ENERGY, ECONOMIC AND ENVIRONMENTAL FEASIBILITY OF ENERGY RECOVERY FROM WASTEWATER TREATMENT PLANTS IN MOUNTAINOUS AREAS: A CASE STUDY OF GHARYAN CITY – LIBYA

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Abstract
Wastewater treatment facilities at high places can give chances for renewable and sustainable energy generation by putting hydroelectric turbines at the input and drain channels of wastewater treatment plants, and they can also use the sludge generated during the treatment process to make biogas, which can be used to generate power. Purified water is subsequently used to irrigate decorative plants along highways, in gardens, and in woods. The fermentation wastes are utilized as organic fertilizer to improve agricultural soil quality. At the Gharyan sewage station, a hybrid system consisting of a hydroelectric station and an electric generator powered by biogas is proposed in this research. This is because the city is distinguished by its high location, which is approximately 713 m above sea level. The results showed that the proposed system would provide an electric power of 490 kW, which is sufficient to cover 87.5% of the electrical energy consumption of the station. The amount of treated water is approximately 13,000 m^3/day, and the amount of organic fertilizer is about

17 tons/day. The investment value is anticipated to be around $1,478,000, while the cost of producing a unit of electric energy is expected to be 2.83 ¢/kWh. This system's yearly net profit is predicted to be $307,765. The capital's recovery period is anticipated to be 3.44 years. The planned hybrid system will limit the discharge of an estimated 1,886 tons of CO_2 gas each year.

Keywords
Biomass Energy; Gharyan; hydroelectric power; Libya; potential energy; sewage treatment plants.

Introduction
Energy is one of the most important aspects of human existence owing to its relevance in infrastructural development and as a driving force in economic development and employment creation. Energy-related concerns took a new turn near the end of the past century, particularly those linked to the generation of electric power from fossil fuels and the advent of major environmental difficulties that endanger human existence on Earth, such as climate change and global warming. Burning fossil fuels generates more than 64% of the world's power and thermal energy (Figure 1a). In Libya, almost 99% of power is generated using fossil fuels (Figure 1b), putting the energy industry ahead of all other human activities in terms of emissions, accounting for around 36% of the country's carbon dioxide emissions [1,2]. Figure 1 depicts the contribution of primary energy utilized in power generation in the globe and Libya in 2020. At the same time, there is a huge growth in global electricity demand. These issues are continually rising, indicating the need for alternative energy sources that are high in efficiency, ecologically benign, and sustainable [3,4]. One of these options is to create electricity as near to the point of consumption as feasible, utilizing locally accessible renewable and clean energy sources such wind energy [5–8], solar energy [9–13], biomass energy [8,14–17], hydropower [18–21].

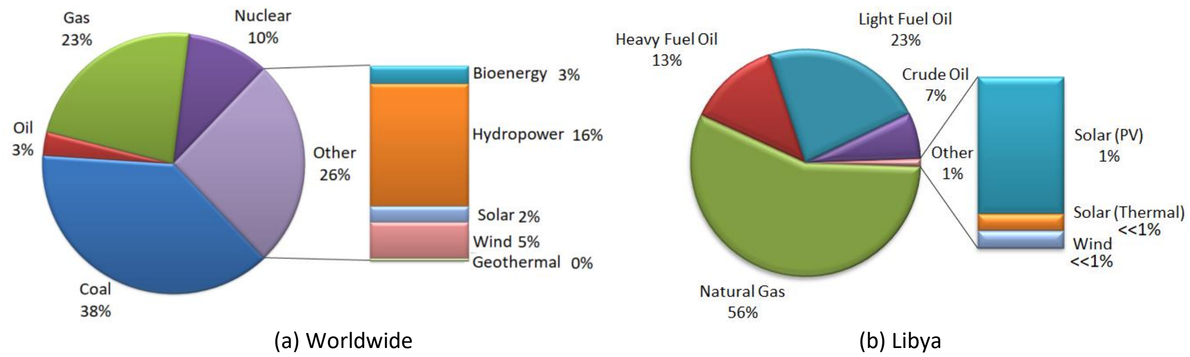

Figure 1. Contribution of fuel type to electrical power generation. *Source: Own.*

