An-Najah National University

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Design and Life Cycle Assessment of Pumped Hydro Energy Storage System for Nablus Western Wastewater Treatment Plant

By

Alaa M. Alqub

Supervisor

Dr.Abdelrahim Abusafa

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Defense Committee Member		**Signatures**
Dr.Abdelrahim Abusafa	**(Supervisor)**	**…..................**
Dr. Mahmoud Salah	**(External Examiner)**	**…......………**
Dr. Mohammed Alsayed	**(Internal Examiner)**	**…......………**

Dedication

This thesis is dedicated with gratitude to:

Allah the Almighty for giving me the strength and the

Health to complete this thesis.

My husband Malik for his continuous support and love.

My dear father and my lovely mother who always wished me continuous progress in my life.

My kids Abdelrahim, Hayat who lightened my life with their love.

My brothers and sisters who always encouraged and

Gave me an endless support.

My friends who always wish the best for me.

All people in my life who touch my heart.

Anyone who reads and appreciates this work.

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الاقرار

انا الموقع ادناه مقدم الرسالة التي تحمل العنوان

Design and Life Cycle Assessment of Pumped Hydro Energy Storage System for Nablus Western Wastewater Treatment Plant

أقر بأن ما اشتملت عليه هذه الرسالة انما هي نتاج جهدي الخاص، باستثناء ما تم الإشارة اليه حيثما ورد، وان هذه الرسالة ككل، أو أي جزء منها لم يقدم لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work and has not been submitted elsewhere for any other degree or qualification.

Student Name:	**الاسم:**
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Date:	**التاريخ:**

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i	interest rate
n	useful life
$.m^3$	Cubic meter
ms	Milliseconds
MJ	Mega joule
η	Efficiency of the device (pump or turbine).
γ ρ g	water specific weight [kN/m3],
Q	Fluid flow rate in during power generation [m3 /s].
Q_t	Flow rate in a single penstock(pipe) at turbine mode (m3/s)
$Q_{t.1...}$	Volumetric fluid flow rate [m^3 /s] in a single pipe (penstock). In turbine mode the sub number 1, 2, … refers to the number of trial
Q_p	Flow rate in a single penstock (pipe) at pump mode (m3/s)
V	Flow velocity (m/s)
V_t	Flow velocity at turbine mode (m/s)
V_p	Flow velocity at pump mode (m/s)
H_f	Headloss (m) or frictional losses as per manning relation
H_{ft}	Headloss at turbine mode (m)
$H_{f.p}$	Headloss at pump mode (m)
H_{total}	total hydraulic head (m)
H :H_{gross}	Hydraulic head in meters [m].
S_{min}	pipe minimum Wall thickness (mm)
S_{max}	pipe maximum Wall thickness (mm)
S	pipe wall thickness (mm)
R	Hydraulic radius (m) = D/4
R_p	Hydraulic radius of the pipe in pump mode (m)
D_t	inner diameter of the penstock (pipe) at turbine mode (m)
D_p	inner diameter of the penstock (pipe) at pump mode (m)

ID	inner diameter of the penstock (pipe) (mm)
DN	nominal diameter (mm)
PN	pressure number (mm)
.n	Manning coefficient (n for HDPE =0.009 {ref:engineering box}
L	length of penstock (length of pipe)
ρ	density of fluid (kg/m3)
g	gravitational acceleration 9.81 m/s2
γ	specific weight [kN/m3], γ = ρ g.
P	generated output power in Watts [kW]
P_h	hydraulic power (kW)
$P_{h.t}$	hydraulic power (kW for turbine mode
Ph.p	hydraulic power (kW) for pump mode
z	The elevation of the fluid above a fixed reference point.
Vol.	Reservoir volume (m3)
Ah	Ampere hour

List of Abbreviations

Btu	British thermal unit
CML	Center of Environmental Science of Leiden University
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
MWh	Mega Watt Hour
MW	Mega Watt
GW	gigawatt
kWh	Kilo Watt Hour
GHG	Green House Gases
PW	Present Worth
AW	Annual Worth
IPCC	Intergovernmental Panel on Climate Change
WWTP	Waste Water Treatment Plant.
EES	Electrical Energy Storage
PHES	Pumped Hydro Energy Storage
HDPE	High Density Polyethylene
rpm	revolution per minute
SLT	Starting Lighting ignition
TES	Thermal Energy Storage
CAES	Compressed Air Energy Storage
MPa	Mega pascal
GWP	Global Warming Potential
UNECE	United Nations Economic Commission for Europe
PEA	Palestinian Energy Authority
F.U	Functional Unit

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Abstract

The global population explosion accompanied by industrial and technological expansion demand an increasing rate for energy consumption, especially, in form of electricity. That urges the search for clean energy sources to reduce the pollution caused by fossil fuel.

The clean (or renewable) energy sources are of intermittent nature that can’t obey stable provision of electricity to our communities, and can’t be sure to follow the peak of electricity demand. To bypass the problem of intermittency and to synchronies between energy production and utilization, an energy storage system must be applied. Different energy storage systems are used, like batteries, pump hydro-energy storage system (PHES), etc.

The current thesis aim to design an energy storage system for Nablus western wastewater treatment plant located in Deir Sharaf. The plant consumes a huge energy of about 2,261,762 kWh annually. The PHES system was chosen as a storage system.

To achieve the requirements for such storage system two reservoirs of water were needed each of them has a capacity 24000 m^3, a pipe connects between the above reservoir and the below reservoir of 310 m long and DN 630 mm and a reversible Francis turbine of 563 kW.

To accommodate such design in wastewater treatment plant a comprehensive study of economic feasibility and environmental impact is needed. This can be accomplished by life cycle assessment (LCA) by which we can assess the construction environmental impact. The LCA was conducted by using openLCA 1.4.2 software. The software includes a CML baseline method which include 10 categories of environmental impact.

Five phases of PHES design; production, transportation, excavation, maintenance and disposal or recycle phase, were underwent LCA according to ISO 14040. The results of environmental impact of production phase of PHES assessed by LCA were compared with lead acid battery storage system within the same range of life span and storage capacity, in addition to the capital cost between two storage systems.

For PHES phases, it was found that the Production phase carries the highest environmental impacts, followed by the End of life phase and maintenance Phase.

The excavation phase and the transportation phase always represented a negligible contribution. The results of comparison between the production phases for the two systems was found to be a higher impact for climate change and acidification categories for the lead acid battery system more than PHES. On the other hand, the production phase in PHES carries a higher contribution on the Eutrophication and Human Toxicity impact categories.

The economic study in this thesis was checked by using the present worth analysis. Based on the technical component's cost and life span for the two system, the feasibility study result shows that the PHES system is more fiscal than lead acid battery storage. The present worth for PHES was estimated at 651765 $ with the same life time of batteries and the same energy storage quantity.

Chapter One

Introduction

Introduction

Energy plays an important role in the world economy, security and politics. Each country needs to develop its resources and policies relating to energy and related environmental contaminants for better future planning. The major source of world energy comes from fossil fuels. Total world consumption of marketed energy expands from 549 quadrillion British thermal units (Btu) in 2012 to 629 quadrillion Btu in 2020 and to 815 quadrillion Btu in 2040—a 48% increase from 2012 to 2040 (EIA, U., 2016). As world population explodes, in earth with limited amount of fossil fuels, it may not be possible that natural resources of fossil obey energy demand of the entire world. Some estimates show that there may be only as few as 20 years of oil left if the world keeps with the increasing consumption, The increasing trend in world energy consumption can be attributed to two main reasons: a growing world population and developing countries [W1]. The world population has been increasing at a more dramatic rate than it ever has been. The other contributor to the increasing amount of production of energy is the developing countries, because they are in the process of becoming industrialized. Countries must take action to promote a greater use of renewable energy resources, so that we can be well prepared when the supplies of fossil fuels are not as plentiful as they seem today.

Renewable energy is a hot topic these days as renewable sources are renewable, sustainable, and abundant and environment friendly. Unlike fossil fuels, they are not going to expire soon as they are constantly replenished. There are a lot of points in favor of renewable energy, like low gas emission, they offer stable energy prices, reliable and continuous, and operation of renewable energy are at low cost. Despite, renewable sources have their own shortcomings. They are intermittency, unable to produce large quantity of energy, their plants need large area and high developmental cost, and not available everywhere

Across the world, renewable energy capacity has increased dramatically due to falling prices, policies favoring renewable energy, and concern over greenhouse gas (GHG) emissions from fossil fuel generators. A key problem with generation from renewable sources is intermittency: solar generators only produce when the sun is shining, but the sun isn't always shining nor the wind is always blowing. Intermittency has the potential to hugely affect the economic value, or equivalently the social costs, of renewable energy. Utilization of energy storage systems will be a major step in the solution to the use of renewable energy along with the current issues of reliability, stability, and power quality. Energy storage systems for a long time have been utilized in many forms and applications. Today's energy storage technologies are used to achieve electric power systems of higher reliability and to contribute to the broader use of renewable energy.

The global demand for electricity is huge, and it’s growing by approximately 3.6 percent annually with the growing importance of renewable energy sources, scientist and engineers are anxious to enhance efficiencies and to lower the costs of these technologies. Yet, there seems to be only a handful of technologies available that are efficient enough and also economical. Storing energy isn’t an easy task, as most of us know. Our smartphone battery only lasts for about a day laptops only a few hours; the range for electric cars is limited to only little more than a 100 kilometers; and these are only examples for comparatively small devices(Oberhofer, & Meisen, 2012). Now imagine the problem of storing energy at the level of hundreds to thousands of wind turbines and photovoltaic cells. For technical reasons, however, the amount of electricity fed into the power grid must always remain on the same level as demanded by the consumers to prevent blackouts and damage to the grid. It leads to situations where the production is higher than the consumption or vice versa. This is where storage technologies come into play — they are the key element to balance out these flaws.

The decision maker has to choose in between of the different modalities of energy storage. Electrical energy storage systems differ in between in many parameters of relevant parameters, cost, and environmental impact. These parameters should be evaluated against the potential benefit of adding storage to reach a decision about the type of storage to be added. The best method to assess the electrical storage systems and to weight the benefits against the drawbacks is the life cycle assessment of these storage systems to put in the hands of decision maker the best method of storage.

Life cycle assessment is a “cradle-to-grave” approach for assessing industrial systems. “Cradle-to-grave” begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. Life cycle assessment enables the estimation of the cumulative environmental impact as well as the cost analysis of industrial systems. LCA methodology is based on ISO 14040 and consists of four distinct analytical steps: defining the goal and scope, creating the life-cycle inventory, assessing the impact and finally interpreting the results. In Palestine among the energy consuming plants are waste water treatment plants, many of these are scattered along the Palestinian map. Near Nablus, about 10km west, a waste water treatment plant is located in Deir Sharaf, it was established by German-Palestinian Financial Cooperation project "Nablus West Sewerage in Dir Sharaf' village”, the plant is planned to treat three million cubic meters of raw sewage. The waste water from the city of Nablus flows by gravity into a valley where it is received by the plant near the west exit of Deir Sharaf town (Saleh, 2014). The average annual energy consumption of the plant is 2,261,762 kWh. It was calculated by taking the average consumption from January until the end of July 2014 (Homeidan, Marie, & Hasson, 2015). The limited revenue of such projects is challenging, and put into account the running energy cost to be obtained from renewable energy sources. The renewable energy use provides an intermittent supply of energy which mandates the use of energy storage system; the pumped hydro-energy storage system is an example of methods to be used in WWTP.

The main objectives of current thesis are:

Highlight the different modalities of energy storage systems and compare between them.

Design a pumped hydro-energy storage system that fits the required energy storage demand of the western wastewater treatment plant.

Perform a Life cycle assessment of the proposed PHES.

Compare the life cycle of the proposed PHES with lead acid batteries.

Chapter Two
Classification of EES systems

2.1 Classification of EES systems

In these days, reduction in greenhouse gas emissions is the important essay, especially with increasing demand of electricity, so Electrical Energy Storage (EES) is recognized as underpinning technologies to have great potential in meeting these challenges. And because the electricity is a flow, so it's important to convert it to storable form such as potential, kinetic, chemical, or thermal energy. This chapter shows a classification of EES according to the form of energy used (Carnegie, Gotham, Nderitu, & Preckel, 2013).

In Figure 2.1 EES systems are classified into mechanical, electrochemical, chemical, electrical and thermal energy storage systems.

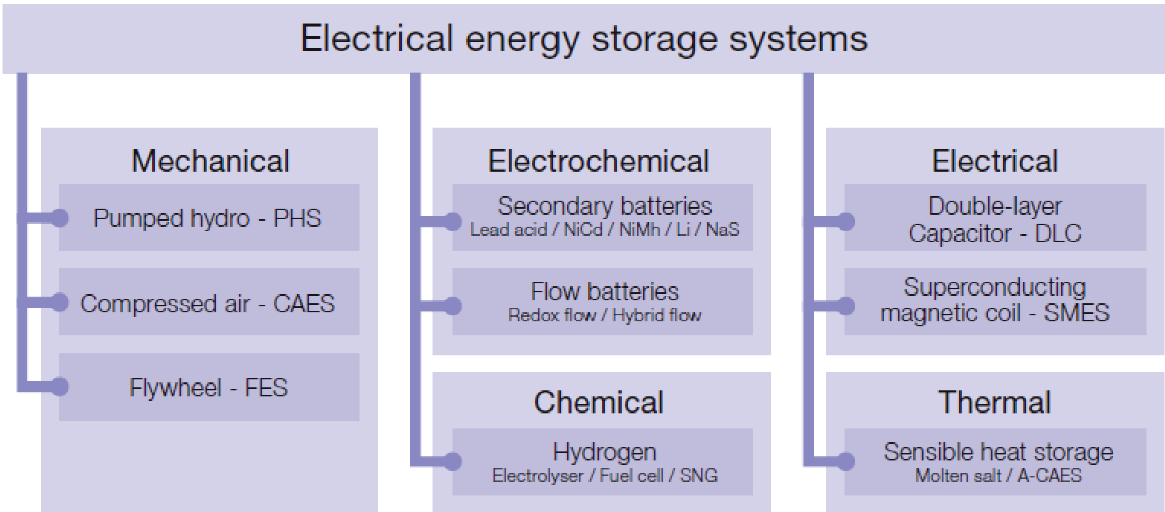

Figure (2.1): Classification of energy storage according to energy form (ICE, 2011)

2.1.1 Mechanical Energy Storage System:

2.1.1.1 Pumped Hydro Energy Storage (PHES):

PHES is the most widely adopted utility-scale electricity storage technology. Furthermore, PHES provides the most mature and commercially available solution to bulk electricity storage. It serves to stabilize the electricity grid through peak shaving, load balancing, frequency regulation, and reserve generation.

PHES first use was in Italy and Switzerland in the 1890s and the first large-scale commercial application in the USA was in 1929. There are over 200 unit and 100 GW of PHES in operation worldwide, which is about 3% of global generation capacity (Chen et al., 2009).

Technology description:

PHES allows to store and generate energy in a mechanical storage mechanism, which stores potential energy from water that is raised against gravity, employing the gravitational differences between two water storage reservoirs. The way it operates is by pumping the water through a pump from a lower reservoir to a higher one. For doing this, it needs an input of electricity in order to run the pumped mode. Then, when there is a requirement for production of electricity, the water is allowed to flow back through a turbine from the higher reservoir back to the lower.

The typical rating of PHES is about 1000 MW (100 MW–3000 MW) and facilities continue to be installed worldwide at a rate of up to 5 GW per year. The rating of PHES is the highest all over the available EES (Chen et al., 2009), and the Typical discharge times range from several hours to a few days (ICE, 2011).

The efficiency of modern pumped storage facilities is in the region of 70% - 85%. However, variable speed machines are now being used to improve this. The efficiency is limited by the efficiency of the pump/turbine unit used in the facilities (Gonzalez *et al.* 2004, p.51) PHES facilities range widely from “10–100 “hours of output energy, at several hundred MWs of rated power with the life time about 30-50 years and more (IPCC, 2009 ; Gonzalez et al.2004).

2.1.1.2 Compressed Air Energy Storage (CAES)

CAES is the only other commercially available technology (besides the PHES) capable of providing very large energy storage deliverability (above 100 MW with single unit).

Conventional gas turbine generation is the work base of CAES. It decouples the compression and expansion cycles of a conventional gas turbine into two separated processes and stores the energy in the form of elastic potential energy of compressed air. During low demand, energy is stored by compressing air into an air tight space, typically 4.0–8.0 MPa. To extract the stored energy, compressed air is drawn from the storage vessel, heated and then expanded through a high pressure turbine, which captures some of the energy in the compressed air. The air is then mixed with fuel and combusted with the exhaust expanded through a low pressure turbine. Both the high and low pressure turbines are connected to a generator to produce electricity. The waste heat of the exhaust is potentially captured via a recuperator before being released.

CAES systems are designed to cycle on a daily basis and to operate efficiently during partial load conditions. This design approach allows CAES units to swing quickly from generation to compression modes. Utility systems that benefit from the CAES include those with load varying significantly during the daily cycle and with costs varying significantly with the generation level or time of day. In addition, CAES plants can respond to load changes to provide load following because they are designed to sustain frequent start-up/shut-down cycles (Chen et al., 2009).

CAES systems also have improved environmental characteristics in comparison with conventional intermediate generating units. CAES has a relatively long storage period, low capital costs and high efficiency (Chen et al., 2009) with storage efficiency of 85% (Andrijanovits et al. 2012).

The storage period can be over a year, longer than other storage methods except for the PHES due to very small losses.

Capital costs for CAES facilities depend on the underground storage conditions, ranging typically between $400 and $800 per kW (Andrijanovits et al. 2012).

2.1.1.3. Flywheels ES.

The functionality of a flywheel system is quite simple and you may have even played with it when you were kid. Remember the toy cars that kept going after spinning their wheels. Those were powered by a flywheel. So, basically a flywheel is a disk with a certain amount of mass that spins, holding kinetic energy.

Modern high-tech flywheels are built with the disk attached to a rotor in upright position to prevent gravity influence. They are charged by a simple electric motor that simultaneously acts as a generator in the process of discharging (Oberhofer, & Meisen, 2012).

