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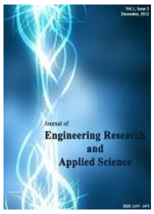

A simple feasibility study of a small hydropower project

Kamil Kaygusuz*

Department of Chemistry, Karadeniz Technical University, Trabzon, Turkey

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Abstract
Hydropower is among the most widely used type of renewable energy. Oppositions to big hydropower projects with reservoirs increased the use of small hydropower plants. Development of a small hydropower project is a challenging engineering task. Different software's are developed and used to make initial estimations of energy generation and initial costs of the project. RETScreen Clean Energy Analysis Software can be used worldwide allows the user to estimate initial energy output and costs. In this study, the Kemerçayır small hydroelectric power project and alternative project formulations are reevaluated using RETScreen. The results of the evaluations of the economical profitability, environmental impacts and sustainability aspects are compared.

Keywords: Small Hydropower, Hydropower, Sustainability, Kemerçayır HEPP, RETScreen

1. Introduction

The demand for energy is increasing day by day with the growing industry and living standards of people. To overcome this demand new energy facilities are under construction all around the world. Dependence on fossil fuels to generate electricity results in high greenhouse gas emissions, which led to global warming and climate change. Moreover, the cost of electricity is getting higher due to the high fossil fuel prices. Those disadvantages increase the importance of renewable energy [1-5].

Hydropower is the most reliable sources of new generation into the future, and its share is more than 92 % among the renewable energy generated. However, there is a great opposition against large scale hydropower projects worldwide. Despite the benefits of large dams, there are social, environmental and economic disadvantages to be concerned. Due to these factors small hydropower (SHP) systems gain more importance. SHP plants combine the advantages of hydropower with those of decentralized power generation, without the disadvantages of large scale installations. We know that SHP emerged as an energy source is accepted as renewable, easily developed, inexpensive and harmless to the environment [6, 7].

The dependence of imported sources to generate electricity is more than 70 % in Turkey. Turkey has a great untapped small hydropower (SHP) potential. Unexploited SHP potential of Turkey is equal to approximately 70 % of unexploited SHP potential of all European Union countries. To use the untapped SHP potential of Turkey, especially after the foundation of Energy Market Regulatory Authority (EMRA) in 2001, many local and foreign investors have entered to the energy market [8-12]. In this study, a number of alternative formulations are developed for Kemerçayır small hydroelectric power plant (SHEPP) located in Of, Trabzon and its profitability compared by using benefit-cost analysis of RETScreen. Alternatives with longer channels instead of tunnels resulted in higher net benefits. However, for Kemerçayır SHEPP's the benefit cost ratios for three cases were very similar to each other. The cost of channel construction is cheaper than cost of tunnel construction, if the topography of the project area is not too steep [13, 14].

2. Hydropower for sustainable development

Renewable hydropower is a reliable, versatile and low cost source of clean electricity generation and responsible water management. Modern hydropower plants are helping to accelerate the clean energy transition, providing essential power, storage, flexibility and climate mitigation services. Hydropower is also a key asset for building secure, clean, electricity systems and reaching global net zero targets. On the other hand, there are four main types of

*Corresponding author: kamilk@ktu.edu.tr

hydropower plants: run-of-river, storage, pumped storage and offshore hydropower. Only a small minority of the world's dams are built for hydropower, with the majority used for irrigation, water supply, flood control and other purposes [1-14].

Many hydropower dams are used for multiple purposes beyond electricity generation, providing infrastructure to supply clean water for homes, industry and agriculture, as well as recreation and transportation services. Hydropower projects can be used to regulate and store water to mitigate the impacts of extreme weather events such as floods and drought, which are on the rise due to climate change. Around 60% of all renewable electricity is generated by hydropower. The sector produces about 16% of total electricity generation from all sources. Hydropower installed capacity reached 1,330 GW in 2020 as generation hit a record 4,370 TWh. China, Brazil, the USA, Canada and India are the largest hydropower producers by installed capacity. Figure 1 shows the global total hydropower capacity by countries [12].

