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Techno-economic Feasibility Study of the Gunde Teklehaymanote Micro-hydropower Plant at Tindwat River, Central Gondar, Ethiopia

A. K. Belay[1]*, D. Atenafu[2], S. Birhan[3], T. Tegengn[1]

[1] Mechanical Engineering Department, Institute of Technology, University of Gondar, Gondar, Ethiopia
[2] Hydraulics Engineering Department, Institute of Technology, University of Gondar, Gondar, Ethiopia
[3] Electrical and Computer Engineering Department, Institute of Technology, University of Gondar, Gondar, Ethiopia

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A B S T R A C T

Ethiopia has a high potential for water for hydro-power development. Even though there is untapped potential, the country's electricity coverage is poor. This paper presents a technical-economic feasibility study of gunde micro hydropower at the Tindwat River, Central Gondar, Ethiopia. In the techno-economics study, the analysis was made for energy modeling, economic scenarios, and sensitivity, risk, and emission analyses. The study shows that this mini-hydropower project can be developed with an installed power of 18 kW, where the Kaplan turbine is recommended. The construction of small scale hydropower in the tindwat river is technically and economically feasible with total net present cost of US $ 253537, cost of energy $0.09/kWh, simple payback period of 5.9 years, and internal rate of return 23.9%. The result also shows that construction of hydropower curtails greenhouse gas emissions of carbon dioxide by 588.65m^3 of gasoil per year. It also showed that small hydroelectric power generation from Tindwat River would improve the electricity supply to Gunde Teklehaymanote monstery and off-grid rural communities.

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INTRODUCTION

In our world, the most important element is energy. It is also a crucial factor in education, health, and transportation for an equitable standard of living, economic development, and employment. Even though it is important, the status and comparison between the regions is as follows. According to literature [1] report, it is revealed that the electric access level of in Latin America 74%, North Africa 98.4%, South Asia 60%, Middle East 72%, and for Sub-Saharan Africa (SSA), it is only 14%.

Among all renewable energy resources, hydropower is the most reliable, new source in the future, and its share is more than 92%, according to literature [2] for generating energy. However, unreality and serious shortage are common features of electricity generation in sub-Saharan African countries [3].

Ethiopia is a country located in the Sub-Saharan region. The country is also lucky with ample water resources that can be used for power generation. Hydropower is the main energy resource for poverty reduction and sustainable development in Ethiopia [4]. The potential to produce electric from hydro power is over 45,000MW [5]. The current installed capacity of 4,284 MW is 97 per cent renewable of which effective hydropower installed capacity is 3,810 MW. Also, 8,864 MW of hydropower development is under construction inculuding Grand reinesance dam (GRED) [5].

Classification of hydropower is different from region to region, but according to literature [6], the definition of small hydropower (SHP) is a plant that will produces electricity power less than 25 MW. This plant also has a subclass into three (small, mini, and micro). The plant, which produces less than 100 kW is called micro hydro power. If the plant produces power between 100 kW to 2MW, which is called a mini-hydropower plant. The power production range from 2MW of 25 MW is called a small hydropower plant. The micro-hydroelectric energy system is planted, which will produce power from 5-100 kW when it is fitted on and across a river. This system stores power in the form of water and performs like a battery. When compared with a similar size, a power plant from another resource. It has high efficiency (70-90%), high capacity factor (>50%), slower rate of change, and maximum power output it is referred to literature finding [7].

In Ethiopia, different pilot MHP sites (cross-flow turbines) in the Sidama Zone/SNNPR with a capacity of 7 kW

*Corresponding Author Email: *anta.energy@gmail.com* (A. K. Belay)

(Gobecho I), 30 kW (Gobecho II), 33 kW (Ererte) and 55 kW (Hagara Sodicha), respectively and upgraded a watermill in Jimma Zone/Oromia (Leku) into a 20 kW MHP, further a 10 kW MHP plant in Kersa were installed. In general several pico hydro schemes as well as 32 cross flow turbines exist, which power flower mills with out put from 5 to 32 kW. But 30-40 % of the plants are not operational due to lack of water (in dry season), management as well as technical problems [8].

Therefore, this paper examine techno-economic feasibility of gunde teklehaymanote micro-hydro-power plant in central gondar, Ethiopia, on a fall river of Tindwat. The paper also gives awareness to NGO who are working on energy, Govermantal body, and private sector, to fund for construction of small hydro power in this area.