When dealing with efficiency however it gets more complicated, as stated by the rules of physics, they will eventually have to deal with friction during operation. Therefore, the challenge to increase that efficiency is to minimize friction. This is mainly accomplished by two measures: the first one is to let the disk spin in a vacuum, so there will be no air friction; and the second one is to bear the spinning rotor on permanent and electromagnetic bearings so it basically floats. The spinning speed for a modern single flywheel reaches up to 16.000 rpm and offers a capacity up to 25kilowatt hours (kWh), which can be absorbed and injected almost instantly (Oberhofer, & Meisen, 2012).

To store energy in an electrical power system, high-capacity flywheels are needed. Friction losses of a 200-tons flywheel are estimated at about 200 kW. Using this hypothesis and instantaneous efficiency of 85%, the overall efficiency would drop to 78% after 5 h, and 45% after one day. Long-term storage with this type of apparatus is therefore not foreseeable.

And the Commercial fly wheel storage units are expected to last 100,000 charge-discharge cycles (Ibrahim, Ilinca, & Perron, 2008).

2.1.2 Electrochemical EES:

Rechargeable/secondary battery is the oldest form of electricity storage which stores electricity in the form of chemical energy. A battery comprised of one or more electrochemical cells and each cell consists of a liquid, paste, or solid electrolyte together with a positive electrode (anode) and a negative electrode (cathode). During discharge, electrochemical reactions occur at the two electrodes generating a flow of electrons through an external circuit. The reactions are reversible, allowing the battery to be recharged by applying an external voltage across the electrodes.

Batteries can respond very rapidly to load changes and accept co-generated and/or third-party power, thus enhancing the system stability. Batteries usually have very low standby losses and can have a high energy efficiency (60–95%).

The construction of a secondary battery is facilitated by the short lead times, potentially convenient sitting, and the technology's modularity (Gonzalez et. al., .2004). However, large-scale utility battery storage has been rare up until fairly recently because of low energy densities, small power capacity, high maintenance costs, a short cycle life and a limited discharge capability. In addition, most batteries contain toxic materials.

Hence the ecological impact from uncontrolled disposal of batteries must always be considered. Batteries that are either in use and/or potentially suitable for utility scale battery energy storage applications include lead acid, nickel cadmium, sodium sulphur, sodium nickel chloride and lithium ion (Chen et al.,2009).

The lead-acid battery is the oldest known type of rechargeable battery and was invented in 1859 by the French physicist Gaston Planté. Even though the concept is over 150 years old the lead-acid battery is still known for its cost-effectiveness today. They are often used in cars (as starter batteries, known as SLI batteries), wheelchairs or golf carts

A lead-acid battery usually has several in-series connected cells, each delivering 2 volts (V) and each consisting several spongy pure lead cathodes, positive loaded lead oxide an-odes and a 20 –40 percent solution of sulfuric acid that acts as an electrolyte. When dis-charged, both the anode and the cathode undergo a chemical reaction with the electrolyte that progressively changes them into lead sulfate that releases electrical energy in the process. This reaction can be almost completely reversed by supplying the electrodes with electricity, which is the reason a lead-acid battery can be recharged.

Lead acid battery has a low cost ($300–600/kWh), and a high reliability and efficiency (70–90%). It is a popular storage choice for power quality, UPS and some spinning reserve applications. Its application for energy management, however, has been very limited due to its short cycle life (500–1000 cycles) and low energy density (30–50 Wh/ kg) due to the inherent high density of lead. Lead acid batteries also have a poor low temperature performance and therefore require a thermal management system (Chen et al., 2009).

2.1.3 Electrical Field (Super Capacitors)

Super capacitors, also known as electric double-layer capacitors, store energy physically in the electrostatic charges of two plates. As their name suggests, they are derived from traditional capacitor technology; however, super capacitors have energy densities on the order of one hundred times that of conventional capacitors: since the energy stored is proportional to the area of the plates, the energy density can be increased dramatically by using porous carbon to maximize surface area.

Although their energy density is still lower than that of most batteries, super capacitors have faster charge/discharge cycles (a unit can be charged in about 10 seconds), higher power densities, and are capable of cycling millions of times and are thus virtually maintenance free (PROSER, 2011).

There are two basic double-layer capacitor electrode configurations, symmetric and asymmetric. Symmetric configurations have identical electrodes, while asymmetric designs have different electrodes (Carnegie, Gotham, Nderitu, & Preckel, 2013).

Moreover, since they store energy physically, they can be deeply discharged without suffering capacity losses or damage. Given these characteristics, super capacitors could potentially be a valuable technology for frequency regulation or other applications that require short, high power bursts of energy. While they have been used in uninterruptible power supply systems, super capacitors are a relatively young technology that will require significant cost reductions before it can be commercialized and made useful on a grid-scale (PROSER, 2011).

2.1.4 Magnetic Energy Storage

Superconducting magnetic energy storage is achieved by inducing DC current into a coil made of superconducting cables of nearly zero resistance, generally made of niobiumtitane.

(NbTi) filaments that operate at very low temperature (-270 C). The current increases when charging and decreases during discharge and has to be converted for AC or DC voltage applications (ICE, 2011).

One advantage of this storage system is its great instantaneous efficiency, near 95% for a charge–discharge cycle (Anzano, 1989). Moreover, these systems are capable of discharging the near totality of the stored energy, as opposed to batteries. They are very useful for applications requiring continuous operation with a great number of complete charge– discharge cycles. The fast response time (under 100 ms) of these systems makes them ideal for regulating network stability (load levelling). Their major shortcoming is the refrigeration system which, while not a problem in itself is quite costly and makes operation more complicated.

Massive storage projects (5000–10,000MWh) require very large coils (several 100m in diameter) that generate enormous electromagnetic forces. They have to be installed underground to limit infrastructure costs (Ibrahim, Ilinca, & Perron, 2008).

2.1.5 Chemical Energy Storage: Fuel cells-Hydrogen Energy Storage (FC-HES)

Fuel cells are a means of restoring spent energy to produce hydrogen through water electrolysis. The storage system proposed includes three key components: electrolysis which consumes off-peak electricity to produce hydrogen, the fuel cell which uses that hydrogen and oxygen from air to generate peak-hour electricity, and a hydrogen buffer tank to ensure adequate resources in periods of need.

Oxidation-reduction between hydrogen and oxygen is a particularly simple reaction which occurs within a structure (elementary electrochemical cell) made up of two electrodes (anode–cathode) separated by electrolyte, a medium for the transfer of charge as ions.

There are many types of fuel cells, such as: Alkaline Fuel Cell (AFC), Polymer Exchange Membrane Fuel Cell (PEMFC), Direct Methanol Fuel Cell (DMFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), and Solid Oxide Fuel Cell (SOFC).

The basic differences between these types of batteries are the electrolyte used, their operating temperature, their design, and their field of application. Moreover, each type has specific fuel requirements.

There are several hydrogen storage modes, such as: compressed, liquefied, metal hydride, etc. For station applications, pressurized tanks are the simplest solution to date. Currently available commercial cylinders can stand pressures up to 350 bars.

2.1.6 Thermal Energy Storage (TES）

Thermal energy can be stored thermo-chemically, or stored as sensible/latent heat. TES technologies balance the energy demand and energy production. For example, the solar energy would be available during the night time or in the winter season if it is stored previously. In hot climates, the primary applications of thermal energy storage are cold storage because of large electricity demand for air conditioning (Chen, 2013).

TES systems can be classified into low-temperature TES and high-temperature TES depending on whether the operating temperature of the energy storage material is higher than the room temperature (Chen et al., 2009).

To some up a detailed table that contains the advantages, disadvantage, power rating and storage time for each system is given in appendix A.

Chapter Three

Life Cycle Assessment

3.1 Introduction

Achieving ‘‘sustainable development’’ needs to select a perfect product which has the minimal environmental impact compared with other products environmental impacts (Nitkiewicz & Sekret, 2014).

Every products pass through stages, starting with resource extraction, production, use/consumption, and finally disposal (Rebitzer et al., 2004).

These activities in the products life have their environmental impacts. To compare which product has minimal environmental impact over their life cycle and to view environmental exchanges life cycle assessment (LCA) is used.

3.2 Life Cycle Assessment Definition

LCA is a technique for estimating the environmental aspects and potential impacts related with a product. The LCA definition from ISO 4040 is compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (ISO 14040, 2006).

LCA can be defined as a tool to assess the environmental impacts used throughout a product’s life cycle and consider all features or aspects of natural environment, human health, and resources (Korres et al., 2010).

The environmental burden of products at all stages in their life cycle can be analyzed by LCA from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product to the management after it is discarded, either by reuse, by recycling, or by final disposal (Guinée, 2002).

In other way, Life cycle assessment (LCA) is a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product from cradle to grave (Rebitzer et al., 2004).

Comprehensive environmental life cycle assessments (LCA) idea was conceived in the USA in the late 1960s and early 1970s. While nearly congruous ideas were being developed in Europe at approximately the same time (Guinee, 2010).

Figure 3.1 shows the stages of LCA starting from extraction and processing of raw materials, pass over manufacturing then transportation and distribution, use, reuse and maintenance, recycling, finally disposal.

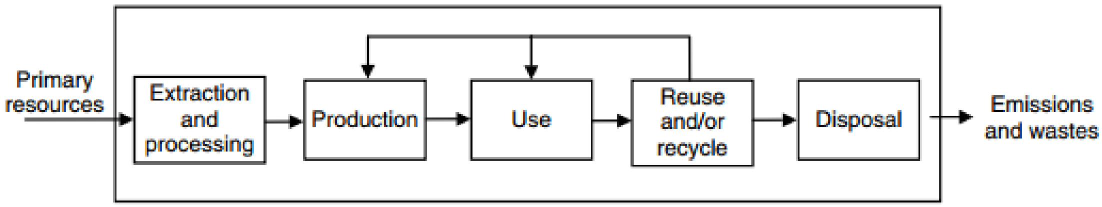

Figure (3.1): LCA stages

3.3 Life Cycle Assessment Phases

According to ISO 14040 the LCA divided into four main phases as illustrated in figure 3.2:

1. Goal and scope.

2. Inventory analysis.

3. Impact assessment.

4. Data interpretation.

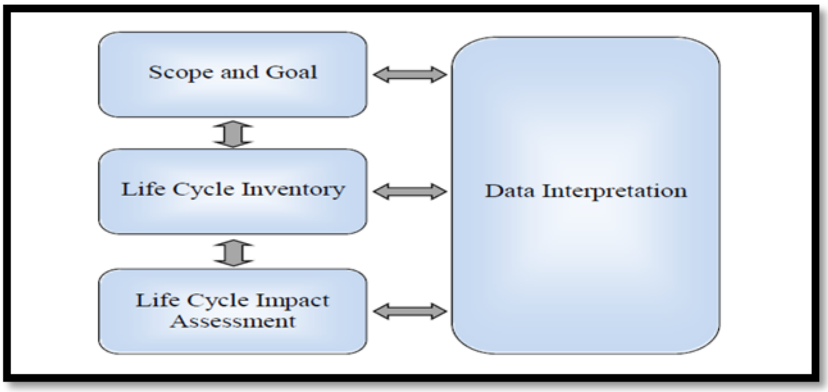

Figure (3.2): Phases of a Life Cycle Analysis

3.3.1. Goal and Scope Definition

The goal and scope determine the process of conducting LCA and its outcome. For example, when one use LCA, the goal used to identify the hot spot in manufacturing process so the company already can use the result to reduce the environmental impact.

As another option, the company may wish to provide the LCA data to customers who use this product as a raw material, or can be utilized from the basis of LCA result to market the product (Curran, 1996).

In each case, the assumptions, data and system boundaries may be different. It is important that these are defined in accordance with the goal of the study.

In goal and scope and before boundaries are determined, functional unit must be defined and presented obviously.

The boundary of the system in full LCA involves all stages in life cycle from extraction of raw to disposal. That's what called from cradle to grave.

In some case it's not suitable or possible to include all stage of the life cycle. In this case, usually the scope of such studies is taken from cradle to gate, not grave, that means follow product from extraction raw material to the factory gate. This because some products have different uses or maybe it is an intermediate product. Figure 3.3 illustrates the above mentioned definition of the boundary (Curran, 1996; Azapagic, 2006).

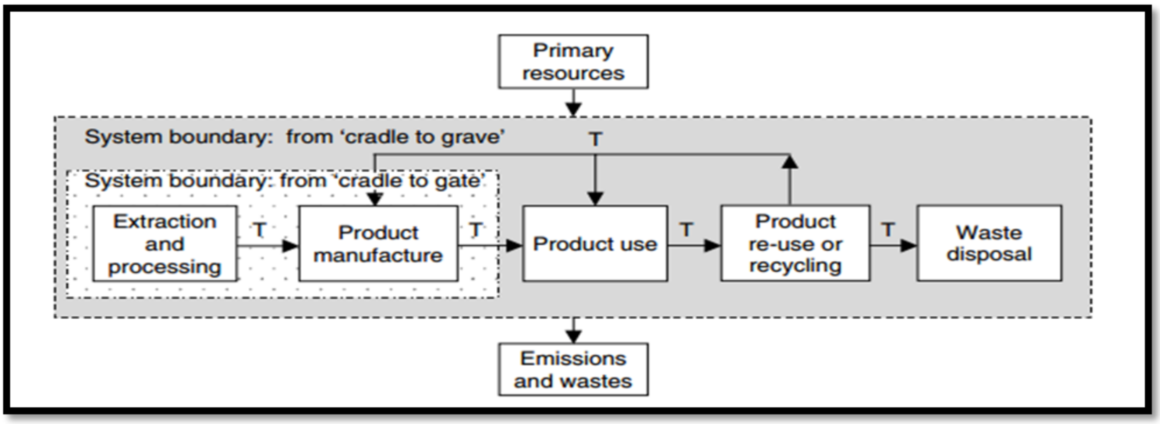

Figure (3.3): Stages in the life cycle of a product from"cradle to gate" and from cradle to grave (Azpagic, 2004)**.**

3.3.2. Inventory Analysis

The aim of the 'Inventory analysis' is to identify and quantify the environmental burdens in the life cycle of the activity under study.

There are many things determine the environmental burden such as the material used energy consumption, emission to air, sewage discharge, and solid waste.

Inventory analysis includes the following steps:

– Detailed definition of the system under study.

– Data collection.

– Allocation of environmental burdens in multiple-function systems.

– Quantification of the burdens.

There are many important factors to determine the authenticity of Impact Assessment, the most important emphasis on the data calculation and flows allocation (Azapagic, 2004).

This data required for each process within the boundary system, which classified under many main heading such as: (ISO 14040, 2006)

Energy inputs, raw materials inputs, ancillary input, other physical inputs

product, co-product and waste, emission to air, discharge to water and soil

Other environmental aspects

An inventory may be conducted to aid in decision making by enabling companies or organizations to:

• Develop a baseline for a system’s overall resource requirements for benchmarking efforts.

• Identify components of the process that are good targets for resource-reduction efforts

• Aid in the development of new products or processes that will reduce resource requirements or emissions.

• Compare alternative materials, products, processes, or activities within the organization.

• Compare internal inventory information to that of other manufacturers. Managers using LCA to aid decision (Babu, 2006).

Following a preliminary system definition in the ‘Goal and scope definition phase’, detailed system specification must be carried out in the ‘Inventory phase’ to identify data needs. A system is defined as a collection of materially and energetically connected operations (including, e.g., manufacturing process, transport or fuel extraction) which performs some defined function. The system is ‘separated’ from the environment by a system boundary; this is illustrated in Figure 3.4 (Azapagic, 2004).

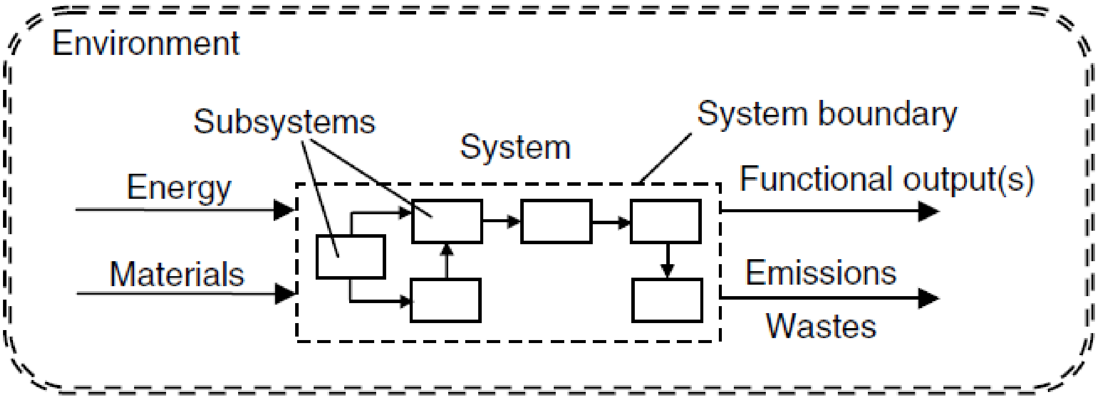

Figure (3.4): Definition of system, system, system boundary and environment (Azapagic, 2004).

3.3.3. Impact Assessment

In LCIA, the inventory is analyzed for environmental impact. This can be achieved by classification, characterization, normalization; and evaluation (Azapagic, 2004).

For each substance, a schematic response pathway needs to be developed to describe the environmental mechanism of the substance emitted. Along this environmental mechanism, impact category indicator result can be chosen either at the midpoint or endpoint level.

Midpoint impact category, or problem-oriented approach, translates impacts into environmental themes such as climate change, acidification, human toxicity, etc.

Endpoint impact category, also known as the damage-oriented approach, translates environmental impacts into issues of concern such as human health, natural environment, and natural resources. Endpoint results have a higher level of uncertainty compared to midpoint results but are easier to understand by decision makers (Chatzisymeon, Foteinis, & Borthwick, 2016).

The impact assessment method implemented in this study is a CML baseline which is defined for the midpoint approach (SimaPro, 2016).