In order to satisfy the Libyan government's obligations to the international community to lower CO_2 emission rates on the one hand, and to provide its society with a safe and sustainable source of energy on the other, the Libyan government unveiled its strategic plan to produce electric power from some of the renewable energies accessible in the country over the next thirty years during COP 27 (The Conference of Nations United Climate Change), which was held in Sharm El-Sheikh, Egypt, from June 6 to June 8, 2010. The strategic plan seeks to increase renewable energy participation in combined electric energy production by 25% by 2025, up to 30% by 2030, and over 60% by 2050 through photovoltaic and thermal generation of solar energy and wind energy [22]. Although hydroelectric energy and biomass energy are not included in the plan, their use is an absolute requirement as a source of energy generation, as is the case with mountainous water treatment facilities, or as a source of biofuel to run electricity generating generators or gas turbines, or to store energy in hydraulic energy tanks (Hydropower Storage) and integration with the sources stated in the plan [23,24]. Hydroelectric energy is also regarded one of the cleanest renewable energies, with a CO_2 emission ratio of roughly 18.5 kg CO_2/kWh over the station's life cycle [25]. Sewer water is a renewable and sustainable energy source, where electrical power may be created by putting turbines inside city sewage pipelines and utilizing regular gravity flow [26]. For example, the Australian government's New South Wales government built its first plant in 2010, with a capacity of 4.5 MW, utilizing treated wastewater falling from 60 m to produce 58% of its power [27]. Rosa et al. offered a list of 49 wastewater hydropower plants from across the world. Two Swiss facilities are harnessing the energy potential of higher elevations. The Profray station (capacity 8,600 m^3/day) in Bagnes generates hydroelectric electricity (851 MWh/year, equivalent to a 380-kW generator) from sewage flow from a height of 449 m. The La Louve station, which also generates in Lausanne (with a capacity of 10,400 m^3), transfers almost half of the energy (460 MWh/year, equal to a 170 kW generator) from the water dump to the station at an altitude of 180 m [28]. The capacity of the water treatment facility in the Austrian city of Seefeld Zirl is 1,192 kW from a height of 94 m [29].

With a capacity of 364,000 m^3/day, Jordan's Samara facility near Amman processes over 70% of the country's wastewater. Internal energy resources meet approximately 80% of the plant's energy requirements. The treated water is also utilized in agriculture, accounting for around 10% of Jordan's total water usage. The facility also avoided the emission of 300,000 tons of CO_2/year into the atmosphere by producing energy [30]. In Turkey, Baran discovered seven prospective geographic areas that might generate 38.53 GWh/year of energy from a hydroelectric wastewater treatment plant, which would be adequate to provide street lights in these seven areas [31]. According to a study of prior studies, wastewater treatment facilities can profit from generating electrical energy to meet a portion of the station's electrical energy requirements, in addition to purifying the water before expelling it into the environment. This is accomplished in numerous ways:

- Making use of the treatment plant's potential energy in high mountain cities.
- Using kinetic energy of wastewater owing to gravity in the sewage network.

Despite its relevance, the topic has gotten little attention at the municipal level. Many studies dealt with the subject of hydroelectric energy from the standpoint of storing energy in high reservoirs or river energy, but only one study dealt with the question of utilizing wastewater to create electric power in Libya [17]. The remainder of the paper is divided into the following sections: Section Two (Materials and Work Methods), which provides a description of the existing site of the sewage plant as well as theoretical energy, economic, and environmental calculations. Section 3 (results and comments) gave the outcomes. Section 4 examines the overall state of wastewater treatment plants in Libya. Section 5 contains the conclusions and suggestions.

