PRODUCTION ENGINEERING ARCHIVES 2022, 28(2), 178-184

PRODUCTION ENGINEERING ARCHIVES

ISSN 2353-5156 (print)
ISSN 2353-7779 (online)

Exist since 4th quarter 2013
Available online at https://pea-journal.eu

Project of Micro-hydroelectric Power Generation System – Case study

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Article history
Received 03.02.2022
Accepted 22.04.2022
Available online 23.05.2022

Keywords
Hydropower
Micro-hydro
Sustainable energy
Energy co-generation
Project Based Learning (PBL)

Abstract
The article describes a student project of installing a micropower generation system utilizing energy from the water drained from underground coalmines. The paper contains a description of the site which is a manmade phenomenon from the anthracite mining era. The project described in the article was completed as part of the project-based learning curriculum. Students had the opportunity to work on a team and apply theoretical knowledge learned in individual courses as part of the engineering curriculum. The article also focuses on the calculation of the potential power capacity to a proposed hydropower generation system. The proposed micro-hydro system is harvesting the potential and kinetic energy of the water discharged from the water-draining tunnel. A commercially available micro-hydro turbine combined with an electric power generator was adapted for this purpose. The article also includes an analysis of the profitability of the project and the time of return on investment. The calculations are based on the current price of electricity (2021), depreciation schedule and present tax incentives (2021) to generate electricity from renewable sources. The article also includes some lessons learned from the project as well as the recommendations for future projects.

DOI: 10.30657/pea.2022.28.21
JEL: Q40, M11

1. Introduction

The project site is located in Northeastern Pennsylvania (NEPA) which used to be a very prosperous anthracite coalmining region. The site is known as the Jeddo Tunnel. Coalmining in the area started around 1850. The water was a major obstacle of the coalmining process. Using the ground configuration of the land, a tunnel (8 km long) was proposed to drain the water from the coalmines using the principle of gravity. [Executive Summary; International Correspondence School, 1907] It took three years (1891-1894) to construct the tunnel (Environmental Protection Agency). The cost to build the tunnel was $1M with two hundred fifty workers employed during the construction of the tunnel. During the construction of the tunnel. One hundred seventy tons of dynamite were used. The construction of the tunnel was listed as one of the major engineering accomplishments in the 19th century (Dorbin, 2021). The Jeddo Tunnel is draining underground water from a coal basin (85 km^2) (Report of the Department of Mines of Pennsylvania, 1901). The average underground water drained at the Jeddo Tunnel site is 150,000 liters/minute. The tunnel is draining underground water from beneath thirteen small municipalities. The anthracite coalmining industry ended in the 1950's. There is still strip-mining on a limited basis. The Jeddo Tunnel is one of the post-industrial sites which does not have any significance and has become more of a liability than asset. The Jeddo Tunnel is draining to the Black Creek which created some pollution in the local watershed. The water discharged from the Jeddo Tunnel includes zinc, iron, aluminum and manganese as well as sulfite and chloride. The contamination of the water in the thirteen municipalities is being analyzed and discussed by environmental groups. (Mendinsky and Dempsey, 2004). Over the years the contamination levels seem to be decreasing. The water discharged from the Jeddo Tunnel carries a significant amount of potential and kinetic energy. A few local investors have expressed interest in installing a micropower generation system harvesting the energy of the water discharged from the Jeddo Tunnel. The analysis of the feasibility of the micropower generation system project was done by a team of engineering students from the Pennsylvania State University-Hazleton Campus.