The impact categories of CML base line are presented below:

1. Acidification

Acidic gases such as sulphur dioxide (SO_2) react with water in the atmosphere to form “acid rain”, a process known as acid deposition. When this rain falls, often a considerable distance from the original source of the gas (e.g. Sweden receives the acid rain caused by gases emitted in the UK), it causes ecosystem impairment of varying degree, depending upon the nature of the landscape ecosystems. Gases that cause acid deposition include ammonia (NH_3), nitrogen oxides (NO_x) and sulphur oxides (SO_x).

Acidification potential is expressed using the reference unit, kg SO_2 equivalent. The model does not take account of regional differences in terms of which areas are more or less susceptible to acidification. It accounts only for acidification caused by SO_2 and NO_x. This includes acidification due to fertilizer use, according to the method developed by the Intergovernmental Panel on Climate Change (IPCC). CML has based the characterization factor on the RAINS model developed by the University of Amsterdam.

2. Climate change

Climate change can be defined as the change in global temperature caused by the greenhouse effect that the release of “greenhouse gases” by human activity creates. There is now scientific consensus that the increase in these emissions is having a noticeable effect on climate. This raise of global temperature is expected to cause climatic disturbance, desertification, rising sea levels and spread of disease. Climate change is one of the major environmental effects of economic activity, and one of the most difficult to handle because of its broad scale. The Environmental Profiles characterization model is based on factors developed by the UN's Intergovernmental Panel on Climate Change (IPCC). Factors are expressed as Global Warming Potential over the time horizon of different years, being the most common 100 years (GWP100), measured in the reference unit, kg CO2 equivalent.

3. Depletion of abiotic resources

There are many different sub-impacts to be considered in this case. In a general way, this impact category in referred to the consumption of non-biological resources such as fossil fuels, minerals, metals, water, etc. The value of the abiotic resource consumption of a substance (e.g. lignite or coal) is a measure of the scarcity of a substance. That means it depends on the amount of resources and the extraction rate. It is formed by the amount of resources that are depleted and measured in antimony equivalents in some models or water consumption (in m^3), kg of mineral depletion and MJ of fossil fuels.

4. Eco-toxicity

Environmental toxicity is measured as three separate impact categories which examine freshwater, marine and land. The emission of some substances, such as heavy metals, can have impacts on the ecosystem. Assessment of toxicity has been based on maximum tolerable concentrations in water for ecosystems. Eco-toxicity Potentials are calculated with the USESLCA, which is based on EUSES, the EU's toxicity model. This provides a method for describing fate, exposure and the effects of toxic substances on the environment. Characterization factors are expressed using the reference unit, kg 1, 4-dichlorobenzene equivalent (1, 4-DB), and are measured separately for impacts of toxic substances on (Acero, Rodríguez, & Ciroth, 2015).

■ Fresh-water aquatic ecosystems

■ Marine ecosystems

■ Terrestrial ecosystems.

5. Eutrophication

Eutrophication is the build-up of a concentration of chemical nutrients in an ecosystem which leads to abnormal productivity. This causes excessive plant growth like algae in rivers which causes severe reductions in water quality and animal populations. Emissions of ammonia, nitrates, nitrogen oxides and phosphorous to air or water all have an impact on eutrophication. This category is expressed using the reference unit, kg PO_4^{-3} equivalents. Direct and indirect impacts of fertilizers are included in the method. The direct impacts are from production of the fertilizers and the indirect ones are calculated using the IPCC method to estimate emissions to water causing eutrophication (Acero, Rodríguez, & Ciroth, 2015).

6. Human toxicity

The Human Toxicity Potential is a calculated index that reflects the potential harm of a unit of chemical released into the environment, and it is based on both the inherent toxicity of a compound and its potential dose. These by-products, mainly arsenic, sodium dichromate, and hydrogen fluoride, are caused, for the most part, by electricity production from fossil sources. These are potentially dangerous chemicals to humans through inhalation, ingestion, and even contact. Cancer potency, for example, is an issue here. This impact category is measured in 1, 4- dichlorobenzene equivalents (Acero, Rodríguez, & Ciroth, 2015).

7. Ozone layer depletion (Stratospheric ozone depletion)

Ozone-depleting gases cause damage to stratospheric ozone or the "ozone layer". There is great uncertainty about the combined effects of different gases in the stratosphere, and all chlorinated and brominated compounds that are stable enough to reach the stratosphere can have an effect. CFCs, halons and HCFCs are the major causes of ozone depletion. Damage to the ozone layer reduces its ability to prevent ultraviolet (UV) light entering the earth’s atmosphere, increasing the amount of carcinogenic UVB light reaching the earth’s surface. The characterization model has been developed by the World Meteorological Organization (WMO) and defines the ozone depletion potential of different gases relative to the reference substance chlorofluorocarbon-11 (CFC-11), expressed in kg CFC-11 equivalent (Acero, Rodríguez, & Ciroth, 2015).

8. Photochemical oxidation (Photochemical ozone creation potential)

Ozone is protective in the stratosphere, but on the ground-level it is toxic to humans in high concentration. Photochemical ozone, also called “ground level ozone”, is formed by the reaction of volatile organic compounds and nitrogen oxides in the presence of heat and sunlight. The impact category depends largely on the amounts of carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxide (NO), ammonium and NMVOC (non-methane volatile organic compounds). Photochemical ozone creation potential (also known as summer smog) for emission of substances to air is calculated with the United Nations Economic Commission for Europe (UNECE) trajectory model (including fate) and expressed using the reference unit, kg ethylene (C_2H_4) equivalent (Acero, Rodríguez, & Ciroth, 2015).

3.3.4 Interpretation

This stage presents the whole and full finding of the impact assessment. The result shall be suitable with the goal and the scope of the study, providing a clarification of the limits of the pattern and some recommendations for further studies.

This phase is aimed at system improvements and innovation, and it includes the following steps:

– Identification of major burdens and impacts;

– Identification of ‘hot spots’ in the life cycle;

– Sensitivity analysis; and

– Evaluation of LCA findings and final recommendations.

Quantification of environmental impacts carried out in ‘Impact assessment’ phase enables identification of the most significant impacts and the life cycle stages that contribute to these impacts. This information can then be used to target these ‘hot spots’ for system improvements or innovation.

Before the final conclusions and recommendations of the study are made, it is important to carry out sensitivity analysis. Data availability and reliability are some of the main issues in LCA since the results and conclusions of an LCA study will be determined by the data used. Sensitivity analysis can help identify the effects that data variability, uncertainties and data gaps have on the final results of the study and indicate the level of reliability of the final results of the study (Azapagic, 2004).

Chapter Four

Methodology

Adoption of pumped hydro energy storage project in wastewater treatment plant -Nablus depends on the consideration of a range of technical and economic factors. A further and increasingly important factor for material specifies, in a world where sustainable development is a key issue, is the associated environmental performance of material applications from the perspective of manufacturing and product performance.

Among the tools available to evaluate the environmental performance of PHES, life cycle assessment (LCA) provides a holistic approach to evaluate environmental performance by considering the potential impacts from all stages of construction the PHES project, including manufacturing, operation, maintenance and end-of-life stages. This is referred to as the gate-to-grave approach (WSA, 2011).

4.1 Goals and scope

The goals of this study are to evaluate the environmental impacts of PHES and perform simple economic feasibility. The obtained results may help decision makers to adopt such method or not.

To achieve the aforementioned objectives; the geographic features of the site should be analyzed. A sufficient elevation difference should be available between the storage tank and the plant where the turbine to be installed. The necessary design of the hydro system should be performed carefully.

The Pumped hydroelectric energy storage is the most mature and largest storage technique available. It consists of two large reservoirs located at different elevations and a number of pump/turbine units during off-peak electrical demand, water is pumped from the lower reservoir to the higher reservoir where it is stored until it is needed. Once required (i.e. during peak electrical production) the water in the upper reservoir is released through the turbines, which are connected to generators that produce electricity (Chen et al., 2009).

In evaluating the environmental performance of PHES, the analysis is divided into five stages or phases: production phase (manufacturing the product), transportation, land excavation to build the reservoir, maintenance, and end of life.

The functional unit chosen in this study is 1MJ stored during one day and it indicates the amount of energy stored in a time unit.

The origin of the input of electricity required to run up the pumped mode can be supplied by any available renewable energy source such as solar PV or biogas.

4.2 Expected Audience

The LCA results of this study can be viewed as a holistic perspective that is capable of providing information about the whole system. That helps stakeholders such as municipalities, scientific researchers, and the Palestinian Energy Authority (PEA), and Environment Quality Authority to take necessary decisions.

4.3 System description overview

4.3.1 Nablus western wastewater treatment plant as a case study (WWTP)

The targeted Wastewater treatment plant is located in western area of Nablus, in Deir Sharaf village between Nablus and Tulkarm cities.

The average annual energy consumption of the plant is about 2,261,762 kWh. This value is calculated based on monthly consumption from January until the end of July 2014 (Homeidan, Marie, & Hasson, 2015; [W2]).

The required area, pipe length, slopes and elevation differences of the slected site for PHES determined using ArcGIS software. Figure 4.1 contains the mentioned parameters based on calculations from the software.

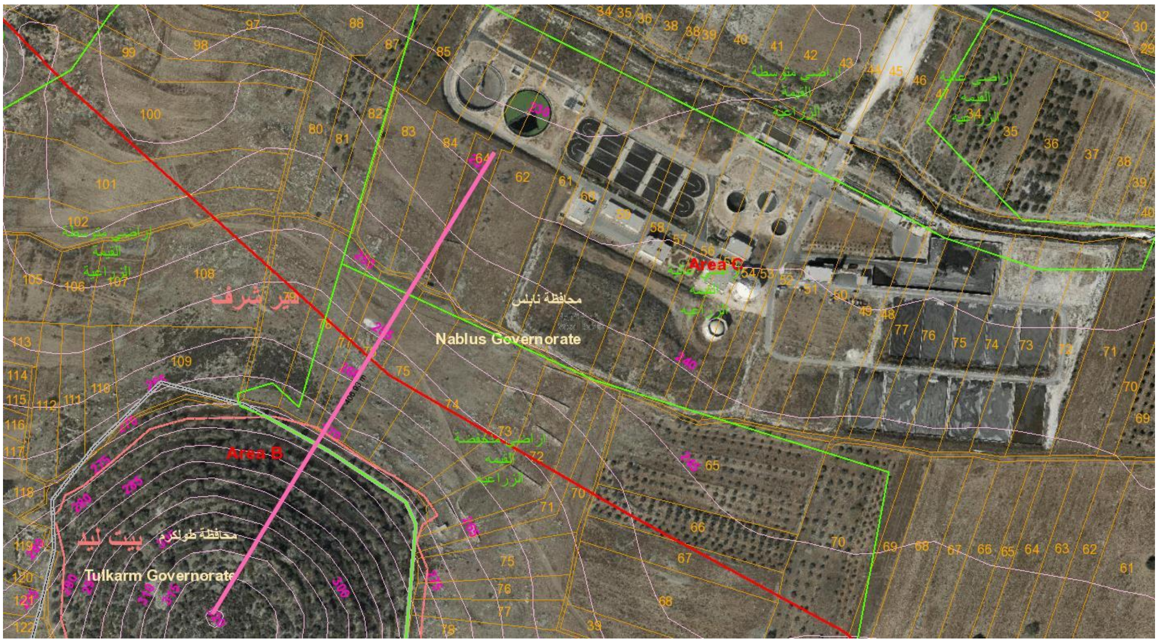

Figure (4.1): GIS for the Proposed PHES

Using figure 4.1, the following data were obtained:

Available maximum head is 320 m, and available area on this point is 6280 square meter.

Available minimum head is 250 m(at wastewater treatment plant level as a reference), and the available area on this point is 18192.50 m^2. Available elevation difference 320-250 = 70 meter.

Referring to the downhill slope, the necessary pipe length between the highest point and the reference point is 310 m.

4.3.2 The pumped hydro reservoir energy storage (PHES) system design

Installing a pumped hydro energy storage system helps to store the energy needed to run the plant from renewable sources when this type of energy is not available, and thus reduces the amount of electricity demand from the municipality and also reduces the operating cost.

Depending on energy consumption of WWTP, the renewable energy source (solar or biogas) should be high enough to provide the necessary power for the plant and store the excess energy to be used as needed (Levine, 2007).

4.4 System Boundaries

4.4.1 Conceptual Boundaries

The following two figures present two sketches of the system boundaries. Figure 4.2 provides a general overview of the system boundaries. More details considering different process and resources employed at each phase are illustrated in Figure 4.3.

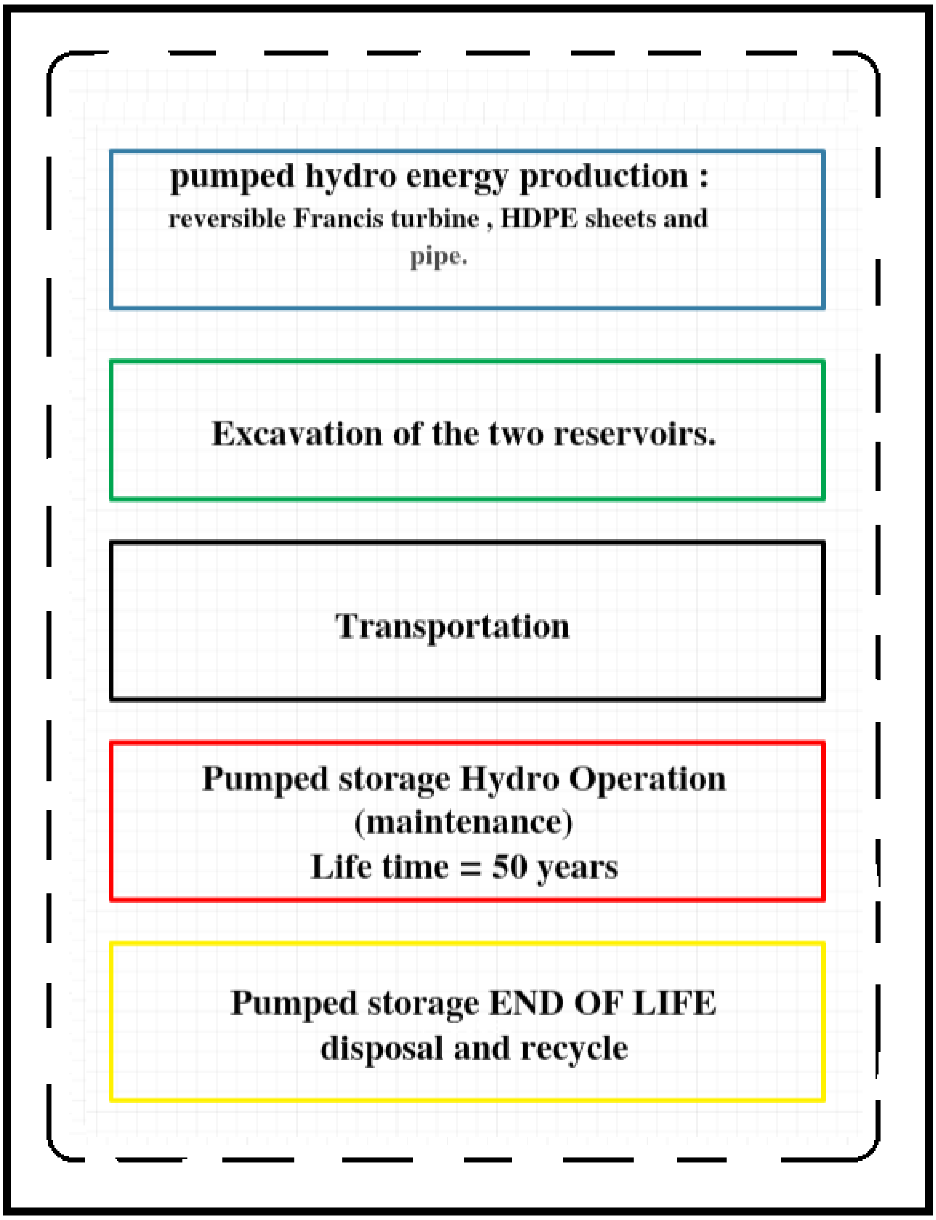

Figure (4.2): general overview for PHES system boundaries**.**

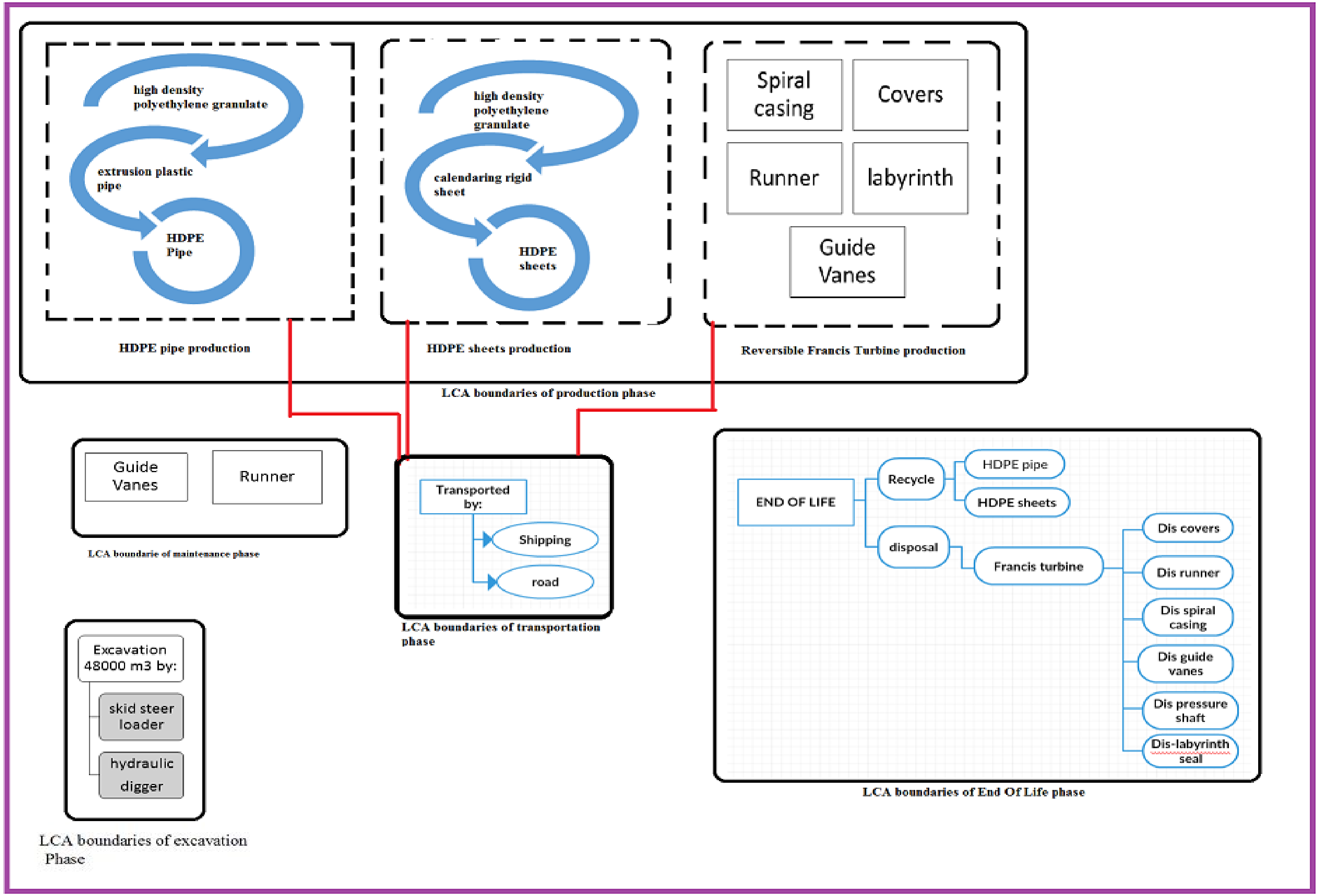

Figure (4.3): Details boundaries for PHES system

4.4.2 Geographical Boundaries

Although Nablus western wastewater treatment plant is considered as a case study for the PHES, the geographical boundaries were extended to include countries where some components are manufactured and imported from.