METHODS AND MATERIALS

Study site and materials

Location

The site is placed in the Misraq Belessa District, Centerla Gondar, Amhara Region of Ethiopia. The Misraq Belesa district is positioned on the south, with the aid of the south Gondar zone, on the west by Mirab Belessa, on the northwest through the Wegera, on the north by using Jan Amora, and on the east through the Wag-Hemra Zone. The towns in Misraq Belessa include Hamusit [9]. The tindawt River is placed eleven km from Hamusit city. It is also 70 km some distance from Gondar town. The region is placed on 12.3 ˚N and 37.65 ˚E. In the selected place, there is a large monastery, which is called Gunde Teklehaymanot. Near the monastery place formerly, there was once a water mill currently it is not in operation. Weir and the water root still exist solely require small maintenance to convert into micro hydropower. The area is proven as follows as shown in Figure 1.

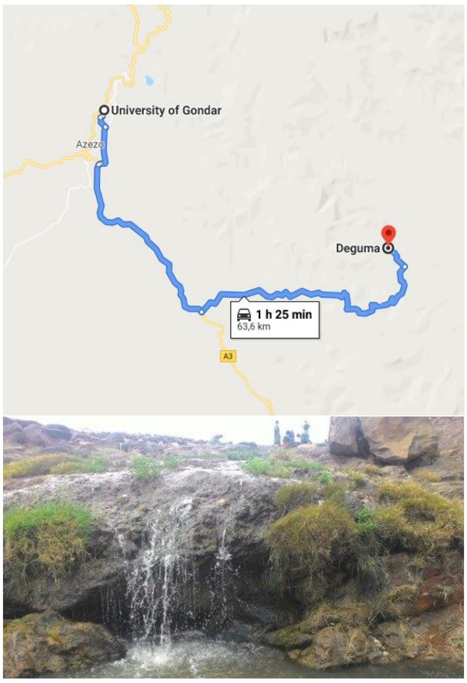

Figure 1. The path from University of Gondar to river at gond teklehaymanot

Climate: The temperature of the place is 25 to 29ºC in the summer season and 20 to 23ºC in winter. The relative humidity varies from 60 to 80%. The duration of rainfall in the area is from June to September, and the average annual rainfall is 1151 mm.

Population: Gunde Teklehaymanote area, the largest village with approximately one hundred households. In the monasteries, there are one hundred twenty monks and student populations in 30 rooms. Thus, the find out about location has 130 households, with a populations of about 620 people.

Social structure of the people: The total vicinity is inhabited by fragile socioeconomic prerequisites belonging to the lower-income group. There is only one foremost school in the village and for high faculties and colleges, college students have to go to neighboring towns. The medical unit is simply a major health center; for hospitals, the inhabitants have to tour to arbaya and Maxesgn. The houses in the cluster are made of mud houses. The literacy charge is very low, and most are school drop-outs. Almost all the humans of the vicinity rear cattle produce sufficient quantities of milk, which is provided close by the arbaya city.

Materials

The materials used for the study were Global Positioning Systems (GPS), Meter, high measurement tools, electronic laser level, and Rescreen software. Different data were collected from the Ministry of Water and Energy as well as EEPCo for policy and supply issues. For consumer data, the project makes a survey of the project area. Moreover, the project collected tariff-related data from EEPCo’s.

Method

Technical method

The Gunde Micro Hydropower Study, two parameters were used to determine the hydropower potential sites, discharge, and head. The head is the altitude difference from the upstream to the downstream water level. The head was measured directly from the site. Discharge is the flow rate of the water, which will be colleted for the consecutive ten years. The leaf floating method was used to determine the optimal discharge.

Power generation

The power equation for any small hydropower plant is as follows: This formula was used in the standard manual of the Japan International Cooperation Agency [10].

$$P = g * \rho * H * Q * \eta generator * \eta turbine \quad (1)$$

where g is the coefficient factor that is the acceleration of free fall 9.81m/s^2, ρ is the density of water, H is gross head in meters, Q is design flow in m^3/s, $\eta_{generator}$ is efficiency of the generator and $\eta_{turbine}$ is the turbine efficiency.

Penstock size determination method

Penstock size was determined using a formula similar to data reported in literature [11]. The penstock diameter d can be calculated as follows:

$$d = 2.69\left(\frac{n^2Q^2L}{H}\right)^{0.1875} \quad (2)$$

where D is diameter, Q is the flow rate, n is the manning coefficient, H is the net head and L is thelength of penstock in meters.