2. Aims of the Project and Literature Review

The aim of the project is to nurture an innovative personality in every student. The experimental project described in the paper is focused on engineering and business students. The objective of this research project was to prepare engineering and business students to take the initiative to pursue innovative ideas, so that they will be better prepared to enter the job market in the knowledge-based economy. An analysis of the literature emphasizes the important of this approach (Grebski and Grebski, 2016; Grebski and Grebski, 2018; Grebski and Grebski, 2019). The project was completed in cooperation with the Business Incubator Center located in Valmont Industrial Park (Hazleton, PA). The literature review emphasizes the importance of cooperation of a university and business incubator center (Wolniak et al., 2019). The project described in the article was completed as part of the project- based curriculum. Often students in the Engineering program take a variety of courses, but they have a problem cross-referencing the knowledge between the courses. Each individual course is being viewed by the students as a disjointed piece of the puzzle (Barron et al., 1998). Without seeing the big picture, the individual pieces of the puzzle do not make sense. The project incorporated into the curriculum allows the students to see the big picture (Blumenfeld et al., 1991; Han et al., 2015). Students are involved in using knowledge gained in statics, dynamics, strength of materials, machine design, tool design and manufacturing processes (Mielikainen, 2022). Students start the project from developing a list of analysis, calculations and other tasks necessary to complete the project (Saad and Zainudin, 2022). The project also includes the process of protecting intellectual property. The literature analysis also emphasizes the importance of that topic (Grebski and Wolniak 2018; Ulewicz and Sethanan, 2021). The concept can be expanded to students from other majors. Micro- hydropower systems are a very desirable method of generating renewable energy. The literature analysis supports that statement (Anderson et al., 2014; Kougias et al., 2019; Ergile et.al, 2020; Uddin et al., 2019). The capstone design project is a component of the project-driven curriculum. The project is linked to two senior-level courses (ENGR 490W-Fall Semester and ENGR 491W-Spring Semester). The topics for the annual capstone design projects are usually supplied by the Pennsylvania Technical Assistance Program (PennTAP). PennTAP is a state-sponsored agency with the objective of helping new and existing companies for the purpose of economic development of the state. New and existing companies needing technical support are contacting PennTAP for assistance. PennTAP maintains contact with local universities and attempts to find the expertise which is needed to solve the technical problems. All the services provided by PennTAP to new and existing companies are free of charge. The procedure for initiating and conducting the micro-hydro project (as well as other projects) is shown in Fig. 1.

The individual blocks in Fig. 1 are as follows:

1. Defining the problem takes place in the summer months each year. There are a couple of meetings between a PennTAP representative, engineering faculty and senior-level engineering students. The prospective clients are also invited to participate to describe the need and problem to be solved. As a part of the PBL project, the clients are usually small start-up companies with some of them in the incubation stage. There are exceptions and some projects are done for well-established companies. The engineering faculty member who will potentially supervise the project is making a judgement related to accepting the project as a part of PBL. The prospective client needs to designate someone from the company to cooperate with the students and provide the assistance in gathering the information and the data needed to conduct the project. The PennTAP representative is also invited as an ongoing liaison between the client and the university. The prospective client is required to sign a liability release form, The university faculty or the students are not liable for any potential legal issues or financial losses resulting from the project. There is no financial compensation to the university faculty or the students as a result of a PBL project. (This is a part of ENGR 490W course.)
2. After the project is accepted as a PBL project, a student team is formed. This student team studies the feasibility and methodology for completing the project. Students meet twice a week with the faculty member supervising the project and the representative of the client. The PennTAP representative attends some of the meetings. The student team is conducting an onsite inspection if the scope of the project requires that. All the meetings are conducted in a democratized culture and psychological safety. The decisions are made based on the team consent. The engineering faculty member sets the tone in assessing the merit. The client's representative is bringing to the forefront the company's expectations. (This is a part of ENGR 490W course.)
3. Requirements and restraints are formulated based on the following:
    - Client's expectations
    - Client's restraints
    - Environmental safety
    - Energy efficiency
    - Sustainability

    The client's company takes the lead in formulating expectations and restraints. (This is a part of ENGR 490W course.)
4. Brainstorming to generate multiple solutions takes place at the end of the Fall semester in the ENGR 490W course. This is a well-organized session with an opportunity for everybody to purpose at least one solution.
5. Evaluation of the different concepts takes place at the beginning of the Spring semester in the ENGR 491W class. Many different factors are considered and carefully weighted. The representative of the client's company is playing an important role in this step. The Engineering faculty oversees this process.
6. Building and testing of the prototype varies significantly based on the scope of the project. The client's company normally covers the expenses associated with building the

prototype. The client's company also actively participates in testing the prototype and collecting the data. The team of students as well as the Engineering faculty participate in testing and collecting the data. This part as well as all the remaining parts of the project are done in ENGR 491W class. The student team including the faculty and representative of the client's company still meet twice a week to discuss the progress and adjust the plans.