The considered Francis turbine (GUGLER Water Turbines GmbH, company) is manufactured in Austria. It was assumed that the turbine has been transported by freight ship from a nearest port called Koper in Austria to the Ashdod port in Israel.

The HDPE sheets are produced in India-Ahmedabad, which were assumed to have been transported by freight ship from India port directly to Ashdod port.

The HDPE pipe is manufactured in Central tube –Italy, it was assumed to have been transported by freight ship from Ravenna port to Ashdod port directly.

The aforementıoned equipment were assumed to be transported by lorry from Ashdod port to the Station of Deir- Sharaf wıth total dıstance of about 87 km.

4.4.3 Time horizon (lifetime)

According to the lifetime for PHES components, the lifetime (time horizon) of the LCA for PHES is set to 50 years (IPCC, 2009; ACPA, 2007; Riesterer, 2013).

4.5 Functional Unit

Functional unit for this study has been predefined as an amount of energy stored over a period of time. Within the scope of this study, the selected functional unit is 1MJ stored during one Day(MJ.Day) and it indicates the amount of energy stored in a time unit of one day.

A regime that the pumped storage hydro plant will be applied in (Deir-Sharaf wastewater treatment plant). The main aspects of this regime ; that interesting for this study, is the possibility of enhancing the renewable share at the grid by storing the capacity of energy from renewable sources as solar, and introducing it back to the market at peak hours.

The objective of this study is to design and assess the environmental impact of installing a pumped hydro energy storage plant that uses treated water that stores sufficient potential energy to be used when needed.

The data about the Deir Sharaf station was collected from several references, the research revealed that the average annual energy consumption of the plant is 2,261,762 kWh.

4.6 Design of Pumped Hydro Energy Storage-Reservoirs

Necessary flow rates, size and dimensions of the reservoirs, diameter penstock pipe, and other important parameters were determined using fluid mechanics and hydrodynamics engineering.

Given hydraulic head, output power and efficiency, the necessary flow rates were calculated using equation 4.1

$P = \gamma.Q.H.\ \eta$ **4.1**

Where,

P = generated output power [kW].

Q = fluid flow in during power generation [m^3 /s].

η = turbine efficiency

$\gamma = \rho\ g$ = water specific weight [9.81 kN/m^3],

Where:

ρ = fluid density in [kg/m^3] = 1000 [kg/m^3] for water.

g = gravitational acceleration [m/s^2] = 9.81 [m/ s^2].

H = hydraulic head height in meters [m].

Depending on the Ludin– Bundschu empirical equation, the inner diameter of the pipe can be calculated using the following equations (BULU, n.d.):

Where:

$H_{gross} < 100\,m \rightarrow D = \sqrt[7]{0.05\ Q^3}$ (m). **4.2**

Hydraulic radius: $R = \frac{D}{4}$ (m). **4.3**

Identical flow velocities: $V = \frac{4Q}{\pi D^2}$ $(\frac{m}{s})$. **4.4**

Friction Loss as Per Manning Relation:

Manning relation computes the friction loss in pipe flow in terms of roughness coefficient, flow velocity, penstock length and hydraulic radius as sgiven in equation 4.5 (Singhal & Kumar, 2015) :

$$h_f = \frac{L\, v^2\, n^2}{R^{4/3}} \qquad \textbf{4.5}$$

The volume of the reservoir is calculated by multiplying the value of flow rate by storage time, as given in the following equation:

V= Q × Time. **4.6**

Then the depth of reservoir calculated by eq.4.7

$$\text{Depth of reservoir} = \frac{volume\ of\ reservoir}{used\ land\ area} \qquad \textbf{4.7}$$

Mechanical energy equation can be used to calculate the pressure in penstocks of a hydroelectric plant as in eq. 4.8:

$$\text{ha-hf} + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 \qquad \textbf{4.8}$$

where:

P is the fluid pressure

ρ is the fluid density

v is the fluid velocity

g is the gravitational acceleration

z is the elevation of the fluid above a fixed reference point.

The above mentioned design steps are summarized in the flow chart shown in figure 4.4.

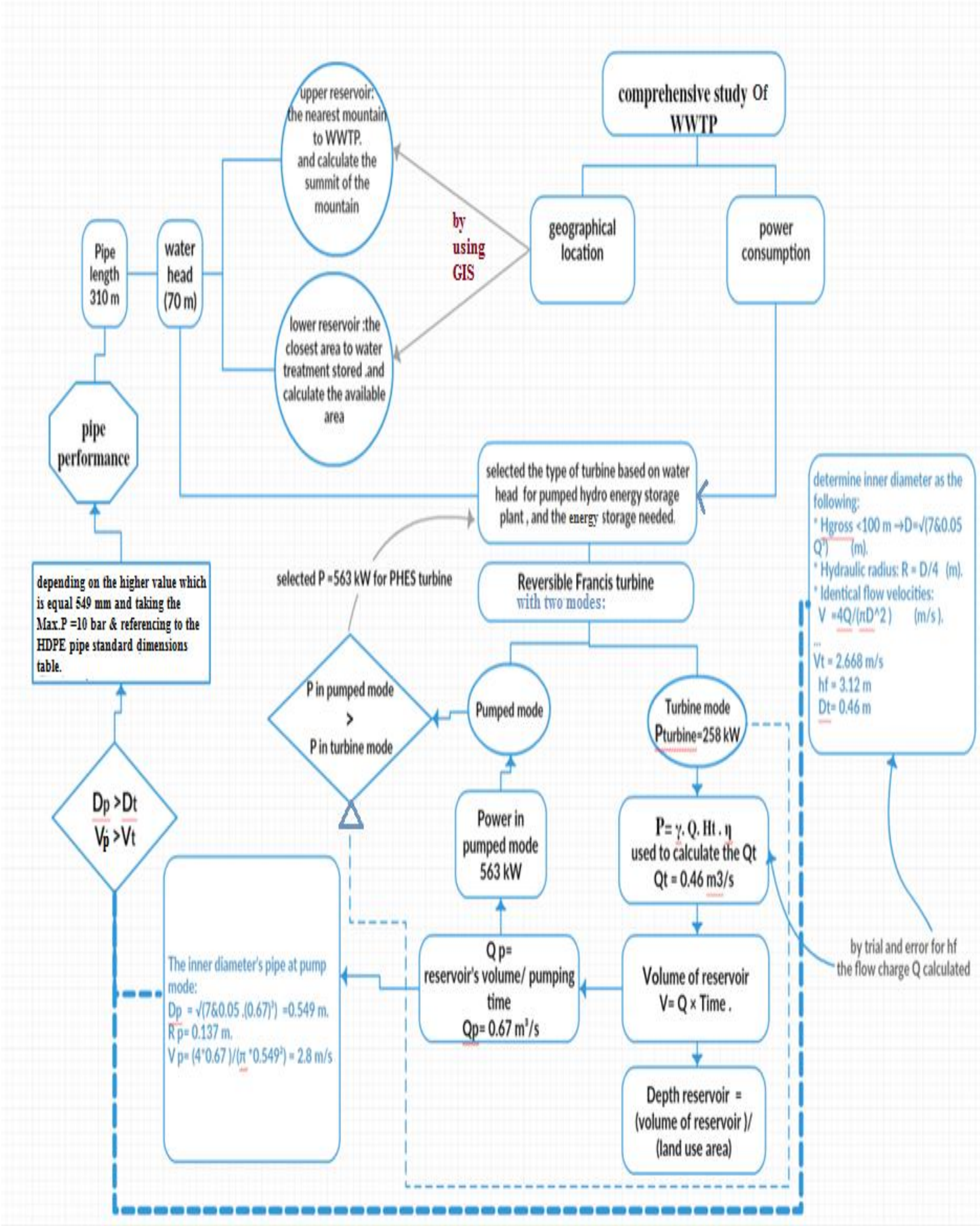

Figure (4.4): *Pumped hydro energy storage design flowchart*

4.7 Economic Analysis

For evaluating cost of the project economically, present worth analysis equation is used (Blank & Tarquin, 2012):

AW= [turbine cost + pipe cost + sheet cost] $[\frac{i(1+i)^n}{(1+i)^n-1}]$ + [land cost +excavation cost][i] + SV[turbine cost +pipe cost +sheet cost]$[\frac{i}{(1+i)^n-1}]$. **4.9**

And the capitalize cost equal: PW=AW/i **4.10**

Where:

SV: salvage value is 0.05 of initial cost.

i: interest rate estimated as 0.1

n: useful life equal 50 years .

The economic analysis for each part of PHES is represented in the flow charts in the following figures:

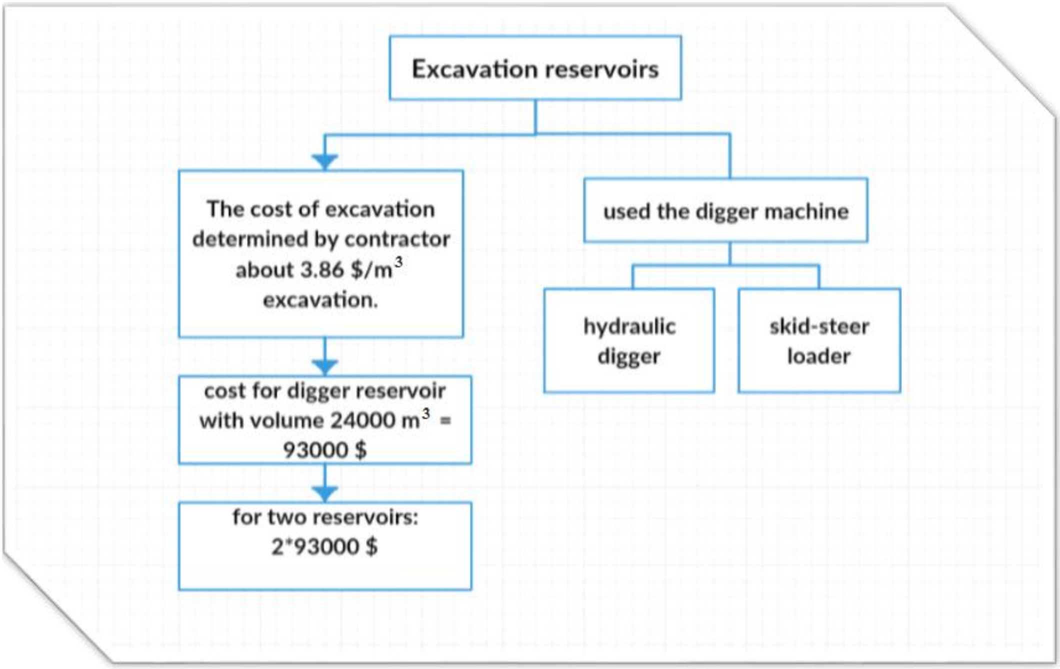

Figure (4.5): Economic analysis of Reservoirs excavation.

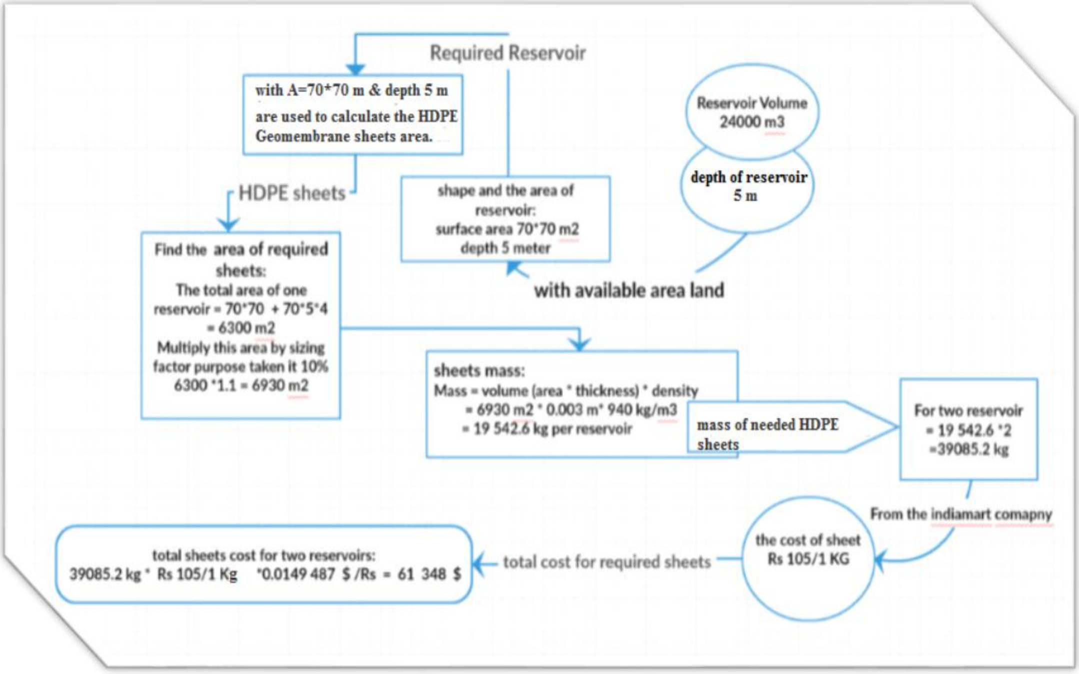

Figure (4.6): Economic analysis of HDPE Geo membrane sheets

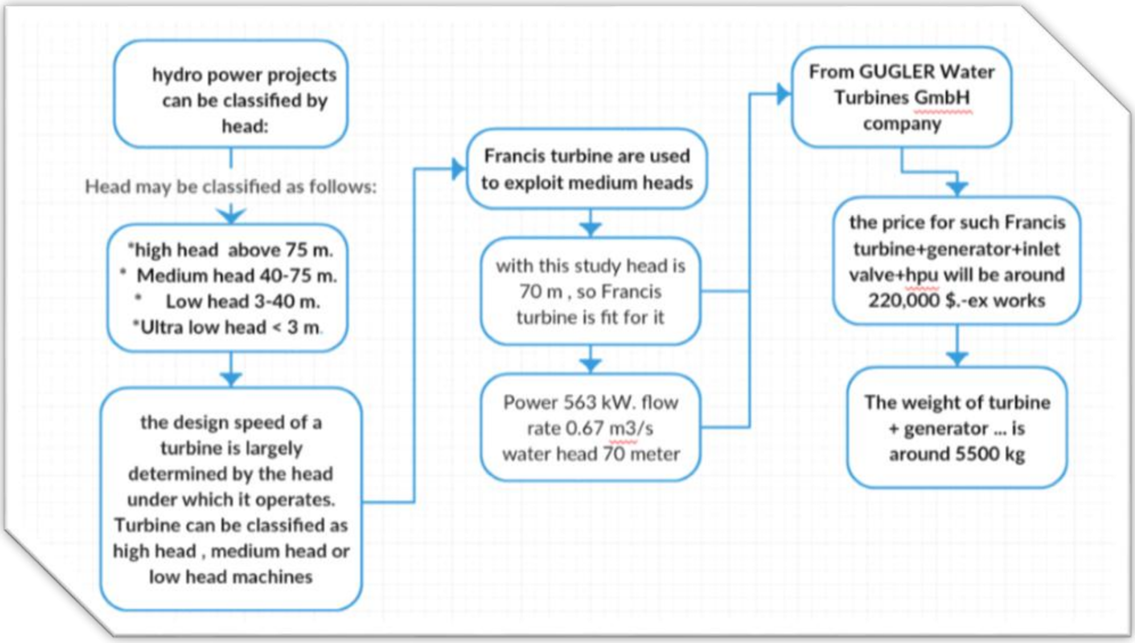

Figure (4.7): economic analysis of Francis turbine.