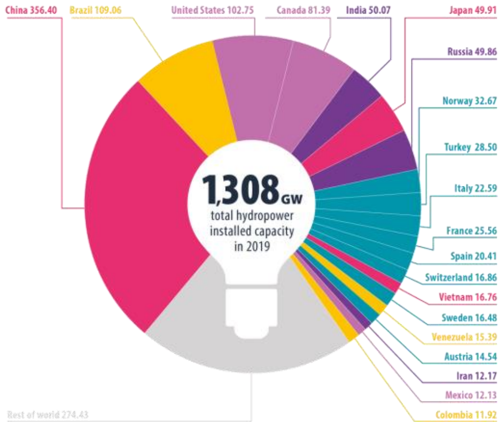

Figure 1. Global total hydropower capacity by countries

As a globally, China, Brazil, the USA, Canada and India are the largest hydropower producers by installed capacity [11]. More. Between 2015 and 2019, the average year-on-year worldwide growth in hydropower installed capacity was 2.1%. Hydropower is an ideal complement to variable renewables like wind and solar, thanks to its flexibility and energy storage services. Hydropower can meet demand when these intermittent sources are unavailable. Pumped storage hydropower, operating like a green, rechargeable battery, absorbs energy when supply exceeds demand [12].

The generation of energy from water can be explained by the law of conservation of energy. The potential energy of flowing water is converted to kinetic energy in the penstock. The kinetic energy of the flowing water turns the blades of the turbine, where it is converted to mechanical energy. Finally, the turbine shaft rotates the generator and the final product, electrical energy is generated. The power generated by using the potential energy of flowing water is given by the following formula [7, 8]:

$$P = \eta * \rho * g * Q * H \qquad (1)$$

Where; P is the power in Watts, η is the general efficiency of the plant, ρ is the density of water in kg/m^3, g is the gravitational acceleration in m/s^2, Q is the discharge passing through the turbine in m^3/s, H is the gross head of the water in m.

2.1. Small Hydropower

2.1.1. Definition of small hydropower

There is no internationally accepted definition for small hydropower. In China, small hydropower can refer to capacities up to 25 MW, in India the limit is 15 MW; whereas the limit in Sweden is 1.5 MW. Moreover, within the range of small hydropower, depending on the installed capacity, the type of the plant is named as; mini, micro, and pico hydropower which have an upper limit for installed capacity as; 1 MW, 100 kW and 5 kW, respectively. By this way, they can provide energy to a central grid, an isolated grid or an off-grid load.

2.1.2. Run-of River Schemes

Run-of river schemes use the flowing water of the river to generate electricity. If the flow drops below the minimum design discharge, the generation will stop. Run-of river type small hydropower plants generate power without flow regulation. Most of the run-of river schemes has no water storage, thus the energy generated will fluctuate with river flow. In the world, most of the small hydropower plants are run-of river type plants in the world. Some of the run-of river type plants have a head pond adds a little storage capacity to the scheme. Figure 2 shows a schematic overview of the run-of-rive type small hydroelectric power plant [7-11].

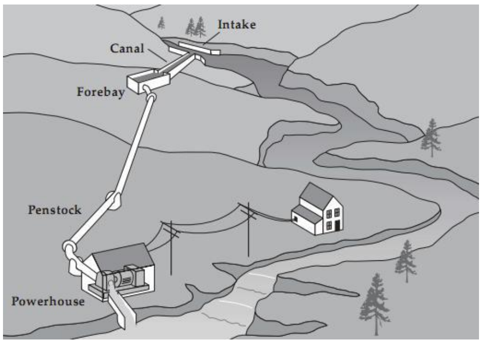

Figure 2. A run-of river scheme.

3. Evaluation of the project formulations using RETScreen

3.1. Introduction

Three project formulations given in the Feasibility Report [18] and four alternative projects formulations are evaluated using RETScreen [19-25]. The values such as discharge, elevations, tunnel and channel lengths used in the evaluation of the alternatives are taken from the Feasibility Reports [18]. A brief explanation about the data requirements is provided here. Moreover, the software has a built-in user manual. Interested reader may refer to these references for further details. RETScreen runs on Microsoft Excel platform and uses empirical equations to calculate the energy output and costs of the projects. Figure 3 shows the general layout of the program. As can be seen in Figure 3, the program has; "Start, Energy Model, Cost Analysis, Emission Analysis, Financial Analysis, Risk Analysis and Tools" sheets. In this study, emission and risk analysis sheets are not used. In the evaluation of the alternatives, first Start and Energy Model sheets are completed with the required data. After that the "Hydro Formula Costing Method" given in the Tools sheet is used to calculate the total initial costs of the project. In the next step the Cost Analysis sheet is completed. Finally, Financial Analysis sheet is filled and as a result benefit-cost ratio of the project is obtained