8. If the prototype complies with all the requirements and the client company is fully satisfied, then the process transfers to the last stage (11).
9. If the prototype does not fully satisfy the requirements, the entire process goes back to stage 10 of making changes into the design. The client company is making the final decision on this.
10. If making changes into the design are required the PBL project is being continued by another team of Students next year. This is due to the limited Amount of time (15 weeks each semester).
11. At the end of the Spring semester, students are submitting a written report with all technical documentation. They are also doing an oral presentation in the front of the Industrial Advisory Committee.

The faculty member teaching PBL courses (ENGR 490W and ENGR 491W) assesses each student in the entire team. A student's grade in the class is affected by the student's contribution, quality of technical written report as well as the quality of the oral presentation. Students are being assessed based on their contribution to the project. Students are not being assessed based on the success or failure of the project. Failure is a part of the innovative process. PBL projects tolerate failures and celebrates successes.

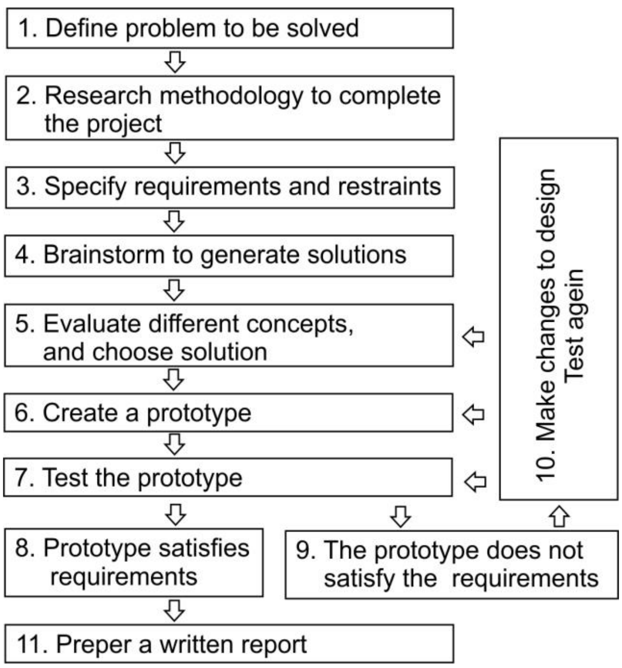

Fig. 1. Sequence of the activities of the capstone design project

3. Evaluation of the Site from the Energy Productivity Perspective

Evaluating the site from the perspective of harvesting the energy from the water is a very important component of this project. The water coming from the Jeddo Tunnel carries a combination of potential energy and kinetic energy. The power of the water being discharged from the tunnel can be determined by calculating the total energy (potential and kinetic) of the water during 1 second interval. Students were applying the body of knowledge learned in college-level physics courses as well as statics, dynamics and fluid mechanics. Then students are able to gain and practice the ability to transfer knowledge from one course to another.

a. Potential Energy of the Water

The potential energy of the water being discharged from the Jeddo Tunnel is a product of the weight of the water, W, (discharged from the tunnel) multiplied by the elevation, h, between the tunnel and the hydro-turbine as shown in Fig. 2.

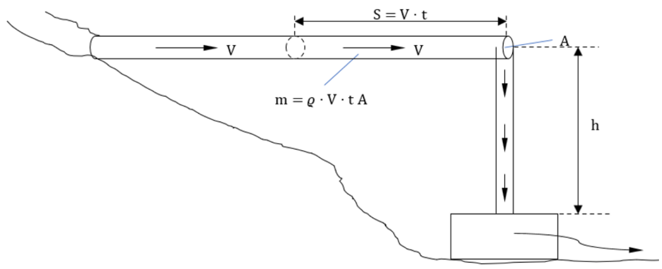

Fig. 2. Schematic drawing of a micro-hydro electric power generation system

It has been determined experimentally that the amount of water discharged in 1 second is 2500 liters. Assuming 1 liter of water has a mass of 1 kilogram, kg, the weight of the water discharged in 1 second is approximately 24525 newtons, N.

$$W = 24525N$$

The elevation, h, between the point of water discharge and the position of the potential water turbine is approximately 3 meters (3m).