Materials and Work Methods

General data of the study site

- Gharyan is located on the Western Mountain in Libya's northwestern region. Gharyan is located around 713 meters above sea level (Figure 2). According to 2021 figures, its population is around 187,854 people, and its area without suburbs is 4,660 m^2 [32]. The wastewater collection and treatment facility, which has a capacity of 2,220 m^3 and handles an estimated 13,000 m^3/day, was built in 1971. It solely serves the Taghsat region, which has a population of around 19,000 people according to 2021 figures, with an average per capita of approximately 0.684 m^3/day. Figure 3 depicts an aerial photograph of the station. The sewage treatment plant is 673 m above sea level. At this height, the potential energy is approximately 6.6 MW/m^3. On June 7, 2019, the writers of this article went to the sewage plant to learn about the facility's components and to acquire design and operating information. Although there is no information accessible on the population's sewage water rates in Libya, the municipality of Gharyan is undertaking research on linking the entire city to a sewage network, as well as creating a new sewage collecting station to replace the present one, which has expired. This offered the present research a design component by emphasizing the prospect of generating electrical energy from the new station and taking this benefit into account while contracting to create the new station. The treatment plant works in phases, which are as follows: Station entrance: The station has two entrances, each with a crusher for breaking up solid materials.
- Sand lifter: a basin with a motor that circulates the water and a pump that returns it to the basin. A scraper is used to clear the sand that has accumulated at the basin's bottom.
- Aeration basins: There are two aeration basins at the station, where air blowers activate microorganisms inside the basins to analyze organic materials and eradicate pathogens.
- Sedimentation basins: they are used to settle organic debris (sludge) within ponds.
- Filters: they remove plankton from the water.
- Chlorine tank: A chlorine tank into which chlorine is fed from chlorine cylinders via a mechanism.
- Return pump: screw pumps that return water from all stages of the station and transport sludge from sedimentation basins to drying basins or return water to aeration basins.
- Drying basins: These are used to dry organic products.

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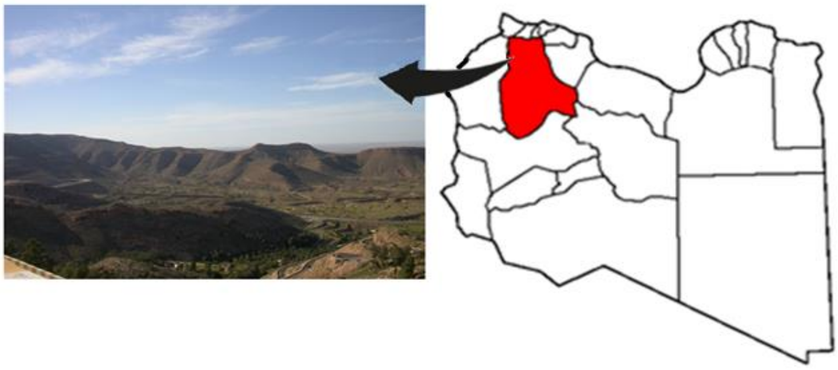

Figure 2. Map of Libya showing the location of the city of Gharyan and a picture of the terrain of the region. *Source: Own.*

Figure 3. An aerial photo of the wastewater treatment plant in Gharyan city.
Source: https://earth.google.com/web/search/32.15153203,13.03476738,662.53720067a

<u>Design and operational data for the wastewater treatment plant in Gharyan city</u>

The station receives wastewater from the city's sewage network via two 0.9-meter-diameter pipes. The treated water volume is approximately 13,100 m^3/day. The amount of solid materials retrieved from the station is predicted to be 360 m^3/month. The wastewater treatment plant's discharge pipe is 4700 m long and 0.5 m in diameter. The slope from the station's departure point is 65 m, and the volumetric flow rate of the treated water is 10.15 m/s. The station's average energy usage is around 9,923 kWh/day. Figure 4 shows a Google Earth view of the geography of the region where the sewage treatment facility is located, as well as the length and slope of the sewage pipe.