The length of a penstock for a given design consideration can be obtained as follows:

$$L = g * H * t_g / V \quad (3)$$

where t_g is water acceleration constant in pipe (s) and V is the flow velocity in ms^{-1}.

Manning's roughness coefficient n is a coefficient that represents the roughness or friction applied to the flow of the channel. Typical values of n are given in Table 1.

Turbines: The turbine converts mechanical energy into electrical energy. There are different types of turbines. Three main types of turbines based on their heads are listed in Table 2. The selection of this turbine depends on the head and discharge. The output of the turbine can be calculated as follows:

$$P_{output} = g * H * Q * \eta_{turbine} \quad (4)$$

where $\eta_{turbine}$ is maximum turbine efficiency, the efficiency of the turbine is different from that of turbine to turbine. Table 3 shows the efficiency of the various turbines used in hydropower.

Financial analyses

RETScreen V.4 software was used in analyze the economic feasibility of the project. This software can assess viability factors like the project site, equipment performance, initial costs, periodic project costs, financing, savings, and environmental features. The Ethiopian National and NASA's meteorological data were incorporated into the software. This paper uses methodology as reported in litertures [13, 14].

TABLE 1. Commercial pipes manning coefficient n [12]

Pipe Made of	n
Steel Welded	0.012
Polyethylene (PE)	0.009
PVC	0.009
Asbestos Cement	0.011
Ductile Iron	0.015
Cast iron	0.014
Wood –stave	0.012
Concrete	0.014

TABLE 2. Classifications of turbines by head [11]

Turbine Type	Head		
	High < 40m	Medium 20-40m	Low 5-20m
Impulse	Pelton Turgo	Crossflow Turgo Pelton	Crossflow
Reaction		Francis Pump-as–turbine(PAT) Kaplan Propellwe	Propeller Kaplan

TABLE 3. Different types turbines Vs efficiency [12]

Turbine Type	Efficiency (%)
Pelton	80-90
Turgo	80-90
Cross-flow	65-95
Propeller	80-95

RESULT AND DISCUSSIONS

Case studies

The project site is situated on the central north and northwest highland plateaus of Ethiopia, under the sub-basin of Tekeze-Setit-Atbara. In this catchment area, the river network as follows: (1) the river called Tekeze in Ethiopia and Setit in Sudan, (2) the river angereb, and (3) the river called Goang in Ethiopia and Atbara in Sudan. The geographic coordinates of the Platte River are shown in the following Figure 2. Latitude-12.4´ North and longitude- 37.68° East.

Data required for analysis of the sites is summarized in Table 4.

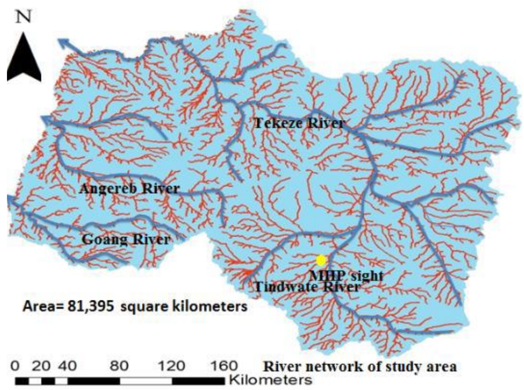

Figure 2. River network of the study area

TABLE 4. Data required for analysis of the sites

Water course	Tindawat river
Water Regulatory Authority	Central Gondar Zone Energy Bearu
Site location	Gunde T/Haymanot monastery, Belesa, Centeral Gondar, Ethiopia.
Latitude	12.4 ^{0}N
Longitude	37.68 ^{0}E
Catchment Area (km^2) Tekeza basin	81,395
Turbine type	Kaplan
Dam crest length (m)	5
Road Length (km)	1.5
Canal length in rock (m)	17
Grid Center	Arbaya City
Transmission line (km)	25km
Transformer Losses (ζt)	1%
Conduit Head Percentage Losses (ζh)	5%
Parasitic Electricity Losses (ζp)	1%
Plant Availability (A)	98%

Power equations for small hydropower

The power generated can be computed using Equation (1), using the following assumptions stated in Table 5.