$$h = 3m$$

The amount of the potential energy, PE, carried by the water in 1 second interval can be calculated as follows:

$$PE = W \cdot h \quad (1)$$

Substituting the numerical values, the potential energy (PE) in joules, J, is calculated as:

$$PE = 24525N \cdot 3m = 73575 \text{ J}$$

b. Kinetic Energy of the Water

The kinetic energy of the water during 1 second interval can be calculated from the following equation.

$$KE = mV^2 / 2 \quad (2)$$

Where,
m – corresponds to the mass of water discharged from the tunnel in 1 second interval (m = 2500 kg)
V – velocity of the water discharged from the Jeddo Tunnel (It was determined that the velocity of the water is 2.5m/sec.)
Substituting the numerical values, the kinetic energy, KE, corresponding to 1 second interval can be calculated.

$$KE = 2500kg \cdot (2.5m/sec)^2 / 2$$
$$KE = 7812.5\ J$$

c. Total Energy of the Water

The total energy of the water (in 1 second intervals) discharged from the Jeddo Tunnel is

$$E = PE + KE \quad (3)$$

Substituting the numerical values,

$$E = 73575J + 7812.5\ J$$
$$E = 81387.5\ J$$

d. Power

The power to be harvested from the water discharged from the Jeddo Tunnel is equal to the amount of energy corresponding to 1 second interval.

$$P = E/t \quad (4)$$

It is already assumed that t is equal to 1 second while calculating the total energy of the water (potential and kinetic). Substituting the numerical values into the equation for power, the following is derived.

$$P = 81387.5\ J / 1\ sec$$
$$P = 81387.5\ W = 81.38kW$$

Assuming the efficient of the micro-hydro system to be 80% (80% of the energy will be utilized), the potential output power in the form of electric energy is estimated to be

$$P_E = 81.38kW \cdot 0.8 = 65kW$$

4. Results and discussion

The micro-hydro system containing the water turbine and electric power generator are commercially available. The selection of commercially available water turbines and electric generators was conducted based on selected product criteria and consumer expectations. The following steps were followed in this procedure.

1. Determining the quantifiable (measurable) product criteria based on brainstorming and reviewing product specifications. The following criteria have been selected.
   C1. Power capacity of the turbine and generator
   C2. Cost of the turbine and generator
   C3. Cost of installation
   C4. Reliability and lifespan
   C5. Cost to overhaul
   C6. Availability of spare parts
   C7. Vibration and noise level
2. Specifying consumer expectations using the Likert Scale (Siwiec and Pacana, 2021)
   1) Practically unimportant criterion
   2) Not important criterion
   3) Important criterion
   4) Very important criterion
   5) Most important criterion
3. Determining the weights of the criteria.
   (The weights of the criteria were determined using the Likert Scale as well as the fuzzy Saaty Scale (Table 1).

Table 1. Weights of criteria assessments (Siwiec and Pacana, 2021)

Assessment of Importance	Assessment in the Likert Scale	Fuzzy Saaty Assessment Scale
Practically unimportant	1	1, 1, 1
Not important	2	1.5, 2, 2.5
Important	3	2.5, 2, 3.5
Very important	4	3.5, 4, 4.5
Most important	5	4.5, 5, 5.5

After processing the assessments, it is necessary to develop a combined fuzzy decision matrix as shown in formula below (Ulewicz, et al., 2021).

$$\tilde{x}_{ij}=\left(a_{ij}, b_{ij}, c_{ij}\right) \quad (5)$$

$$a_{ij} = \min_k\{a_{ij}^k\}, b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^k, c_{ij} = \max_k\{c_{ij}^k\} \quad (6)$$

where:
a – fuzzy rating, left
b – fuzzy middle rating
c – fuzzy rating on the right
K – customer
i, j = 1, 2, …, n

Then, it is necessary to follow the FAHP method, as is shown in the literature on the subject (Oguztimur, 2011; Ozdemir et al., 2018; Shukla et al., 2014; Ulewicz et al.2021).