Figure 4. Image from Google Earth of the topography of the area where the sewage treatment plant is located and the length of sewage pipe elevations. *Source: Own.*

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Mathematical analysis of hydroelectric energy

Water treatment facilities may create electrical energy in two ways:

- hydropower energy and
- biomass energy

Hydropower energy potential EH; kW

To calculate the energy potential of the input and outflow wastewater to the treatment plant, the water flow rate and the height from which the water drops must be determined. The generated energy may be computed as follows [18].

(1) $$E_H = \left[\rho g Q\left(H - h_f\right)\eta_t\right]_{\text{inlet}} + \left[\rho g Q\left(H - h_f\right)\eta_t\right]_{\text{outlet}}$$

where:

η_t represents the turbine's hydraulic efficiency, 90%, ρ is the density of water (kg/m^3),

g is the Earth's gravitational acceleration, 9.81 m/s^2.

The volumetric flow rate of water (m^3/s) is represented by Q. H is the height from which the water drops (m), and h_f is the pressure loss due to friction in the drainage pipe (m).

Biomass energy potential

The potential energy (E_B, kW) in the sludge may be calculated using the following equation [33]

(2) $$E_B = W_{SW}\ SR\ G_{SW} H_{BG}\ \eta_{\text{ele}}$$

where:

W_{SW} refers to the average amount of treated wastewater m^3/hr

G_{SW} represents the rate of biogas production from sludge and is estimated at 243 m3/ton [34].

SR represents the amount of sludge in wastewater estimated at 1.3 kg/m^3 [15].

H_{CH4} represents the calorific value of biogas (5.56 kWh/m^3) [35].

η_{ele} represents the electricity generation system's efficiency, 38% [1].

Total energy produced by the station

The total electricity (E_t, kW) that the wastewater treatment facility can generate on its own:

(3) $$E_t = E_H + E_B$$

Hydraulic calculations

Hydraulic calculations aim to find the indications' values in the available energy calculation equation (1). The frictional losses hf are calculated from the Darcy equation [36]:

(4) $$h_f = \frac{8\,L\,f\,Q^2}{\pi^2\,g\,D^5}$$

where:

D represents the diameter of the drainpipe (m)

L represents the length of the drainpipe (m)

f represents the coefficient of friction, calculated from equation (5) [36]:

(5) $$f = \left\{1.8\,log\left[\frac{6.9}{Re} + \left(\frac{\varepsilon}{3.7\,D}\right)^{1.11}\right]\right\}^{-2}$$

where:

ε represents the roughness of the inner surface of the drainpipe (m)

Re represents the Reynolds number and is calculated from equation (6) [36].

(6) $$Re = \frac{4\,Q}{\pi D \nu}$$

where:
v represents the kinematic viscosity of water (m^2/s).

Economic and environmental calculations

The cost of generated energy unit (LCOE) is an economic measure used to estimate project profit and a reference for comparison with other production choices. The cost of environmental damage produced by carbon dioxide (C_{CO2}) may be used to compute LCOE using the following equation [37]:

$$LCOE = \frac{\left(\frac{r(1+r)^n}{(1+r)^n-1}\right) \times (C_{C,H} + C_{C,B}) + (C_{O\&M,H} + C_{O\&M,B}) - C_{CO2}}{8760 \times E_t} \quad (7)$$

where:
$C_{O\&M}$ denotes the cost of operation and maintenance ($/year)
C_C the capital cost in $
E_t the power of the proposed system in kW (the number 8760 denotes the number of working hours in a year) n the device lifetime (30 years)
r the annual inflation rate (8%).
The subscripts H and B denote the two power generation systems: hydropower turbine and biogas-based generator.

The cost of environmental damage caused by CO2 gas can be calculated by the following equation [38].

$$C_{CO2} = EF_{CO2} \times 8.760 \times E_t \times \emptyset_{CO2} \quad (8)$$

where:
EF_{CO2} represents the CO_2 emission factor of the electric power generation system in Libya, 0.983 kg CO_2/kWh $\emptyset_{CO2}$ represents the environmental damage cost per unit ($/ton CO_2).
All costs in Equation (7) are included in Table 1.