Penstock size determination

The water was transported from the intake to the powerhouse through penstocks. Depending on the nature of the ground, the penstock and be installed over and under the ground. In our design, the penstock can be installed above the ground. The internal penstock diameter (Dp) can be calculated from the flow rate pipe length and growth head [15]:

$$Dp = 2.69 * [n_p^2 * Q^2 * \frac{L_g}{H_g}]^{0.1875} \; m \qquad (5)$$

where n_p is Manning's coefficient, Q is thewater flow rate (m^3/s), Lp is penstock length in (m) and Hg is the gross head in (m).

Hydrology and load

Figure 3 shows discharge duration curve and the hydrology data analysis is shown in Figure 4.

TABLE 5. Assumption for calculating the power

Specification	Value
Gross Head (m)	17
Design flow(m^3/s)	0.14
Generator Efficiency (ηg)	98%
Turbine Efficiency (ηt)	88.5%
Density of the water kg/m^3	1000
P=1000*0.14*17*0.80*0.98	18304.75kgm^2/s^3=18.304 kw

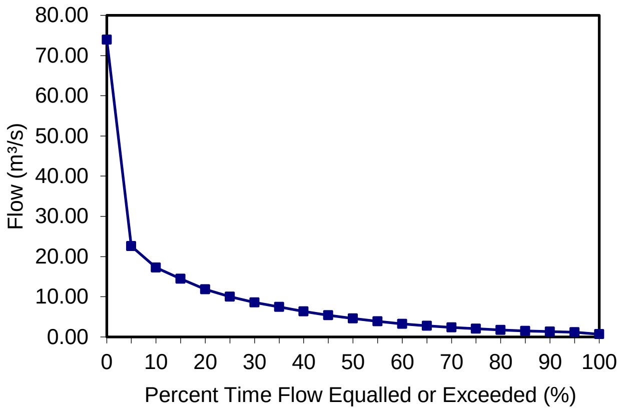

Figure 3. Discharge duration curve

Turbine selection

The turbine was selected considering the discharge and head. Based on the Figure 5, the fundamental component to select for a turbine is based on the head and flow rate. In our case, the head is 17 m and the flow rate of the revir stream is 0.14 m^3/s, the best turbine would be Kaplan. The main characteristics of Selected turbine are listed in Table 6.

Finical analyses

Financial parameters

Undertaking was calculated for 50 years of lifetime. From the completion of a fifty-year lifetime in each 15-year small repaire cost was calculated once. The annual escalation cost of Gasoil used to be calculated with the records from 2007-2014, as referred literature from previous work [16]. The inflation rate in Ethiopian was once calculated from the facts

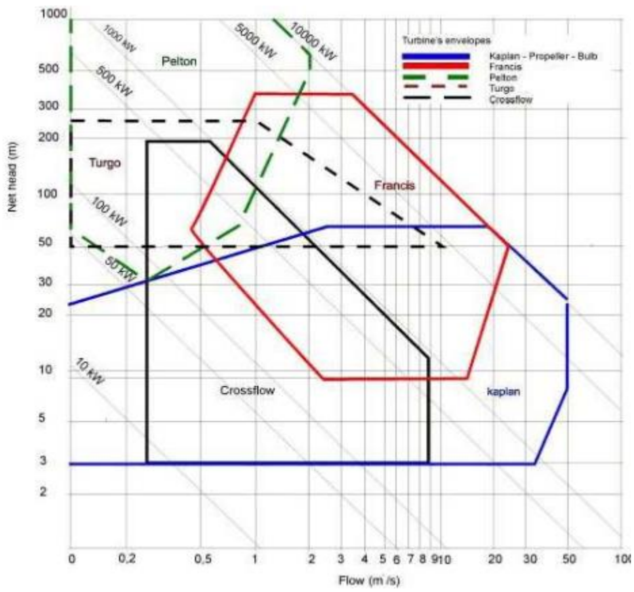

Figure 5. Trubine types and ranges of application [15]

TABLE 6. Selected turbine with key characteristics

Turbine Feature	
Maximum head	19 m
Design Head	17 m
Runner diameter	0.5 m
Design flow	0.14 m^3/s
Unit output	18.34 kW
Turbine efficiency	88%

Hydrology Analysis		Estimate	Notes/Range
Project type		Run-of-river	
Hydrology method		Specific run-off	
Hydrology Parameters			
Residual flow	m^3/s	0.05	
Percent time firm flow available	%	95%	90% to 100%
Firm flow	m^3/s	1.09	

Figure 4. Analysis of hydrology data

from 1988-2010. The obtained value of the former is 1.1% that of the latter 2.6%. A discount rate of 10% was chosen once.

