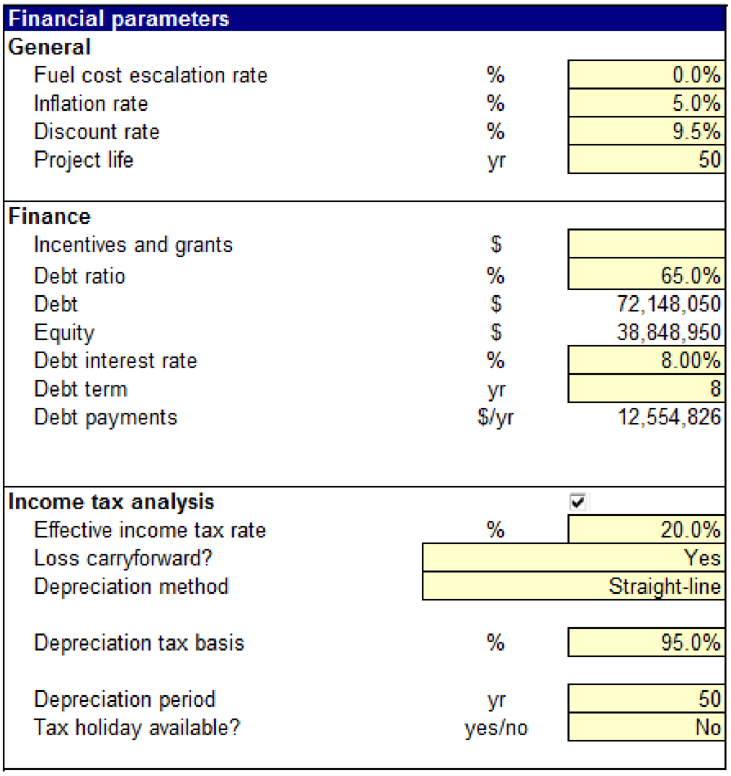
**Difficulty of terrain** over which the transmission line will be constructed is assumed as 1.5 since no information is available. RETScreen suggests a value between one and two. One is used for flat terrains, and two is used for mountainous terrains.

All of the other parameters are taken from the Master Plan Report [88] and the Feasibility Report [96].

### 4.1.4 Financial Analysis Sheet

The financial parameters entered to the software are given in Figure 36. The following information is used:

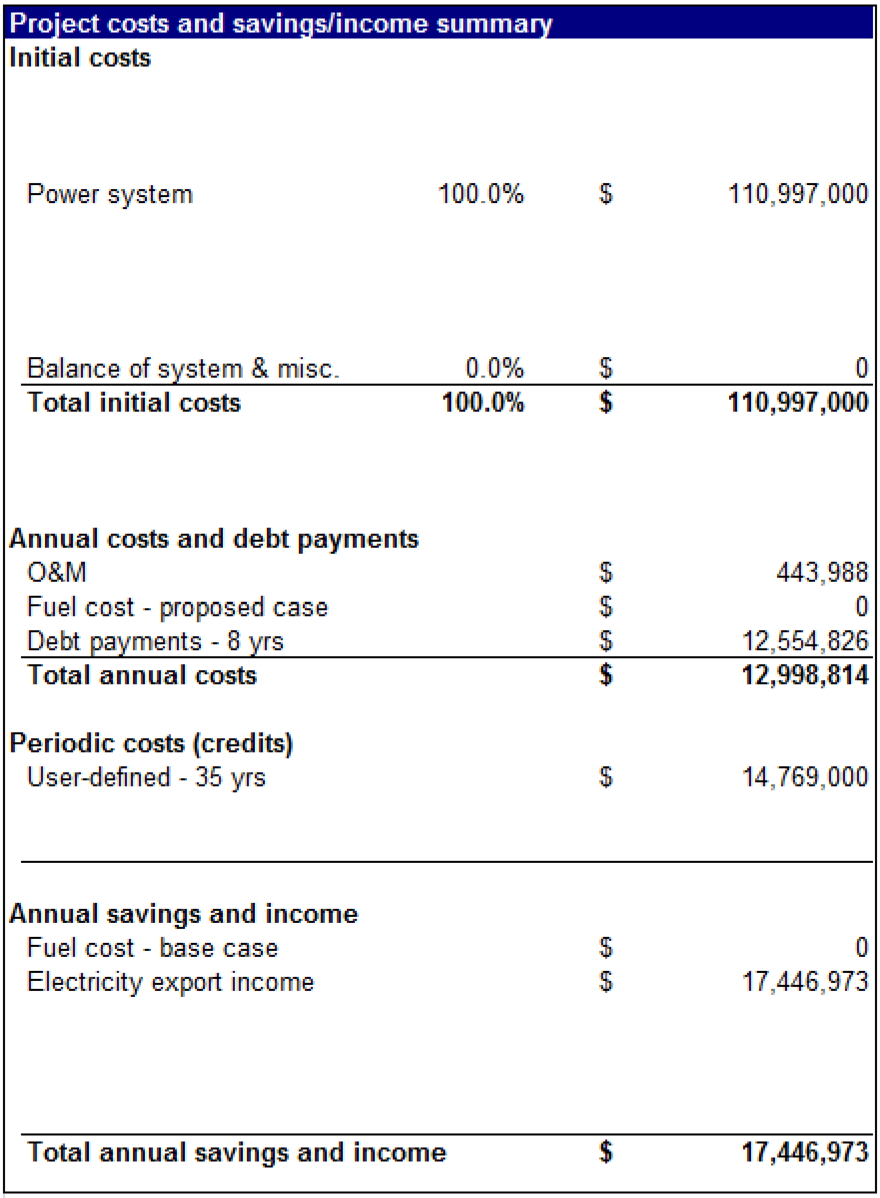
- Fuel cost escalation rate is taken as 0 % since hydropower plants do not consume fuel to generate electricity. Fuel is used only in the construction period to run the construction machinery. Therefore the effect of this rate can be assumed to be negligible.
- Inflation rate is taken as 5 % [9].
- Discount rate is taken as 9.5 % [88]
- Project life is taken as 50 years.
- 65 % of the total cost is assumed to be paid from the loans taken from the banks with an interest rate of 8 %. This amount is to be paid back in 8 years.
- Effective income tax rate is taken as 20 % [9].
- Depreciation period is taken as 50 years which is equal to the project life. The percentage of total costs to be depreciated (depreciated tax basis) is 95 %. The remaining 5 % accounts for the cost items that cannot be depreciated. Depreciation method is selected as straight line.