4. Selection of the criteria.
   (The importance of the selected criteria is shown in Table 2).

Table 2. Importance of individual criteria

Criteria	Mark	a	b	c
Power capacity of turbine and generator	C1	2.5	3.8	5.5
Cost of turbine and generator	C2	1.5	3.7	5.5
Cost to install	C3	1.5	3.7	5.5
Reliability and lifespan	C4	1.5	3.6	5.5
Cost of overhaul	C5	1.0	2.7	5.5
Availability of spare parts	C6	1.0	2.7	5.5
Vibration and noise level	C7	1.0	2.6	5.5

Based on the selected criteria and their importance, the company manufacturing the turbines (and the generator) have been contacted. Based on the provided criteria the company has submitted a proposal. The proposal satisfied the specified criteria and was accepted for implementation.

The system suitable for installation at the Jeddo Tunnel cost approximately \$300,000. That amount includes the professional installation. The cost of the unit itself is around \$180,000. The installation in the Jeddo Tunnel was estimated to be \$120,000. This amount includes the necessary foundation on which the micro-hydro system is mounted as well as the necessary piping supplying the water into the micro-hydro unit and then discharging the water into the creek. The warranty on the micro-hydro unit is ten years with a minimal maintenance fee during the ten-year interval. It would be desirable for the project to have a return on investment in less than the ten-year period. After the ten-year period, some significant overall would need to be scheduled at a cost of approximately \$60,000. After that overall, the unit should be operational for another ten years.

5. Financial Analysis of the Project

Each engineering project requires an initial investment. The initial investment for the installation of the micro-hydro power generation system at the Jeddo Tunnel site is \$300,000. The funding for this project will be secured through a bank loan. The weighted average cost of capital (WACC) for this project is the cost of credit after tax incentives.

$$WACC = K_{dT} \qquad (7)$$

Where,
K_{dT} – cost of the credit after tax incentive (tax incentive lower the interest rate)

$$K_{dT} = K_d(1 - T) \qquad (8)$$

Where,
K_d - cost of credit (5% for this project)
T – corporate tax rate (28% for this project)
Substituting numerical values

$$K_{dT} = 0.05(1 - 0.28)=0.036\ (3.6\%)$$

Therefore,

$$WACC=0.036\ (3.6\%)$$

The financial profitability of the project can be assessed by calculating the following indicators.

- Net present value (NPV)
- Internal rate of return (IRR)
- Profitability index (PI)
- Return on investment
  (Number of years needed for the full return on the investment)
- Discounted rate of investment
  (Number of years needed for the full return on the investment considering the discounted income)

The most important indicators of the profitability of the investment are the net present value (NPV) and the internal rate of return (IRR).

The net present value (NPV) of the project is the discounted income minus the initial investment. NPV can be calculated using the following equation.

$$NPV = CF_o + CF_1/(1+WACC) + CF_2/(1 + WACC)^2 + \ldots CF_n/(1 + WACC)^n \qquad (9)$$

Where,
CF_0 = initial investment
WACC = cost of capital
CF_1, CF_2, ……. CF_n - incomes in different years
If ,
NPV > 0 (The investment is a good investment.)
NPV < 0 (The investment is a bad investment.)

Net present value represents the growth of the company's assets. Therefore, the objective is to maximize the NPV.
Assuming the cost of electricity is constant and equal to 10 cents/kWh, the annual income was calculated to be \$56,940. (Assuming the system would operate 24hrs/day for 365 days/year. Table 3 shows the discounted income for the first ten years of operation of the micro-hydro power generation system. (The income is discounted based on the cost of capital.

Table 3. Discounted Annual Income

Year of Operation	**Factor Discounting the Income** $1/(1 + WACC)^n$	**Discounted Income** (CF_n)
1	0.965	\$54,947
2	0.931	\$53,011
3	0.899	\$51,189
4	0.867	\$49,367
5	0.837	\$47,659
6	0.807	\$45,951
7	0.779	\$44,356
8	0.752	\$42,819
9	0.725	\$41,282
10	0.700	\$39,858

The calculated NPV after ten years is \$170,439. The return on investment was calculated to be 5.5 years. The discounted return on investment was calculated to be six years.