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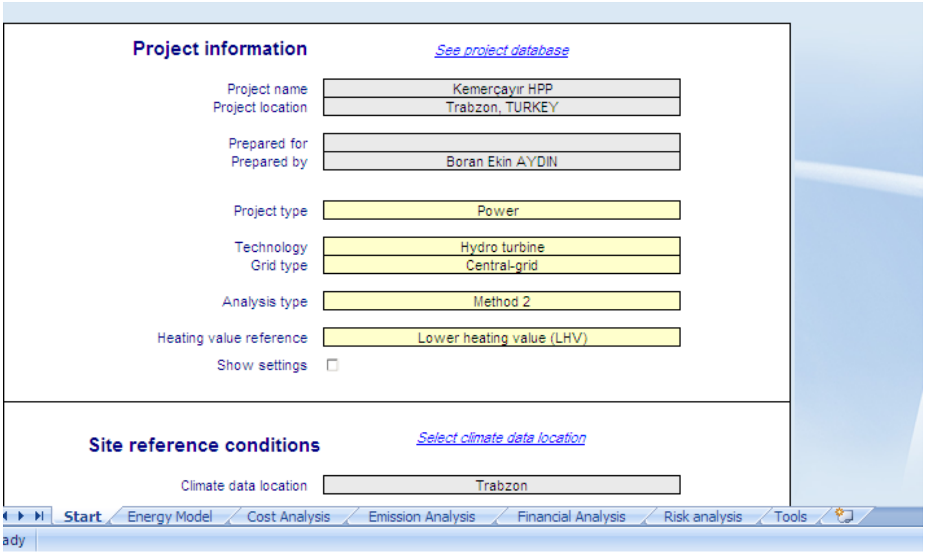


Figure 3. General Layout of RETScreen.

Input requirements of RETScreen are explained in the following sections. The sheets that are completed for Kemerçayır HEPP are provided as examples.General information about the project is entered to the Start Sheet of the program. The Start Sheet of Kemerçayır HEPP is given in Figure 4.

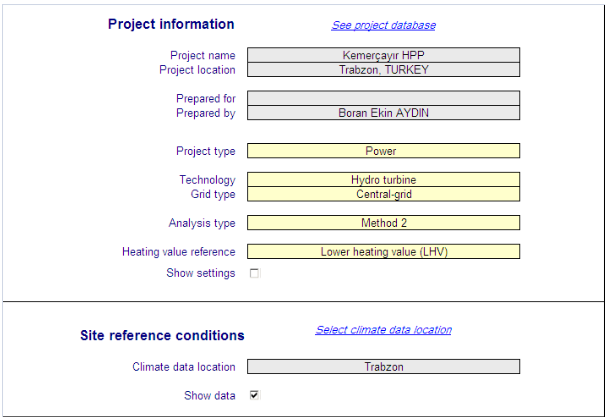


Figure 4. The Start Sheet Project type and technology.

The data entered to the energy model sheet is used to calculate the energy output of the project. As an example, the energy sheet prepared for the Kemerçayır HEPP is shown in Figure 5.

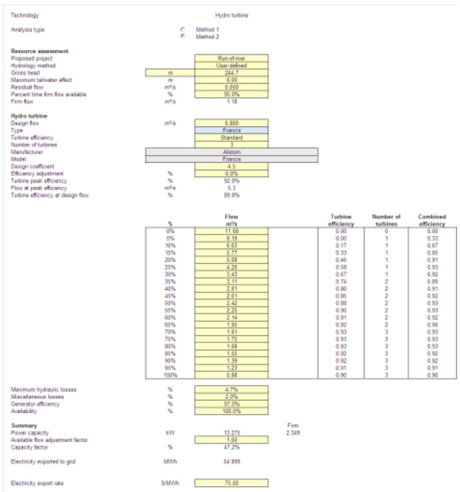


Figure 5. The Energy Sheet for RETScreen.