Table 1. List costs of the proposed hybrid power generation system. *Source: Own.*

Item		Cost
1. Hydroelectric Energy System [17]		
1.1	Cost of Capital	7500 $/kW
1.2	Operation and Maintenance Cost	3.88 $/kW/year
2. Biomass Energy System [39]		
2.1.	Cost of Capital	1410 $/kW
2.2.	Operation and Maintenance Cost	3.5 % of Capital/year
3. Cost of Environmental Damage		15 $/ton CO_2

Hypotheses, limitations of study, and sources of uncertainties

To assist computations, researchers must make some assumptions, which in most circumstances have no substantial influence on the conclusions. In this study, the following hypothesis were established:

- There is a continual flow of sewage to and from the treatment facility.
- There are no losses in power transmission or consumption within the station.
- Biogas is composed of 50% methane and 50% CO_2.
- Due to a paucity of research in biomass energy, the biogas generation rate from sludge was set at 243 m^3/ton sludge [40].
- Ignoring the bulk of sludge in hydraulic and potential energy calculations since it accounts for a negligible amount (0.1%).
- Assuming that the hydraulic losses in the drainpipe and inflow pipes are equivalent.

The study's drawback is the lack of an investigation of the sensitivity of the implications of design and operation to the results, which the researchers will address in a further study.

The data is a source of uncertainty since there is a large variance in employment statistics, prices, and values, all of which are used by the study to establish economic and environmental indicators [41].

Results and Discussions

The planned hybrid system contains a Pelton turbine at the station's entry and a Francis turbine at the station's discharge pipe, as well as a biomass energy system that includes an anaerobic digester for sludge fermentation and a biogas-powered electric generator. Trucks deliver fermentation waste as organic fertilizer to grow trees and enhance soil quality. Figure 5 depicts the components of the proposed hybrid system as well as a representation of the energy and mass flow in the suggested technique.

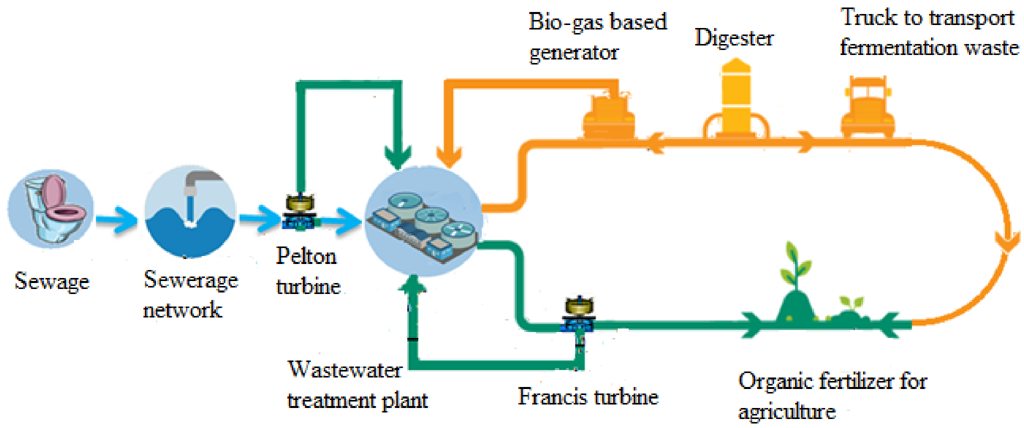

Figure 5. Energy and mass flow diagram in the proposed system. *Source: Own.*

The available energy may be computed using the energy and mass balance diagram illustrated in Figure 6 utilizing data obtained from the wastewater treatment facility in Gharyan, which is listed in Section 2.2.