Costs

The complete preliminary value of the turbine and related equipment of the project are provided in Table 7. The complete initial price of the challenge is US$ 253537.

The feasibility study, development, and engineering value were estimated at 12% of the initial cost, and the balance of plant and energy equipment was 42.7% and 35%, respectively. This discovery used to be similar to the finding said with the aid of the Instituto parala Diversificación y Ahorro de Energía [17].

Results of the pre-feasibility study

The economic indicators resulting from the profitability analysis carried out are summarized in Table 8.

As the ensuing economic indicators show, the herein described challenge would be fantastically profitable, the funding of which would be recovered then again shortly as the year positive cash flow is 5.9 years. That would produce advantages in the course of its complete lifetime. The research shows a very excessive internal rate of return (23.7%), which is pretty most dependent on the discount rate (10%). Figure 6 shows the growth of the net present value in the cumulative money float all via the project's lifetime. The benefit-cost ratio indicates that for every dollar invested, $2.03 will be received inclusive of all expenditures, which equates to $7824 as annual savings.

Risk analysis

In the sensitivity analysis, the outcomes of viable variants of preliminary costs, preservation cost, and the price of fuel on the internal rate of return, the net current value, and the payback duration were considered. The results are summarized and showcase that the most influential factor is the charge of facial gasoil followed by means of the preliminary costs. The price of fossil gasoil has an impact on all three financial indicators, while the initial value impacts the internal rate of return and the payback period mostly. The operation and preservation costs do not reflect on the showcase a necessary relative impact.

TABLE 7. Costs of turbine and related equipment

Initial Costs	**Percentage**	**US $**
Feasibility study	7.6	19,260
Develeopement	8.0	20,330
Engineering	6.4	16,264
Energy equipment	29.4	74,633
Balance of plant	41.4	105,074
Miscellaneous	7.1	17,976
Total Intitial Costs	100	253,537

TABLE 8. Economic indicators of project's profitability

Pre-tax Internal Rate of Return (IRR) and Rate of Return (ROI)	26%
After-tax IRR and ROI	23.7%
Simple Payback	10.7 years
Year to Positive Cash Flow	5.9 years
Net Present Value (NPV)	US$ 52,112
Annual Life Cycle Savings	US$ 7,824
Benefit/Cost (B/C) Ratio	2.03