| **Financial parameters** | | |
|---|---|---|
| **General** | | |
| Fuel cost escalation rate | % | 0.0% |
| Inflation rate | % | 5.0% |
| Discount rate | % | 9.5% |
| Project life | yr | 50 |
| **Finance** | | |
| Incentives and grants | $ | |
| Debt ratio | % | 65.0% |
| Debt | $ | 72,148,050 |
| Equity | $ | 38,848,950 |
| Debt interest rate | % | 8.00% |
| Debt term | yr | 8 |
| Debt payments | $/yr | 12,554,826 |
| **Income tax analysis** | | ☑ |
| Effective income tax rate | % | 20.0% |
| Loss carryforward? | | Yes |
| Depreciation method | | Straight-line |
| Depreciation tax basis | % | 95.0% |
| Depreciation period | yr | 50 |
| Tax holiday available? | yes/no | No |

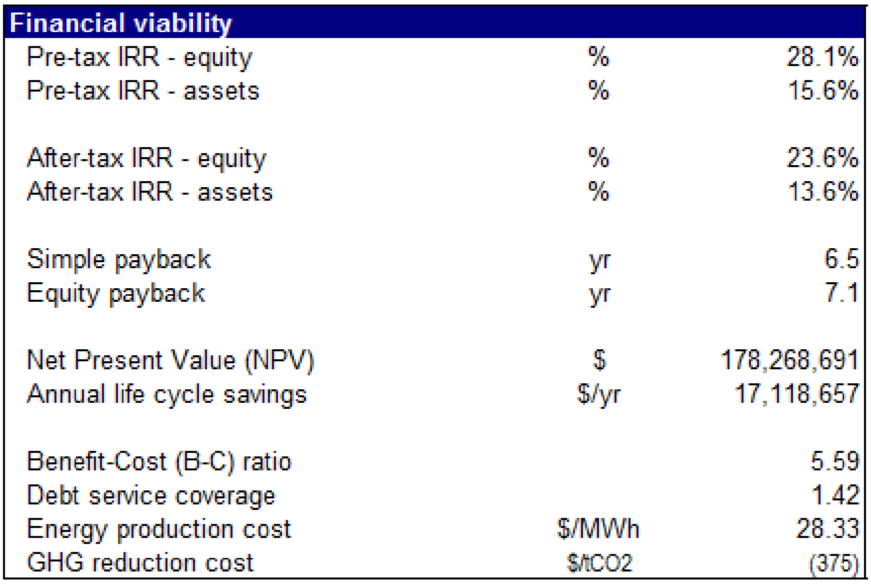
Figure 36 Financial Parameters, Niksar HEPP

The outputs of the financial analysis include project costs and income summary, financial viability parameters, yearly cash flow table and cumulative cash flow graph. These results are shown in Figure 37, Figure 38, Figure 40, and Figure 39, respectively.



| Project costs and savings/income summary | | | |
|---|---|---|---|
| **Initial costs** | | | |
| Power system | 100.0% | $ | 110,997,000 |
| Balance of system & misc. | 0.0% | $ | 0 |
| **Total initial costs** | **100.0%** | **$** | **110,997,000** |
| **Annual costs and debt payments** | | | |
| O&M | | $ | 443,988 |
| Fuel cost - proposed case | | $ | 0 |
| Debt payments - 8 yrs | | $ | 12,554,826 |
| **Total annual costs** | | **$** | **12,998,814** |
| **Periodic costs (credits)** | | | |
| User-defined - 35 yrs | | $ | 14,769,000 |
| **Annual savings and income** | | | |
| Fuel cost - base case | | $ | 0 |
| Electricity export income | | $ | 17,446,973 |
| **Total annual savings and income** | | **$** | **17,446,973** |

**Figure 37 Project costs and savings/income summary**



| Financial viability | | |
|---|---|---|
| Pre-tax IRR - equity | % | 28.1% |
| Pre-tax IRR - assets | % | 15.6% |
| | | |
| After-tax IRR - equity | % | 23.6% |
| After-tax IRR - assets | % | 13.6% |
| | | |
| Simple payback | yr | 6.5 |
| Equity payback | yr | 7.1 |
| | | |
| Net Present Value (NPV) | $ | 178,268,691 |
| Annual life cycle savings | $/yr | 17,118,657 |
| | | |
| Benefit-Cost (B-C) ratio | | 5.59 |
| Debt service coverage | | 1.42 |
| Energy production cost | $/MWh | 28.33 |
| GHG reduction cost | $/tCO2 | (375) |