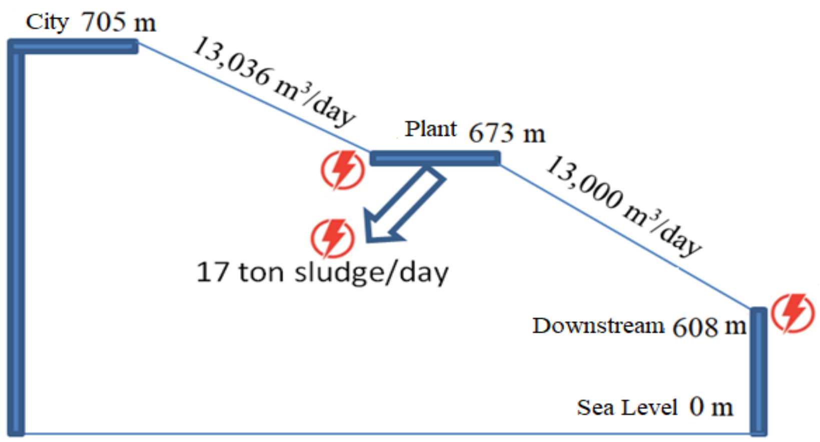

Figure 6. Energy and mass balance diagram. *Source: Own.*

The hydropower energy potential

Equation (2) is used to calculate the quantity of hydroelectric energy (EH) in kW in the treated water in the station at the input and discharge pipes.

$$E_H = (1000) \times (9.81) \times (0.151) \times (0.9) \times [((673 - 608) - 5) + ((710 - 673) - 5)] \cong 129 \text{ kW} \tag{9}$$

The biomass energy potential

The amount of energy potential (EB) in kW in sludge can be estimated from equation (3):

$$E_B = (542.92)(1.3)(0.243)(5.56)(0.38) \cong 362 \text{ kW} \tag{10}$$

Therefore, the total energy available from the water treatment plant is estimated at 490 kW. This covers 87.5% of the station's electrical energy consumption.

Economic-environmental analysis

Table 2 shows the CO_2 emission factor for several fuel types based on several indicators [42].

Table 2. CO_2 emission factor based on several units.

Fuel Type	**Volume unit kg CO_2/m^3**	**Thermal energy unit kg CO_2/GJ**	**Electrical energy unit kg CO_2/MWh**
Biofuel	1.06	84.2	441.4
Natural gas	1.77	55.8	433.0
Light fuel	2,752	71.0	849.2
Heavy fuel	3,156	81.3	909.7
Crude oil	3,266	92.5	966.2

Therefore, the amount of CO_2 gas (m_{CO2}) emitted annually from the proposed system can be estimated as follows:

(11) $$m_{CO2} = 0.4414 \times 362 \times 8760 = 1{,}400\ ton\ CO_2/year$$

The CO_2 emission factor for Libya's power production system is estimated to be around 1.037 kg CO_2/kWh [1]. As a result, the amount of CO_2 gas trapped from emission into the atmosphere may be approximated as follows:

(12) $$0.875 \times 9{,}923 \times 365 \times 1.037 \times 10^{-3} - 1{,}400 = 1{,}886\ \text{ton}\ CO_2/year$$

The amount of CO_2 gas released by the station per year is equal to:

(13) $$(1 - 0.875) \times 9{,}923 \times 365 \times 1.037 \times 10^{-3} + 1{,}400 = 1{,}870\ \text{ton}\ CO_2/year$$

Thus, using equation (9) the cost of CO_2 gas is projected to be \$140,250 per year. As a result, the LCOE of the station's electrical energy may be determined using equation (8) as follows:

(14) $$LCOE = \frac{\left(\frac{0.08(1.08)^{30}}{(1.08)^{30}-1}\right) \times (7500 \times 129 + 1410 \times 362) + (3.8 \times 129 + 0.035 \times 1410 \times 362) - 1886 \times 15}{8760 \times 490} = \$0.0283\ per\ kWh$$

Knowing that the General Electricity Company purchases electrical energy produced from renewable energy providers at \$0.1/kWh, the annual net profit from this system is estimated at approximately \$307,765/year. The capital recovery period is estimated at around 3.44 years.