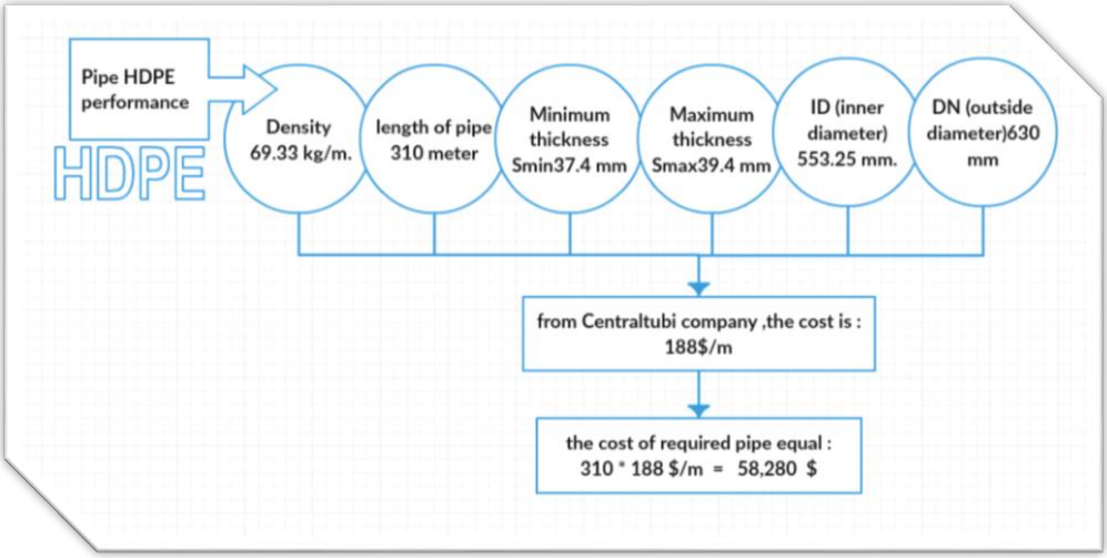

Figure (4.8): Economic analysis of HDPE pipe.

4.8 Impact Assessment

The open LCA software (version 1.4.2) has been used to implement life cycle impact analysis. There are several impact assessment methods in this software, the most updated databases are Ecoinvent 3.1, needs, elcd, and agribalys [W3].

This section describes the impact categories that will be investigated in this study. These impact categories are calculated using CML (baseline) method.

CML (Institute of Environmental Sciences) method created by the University of Leiden in the Netherlands in 2001 contains more than 1700 different flows (Guinée et al., 2001).

The method is divided into baseline and non-baseline, the baseline being the most common impact categories used in LCA. This is considered in this study. Table 4.1 shows the impact categories that the software considers (Acero, Rodríguez, & Ciroth, 2015).

Table 4.1: Impact categories included in the method CML (baseline).

(Source: Acero, Rodriguez, &Ciroth, 2015)

Method: CML (baseline)	
Impact category group	Name of the impact category in the method
acidification	Acidification potential - average Europe
Climate change	Climate change - GWP100
Depletion of abiotic resources	Depletion of abiotic resources - elements, ultimate reserves
	Depletion of abiotic resources - fossil fuels
Ecotoxicity	Freshwater aquatic ecotoxicity - FAETP inf
	Marine aquatic ecotoxicity - MAETP inf
	Terrestrial ecotoxicity - TETP inf
Eutrophication	Eutrophication - generic
Human toxicity	Human toxicity - HTP inf
Ozone layer depletion	Ozone layer depletion - ODP steady state

The inventory process is considered as that challenging step in investigating the life cycle assessment of any process or product. In this research, and since there is no enough data available in the literature, the inventory was created by scaling down some systems. Some necessary data were also obtained from the manufacturers.

4.9 Life Cycle Phases

Figure 4.9 summarizes the analysis phases of LCA by a flow chart

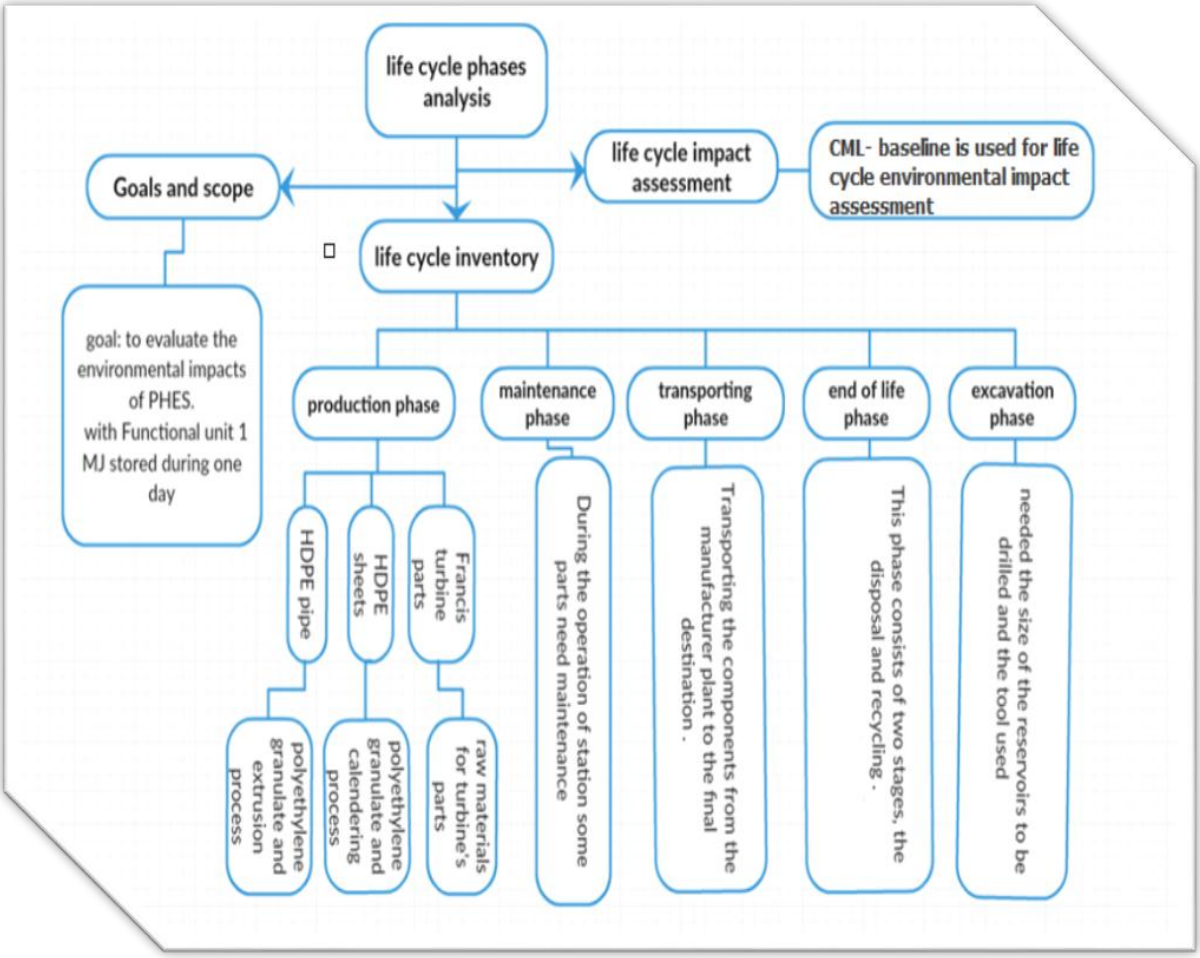

Figure (4.9): *LCA phase's flow chart for PHES*

4.9.1The production phase

Production phase analysis includes the manufacturing process of the PHES components. These components are reversible Francis turbine including generator, inlet valve, fluid transferring pipe, and HDPE (geomembrane) sheets for reservoirs.

4.9.2 The Transporting phase

Transporting the components from the manufacturer plant to the final destination represent an important part of studding life cycle assessment. It necessary to take into account all intermodal freight transport as needed.

Internet website [W4] has been used to determine the distance from origin of manufacturer plant to the final destination charge.

4.9.3 The Maintenance phase

During the operation of station some parts need maintenance. Based on life time of PHES only some parts from subsystem of PHES needs maintenance. This part was also considered in this study.

4.9.4 The End-Of-Life phase

This phase consists of two stages, the disposal and recycling if possible. The nature of the materials is the key to decide the best method for end of life for each.

4.9.5 The excavation phase

This phase considers the excavation of necessary reservoirs. The hydraulic digger and skid steer digger are considered as the main used machines for this purpose.

Chapter Five

Results and Discussion

Energy storage systems have been utilized in many forms and applications for a long time. Today's energy storage technologies are used to achieve electric power systems of higher reliability and to contribute to the broader use of renewable energy.

Energy storage technologies can be generally divided into three main groups: mechanical, electrochemical and electromagnetic storage (ICE, 2011). From these technologies the Pumped hydroelectric storage system (PHES) is the most mature form of energy storage.

Pumped hydroelectric facility construction is often constrained by low variation in topographic elevation and water availability (Carnegie et al., 2013).

In Palestine, the availability of surface water, i.e rivers and lakes is of major constrains, but water treatment plants offer a solution that overcome the water availability constrains. In Nablus, the West Wastewater treatment plant is in hand to implement the PHES as there is large water amount available nearby mountainous area with sufficient altitude; in addition the Wastewater treatment plant itself needs an enormous energy supply, PHES can offer part of this supply to reduce the energy costs. Wastewater treatment plants consume large amounts of energy then it's necessary to find renewable energy sources for example solar, wind energy, etc. As the renewable energy is often intermittent, the need of storage system is mandatory to run the Wastewater treatment plant facilities continuously without interruption.

This thesis entails the life-cycle assessment of PHES as an energy storage option to be applied in the Nablus western wastewater treatment plant. In order to assess this system according to environmental and economic impact; a simplified design of the PHES was carried out based on real energy consumption data of the plant.

The design, the economic feasibility, and the environmental impact of PHES for Nablus western wastewater treatment plant were conducted in details and the results are illustrated in the following sections.

5.1 Pumped Hydroelectric Energy Storage (PHES) design:

The design of a PHES plant often begins with a site that is in a desirable location and has favorable geotechnical with an adequate water source, upper and lower reservoirs possibilities, and reasonable head conditions. For this purpose, a reasonable geotechnical site is assumed to exist, and the focus is on the technical characteristics and the facilities that contribute to a successful PHES plant.

5.1.1 Power Consumption of the plant:

To calculate the technical specifications of a pumped hydroelectric site, basic fluid power equations are used. Given hydraulic head, system efficiency, and an upper bound on flow rate, the power generation capacity of the pumped hydroelectric istation can be calculated by use equation (Eq. 4.1) in the case of Nablus WWTP, the hydraulic head, the flow rate can be determined depending on proposed storage and operating time, this leads to know the pipe diameter which will be adopted.

The hydraulic head is given by analysis the topographic area of the site by ArcGIS and GeoMOLG software, the analysis revealed that the two main points, namely the lowest and the highest points of the of the proposed site are 250 and 320 m above the sea, respectively. As a result, available hydraulic head is 70 m.

Efficiency of such pumped storage plant is equal to 85% (Tilahun, 2009).

The corresponding flow rate required to achieve the specified power was identified by trial and error, an evaporation losses of 5% was considered in this study.

The design is based on 10 hours of storage to cover 14 hours of operating, this assumption is generally reasonable when solar energy (PV) is considered as the source of renewable energy.

5.1.2 The required storage capacity:

The average annual power consumption of the WWTP is 2,261,762 kWh (Saleh, 2014) this value is equivalent to a power of $\frac{2261\,762\ kWh}{8760\,\frac{h}{year}}$ = 258 kW. Operating power: 258 kW.

Operating and needed power for storage is approximately 620 kW, considering that the operating time equals to 10 hours and storage time equals to 14 hours.

$$258 *[\ 1+(\frac{14\ h\ (operate)}{10\ h\ (storage)})\ ]\ = 619.6\ kW$$

This value needed for storing energy by PHES for 10 hours.

5.1.3 Hydraulic dimensions of Penstock:

Studying pumped hydro energy storage system in any site needs good knowledge of the area and also there is a need to create a preliminary design for such systems.

Pumped hydro energy system PHES in this study consists of two large reservoirs located at two different elevations, pump/turbine unit, pipe (penstock) that connects between the two reservoirs where water flows through. Figure 5.1 illustrates the layout of PHES system.

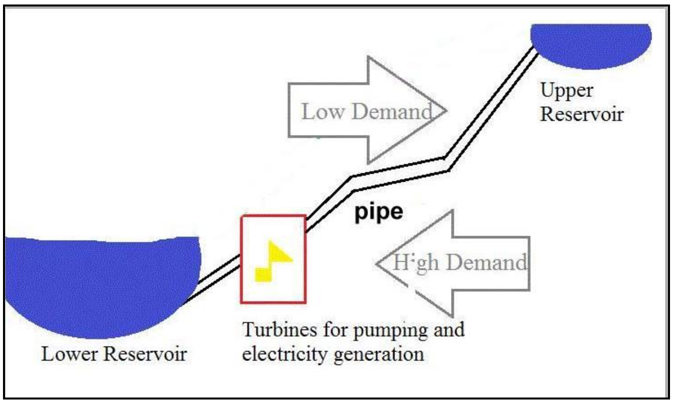

Figure (5.1): layout of the pumped hydro energy storage system

During off- peak electrical demand, water is pumped from the lower reservoir to the higher reservoir where it is stored until it is needed.

Water head is 70 meter, and pipe length is 310 meter, these are determined by the use of the Geo-MOLOG and ArcGIS software.

Figure 5.2 illustrates the horizontal dimension between the reservoirs; it was important to determine the decline (slope) of hill which refers to the length of the pipe. Pythagorean Theorem was used to determine the length of the pipe as:

Pipe's Length = $\sqrt{302.47^{\,2} + 70^2}$ =310 m.

Figure (5.2): the horizontal distance between the reservoirs (source: Geo-MOLOG)

The power generation capacity of a pumped hydroelectric installation can be calculated using equation (4.1) depending on the type of the turbine which is reversible Francis turbine which can operate as a pump during the off peak hours, and as a turbine for power generation during peak demand [W5].

The necessary flow rate and the diameter of the penstock can be calculated by trial and error method in both modes as the friction losses depends on the flow rate.

In turbine mode:

$P_{h.t} = \gamma.\ Q.\ H_t\ .\eta$

$P_{h,t}$: generated output power [kW] in turbine mode.

Q : volumetric fluid flow rate [m^3 /s].

$Q_{t1:}$ volumetric fluid flow rate [m^3 /s]. In turbine mode the sub number 1, 2 … refers to the number of trial.

H_t: total head in turbine mode where, H_t (total) = H gross - h_f.

The following relation can be used to the pipe diameter.

$$\left(9.81\ \frac{KN}{m3}\ \ .Qt1\ .(70\ m - hf)\ \ .0.85\right) = 258\ \mathrm{kW}$$

h_f is unknown and depends on the liquid velocity which also depends on volumetric flow rate. The unknown can be solved by trial and error as illustrated in the following steps:

Trial 1:

Assume hf_1 = 0 (initial guess) then:

258 =$(9.81 * \ 0.85 * \ 70 * \ \ Q1 \ )$

$Q_{1=}$ 0.44 $\frac{m3}{s}$.

When $Q_{1=}$ 0.44 $\frac{m3}{s}$, H_t (total) = 70 m.

Depending on the Ludin– Bundschu empirical equation, one can determine the inner diameter of the pipe as the following (BULU, 2016):

$H_{gross} < 100\ m\ \rightarrow D = \sqrt[7]{0.05\ Q^3}$ (m).

Hydraulic radius: $R = \frac{D}{4}$ (m).

Identical flow velocities: $V = \frac{4Q}{\pi D^2}$ $(\frac{m}{s})$.

By using the previous three equations the diameter and radius and identical flow velocity will be:

$D_1 = \sqrt[7]{0.05 \times 0.44^3}$ = 0.459 m.

$R_1 = \frac{0..459}{4}$ = 0.11 m.

$V_1 = \frac{4Q}{\pi D^2} = \frac{4*0.44}{\pi*0.459^2} = 2.65 \frac{m}{s}$.

Friction Loss as Per Manning Relation:

Manning relation computes the friction loss in pipe flow in terms of roughness coefficient, flow velocity, penstock length and hydraulic radius as sgiven in equation 4.11 (Singhal, & Kumar, 2015):

$$h_f = \frac{L v^2 n^2}{R^{4/3}} \qquad \textbf{4.11}$$

$h_f = \frac{310*2.65^2*0.009^2}{0.11\text{^}4/3}$ = 3.35 m, this value named h_{f2}.

Trial 2, new guess for h_{f2}=3.35 m

Using equation ……….

$P_{h.t} = \gamma.Q.\ (H_{gross} - hf_2).\eta$

258 = [9.81 $*$ Q_2 $*$ (70-3.35) $*$ 0.85]

$Q_2 = 0.464 \frac{m3}{s}$.

Using the second value of flow rate and Friction Losses

Q_2= 0.464 $\frac{m3}{s}$, h_{f2}=3.35 m.

D_2= $\sqrt[7]{0.05\,Q^3}$ =$\sqrt[7]{.05\,.(0.464)^3}$ = 0.469 m.

R_2 = $\frac{0.464}{4}$ = 0.117 m.

V_2 = $\frac{4*0.464}{\pi*0.4692}$ = 2.68 m/s. then h_{f3} will be:

h_{f3}= $\frac{(310*2.68^2*0.009^2)}{(0.117\text{^}4/3)}$ = 3.16 m.

These lead to:

Q3=0.46

D3=0.468 m

R_3 = 0.117 m

V_3 = 2.667 m/s

h_{f4} = 3.12 m.

Third iteration

$h_{f4=}$ 3.12 m

258 =9.81 $*$ Q_2 $*$ (70-3.12) $*$ 0.85

Q_4=0.46

D_4=0.468

R_4=0.117

V_4=2.668 m/s

$h_{f5} = \frac{(310 * 2.668^2 * 0.009^2)}{(0.117^{4/3})} = 3.12$ m

With equal last two value, the desired value of $h_{f.t}$ can be taken as 3.12 meter.

After all above steps the Preliminary penstock design at turbine mode is:

$V_t = 2.668\ (\frac{m}{s})$, hf = 3.12 m, $Q_t = 0.46(\frac{m^3}{s})$, $D_t = 0.46$ m, $P_{h.t} = 258$ kW.

The obtained value of flow rate (in turbine mode) ($Q_t = 0.46\frac{m3}{s}$), the volume of the reservoir can be calculated as

Vol. = Q × Time.

Vol. = $(0.46\frac{m3}{s})$. (14 h). $(3600\frac{s}{h})$ = 23184 m^3.

Assume evaporation losses of 5%. (Postel et al., 1996)

Vol. =23184 m^3 *1.05 = 24 000 m^3.

The volume of one reservoir is = 24000 m^3.