Figure 38 Financial viability, Niksar HEPP

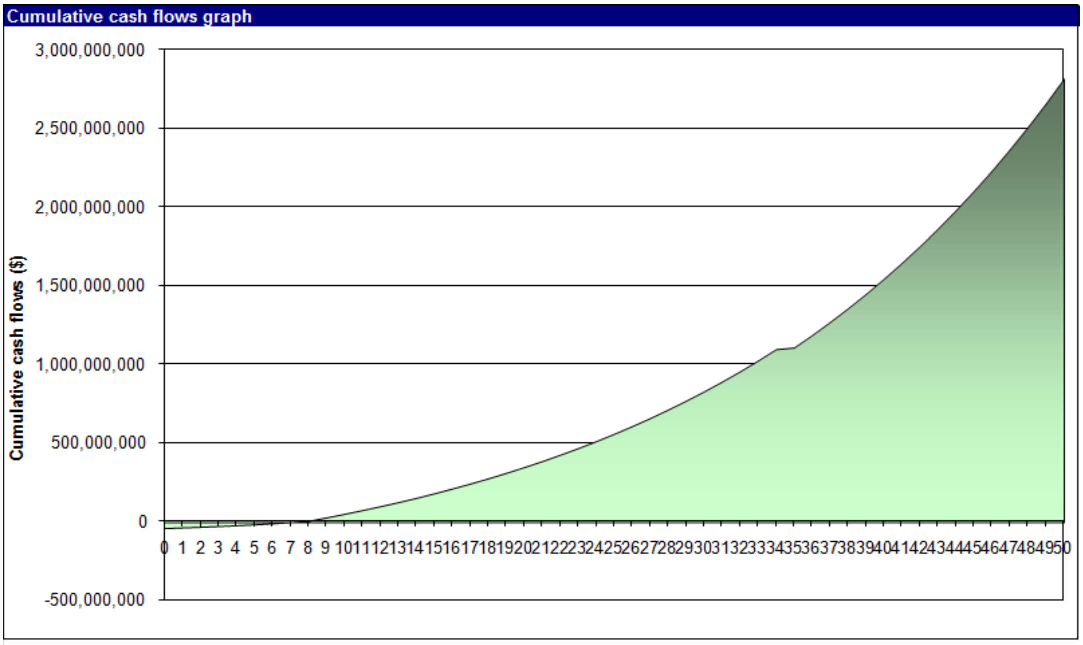
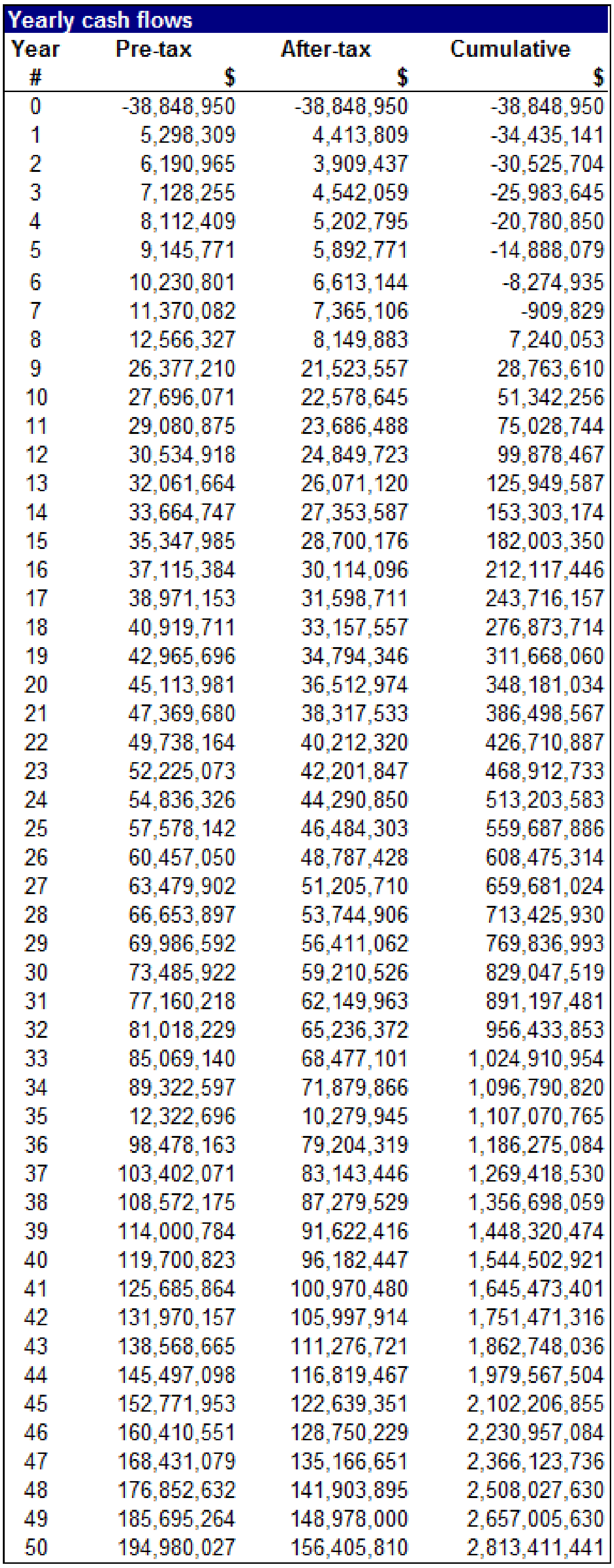