Internal rate of return (IRR) represents the return received by the company on the project investment. IRR needs to be higher than the cost of capital. Internal rate of return can be calculated by solving the following equation.

$$0 = CF_o + CF_1/(1+IRR) + CF_2/(1 + IRR)^2 \ldots\ldots + .CF_n(1 + IRR)^n \qquad (10)$$

Where,
CF_0 - initial investment
CF_1, CF_2,………..CF_n - annual income received from investment

Substituting the numerical values and solving the equation for IRR, the internal return rate was calculated to be IRR = 0.12 (12%). The internal rate of return (12%) is much higher than the cost of capital.

Profitability index (PI) is the ratio of the total income divided by the initial expense. The profitability index can be calculated using the following formula.

$$PI = [CF_1/(1+WACC)^1 + CF_2/(1 + WACC)^2 \ldots\ldots\ldots + .CF_n/(1 + WACC)^n]/CF_0 \quad (11)$$

Substituting the numerical values, the profitability index was calculated to be PI = 1.568. The profitability index indicates
that for each $1 investment the company assets increased by $1.568.

5. Conclusions

The project is an example of an innovative way for transforming an existing post-coalmining site into a profitable venture. The internal rate of return on investment (12%) for the micro-hydro power generation project is much higher than cost of capital. There are many post-industrial sites in both countries (Poland and the United States) which can be developed into profitable business ventures. This type of business venture may not be of interest to a major power company, but it can be very appealing to small local investors and local municipalities. The post-industrial sites can often be purchased for an affordable price. The original owners of the site may no longer be in existence and local municipalities may be looking for a way to either sell or develop the site. The closing of outdated industries creates opportunities for new innovative ideas.

The project provided students with a comprehensive approach to engineering design. During the design process, students were working as a team supervised by faculty. Students were applying the knowledge from engineering courses (Statics, Dynamics, Fluid Mechanics, Thermodynamics, Machine Design and Manufacturing Processes). There was also a significant technical writing component as well as an Economics course. An Economics course is a requirement in the Engineering curriculum, and it was needed to determine the parameters of profitability and rate of return on investment. The project was successful in capturing the students' interest and increasing students' motivation. The project provided a comprehensive approach to Engineering education including writing a technical report and an analysis of the economic justification of investment.

Reference

Anderson, D., Moggridge, H., Warren, P., Shucksmith, J., 2014. The impacts of "run-of-river" hydropower on the physical and ecological condition of rivers. Water and Environment Journal, 29(2), 268-276. DOI: 10.1111/wej.12101

Barron, B.J.S., Schwartz, D.L., Vye, N.J., Zech, L., Brans-ford, J.D., 1998. Doing with Understanding: Lessons from Research on Problem- and Project-Based Learning. Journal of the Learning Sciences, 7(3-4). 271-311.

Blumenfeld, P.C., Soloway, E., Marx, R.W., Guzdial, M., Palincsar, A., 1991. Motivating Project-Based Learning: Sustaining the Learning. Educational Psychologist, 26(3-4), 369-398.

Dorbin, Ann E., 2021. Saving the Bay: People Working for the Future of the Chesapeake. Published by Johns Hopkins University Press.

Erinle, T.J., Ejiko, S.O., Oladebeye, D.H., 2020. Design of Micro Hydro Turbine for Domestic Energy Generation. IARJSET, 7(4), 85-93. DOI: 10.17148/iarjset.2020.7414

Grebski, M.E., Wolniak, R., 2018. Global Perspective for Protecting Intellectual Property-Patenting in USA and Poland. Management Systems in Production Engineering, 26(2), 106-111. DOI: 10.2478/MSPE-2018-0017

Grebski, W., Grebski, M., 2016. Keeping Technical Education Aligned to the Needs and Expectations of Industry. Management Systems in Production Engineering, 22(2), 77-80. DOI: 10.2478/mspe-01-02-2016

Grebski, W., Grebski, M. Keeping Higher Education Aligned with the Requirements and Expectations of the Knowledge-Based Economy. Production Engineering Archives, 2018, 21(21), 3-7. DOI: 10.30657/pea.2018.21.01

Grebski, M., Grebski, W., 2019. Project-based Approach to Engineering Technology Education. Production Engineering Archives, 25(25), 56-59. DOI: 10.30657/PEA.2019.25.11

Han, S., Capraro, R., Caprano, M.M., 2015. How Science, Technology, Engineering and Mathematics (STEM) Project-Based Learning (PBL) Affects High, Middle and Low Achievers Differently: The Impact of Student Factors on Achievement. International Journal of Science and Mathematics Education, 13(5), 1089-1113.