Design coefficient is a dimensionless factor used to adjust the turbine efficiency by taking into account varying manufacturing techniques [23-25]. In this study, software default value is used since there is no information about the manufacturing techniques of the turbines. Efficiency adjustment factor is used to adjust the turbine efficiency curves [20-25]. As mentioned above, in this study, standard turbine efficiency is used; so there is no need for efficiency adjustment. Installed capacity of the project is calculated in the energy model sheet. Figure 6 shows the flow and power duration curves for Kemerçayır HEPP generated in the energy model sheet.

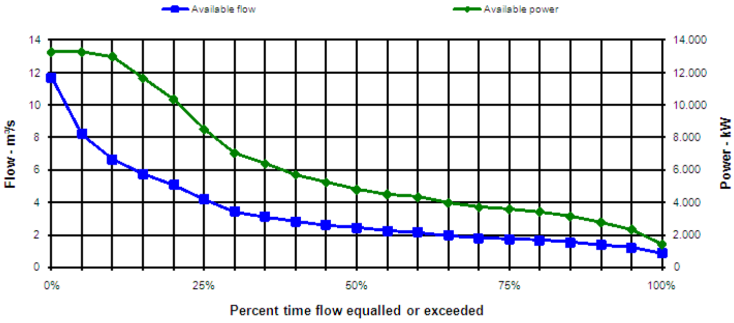
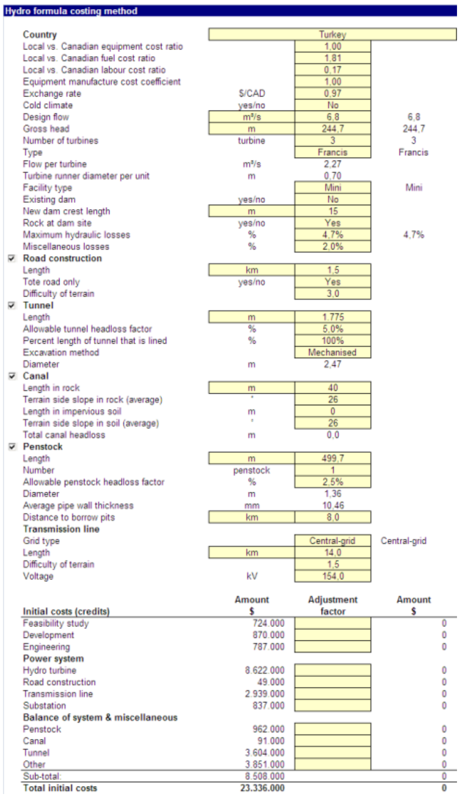


Figure 6. Flow and Power Duration Curves for Kemerçayır HEPP

The Hydro formula costing method tool is used to estimate small hydro project costs using formulae derived from the costs of numerous completed small hydro projects (RETScreen, 2010). Figure 7 shows the hydro formula costing method sheet prepeared for Kemercayır HEPP.



Hydro formula costing method

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

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

Figure 7. The Hydro Formula Costing Method Sheet for Kemerçayır HEPP

Allowable tunnel head-loss factor is a ratio between the allowable headloss in the tunnel and the available gross head [20-25]. A ratio between 4 % and 7 % is suggested by the software. In this study, 5 % is used as the allowable tunnel head-loss factor. The tunnel diameters obtained in RETScreen is similar to the diameter calculated in the Feasibility Report [18]. As an example, the diameter of the tunnel of Kemerçayır HEPP is given as 2.50 m while RETScreen calculated the diameter of the tunnel for this project as 2.57 m. In Turkey, minimum diameter used in tunnel construction is 3.0 m. Although, smaller tunnel diameters are obtained in design stage, due to the restrictions of the equipment used a diameter of 3.0 m is used for the tunnel [19].

3.2. The cost analysis sheet

If the quantity and unit cost of the main items calculated in the hydro formula costing method are known, the user should enter all of them into the cost analysis sheet. However, in this study, since the quantity and unit costs of the items are not known the total initial cost obtained in the hydro formula costing method sheet is directly entered to the cost analysis sheet. Figure 8 shows the cost analysis sheet prepared for Kemerçayır HEPP.

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

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Parts & labour	project	1	$ 46.672	$ 46.672
User-defined	cost			$ -
Contingencies	%		$ 46.672	$ -
Sub-total:				**$ 46.672**

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost	35	$ 4.311.000	$ 4.311.000
				$ -
End of project life	cost			$ -

Figure 8. The Cost Analysis Sheet for Kemerçayır HEPP

In this study, we suggested using 0.6 % of total initial cost as annual cost. Periodic costs are the costs are paid at regular intervals to maintain the project in working condition [20-24]. As the periodic costs we also suggested using 80 % of initial electromechanical equipment cost in the 45th year of the projects life time.