Figure 39 Cumulative cash flow graph, Niksar HEPP



| Yearly cash flows | | | |
|---|---|---|---|
| Year<br>#| Pre-tax<br>$ | After-tax<br>$ | Cumulative<br>$ |
| 0 | -38,848,950 | -38,848,950 | -38,848,950 |
| 1 | 5,298,309 | 4,413,809 | -34,435,141 |
| 2 | 6,190,965 | 3,909,437 | -30,525,704 |
| 3 | 7,128,255 | 4,542,059 | -25,983,645 |
| 4 | 8,112,409 | 5,202,795 | -20,780,850 |
| 5 | 9,145,771 | 5,892,771 | -14,888,079 |
| 6 | 10,230,801 | 6,613,144 | -8,274,935 |
| 7 | 11,370,082 | 7,365,106 | -909,829 |
| 8 | 12,566,327 | 8,149,883 | 7,240,053 |
| 9 | 26,377,210 | 21,523,557 | 28,763,610 |
| 10 | 27,696,071 | 22,578,645 | 51,342,256 |
| 11 | 29,080,875 | 23,686,488 | 75,028,744 |
| 12 | 30,534,918 | 24,849,723 | 99,878,467 |
| 13 | 32,061,664 | 26,071,120 | 125,949,587 |
| 14 | 33,664,747 | 27,353,587 | 153,303,174 |
| 15 | 35,347,985 | 28,700,176 | 182,003,350 |
| 16 | 37,115,384 | 30,114,096 | 212,117,446 |
| 17 | 38,971,153 | 31,598,711 | 243,716,157 |
| 18 | 40,919,711 | 33,157,557 | 276,873,714 |
| 19 | 42,965,696 | 34,794,346 | 311,668,060 |
| 20 | 45,113,981 | 36,512,974 | 348,181,034 |
| 21 | 47,369,680 | 38,317,533 | 386,498,567 |
| 22 | 49,738,164 | 40,212,320 | 426,710,887 |
| 23 | 52,225,073 | 42,201,847 | 468,912,733 |
| 24 | 54,836,326 | 44,290,850 | 513,203,583 |
| 25 | 57,578,142 | 46,484,303 | 559,687,886 |
| 26 | 60,457,050 | 48,787,428 | 608,475,314 |
| 27 | 63,479,902 | 51,205,710 | 659,681,024 |
| 28 | 66,653,897 | 53,744,906 | 713,425,930 |
| 29 | 69,986,592 | 56,411,062 | 769,836,993 |
| 30 | 73,485,922 | 59,210,526 | 829,047,519 |
| 31 | 77,160,218 | 62,149,963 | 891,197,481 |
| 32 | 81,018,229 | 65,236,372 | 956,433,853 |
| 33 | 85,069,140 | 68,477,101 | 1,024,910,954 |
| 34 | 89,322,597 | 71,879,866 | 1,096,790,820 |
| 35 | 12,322,696 | 10,279,945 | 1,107,070,765 |
| 36 | 98,478,163 | 79,204,319 | 1,186,275,084 |
| 37 | 103,402,071 | 83,143,446 | 1,269,418,530 |
| 38 | 108,572,175 | 87,279,529 | 1,356,698,059 |
| 39 | 114,000,784 | 91,622,416 | 1,448,320,474 |
| 40 | 119,700,823 | 96,182,447 | 1,544,502,921 |
| 41 | 125,685,864 | 100,970,480 | 1,645,473,401 |
| 42 | 131,970,157 | 105,997,914 | 1,751,471,316 |
| 43 | 138,568,665 | 111,276,721 | 1,862,748,036 |
| 44 | 145,497,098 | 116,819,467 | 1,979,567,504 |
| 45 | 152,771,953 | 122,639,351 | 2,102,206,855 |
| 46 | 160,410,551 | 128,750,229 | 2,230,957,084 |
| 47 | 168,431,079 | 135,166,651 | 2,366,123,736 |
| 48 | 176,852,632 | 141,903,895 | 2,508,027,630 |
| 49 | 185,695,264 | 148,978,000 | 2,657,005,630 |
| 50 | 194,980,027 | 156,405,810 | 2,813,411,441 |

**Figure 40 Yearly cash flow, Niksar HEPP**

Projects are called feasible when benefit-cost ratio is greater than 1. The financial analysis of the project indicates that the project is profitable. As can be seen in Figure 38, Benefit-Cost Ratio is calculated as 5.59. Therefore, DSİ formulation for Niksar HEPP project is worth investing.

As can be seen in Figure 39 and Figure 40, cumulative cash flow is negative until the 8th year. After the 8th year it turns positive meaning that the investor starts making profit.

### 4.1.5 Identification of Design Discharge

In order to obtain the optimum design discharge for a given project, various design discharges are selected and change of the net income with respect to the selected discharge is evaluated. The discharge resulting in the maximum annual net benefit (i.e. annual income-annual cost) is selected as the design discharge for that project for a given electricity export rate. Alternatives are created for three different electricity export rates and the optimum design discharges for each alternative formulation are identified for each one of these export rates.

Selection of electricity export rates:

The first electricity export rate is selected as 75 USD/ MWh. This value is used by Korkmaz [9] and Küçükbeycan [10] as well. The Turkish Government guarantees to pay 5.5 Euro Cent for every kilowatt-hour produced by renewable energy technologies [111]. 75 USD/MWh is very close to 5.5 Euro Cent/kWh (which is equal to 77.8 USD/ kWh as of January 25, 2010 [112]). Therefore 77.8 USD/kWh is selected as the first electricity export rate.