The depth of the reservoir can be calculated by dividing the reservoir volume by available land as:

Reservoir Depth = $\frac{volume\ of\ reservoir}{land\ use\ area} = \frac{24000\ m^3}{6280\ m^2}$ = 3.8 m, to save some area the depth can be taken as 5 m.

After studying the available area in the site and comparing them with the desired size, an upper reservoir size is designed with 70-meter length, 70-meter width and 5 meter depth, this also was applied to the lower reservoir.

Pump mode:

$Q_p = \frac{reservoir's\ volume}{pumping\ time}$

$Q_p = \frac{24000\,m^3}{10\,h * 3600\,\frac{s}{h}} = 0.67\ \frac{m^3}{s}$.

The inner diameter of the pipe at pump mode:

$D_p = \sqrt[7]{0.05\,.\,Q^3} = \sqrt[7]{0.05\,.\,(0.67)^3}$ =0.549 m.

R_p= 0.137m.

$V_p = \frac{4*0.67}{\pi * 0.549^2}$ = 2.8 m/s .

$h_{f.p} = (310 * 2.8^2 * 0.009^2)/(0.137^{4/3}) = 2.8$ m.

$P_{h.p} = \frac{\gamma.Q.(Hgross+hf.p)}{\eta} = \frac{[0.81 * 0.67 *(70 +2.8)]}{0.85}$ = 563 Kw.

The summary of Preliminary design of penstock at pump mode:

Vp= 2.8 m/s, $h_{f.p}$ =2.8 m/s, Qp= 0.67 m^3/s, Dp =0.549 m, Ph.p= 563 kW.

5.2 maximum pressure in the penstocks

In order to determine the pipe thickness, the maximum possible pressure in the pipe should be determined. General the maximum pressure in such system is at the pump exit, by applying the mechanical energy equation between the pump exit and the surface of water at upper reservoir as in equation 4.8.

$$ha\text{-}hf + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

where

Ha is 0 m (no mechanical device between the pump exit and the water surface in the upper reservoir.

H_f is Headloss (m) or frictional losses as per manning relation (here hf 2.8 m).

P_1=$(-\frac{2.8^2}{2*9.81}+2.8+70)$*9.81 =710 kPa; (P1 is the maximum pressure). Because the mire losses were neglected nd taking in to account safety factor larger pipe that resist higher pressure was selected (10 bars).

Comparing the cases of pump and turbine modes, the higher value for the pipe diameter is in pumping mode, which is depending on the higher 549 mm. from HDPE pipe dimensions standards in (appendix B) choose the closest pipe is sdr =17; And PN 10 Table 5.1 shows the other specification of the pipe .

Table (5.1): HDPE pipe specifications

DN (outside diameter)	630 mm
Minimum thickness Smin	37.4 mm
Maximum thickness Smax	39.4 mm
Tolerance S	3.9
Density	69.33 kg/m.
Length of pipe	310 m.
ID (inner diameter)	553.25 mm.
Pipe Weight	21492.3 kg

5.3 Characteristic of the final design for PHES

The proposed pumped hydro energy storage system (PHES) for WWTP in Deir-Sharaf -Nablus is a 563 kW reversible Francis turbine plant.

During off-peak electrical demand, water is pumped, using excess energy generated by other sources like renewable energy, from the lower reservoir to the higher reservoir where it is stored until it is needed.

Once required, i.e. during peak electrical demand, the water in the upper reservoir is released through the turbines, which are connected to generators that produce electricity.

Generation and pumping can be accomplished by single-unit, reversible pump-turbines, that allow the power station to generate electricity during peak hours then pump it back into the reservoir during low demand hours.

The PHES consists of two reservoirs, the upper reservoir located at elevation of 70 meter above the lower reservoir. Treated wastewater effluents from the wastewater plant is considered as the storage medium.

It has been previously described in details how to determine the size and dimensions of the reservoirs. The reservoirs are designed with equal capacity and capable of storing enough water to store and generate the needed energy

And along the slope of the selected hill, a HDPE pipe (penstock) of 310 meters was designed for transferring the water between the reservoirs through the turbine-pump assembly.

5.4 Economic Analysis for PHES

The prices of turbine is considered to be 22 thousand euros as indicated by manufacturing company (GUGLER Water Turbines GmbH) The price includes the Francis turbine, generator, inlet valve and HPU (hydraulic power unit) (Gugler, 2016).

The price of previously specified HDPE pipe was taken as 188 $/meter, based on cost index for Palestine Plastic Industrial Co. (PPIC).

The geomembrane sheet price was taken as 105 Rs/kg (Rs: Indian Rupee, 1USD=65 Rs), as indicated by IndiaMART company [W6].

The cost of land was taken according to the local land price within the specified location as 16925 $ per dunam.

The cost of excavation was specified by local contractors of 3.86 $ per cubic meter excavation.

By applying eq.4.10 and eq.4.11 and using costs in table 5.2 the present worth and annual worth analysis for PHES were calculated. The annual worth (AW) and the present values (PW) of the plants were 65176.54, 651765.4 $, respectively.

Table (5.2): PHES elements costs

Items	Cost ($)
Land(area 4900 m^2)	82 932.5
Turbine + generator +inlet valve +HPU	220,000
HDPE pipe(310 meter)	58,280
HDPE sheet for lower reservoir	30674
HDPE sheet for upper reservoir	30674
Excavation two reservoirs	*2*(93000)*
HDPE pipe	2480
HDPE sheet for upper reservoir (civil work /local market/3$/m²)	18900
HDPE sheet for lower reservoir(civil work /local market/3$/m²)	18900

5.5 Life Cycle Assessment of Phases

5.5.1 The production phase

The Production phase analysis includes: the manufacturing process of the Parts of PHES system the materials used for manufacturing the main parts of the reversible Francis turbine, the polymer and manufacturing process of HDPE sheets and pipe. The necessary data were obtained from literature and Ecoinvent 2.2, and ecoinvent 3.1 data base included within the life cycle assessment.

5.5.2 The Transportation phase

The transportation of materials were consider through roads and ships from the production sites to the location of the PHES plant as needed.

The aforementioned products are expected to be transported by ships to a port called Ashdod and then by roads to the specified location. SeaRates.com website was used to determine the distance from origin destination [W4].

The Francis turbine is manufactured in (GUGLER Water Turbines GmbH, company) in Austria, It was assumed to be transported by freight ship from nearest port called Koper in Austria to the Ashdod port.

The HDPE sheets are produced in India-Ahmedabad, which were assumed to be transported by freight ship from India port directly to Ashdod port.

The HDPE pipe is manufactured in Centraltubi –Italy, it was assumed to have been transported by freight ship from Ravenna port to Ashdod port directly.

Then they were transported by lorry from Ashdod port to Station of Deir-Sharaf, Nablus. Over a distance of 86.9 km. the data inventory for Transporting the Turbine, Pipe and sheets is given in appendix C.

Figure 5.3 below represents the maps of transportation of each component.

Pipe transportation

Turbine transportation

Sheets transportation

Figure 5.3: map of transportation of PHES elements [W4]

5.5.3 Maintenance phase

The life span of the PHES plant is taken as 50 years. For maintenance phase, only the moving parts were considered, of these, the turbine system is the most part that needed maintenance. For this reason, maintenance and replacement of the turbine parts such as Guide Vanes and a runner were considered, as needed (Torres, 2011).

5.5.4-End of life phase

The end of life phase is an important phase where the disposal of some components and the possibility of recycling others are considered. In case of PHES, the disposal of most part of the turbine while recycling of HDPE sheets and pipe can be investigated.

The used Ecoinvent database considers only incineration and landfilling but not recycling. Thus, the disposal routes for polyethylene considers only the energy required for crushing HDPE pipe or sheet. The environmental impact for this phase was taken as the same impact from producing the required electrical energy.

The turbine and similar metallic material were not considered as a recyclable material due to complexity of alloys. Thus these material was considered as a disposable ones.

5.5.5- Excavation phase:

At this stage, mainly a hydraulic digger and skid-steer loader were the necessary machines for digging and excavation of the reservoirs. The resultant environmental for the excavation process was investigated using the Eco-invent database.

5.6 Environment Impact Assessment

The CML base line (Center of Environmental Science of Leiden University) method was used to investigate the environmental impacts of PHES. The results of the environment impact of the aforementioned phases will be discussed in the next sections.

CML proposes a set of impact categories and characterization methods for the impact assessment step. The impact assessment method implemented in this study was CML-IA methodology which is based on midpoint approach. There are two versions of CML methods. The baseline and non-baseline methods. The baseline method considers the most common impact categories. In this study baseline method is used (Guinée et al., 2001*)*.

Tables 5.3 – 5.6 tables includes LCA input data (inventory data) for PHES system. Which are used as a base to assess the impact of each phase in the PHES.

Table (5.3): inventory data for production phase

	material	activity	Database process	Flow property	Unit	Quantity
Reversible Francis Turbine	**Labyrinth Seal**	high strength micro alloyed steel & stainless steel	steel, low-alloyed - GLO	Mass	kg	9.29E-07
		carbon steel	steel, unalloyed - GLO	Mass	kg	4.64E-07
		heat treatment steel	hot rolling, steel - GLO	Mass	kg	4.64E-07
	Spiral Casing	Stainless steel	sheet rolling, chromium steel - GLO	Mass	kg	2.55E-06
		Carbon Steel	steel, unalloyed - GLO	Mass	kg	2.55E-06
	Guide Vanes	Stainless steel	steel, chromium steel 18/8 - GLO	Mass	kg	4.64E-07
	Runner	Stainless steel	steel, chromium steel 18/8 - GLO	Mass	kg	1.21E-06
			hot rolling, steel - GLO	Mass	kg	4.64E-07
	Pressure Shaft	Stainless steel	steel, chromium steel 18/8, hot rolled – GLO	Mass	kg	2.31E-02
	Covers	High Strength Microalloyed Steel& Stainless steel	steel, low-alloyed - GLO	Mass	kg	6.49E-07
HDPE	**HDPE sheets**		polyethylene, high density, granulate – GLO	Mass	kg	3.91E+04
			calendering, rigid sheets - GLO	Mass	kg	3.91E+04
	HDPE pipe		polyethylene, high density, granulate – GLO	Mass	kg	2.15E+04
			extrusion, plastic pipes - GLO	Mass	kg	2.15E+04

Table (5.4): inventory data for maintenance phase

Material	activity	Database process	Flow property	Unit	Amount
Guide Vanes	chromium steel	steel, chromium steel 18/8	Mass	kg	6.43E-03
Runner	chromium steel	steel, chromium steel 18/8	Mass	kg	1.67E-02

Table (5.5): inventory data for End of life phase

Disposal for turbine	Material	Flow	Flow property	Unit	Amount (per FU)
Dis covers	Covers	steel, low-alloyed - GLO	Mass	kg	6.49E-07
Dis runner	Runner	steel, chromium steel 18/8 - GLO	Mass	kg	3.62E-06
Dis spiral casing	spiral casing	sheet rolling, chromium steel - GLO	Mass	kg	5.10E-06
Dis guide vanes	guide vanes	steel, chromium steel 18/8 - GLO	Mass	kg	1.39E-06
Dis pressure shaft	pressure shaft	steel, chromium steel 18/8, hot rolled - GLO	Mass	kg	2.31E-02
Dis-labyrinth seal	labyrinth seal	steel, unalloyed - GLO	Mass	kg	1.02E-06
		hot rolling, steel - GLO	Mass	kg	1.02E-06
		steel, low-alloyed - GLO	Mass	kg	1.02E-06

Table (5.6): inventory data for Excavation phase

Machine used	Flow property	Unit	Amount
excavation, skid-steer loader – RER	Volume	m^3	2.02E-01
excavation, hydraulic digger – RER	Volume	m3	2.02E-01

5.6.1 Environmental Impact of the Production Phase:

The environmental impact analysis of the production phase of PHES system was analyzed using the LCA software. As clear in figure 5.4, the marine aquatic eco-toxicity is the predominate impact of this phase. the marine aquatic eco- toxicity of production phase was found to be equivalent to the effect 453.97 kg 1,4- dichlorobenzene According the depletion fossil fuel of 19.50342 MJ) was found to be the second largest effect of this phase. This can be explained by the high energy input used in manufacturing of components needed in production of the devices. The use of large quantities of chromium steel in constructing the turbine which contributes in 61.35% of Marine aquatic eco-toxicity due to the use of Nickel and chromium in steel manufacturing Nickel contribution in marine Eco toxicity of more than 37% of total impact. Using of chromium VI contributes in 88.56% of human toxicity in the production phase.

The Human toxicity, fresh water aquatic eco toxicity, and climate change were also found to be affected during the production phase. The effect was less pronounced than others.

In the production phase, high energy input is linked to turbine manufacturing, calendaring and extrusion processes of HDPE sheets and pipe. Burning fossil fuel will lead to an increase in greenhouse gas emissions ecotoxicity, and human toxicity. Using CML (baseline) method, the fossil fuel consumption values in this stage were found to be: 55.0% Oil, 38.54% natural Gas, and 6.03% Coal corresponding to 10.72677, 7.51730 and 1.17528 MJ, respectively. Note that the use of Oil has a very high impact on Marin Eco toxicity. studies of the emission levels from experimental burns have shown that about 85 to 95% of the burned oil becomes carbon dioxide and water, 5 to 15% of the oil is not burned efficiently and is converted to particulates, mostly soot, and the rest, 1-3%, is composed of other combustion by-products (e.g. nitrogen dioxide, sulphur dioxide, carbon monoxide and poly aromatic hydrocarbons) (Broje, 2015).

Table (5.7): shows detail about the environmental impacts of the production phase

Impact category	**Reference unit**	**Result**
Acidification potential - average Europe	kg SO2 eq.	0.00282
Climate change - GWP100	kg CO2 eq.	0.702645
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	3.93E-06
Depletion of abiotic resources - fossil fuels	MJ	19.50342
Eutrophication - generic	kg PO^{-4}_4 eq.	0.003426
Freshwater aquatic ecotoxicity - FAETP inf	kg 1,4-dichlorobenzene eq.	0.348755
Human toxicity - HTP inf	kg 1,4-dichlorobenzene eq.	1.908263
Marine aquatic ecotoxicity - MAETP inf	kg 1,4-dichlorobenzene eq.	453.9788
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	1.06E-08
Photochemical oxidation - high Nox	kg ethylene eq.	0.000224
Terrestrial ecotoxicity - TETP inf	kg 1,4-dichlorobenzene eq.	0.062322

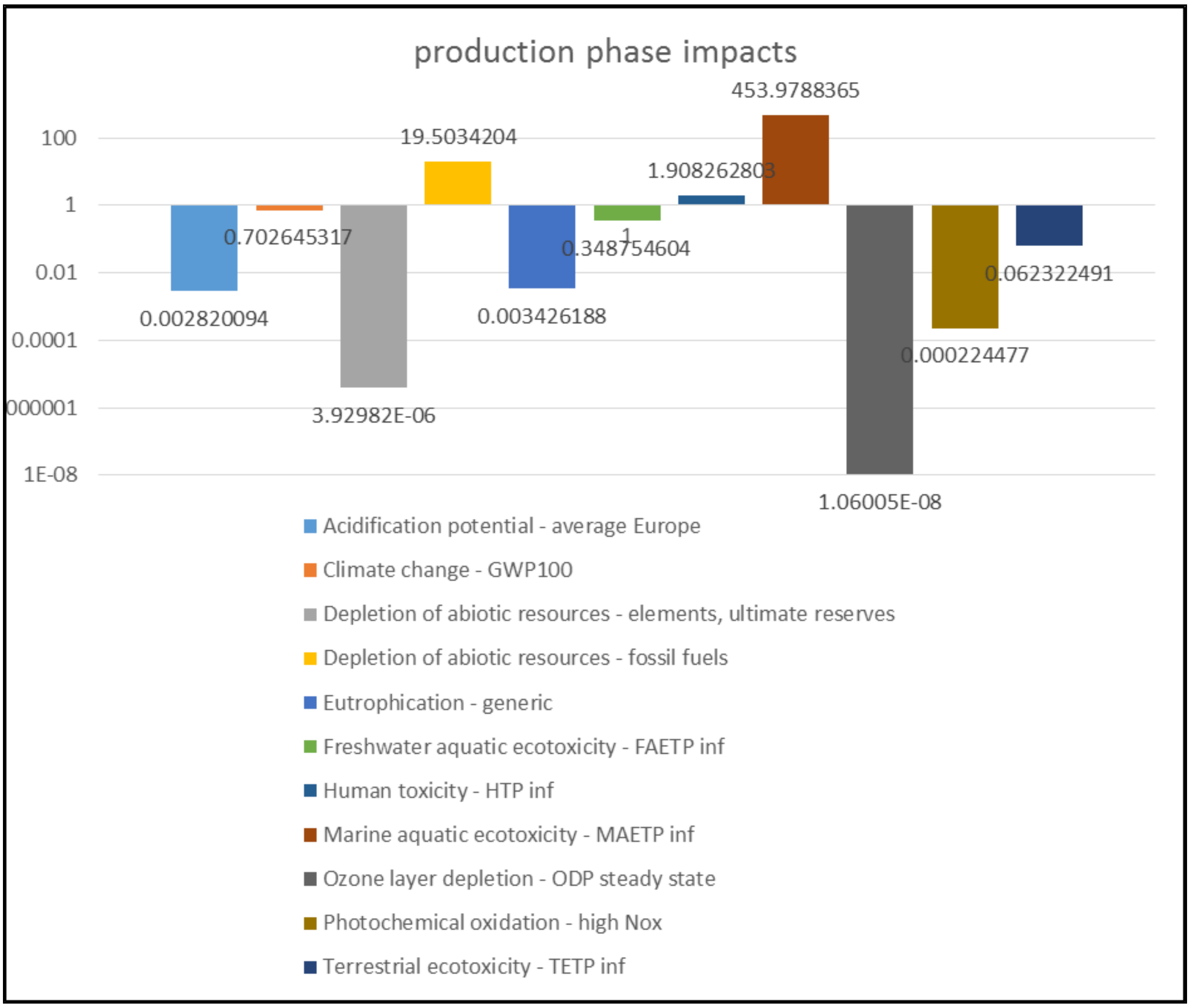

Figure (5.4): environmental impact assessment results for production phase.