3.3. The Financial Analysis Sheet

Parameters related with financial analysis of the project are entered into the financial analysis sheet. Figure 9 shows the financial parameters entered for Kemerçayır HEPP.

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

Figure 9. Financial Parameter entered for Kemerçayır HEPP.

Hydropower projects do not consume any fuel; therefore, fuel cost escalation rate is taken as 20 %. Inflation rate and effective income tax rate are considered as 20 % and 40 %, respectively; and these values are used in this study. Discount rate and project life is taken from the Feasibility Report [19] as 12 % and 50 years, respectively. Also, debt ratio, interest rate and term for the project are selected as 65 %, 8 % and 8 year, respectively. Depreciation method is selected as "straight line" and depreciation tax basis is used as 95 %. Depreciation period is used as the project life of the project. After entering these values to the financial analysis sheet, project costs and savings/income summary (Fig. 10) calculated by RETScreen.

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

Figure 10. Project Costs and Savings/ Income Summary prepared for Kemerçayır SHEPP.

4. Conclusions

Turkey is important developing country and it needs much more energy to development. But Turkey's domestic fossil energy sources such as hard coal, natural gas and petroleum are very poor and it need a lot of such energy sources importing from other countries throughout the world. On the other hand, hydropower as a sustainable and renewable resource is a major energy source for Turkey. A significant portion of the economically viable hydropower potential of Turkey has not been utilized yet. Thus, many small HEPPs are under construction and in program to harness this economically viable potential. Developing a hydropower project requires time and money as well as engineering experience. In order to assist engineers in conducting feasibility analysis of hydropower projects many computer tools have been developed. One such software is RETScreen.

In this study, three alternatives for three formulations provided in the Feasibility Report [19] was developed. The design discharges are calculated for Kemerçayır HEPPs in the Feasibility Report. However, the details of these calculations are not provided in the Feasibility Report .In this study, design discharges for all the suggested alternative methods are calculated through an optimization procedure. Finally, the economic analysis for Alternative 2 is conducted using the design discharge obtained from the optimization procedure conducted in this study. The inputs and some of the important outputs of the Kemerçayır HEPP and their alternatives are given in Table 1.

Table1. Kemerçayır HEPP and Alternatives

		Case 1 Kemerçayır $Q_d = 7.0\ m^3/s$	Case 2 Alternative 1 $Q_d = 7.0\ m^3/s$	Case 3 Alternative 2 $Q_d = 7.20\ m^3/s$
INPUTS	Gross Head (m)	267.65	268.54	267.86
	Tunnel length (m)	1 780	768	774
	Channel Length (m)	65	896	896
	Penstock length (m)	500.2	500.2	500.2
OUTPUTS	Power capacity (kW)	13,865	13,768	14,012
	Total Initial Cost ($)	24,788,643	23,564,462	27,878,546
	Annual costs ($)	48,786	47,465	49,214
	Periodic costs ($)	4,868,111	4,846,324	4,834,234
	Total annual savings And income($)	5,447,766	5,456,644	5,464,424
	Simple Payback (year)	6.8	6.9	6.8
	Benefit-Cost Ration	7.45	7.86	7.42

RETScreen International Clean Energy Analysis Software is a decision support tool which could be applied internationally. RETScreen is useful software which may be utilized in comparing various alternative project formulations. The main advantage provided by RETScreen is the capability to conduct benefit-cost analysis in a timely manner. In this study, a number of alternative formulations are developed for Kemerçayır small hydropower plant located in Of, Trabzon and it profitability are compared by using benefit-cost analysis of RETScreen. Alternatives with longer channels instead of tunnels resulted in higher net benefits. Within the scope of this study, best design discharges are identified and benefit-cost analysis is carried for various electricity prices for a number of alternatives. Realization of many runs required for this analysis is conducted by RETScreen in a timely manner. It can be concluded that especially at the pre-feasibility stage, RETScreen is a useful tool which can be used to compare the possible project alternatives. Its user friendly environment, ease of utilization and timely calculations can decrease the cost of pre-feasibility studies.

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