The second electricity export rate to be used in RETScreen analysis is taken as the average wholesale electricity price for 2009 in Turkey. It is suggested as 13.32

Krş/kWh by the Energy Market Regulatory Authority of Turkey [113]. 13.32 Krş/kWh is equal to 91.30 USD/MWh [112].

The third electricity export rate is taken as 7.5 Euro Cent/kWh (=106.125 USD/MWh). This value is selected to evaluate the profitability of the HEPPs if the Turkish Governments raises 5.5 Euro Cent/kWh guarantee to 7.5 Euro Cent/kWh in the future. This will allow us to see if the profitability of the alternative projects increases as the electricity export rate increases.

Selection of alternative design discharge rates:

In the master plan report [88] and the Feasibility Report [96], the design discharge of Niksar HEPP is selected as 60 $m^3/s$. Therefore, it is reasonable to carry out the analyses for discharges around 60 $m^3/s$. In this study, all the alternative formulations are evaluated for design discharges starting from 50 $m^3/s$ to 80 $m^3/s$ with 5 $m^3/s$ increments. RETScreen is used to evaluate the annual net benefits corresponding to each one of these alternative design discharge values (i.e. 50, 55, 60,…, 80 $m^3/s$). Then a curve is fitted to the results and the interval in which optimum design discharge occurs (i.e. the value corresponding to the maximum net benefit) is identified. A more detailed analysis is carried out in this interval: RETScreen is used to evaluate annual net benefits for discharges with 1 $m^3/s$ increments. As a result of this analysis, the optimum design discharge is identified.

As an example, annual net benefits associated with alternative discharges for an electricity export rate of 75 USD/MWh for DSİ formulation are given in Table 18. Discharge versus annual net benefit graph for this formulation is presented in Figure 41. The results of analyses for other alternatives and electricity export rates are given in Section 4.3.

**Table 18 Discharge optimization for DSİ formulation**

| Discharge ($m^3/s$) | Installed Power (MW) | Annual Cost (AC) ($) | Annual Benefit (AB) ($) | Annual Net Benefit AB-AC ($) |
|---|---|---|---|---|
| 50 | 24.37 | 11311230 | 15327473 | 4016243 |
| 55 | 26.82 | 12086936 | 16491881 | 4404945 |
| 60 | 29.28 | 12954826 | 17446973 | 4492147 |
| 65 | 31.73 | 13710624 | 18197552 | 4486928 |
| 70 | 34.19 | 14455451 | 18815543 | 4360093 |
| 75 | 36.65 | 15189984 | 19299919 | 4109934 |
| 80 | 39.10 | 15915469 | 19720886 | 3805416 |

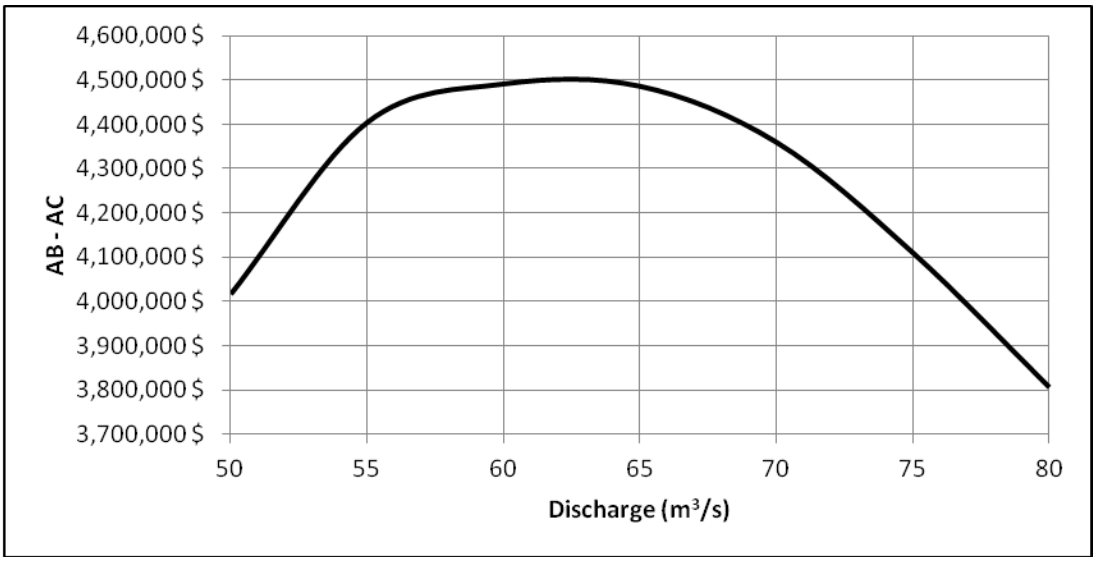


**Figure 41 Discharge optimization graph for DSİ formulation**

As can be seen from Table 18 and Figure 41, the annual net benefit reaches to its maximum value between 60 $m^3/s$ and 65 $m^3/s$. In order to determine the optimum discharge, the discharges between 60 $m^3/s$ and 65 $m^3/s$ are evaluated for 1 $m^3/s$ increments. These calculations and the related graph are shown in Table 19 and Figure 42 , respectively.