5.6.2 Environmental Impact Assessment Analysis of End-of-Life Phase

The result of the environmental impact assessment analysis of the end of life phase is given in Figure 5.5, it contributes significantly to the environmental impacts of they take the second rank after the production stage.

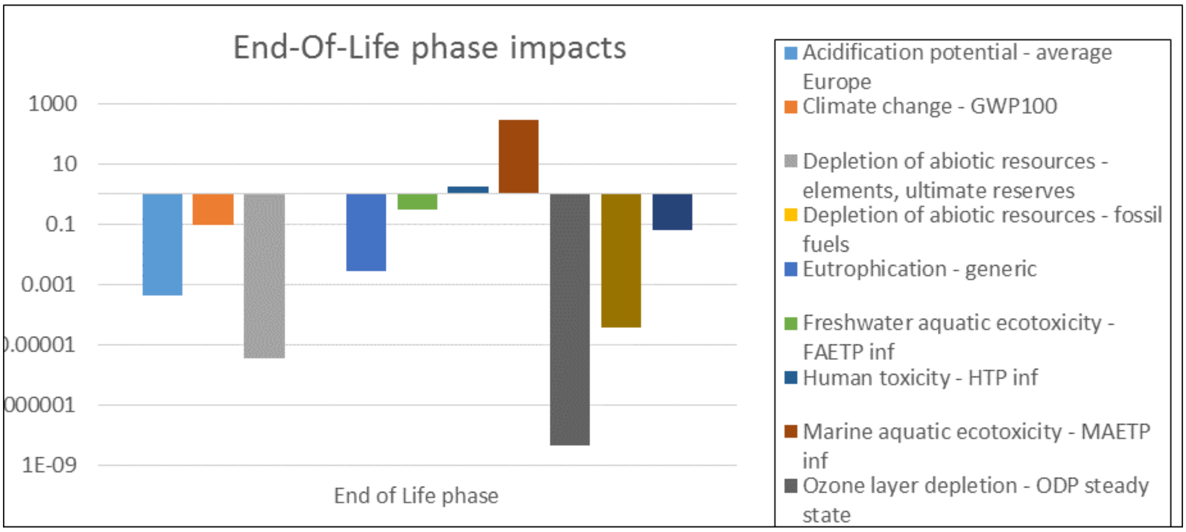

Fig (5.5): Environmental impact assessment analysis for end of life phase.

This phase includes two end of life processing methods, the disposal and recycling in many opportunities, recycling is impossible whenever it is necessary to re-extract the heavy metals from the dead turbine parts. On the other hand, the HDPE is easy to be recycled either to be partially used in production of new product or to be pyrolyzed.

According to the results of the environmental impact of disposal and recycle phase as given in table 5.8 , the Marine aquatic ecotoxicity has the highest value of 278.4136 kg 1,4-dichlorobenzene eq. this is due to nickel, ion, and chromium VI in steel which generally used in the production of turbine set parts.

Table (5.8): analysis results of the end of life for disposal and recycling methods ways.

Impact category	**Reference unit**	**Disposal impact**	**Recycling impact**
Acidification potential - average Europe	Kg SO2 eq.	4.12E-04	1.21E-05
Climate change - GWP100	Kg CO2 eq.	8.74E-02	4.06E-03
Depletion of abiotic resources- elements, ultimate reserves	Kg antimony eq.	3.59E-06	2.07E-09
Depletion of abiotic resources - fossil fuels	MJ	1.06E+00	2.52E-03
Eutrophication - generic	Kg $PO^{-4}{}_{4}$eq.	2.83E-03	5.39E-06
Freshwater aquatic ecotoxicity - FAETP inf	Kg 1,4-dichlorobenzene eq.	3.05E-01	2.01E-03
Human toxicity - HTP inf	Kg 1,4-dichlorobenzene eq.	1.82E+00	1.90E-03
Marine aquatic ecotoxicity - MAETP inf	Kg 1,4-dichlorobenzene eq.	2.78E+02	6.35E+00
Ozone layer depletion - ODP steady state	Kg CFC-11 eq.	4.46E-09	1.09E-11
Photochemical oxidation - high Nox	Kg ethylene eq.	3.73E-05	4.66E-07
Terrestrial ecotoxicity - TETP inf	Kg 1,4-dichlorobenzene eq.	6.11E-02	2.03E-05

The striking in the results in Table 5.8 is the high values of Human toxicity, Freshwater aquatic Eco toxicity, Climate change, Ozone layer depletion, photochemical oxidation, and Depletion of a biotic resources.

Due to turbine element disposal compared to the recycling HDPE sheets and pipe, this means that most of the environmental impact at this stage is due to disposal of the turbine where it consumes about 1.061958648 MJ of fossil fuel energy.

5.6.3 Environmental Impacts of Maintenance Phase

The distribution of environmental impacts along the different phases of the plant life cycle can varies significantly depending on the mass of material's parts that are format the system.

In this phase some of turbine parts like Guide Vans and runner have to be replaced, because the guide vane system is highly affected by sediment erosion due to highest absolute velocity and acceleration, and the runner is effected by turbulence erosion due to fine sand is always susceptible at the trailing edge of the blade. Also because of high relative velocity, most of the particles will also move towards outer diameter in the runner outlet and hence more effect of erosion can be observe there (Neopane, Dahlhaug, & Cervantes, 2011).

According to Table 5.4 which contains the data inventory of the reversible Francis turbine that need maintenance. Steel has the major share of parts need maintenance. As previously stated, the elements included in the fabrication of steel have high environmental impact especially on marine aquatic eco toxicity. Figure 5.6 and Table 5.9 show the environmental impact results of the maintenance phase.

Table 5.9: Environmental impact assessment results for maintenance phase.

Impact category	Reference unit	Result
Acidification potential - average Europe	kg SO_2 eq.	3.86E-04
Climate change - GWP100	kg CO_2 eq.	7.97E-02
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	3.58E-06
Depletion of abiotic resources - fossil fuels	MJ	0.944309
Eutrophication - generic	kg $PO4^{-4}$ eq.	0.002476
Freshwater aquatic ecotoxicity - FAETP inf	kg 1,4-dichlorobenzene eq.	0.302077
Human toxicity - HTP inf	kg 1,4-dichlorobenzene eq.	1.811413
Marine aquatic ecotoxicity - MAETP inf	kg 1,4-dichlorobenzene eq.	277.3893
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	3.97E-09
Photochemical oxidation - high Nox	kg ethylene eq.	3.42E-05
Terrestrial ecotoxicity - TETP inf	kg 1,4-dichlorobenzene eq.	0.061089

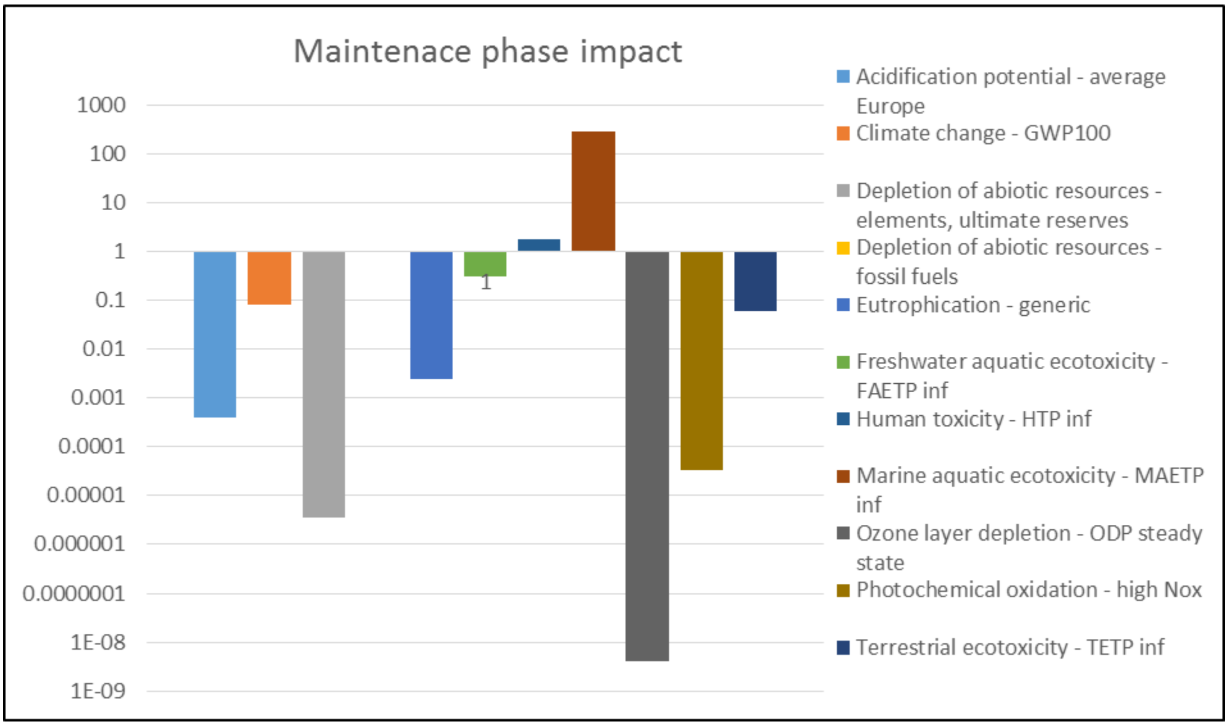

Fig (5.6): environmental impact results of maintenance phase

5.6.4 Environmental Impact of Excavation Phase:

The environmental impact analysis results of the excavation stage (phase) are presented in Fig 5.7, significant effect on marine aquatic eco-toxicity, depletion of abiotic resources - fossil fuels and Climate change - GWP100 can be seen..

The aforementioned Increase in Depletion of abiotic resources - fossil fuels and Climate change is due to high consumption of diesel fuel by skid steer loader and hydraulic digger.

Based on LCA software results, Marine aquatic eco-toxicity - MAETP, and climate change GWP are mainly affected by the type of fuel used. In this case 89.33% of fuel used from oil crude while only 6.36% is from natural gas.

The environmental impact results of excavation phase is listed in table 5.10:

Table (5.10) environmental impact assessment results of excavation phase.

Impact category	Reference unit	Result
Acidification potential - average Europe	kg SO_2 eq.	1.60E-03
Climate change - GWP100	kg CO_2 eq.	2.13E-01
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	4.85E-08
Depletion of abiotic resources - fossil fuels	MJ	2.94E+00
Eutrophication - generic	kg $PO4^{-4}$ eq.	3.80E-04
Freshwater aquatic ecotoxicity - FAETP inf	kg 1,4-dichlorobenzene eq.	1.21E-02
Human toxicity - HTP inf	Kg 1,4-dichlorobenzene eq.	3.32E-02
Marine aquatic ecotoxicity - MAETP inf	Kg 1,4 dichlorobenzene eq.	3.89E+01
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	2.60E-08
Photochemical oxidation - high Nox	kg ethylene eq.	4.24E-05
Terrestrial ecotoxicity - TETP inf	Kg 1,4-dichlorobenzene eq.	6.76E-04

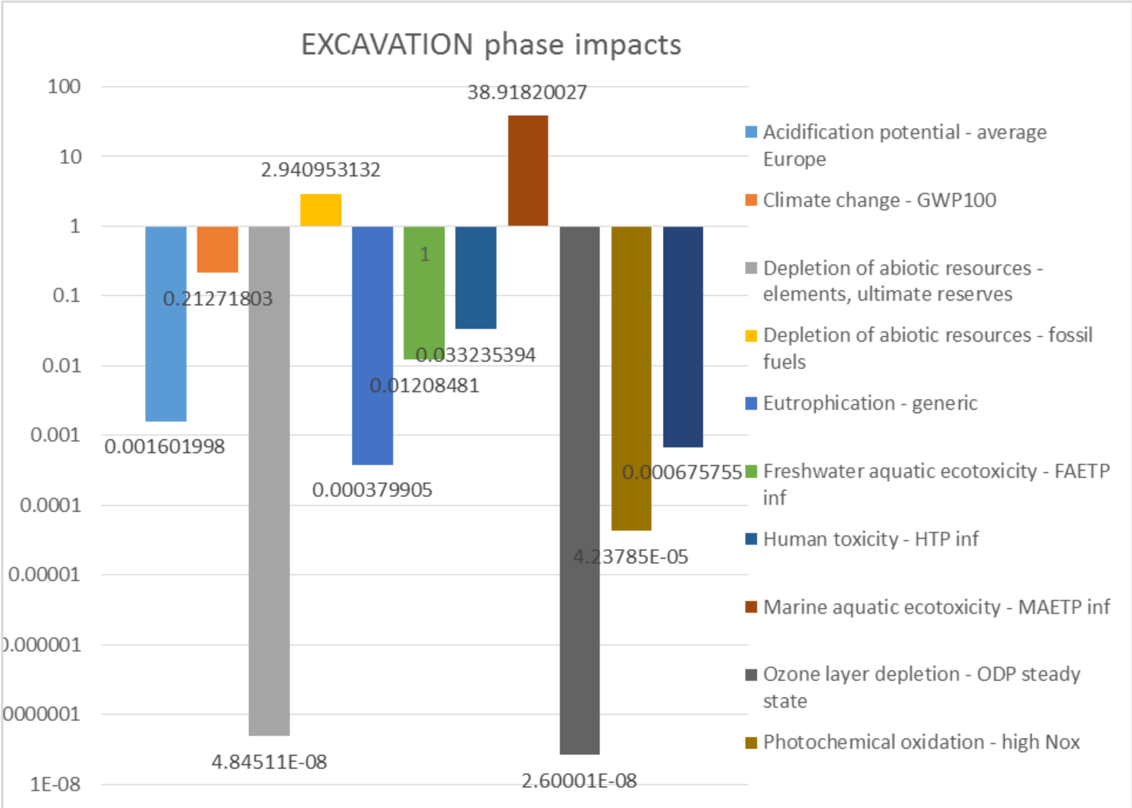

Figure (5.7): the environmental impacts results of excavation phase for PHES

Fig.5.8 shows the environmental impacts during the five phases of the life of PHES. It seems that the production Phase contributes to the bulk of the damages. End of life phase and maintenance also contribute significantly in the system's life cycle impact. Therefore, the mass of the PHES's components plays an important role in its life cycle. Excavation phases does not contribute significantly as the case in previous phases with the exception of their impact on the Marine aquatic eco-toxicity, which somewhat looks big. The impact of Transportation phase almost non-exist compared with the other phases.

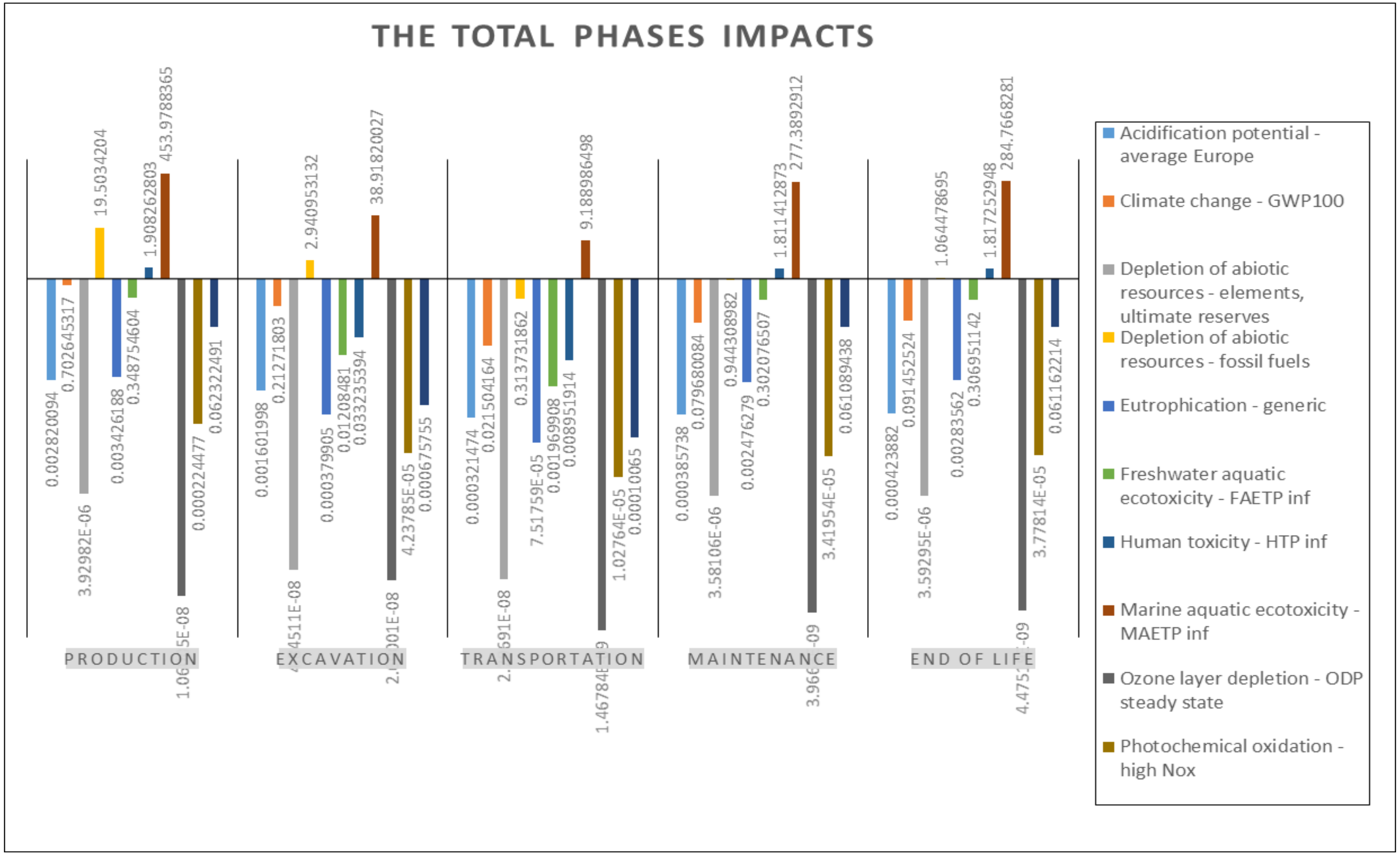

Figure (5.8): Comparison between the impacts of all phase in PHES life

5.7 Comparison between Pumped hydro and lead acid battery energy storage systems.

To determine if the Hydro pumped energy storage system is of a value over other storage systems, the LCA of this system must be compared to another storage system which can store the same quantity of energy required; 362 kW in 10 hours. One of these systems is the batteries. Literature review offered many studies of LCA for batteries, and the results shows that lead-acid batteries have the lowest cradle-to-gate production energy, fewest carbon dioxide and pollutant emissions, while other batteries have higher values in all three categories (Sullivan, & Gaines, 2012).