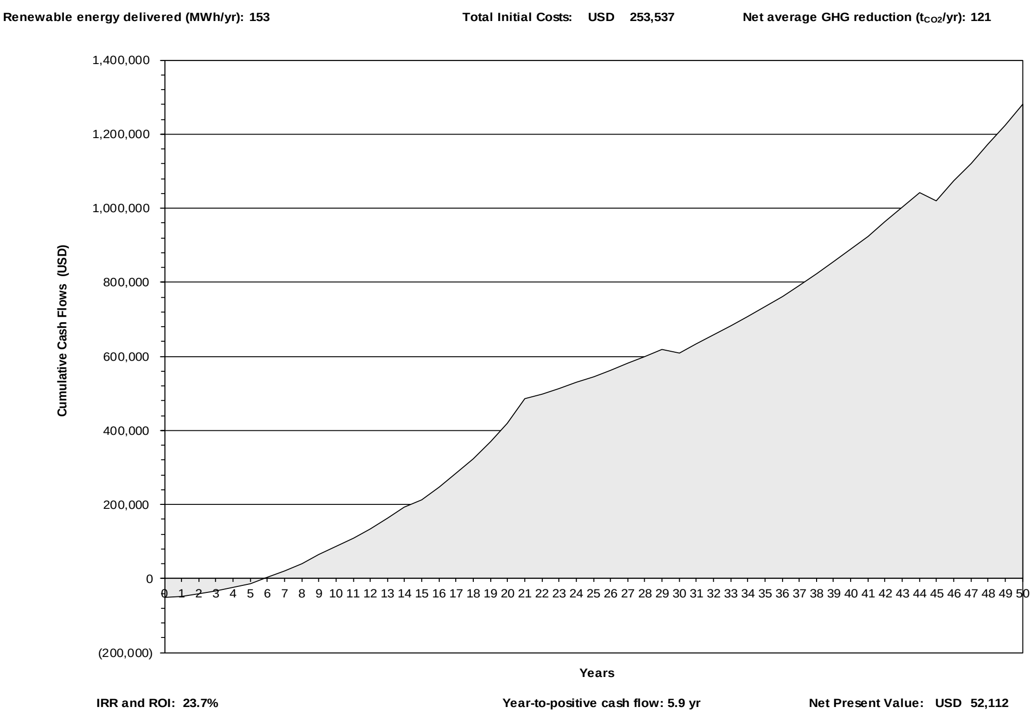

Figure 6. Cummulative cash flow

Resulting of the consequences of the sensitivity analysis, have an effect on the price of gasoil, and the initial cost on the profitability of the mission has been quantified with risk analysis. A large sensitivity vary of 20% was used to view both factors, that is, eventualities that mixed variations of each element ranging from -20% to 20% of the unique values have been considered. The results of the chance evaluation are tested in for the internal rate of return and a pay-back period, an multiplied of 20% in the preliminary costs, and a decrease of 20% in the rate of the gasoil end result in the worst-case scenario: an inside fee of return of 92% and a payback duration of 5.9 years. These are much less attractive, however nonetheless, very rewarding indicators, which shows that, even even though the mission is very touchy to variants in preliminary costs and the price of gas oil.

Emission analysis

The result indicates that the greenhouse gas emission discount from the find out is 137 tonnes of equal CO_2 per year. This quantity is equivalent to keeping the consumption of 318.58 amount barely gasoil or 588.65 m^3 of gasoil per year.

CONCLUSIONS AND RECOMMENDATIONS

The aim of this project is the techno-economic feasibility study of gunde teklehaymanot mini hydropower in the Tindwat River. The installation feature is a run-of-river hydraulic power plant. Based on the head and discharge data of the river, the total installed is 18 kW of a standalone system. The recommended turbine for the gadget is the Kaplan turbine. The end result indicated that a total asset of US$ 253537 are required to install the plant. The payback period of the undertaking is 6.9 years. The internal rate of return, payback period, and benefit-cost ratio were 23.7%, 5.9, and 2.03, respectively.

The threat and sensibility analyses of the assignment been proved that the task can stop profitable even on the critical cost variant of facial and fuel oil and initial costs. Based on environmental analyses, the task ought to minimize 137tonnes CO_2 per annum.

The assessment results showed that small hydroelectric energy technology from Tindwat, River can make contributions to small measures to improve the electricity supply to close by rural communities because the electrical energy needs of these communities are modest. Widespread improvement of small hydropower can make a contribution immensely to improving rural electricity get entry to degrees all through Ethiopia.

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Persian Abstract

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چکیده

اتیوپی پتانسیل بالایی برای منابع آب و توسعه انرژی حاصل از آب را دارد. حتی اگر پتانسیل بلااستفاده ای وجود داشته باشد، پوشش برق کشور ضعیف است. در این مقاله یک مطالعه امکان‌سنجی فنی و اقتصادی از نیروگاه آبی روستایی در رودخانه تیندوات، گوندار مرکزی، اتیوپی ارائه شده است. در مطالعه فنی و اقتصادی، تجزیه و تحلیل برای مدل‌سازی انرژی، سناریوهای اقتصادی، و تجزیه و تحلیل حساسیت، ریسک و انتشار گاز انجام شده است. این مطالعه نشان می‌دهد که این پروژه می‌تواند با توان نصب شده ۱۸ کیلووات توسعه یابد، جایی که توربین کپلان توصیه می‌شود. ساخت نیروگاه آبی مقیاس کوچک در رودخانه تیندوات از لحاظ فنی و اقتصادی با هزینه خالص فعلی ۲۵۳۵۳۷ دلار، هزینه انرژی ۰/۰۹ دلار به ازای هر کیلووات ساعت، دوره بازپرداخت ساده ۵/۹ سال و نرخ بازده داخلی ۲۳/۹ درصد امکان پذیر است. نتایج همچنین نشان می‌دهد که ساخت نیروگاه آبی باعث کاهش انتشار گازهای گلخانه‌ای دی اکسید کربن توسط ۵۸۸/۶۵ متر مکعب بنزین در سال می‌شود. همچنین نتایج نشان داد که نیروگاه برق آبی کوچک از رودخانه تندوات نیاز برق مساجد گوند تکلهایمانوت و جوامع روستایی خارج از شبکه را بهبود می بخشد.