**Table 19 Discharge optimization for DSİ formulation**

| Discharge ($m^3/s$) | Installed Power (MW) | Annual Cost (AC) ($) | Annual Benefit (AB) ($) | AB-AC |
|---|---|---|---|---|
| 60 | 29.278 | 12954826 | 17446973 | 4492147 |
| 61 | 29.769 | 13106958 | 17608383 | 4501425 |
| 62 | 30.26 | 13258638 | 17765258 | 4506620 |
| 63 | 30.751 | 13409639 | 17916057 | 4506418 |
| 64 | 31.242 | 13560414 | 18057989 | 4497574 |
| 65 | 31.733 | 13710624 | 18197552 | 4486928 |

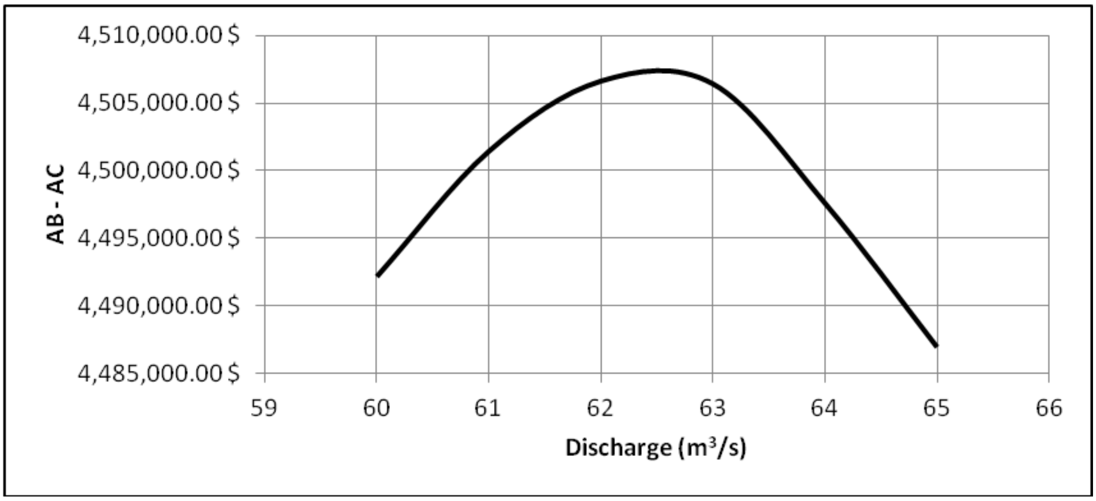


Figure 42 Discharge optimization for DSİ formulation

It can be seen from Table 19 that both annual income and annual cost increases as the discharge increases. However, the annual net benefit increases up to a discharge of 62 m$^3$/s. After this discharge, it decreases with increasing discharge. This means that the costs increase more rapidly than benefits after the discharge of 62 m$^3$/s. It would be unreasonable to select larger discharges; therefore, 62 m$^3$/s is selected as the design discharge for DSİ formulation for an electricity price of 75 USD/MWh. The results of the analyses for other alternatives and electricity export rates are given in Section 4.3.

## 4.2 Application of RETScreen to Alternative 1 and Alternative 2

In order to decide which alternative project (i.e. Alternative 1, Alternative 2 or DSİ formulation) introduced in Section 3.4 is better, annual net benefits for each of these alternatives are evaluated using RETScreen. Schematic representation of this procedure is presented in Figure 43.