Kougias, I., Aggidis, G., Avellan, F., Deniz, S., Lundin, U., Moro, A., Theodossiou, N., 2019. Analysis of emerging technologies in the hydropower sector. Renewable and Sustainable Energy Reviews, 113, 109257. DOI: 10.1016/j.rser.2019.109257

Mendinsky, J.J., Dempsey, B.A., 2004. Effects of AMD Pollutant Loading on Streams in the Hazleton PA Area. Journal American Society of Mining and Reclamation, 1, 1289-1303, DOI: 10.21000/jasmr04011289

Mielikainen, M., 2022. Towards Blended Learning: Stakeholders' Perspectives on a Project-Based Integrated Curriculum in ICT Engineering Education. Industry and Higher Education, 36(1), 74-85.

Oguztimur, S., 2011. Why Fuzzy Analytic Hierarchy Process Approach For Transport Problems? ERSA conference papers ersa11p438, European Regional Science Association.

Özdemir, ónal, Altinpinar, İ., Demirel, F.B., 2018. A MCDM Approach with Fuzzy AHP Method for Occupational Accidents on Board. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 12(1), 93-98. DOI: 10.12716/1001.12.01.10

Saad, A., Zainudin, S., 2022. A Review of Project-Based Learning (PBL) and Computational Thinking (CT) in Teaching and Learning. Learning and Motivation, 78, 101802.

Siwiec, D., Pacana, A., 2021. Model Supporting Development Decisions by Considering Qualitative Environ-mental Aspects. Sustainability, 13, 9067, DOI: 10.3390/su13169067

Shukla, R., Garg, D., Agarwal, A., 2014. An Integrated Approach of Fuzzy AHP and Fuzzy TOPSIS in Model-ling Supply Chain Coordination. Production and Manufacturing Research: An Open Access Journal, 2(1), 415-415, DOI: 10.1080/21693277.2014.919886

Uddin, W., Ayesha, Zeb, K., Haider, A., Khan, B., Islam, S. ul, … Kim, H.J., 2019. Current and future prospects of small hydro power in Pakistan: A survey. Energy Strategy Reviews, 24, 166-177, DOI: 10.1016/j.esr.2019.03.002

Ulewicz, R., Siwiec, D., Pacana, A., Tutak, M., Brodny, J., 2021. Multi-Criteria Method for the Selection of Renewable Energy Sources in the Polish Industrial Sector. Energies, 14, 2386, DOI: 10.3390/en14092386

Ulewicz, R., Sethanan, K., 2020. Experience with the accreditation of technical studies in Poland and Thailand's. International Symposium on Project Approaches in Engineering Education, 10, 149-156

Wolniak, R., Grebski, M.E., Skotnicka-Zasadzien, B., 2019. Comparative Analysis of the Level of Satisfaction with the Services Received at the Business Incubators (Hazleton, PA, USA and Gliwice, Poland), Sustainability, 11(10), 2889. DOI: 10.3390/SU11102889

微型水力发电系统项目-案例研究

關鍵詞
水电
微型水电
可持续能源
能源热电联产
基于项目的 (PBL)

摘要
这篇文章描述了一个学生项目，该项目利用从地下煤矿排出的水中的能量安装一个微型发电系统。该论文包含对该地点的描述，该地点是无烟煤开采时代的人造现象。文章中描述的项目是作为基于项目的学习课程的一部分完成的。作为工程课程的一部分，学生有机会在团队中工作并应用在个别课程中学到的理论知识。本文还侧重于计算拟建水力发电系统的潜在电力容量。拟议的微型水力系统正在收集从排水隧道排出的水的势能和动能。为此目的，采用了与发电机相结合的商用微型水轮机。文章还包括对项目盈利能力和投资回报时间的分析。计算基于当前的电价（2021 年）、折旧计划和当前的税收激励措施（2021 年），以利用可再生能源发电。文章还包括从该项目中吸取的一些经验教训以及对未来项目的建议。