Analysis of the general situation of wastewater treatment plants in Libya

Approximately 200 sewage treatment facilities were erected across the nation between 1966 and 1990, however the majority are no longer in use due to their age. The main wastewater treatment plants are located in Tripoli (capacity: 101,000 m^3/day), Misurata (capacity: 24,000 m^3/day), and Sirte (capacity: 21,000 m^3/day). The remaining stations are modest and medium-sized, with design capacities ranging from (370-6,700 m^3/day). The volume of wastewater generated each day is projected to be 1,324,054 m^3. Only 145,800 m^3/day of this total gets processed, accounting for 11% of total wastewater production. The remainder of the wastewater is discharged untreated into the sea, valleys, and manmade lakes, inflicting serious harm to the surrounding ecology. Because no information on the geographical location of these factories is currently available, just the available sludge energy will be computed. The available energy may be determined using Equation 3 as follows:

(15) E_S= (55,169)(1.3)(0.243)(5.56)(0.38)≅36,820 kW

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Perhaps the most significant loss due to neglecting the critical role of this sector and leaving wastewater treatment plants without maintenance development, in addition to environmental damage and the loss of 37 MW of sustainable energy, is the loss of approximately 4 million cubic meters per day in a desert country that lacks water, which could have made a difference in the area of vegetation cover of the state, protecting cities from sandstorms, desert encroachment, and the establishment of forests and natural reserves.

The loss of almost 4 million m^3/day in a desert nation without water, which might have made a difference in the state's vegetation cover, protecting towns from sandstorms, desert encroachment, a loss of 37 MW of sustainable energy, is possibly the most significant loss as a result of abandoning the crucial role of this sector and leaving wastewater treatment plants without maintenance.

Impacts of the research results on economy, environment and society

To counteract the degradation of terrestrial and marine ecosystems, it is imperative to focus on wastewater treatment stations, monitoring, and continuous development. There is a growing interest in recycling these resources, leading to the preservation of natural resources, decreased energy consumption, and reduced pollution from burning fossil fuels. Wastewater treatment plants, within this framework, are acknowledged as sustainable sources of irrigation water, organic fertilizer, and energy. The implementation of such projects can yield various eco-environmental and socio-economic impacts, including:

- Reducing irrigation water usage by incorporating treated water from the station.
- Conserving fossil fuels for energy and minimizing CO_2 emissions through the use of renewable energy sources.
- Preserving natural resources and essential elements like phosphorus for fertilizer production.
- Creating new job opportunities for the local community.
- Maximizing economic returns by utilizing treated wastewater in forestry for cultivating trees and establishing wood industries.
- Contributing to forests' roles in purifying the air, moderating the climate, combating desertification and sand encroachment, preserving vegetation, and protecting cities and residential areas from sand and dust storms.

Conclusions and future studies

The research focused on evaluating the energy potential of the wastewater plant in Gharyan city. The article introduced a hybrid generation system comprising two hydroelectric plants and a biogas-powered power plant using sludge fermentation in a biomass reactor. Economic and environmental assessments were conducted to demonstrate the viability of this proposed system. Projections indicate that the hybrid system could generate 490 kW of electrical power, covering 87.5% of the plant's electricity needs.

The estimated investment for implementation is $1,478,000, with an annual maintenance cost of approximately $18,355, and a production cost of 2.83¢/kWh. Notably, the proposed hybrid system is anticipated to prevent the annual release of 1886 tons of CO_2, resulting in an annual cost saving of $28,290 for the plant. Future plans involve extending the study to all sewage plants in Libya by conducting topographic surveys to identify stations situated at higher elevations, thereby assessing their potential energy contribution.

Author Contributions

"Conceptualization, Nassar and Manager; methodology, Nassar and El-Khozondar; formal analysis, Khaleel, Ahmed and Alsharif, data collection, Manger and Elzer; writing—original draft preparation, Nassar and Awad; writing—review and editing, Hafez. All authors have read and agreed to the published version of the manuscript."

Declarations

Ethical Approval: (Not applicable)
Availability of data and materials: (The data are available at request)

Conflict of interest

There is no conflict of interest.

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