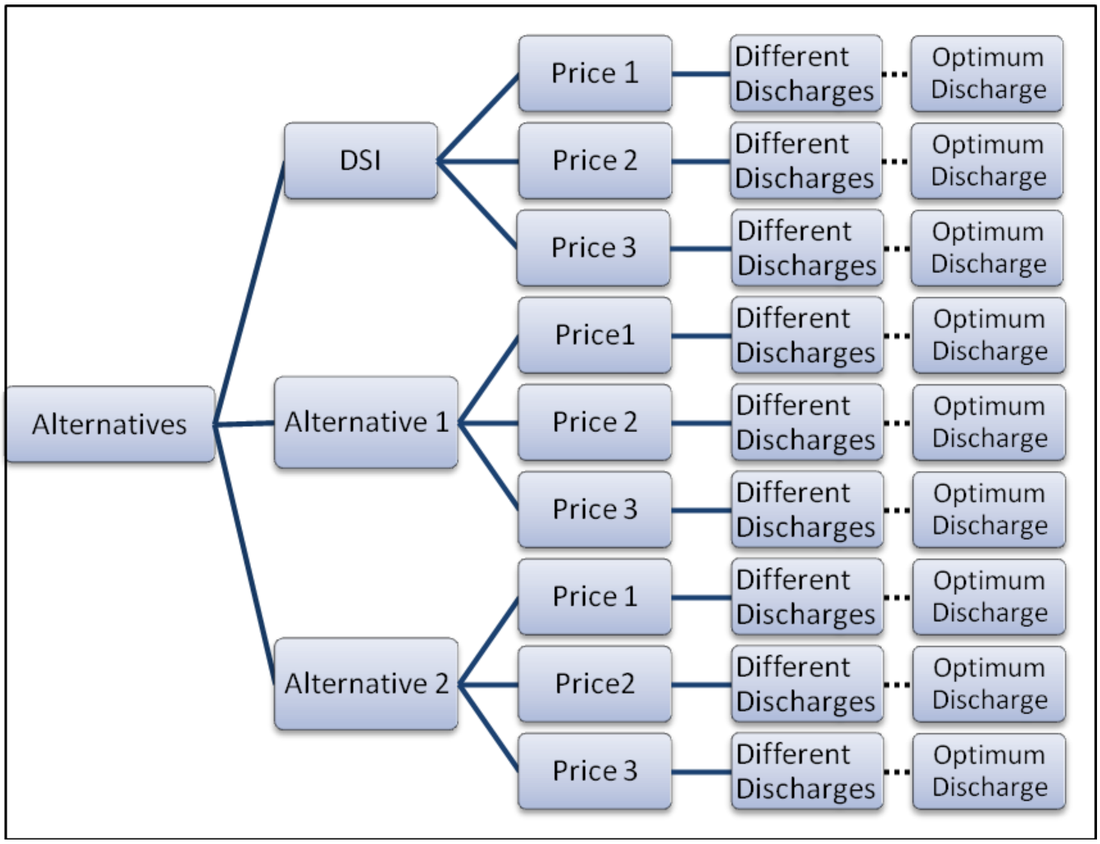


**Figure 43 Evaluation of alternatives for various design discharges and electricity prices**

Alternative projects are evaluated by using RETScreen using the same procedure used for DSİ formulation. This procedure was explained in Section 4.1 in detail thus it is not repeated here. Only the parameters which are changed for Alternative 1 and

Alternative 2 are explained in the following sections. The main parameters which are revised for these two alternatives are:

- Lengths of tunnel and channel sections,
- Allowable tunnel headloss factors.

### 4.2.1 Lengths of Tunnel and Channel Sections

For DSİ formulation, the lengths of tunnel and channel sections were taken from the master plan report. For Alternative 1 and Alternative 2, these lengths are measured from a 1:25000 scale topographic map of the region. The lengths of tunnel and channel sections for the two alternatives are given in Table 20.

**Table 20 Lengths of tunnel and channel sections for different alternatives**

| | **Tunnel Length (m)** | **Channel Length (m)** | **Total length (m)** |
|---|---|---|---|
| **DSİ formulation** | 3320 | 11080 | 14400 |
| **Alternative 1** | 9000 | 3800 | 12800 |
| **Alternative 2** | 0 | 15205 | 15205 |

### 4.2.2 Alowable Tunnel Headloss Factors

The tunnel slope is calculated from the topographic map of Niksar HEPP as 0.0006 for DSİ formulation, and 0.0004 for Alternative 1. There is no tunnel in Alternative 2.

Selection of allowable headloss factor is done by a trial-and-error procedure as explained in Section 4.1.3. For DSİ formulation, the allowable headloss factor was adjusted to a value of 49 % in order to correct for the diameters. Since the tunnel length and the bed slope are different from DSİ formulation, for Alternative 1, the allowable headloss factor is calculated as 89 %.

## 4.3 The Results of the Analyses

The procedure used to select the optimum design discharge, which is explained in Section 4.1.5 is repeated for all three alternative projects (DSİ formulation, Alternative 1 and Alternative 2) and for three different electricity price levels. The optimum discharges found through this analysis are given in Table 21 and the annual net benefits corresponding to these optimum discharges are presented in Table 22.

**Table 21 Results of Analyses**

| OPTIMUM DESIGN DISCHARGE ($m^3/s$) | | | |
|---|---|---|---|
| | Electricity Export Rate | | |
| **Alternative** | **75 $/MWh** | **91.3 $/MWh** | **106.125 $/MWh** |
| **DSİ formulation** | 62 | 67 | 70 |
| **Alternative 1** | 56 | 61 | 66 |
| **Alternative 2** | 66 | 71 | 74 |

**Table 22 Annual net benefits for optimum discharges of the alternative projects**

| ANNUAL NET BENEFIT ($) | | | |
|---|---|---|---|
| | Electricity Export Rate | | |
| **Alternative** | **75 $/MWh** | **91.3 $/MWh** | **106.125 $/MWh** |
| **DSİ formulation** | 4506620 | 8462688 | 12168543 |
| **Alternative 1** | 544099 | 4210446 | 7769386 |
| **Alternative 2** | 7041697 | 11108134 | 14888180 |

As can be seen from Table 22 for all electricity export rates, Alternative 2 is the best alternative among the proposed alternative projects, while Alternative 1 is the worst option. For each electricity export rate, the annual net benefit of Alternative 2 is the highest and that of Alternative 1 is the lowest. The annual net benefit of DSİ formulation is between the annual net benefits of Alternative 1 and Alternative 2.

Table 22 shows that for a given alternative project, if the electricity selling price increases, the net benefit corresponding to the optimum design discharge also increases. When the design discharge of a project is increased, the total amount of electricity generated in a year increases. Since the electricity can be sold at a higher price, the total income increases as well. However, higher discharges require larger turbines, larger tunnels, larger channels and larger penstocks. Therefore, costs associated with such items also increase. Since the net benefit increases as electricity prices increases (see Table 22) it can be concluded that benefits increase at a higher rate than costs in the electricity price range of 75-106.125 $/MWh.

It should be recalled that the differences between the alternative projects are the lengths of tunnel and channel sections. Alternative 1 has the longest tunnel section (9000 m) and it resulted in the least amount of benefit as a result of RETScreen analysis. On the other hand, Alternative 2 has no tunnel section at all, and provided the maximum net benefit among the alternatives. These results imply that tunnel construction is more costly when compared to channel construction. Actually, this can as well be observed from the tunnel and channel costs calculated by RETScreen for all the alternatives for Niksar HEPP (see Table 23). As can be seen from Table 23, construction of 1 m of tunnel is approximately five times more expensive than that of channel.

**Table 23 Comparison of Tunnel and Channel Costs (Q = 60 $m^3/s$)**

| | DSİ | Alternative 1 | Alternative 2 |
|---|---|---|---|
| **Tunnel length (m)** | 3320 | 9000 | 0 |
| **Tunnel cost ($)** | 25083000 | 68851000 | 0 |
| **Tunnel Cost Per Length ($/m)** | 7555 | 7650 | - |
| **Channel Length (m)** | 11080 | 3800 | 15205 |
| **Channel Cost ($)** | 16455000 | 6281000 | 21878000 |
| **Channel Cost Per Length ($/m)** | 1485 | 1653 | 1439 |
| **Total Initial Cost ($)** | 110997000 | 147052000 | 89530000 |

It should be noted that the best alternative is selected solely with respect to economic terms. The environmental aspects, earthquake conditions, sediment and erosion problems are not taken into account. Moreover, the software does not calculate expropriation costs of canals. It just considers excavation costs. If the expropriation costs are high in the project area this may change the feasibility of the project. The software also does not consider the sediment conditions in the river which may necessitate additional measures for sediment removal, thus increasing the costs. These are other important weaknesses of the software.

# CHAPTER 5

# CONCLUSION

Hydropower projects offer great opportunities for sustainable development of the countries. Being the cheapest, domestic, and renewable resource of energy, it deserves to be high up on the governments' investment agenda. It is also a great market that creates business opportunities for private companies, especially in the developing countries.

RETScreen Clean Energy Project Analysis Software is a decision support tool developed in order to assist the planners and decision makers in developing the renewable energy and energy efficient projects. The software can be utilized worldwide and it reduces the money and time spent while identifying and assessing potential energy projects and alternatives at the initial planning stage.

In this study, RETScreen is used to evaluate the economical feasibilities of different alternatives of the Niksar HEPP project. For each of these alternatives, the optimum design discharges for different electricity export rates are also calculated.

Using RETScreen, change of financial parameters with respect to electricity prices is also observed. This allows the developers to see the financial performance of the projects in different market conditions. The software makes it a lot easier to observe the effects of the changes in the project formulation, which could otherwise take considerable amount of time.

The hydro formula costing method tool in RETScreen uses empirical formulas which are based on the completed projects in Canada. Therefore, these cost calculations include uncertainties when used in Canada as well as the other countries. The tuning parameters such as local manufacture coefficient and labor cost coefficient should carefully be selected to better estimate the initial costs.

The software considers only economic aspects when calculating total cost of the project. It does not take into account the environmental aspects. It cannot evaluate environmentally favorable solutions. The only environmental analysis available in RETScreen is the Emission Analysis and it can be used to calculate the emissions reduced when a hydropower project is implemented instead of a conventional thermal plant. Moreover, the software ignores earthquake, erosion, and sediment problems. If such problems exist in the project area, the software must be used with caution.

The software has some deficiencies in calculating tunnel and channel costs as well. It uses only the excavation amounts but does not consider the expropriation costs. Another major drawback of the software is that some of the hydraulic parameters internally calculated by the software may be incorrect. For example, the tunnel diameters calculated by the software was incorrect for the case studies used in this thesis. The tunnel diameters are tuned by changing allowable tunnel headloss factor which resulted in unreasonable headloss values. It might be worth investigating impact of changing other parameters such as percent length of tunnel that is lined for tuning tunnel diameters.

Results of the analyses reveal that, tunnel construction is a major item in total costs. Length of the tunnel section significantly affects the economical feasibility of the project. Long tunnel sections had better be avoided if possible. However, these analyses do not cover the assessment of the environmental effects or social and cultural issues. In some cases a tunnel section may be preferred to a channel section even if it is more expensive. As far as the number of trees cut is concerned, tunnel construction is a better alternative. For earthquake-prone areas, tunnels may be preferred since tunnels are known to be the most earthquake-resistant structures in a hydropower scheme. However, a collapse in the tunnel can cost a lot more than a failure in a channel, and can be more difficult to restore. Long tunnels can also cause groundwater disturbance and dewatering in some places. During the tunnel construction, noise and the vibration created by explosions may impact the fauna. On the other hand, land acquisition costs for channels may be very costly in some regions or even impossible in cultural and historical sites. Therefore, economic considerations are not solely enough in planning of hydropower projects. All of the other aspects should be taken into account starting from the very beginning of the project development process.

As explained in the previous paragraphs RETScreen has some weaknesses; but it still can be used in prefeasibility and feasibility studies, where the cost calculations are expected to have an accuracy of around ± 40 %. It takes about a couple of weeks to learn how to use the software, and when the required data is available, it takes two to three hours to conduct economical analysis for a hydropower project. Moreover, when the input parameters of the program are changed, the results are updated within seconds, which helps to save time. It can be concluded that the decision maker may benefit from the analysis results of RETScreen software in evaluating various alternatives of the hydropower project if he or she is informed about all the weaknesses of the software.

Being one of the fastest growing economies in the world, Turkey needs to develop energy projects in order to provide the industry with the energy it requires. Significant amount of electricity is generated in thermal plants using natural gas in Turkey. This makes Turkey reliant on natural gas imported from other countries. Energy is an important power in politics. Therefore, countries should try to utilize their domestic energy resources as much as possible. Turkey has a huge untapped potential in hydroelectric power. Two-thirds of its hydropower potential remains to be developed. Harnessing this potential should be prioritized in the energy policy. This will ensure the self reliance of the energy market in Turkey and help to decrease GHG emissions for a cleaner future.

Utilizing the hydropower potential does not mean that the hydropower plants should be constructed whatever the cost. Sustainable development of hydropower plants is essential. Environmental and social aspects of these projects should be carefully assessed. Legislative and administrative arrangements complying with international standards should be prepared to guarantee the utilization of resources in an environmentally, socially and economically sustainable way.

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