For this reason, a comparison between the PHES system with the lead acid battery. Will be carried out. Mainly the production stage of PHES will be considered as it has highest environmental impact.

The comparison is based on the results of this study and a study that was published in (Diyala Journal of Engineering Sciences, 02, June 2016) which entitled GATE" LIFE CYCLE ANALYSIS OF BABEL LEAD ACID BATTERY (Kassir et al., 2015).

Lead acid battery of 135Ah capacity is investigated according to International Organization for Standardization (ISO)14040 framework for LCA, to identify the four major contributors to the environmental impacts; Eutrophication, Global Warming, Human Toxicity, Acidification (Kassir et al., 2015).

The goal of the study has to explore the potential environmental impact of Babel Lead acid battery and highlight the processes where the hotspots of environmental impact occur, while scope definition involves specifying the Functional Unit (FU), which has “delivering electricity throughout a chemical reaction with an energy storage capacity of 135Ah which corresponds to the weight of (29.207) kg (Kassir et al., 2015).

The number of batteries needed for store 362 kW in 10 hours, for 50 years:

$\frac{362\ kW \times 10\ h}{135\ Ah \times 12\ V/_{1000}} \times \frac{50\ years}{10\ years}$ =11,173 battery for the whole system.

5.7.1 Environmental impact comparison results:

In this section, comparison of the environmental impacts for Lead acid battery (capacity of 135Ah) throughout the production processes and pumped hydro energy storage system, according to the ISO (14040-14043) series of standards. The impact assessment method employed was; the Centre of Environmental Studies (CML–midpoint). Software is used to process the collected data. The comparison was focused on four potential environmental impact categories. These are: [Global Warming Potential (GWP), Acidification, Eutrophication, and Human toxicity].

Environmental impacts of lead acid battery production and PHES system are given in table 5.11.

Table (5.11): Environmental impacts of lead acid battery production and PHES system.

Impact category	Reference unit per F.U	result of PHES F.U=1MJ.1day.	result of Lead acid battery F.U=29.207 kg.
Acidification potential	kg SO_2 eq.	2.82E-03	2.15E-01
Climate change	kg CO_2 eq.	7.03E-01	1.34E+02
Eutrophication	kg PO^{-4}_4 eq.	3.43E-03	2.08E-03
Human toxicity	kg1,4-dichlorobenzene eq.	1.91E+00	4.14E-01

A unified functional unit for the two system should be used for a valid comparison, the function unit of lead acid battery, as per the literature, is 29.207 kg.

If the impact category multiplied by (326,330 kg) -which is the weights of 11,173 batteries-, the impact will definitely in (kg equivalents).

Global Warming: $\frac{134\ kg\ CO2\ eq.}{F.U}$ × 326,330 kg =43,728,220 kg CO_2 eq.

Acidification : $\frac{0.215\ kg\ SO2\ eq.}{F.U}$ × 326,330 kg = 70,160.95 kg SO_2 eq.

Eutrophication :$\frac{0.00208\ kg\ PO4\ eq.}{F.U}$ × 326,330 kg =678.7664 kg PO_4 eq.

Human Toxicity: $\frac{0.414\ \text{kg 1,4-dichlorobenzene eq}}{F.U}$× 326,330 kg = 135,100 kg 1,4-dichlorobenzene eq.

For pumped hydro energy storage system (PHES), the Functional unit as default is

237,834 MJ. 1day.

Global Warming: $\frac{0.702645\ kg\ CO_2\ eq.}{F.U}$ ×237834 MJ.1day = 167,112.8 kg CO_2 eq.

Acidification : $\frac{0.00282\ kg\ SO_2\ eq.}{F.U}$× 237834 MJ.1day = 670.69 kg SO_2 eq.

Eutrophication :$\frac{0.00208\ kg\ PO_4\ eq.}{F.U}$ ×237834 MJ.1day= 814.819 kg PO_4 eq.

Human Toxicity:$\frac{1.908263\ kg 1{,}4-diclorobenzene\ eq.}{F.U}$ × 237834 MJ.1day = 453849 kg 1,4-dichlorobenzene eq.

The results for the two system after a unified functional unit summarized in the following figure 5.9.

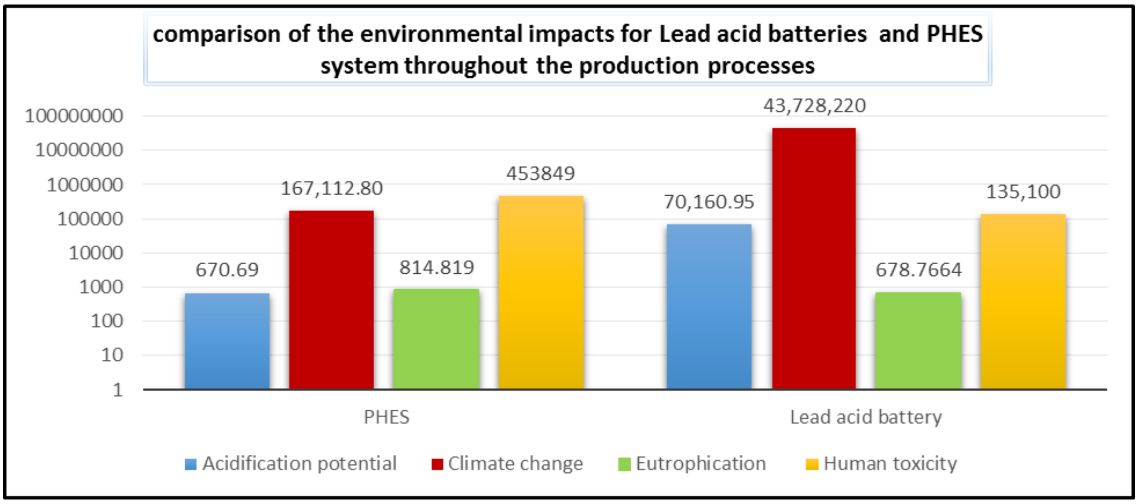

Figure (5.9): the comparison of the environmental impacts for lead acid batteries and PHES system throught the production process

The results for comparison analysis (figure 5.9) show the great differences in GWP and acidification impact categories between the two storage systems in the production phase. The reason for that is a Lead oxide emissions result from the discharge of air used in the lead oxide production process.

The greatest global warming impact occurred mainly as a result of using lead in manufacturing.

The impact was found to be the result of using energy in the extraction, smelting and purification at the first stage of manufacturing process. The acidification impact was caused from the manufacture of pure lead and lead alloy where both of them had an effect akin to that on global warming (PREMRUDEE et al., 2013).

For the Eutrophication and Human Toxicity impact categories, the PHES effects higher. This is due to the manufacturing steel that include nickel

(Cempel, &Nikel, 2006) that significantly effects in human toxicity and eutrophication as explained previously.

5.7.2 The Economic analysis comparison:

Pumped hydro energy storage system is an interesting venture if the capital cost for the entire life of the system is economically feasible. Therefore we must compare the total cost of the system with the other system. In this study, the PHES is compared with lead acid battery storage system.

Based on actual project in Palestine, The cost of one battery:

170 $\frac{\$}{kWh}$× 1.62 kWh= 275.4 $\frac{\$}{battery}$;(135 A.12V =1.62 kWh for one battery).

The cost of the whole batteries in the storage system for 50 years =275.4 $\frac{\$}{battery}$×11,173 batteries = 3,077,044.2 $.

Based on the analysis performed in section 5.4 capital cost of the PHES was 651765.4 $. While it was 3,077,044.2 $ for Battery storage system

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Chapter Six

Conclusions and Recommendations

6. 1 Conclusions

In this study a pumped hydro energy storage system was designed for western waste water treatment plant in deir sharaf-nablus. By studying the geographical location of the plant, the elevation and availability of water in addition to the available unused area were among the factors that give enormous opportunity to use this type of storage system (PHES).

The final design consists of two water storage reservoirs with a capacity of 24000 m^3 for each. Water transfers between them through a pipe of 310 meter in length. The most important element in this storage system is the turbine which depends on the height difference between the reservoirs and the water flow rate. The most appropriate option for the PHES in this study was found to be a Francis turbine of 563 kW.

After finishing the design, a life cycle assessment was applied for evaluation the system (PHES), which divided into five phases, based on CML-baseline method.

The LCA of this system was compared to another storage system (Batteries) which stored the same quantity of energy required. Based on ISO14040 used CML base line method.

For PHES phases, it was found that the Production phase has the highest environmental impacts, The next is the End of life phase and maintenance Phase.

The excavation phase and the transportation phase always had a negligible contribution. For this reason, only the production phase was chosen in comparison with LCA battery.

The results comparison between the production phases for the two system shows the higher impacts for climate change and acidification categories for the lead acid battery system in comparison with PHES.

On the other hand, the production phase in PHES has a higher contributor on the Eutrophication and Human Toxicity impact categories.

The economic study in this thesis was checked by using the present worth analysis. based on technical component's cost and life span for the two systems, the feasibility study result shows that the PHES system more economically feasible than lead acid battery storage, because present worth for PHES was estimated at 651765.4 $ with the same life time of batteries and the same energy storage quantity .

Annual worth value (65176.52 $) was used in this thesis to know the price of energy storage by PHES during the life time (50 years). In Palestine by use an easy way; AW will be divide on (5630 *365 kWh /year), so that the result will be 0.0317 $/kWh. This indicates that the PHES is very feasible as a storage system in Palestine compared with the cost and consumer prices of electricity in Palestine which reaches the average of 0.13 €/kWh. (0.14 $/kWh).

6.2 Recommendations

Based on the finding in this research, the following recommendations can be drawn:

1- Western waste water treatment plant for Nablus city was taken as the case study for this research. Since there are a lot of such plants in west bank it is recommended to study the technical and feasibility of applying such systems in other waste water treatment plants.

2- The most of energy in wastewater treatment plant is consumed by the aerobic digestion which requires to pump large quantities of air through the wastewater.

Therefore, compressed air storage system could be a good choice for wastewater treatment. So its recommended to study such systems where is no need to recover the stored energy as electrical energy but the compressed air can be used directly for the aeration process.

3- During this study, there was a lack of information regarding the inventory of Francis turbine, so it’s recommended to perform a detailed study of life cycle assessment of hydro turbines in general and particularly the Francis turbine.

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Appendices

APPENDIX A

A. comparison table for electrical energy storage

Energy storage system	Advantages	Dis advantages	Power rating	Storage time
Pumped storage hydro plant technologies	1. Fast respond on turning on turbines.	1. Requirement of large volume of water resources	100-5000 MW	Hours to months
	2. Rapid response to offset generation variability	2. Requirement considerable amount of land and with specific type of		
	3. Store energy output during lower value periods	3. conditions		
	4. Prevent wind curtailment and avoid new transmission investments	4. Construction of reservoirs and dams is resources intensive and		
	5. “Shape” prices by optimizing schedules of wind output and storage	5. expensive		
	6. Allows for better integration of renewable into the system	6. Is highly dependent of location, can’t be constructed anywhere.		
	7. Opportunities of utilizing energy/power storage as solutions for			
	8. ensuring a constant output of energy from renewable production			
	9. sources as wind, solar and others			
	10. Expand reserve capacity to protect the system of load conditions where			
	11. Faults cause load excess.			
	12. Low operation and maintenance requirements			
CAES	CAES is its large capacity.	low round-trip efficiency and geographic limitation of locations.	5-300 MW	Hours to months

flywheels	1. Low maintenance and	1. High acquisition costs	0-250 KW	Second to minutes
	2. Long lifespan: up to 20 years.	2. Low storage capacity.		
	3. Almost no carbon emissions.	3. High self-discharge (3 –20 percent per hour).		
	4. Fast response times.			
	5. No toxic components.			
Lead acid battery	1. Easy and therefore cheap to produce	1. Very heavy and bulky.	< 50 MW	
	2. Mature technology, more than 150 years of experience and development.	2. Rather short lived.		
	3. Very high surge-to-weight-ratio; capable of delivering a high jolt of electricity at once, which is why they are as suitable as car starters.	5. Cannot be stored in a discharged condition.		
	4. Easily recyclable.	3. Environmental concerns: although pretty safe, lead is very toxic and exposure can cause severe damage to people and animals.		
		4. Corrosion caused by the chemical reactions.		
		5. Low energy density — poor weight-to-energy density limits use to stationary and wheeled applications.		
Lithium Ion battery	1. Highest energy density in commercial available batteries with huge potential	1. Very expensive	< 1MW	
	2. Provides higher voltages per cell (3.7V compared to 2.0V for lead-acid)	2. Complete discharge destroys the cells		
	3. Low energy loss: only about 5 percent per month	3. Deteriorates even if unused (Lifecycle of about 5 years)		
	4. Lithium and graphite as resources are available in large amounts	4. Lithium is flammable in contact with atmospheric moisture		

	5. Relatively low self-discharge — self-discharge is less than half that of NiCd and NiMH.			
	6. 6. Low Maintenance — no periodic discharge is needed; no memory			
Nickel cadmium batteries	1. high energy density (50–75 Wh/kg),	1. Relatively high cost (_$1000/kWh) due to the expensive manufacturing process.	< 50 MW	
	2. a robust reliability	2. Cadmium is a toxic heavy metal hence posing issues associated with the disposal of NiCd batteries.		
	3. Very low maintenance requirements.	3. High maintenance — battery requires regular full discharge to prevent crystalline formation		
Sodium sulphur	1. Very high energy density.	1. The NaS battery needs to operate at a high temperature (300_350 _C).	< 10 MW	Hours up to 3,000 cycles
	2. Excellent cycle life,	2. Initial capital cost is another issue (_$2000/kW and _$350/kWh).		
	3. Low-cost materials,			
	4. High efficiency.			
ZEBRA	1. High energy density (5 times higher than Lead acid)	1. low energy density (_120Wh/kg)	5-500 Kw	
	2. Large cells (up to 500Ah) possible	2. .power density (_150 W/kg).		
	3. Cycle life better than 1000 cycles	3. only one company, the Beta R&D (UK), in the world produces this kind of battery		
	4. Tolerant of short circuits			
	5. Safer than Sodium Sulfur cells			
	6. Typical cell failure is short circuit which does not cause complete failure of the battery.			

	7. Low cost materials			
Vanadium redox battery (VRB)	1. High energy efficiency.	1. 1.The power density and energy density of RFBs are low	< 3 MW	
	2. Short response time.	2. require the most cells (each cell has a voltage of 1.2 V) in order to obtain the same power output as other flow batteries.		
	3. Long cycle life.	3. VR batteries are very complicated in relation to conventional batteries, as they require much more parts (such as pumps, sensors, control units) while providing similar characteristics.		
	4. Independently tunable power rating energy capacity.			
	5. do not have the issue of cross-mixing of positive and negative electrolytes			
	6. (Unique versatility, specifically their MW power and storage capacity potential).			
Zinc bromine battery (ZnBr battery)	1. low cost and wide availability of the active materials	1. not fully developed for commercial applications yet, probably because of its high self-discharge rate	< 1 MW	
	2. highest energy density of all flow battery	2. (100% discharge).		
	3. cell voltage 1.8v	3. Low energy density.		
		4. low efficiency.		
Polysulphide bromide battery (PSB).	High power capacity; long life time	1. During the chemical reaction small quantities of bromine, hydrogen, and sodium sulphate crystals are produced.	< 15 MW	
		2. Low energy density;		
		3. low efficiency		
Super Capacitors	1. High efficiency;	Low energy density; few power system applications Note: their energy density is still lower than that of	0-300 Kw	Sec-hours
	2. long life cycle			
	3. faster charge/discharge cycles(a unit can be			

	charged in about 10 seconds)	most batteries		
	4. higher power densities, and “are capable of cycling millions of times and are thus virtually maintenance free.			
Superconducting magnetic energy storage (SMES)	1. its great instantaneous efficiency	1.Low energy density;	0.1-10 MW	Minutes - hours
	2. Near 95% for a charge–discharge cycle.	2.high production cost;		
	3. Are capable of discharging the near totality of the stored energy, as opposed to batteries.	3.potential adverse health impact		
	4. Fast response time (under 100 ms) of these systems makes them ideal for regulating network stability (load levelling).			
Fuel cells—Hydrogen energy storage (FC–HES)	1. High efficiency	1. High cost due to expensive materials like platinum	0-50 MW	Hour - months
	2. Clean. Carbon free when using H2 and O2.	2. Requires fuel		
	3. Can use renewable fuels	3. Reliability still evolving.		
	4. Do not need recharging.	4. Durability, particularly at high temperatures.		
	5. Can run continuously (as long as fuel is available)	5. Robustness. Many are sensitive to temperature and contamination.		
	6. Provides base load power (good complement to renewables)	6. Hydrogen fuel not readily available		
	7. No moving parts	7. Little (but growing) infrastructure for hydrogen delivery		
	8. No noise	8. Safety concerns with hydrogen (though it is less dangerous than gasoline)		
	9. Certain types are well suited to CHP applications	9. Low density of fuel, compared to gasoline		

	10. Fuel can be made from water which is abundant or many other things 11. Highly scalable–cell phones to power plants. 12. Well suited for distributed generation, eliminating distribution losses. 13. Can be run in reverse for energy storage, producing hydrogen from electricity and water	10. Could become irrelevant if batteries got good enough		
TES.CPS.CHP	1. Reduced energy consumptions and carbon footprint. 2. Reduced initial equipment and maintenance costs. 3. Reduced pollutant emissions such as CO2. 4. Increased flexibility of operation, efficiency and effectiveness of equipment utilization. 5. Process application in portable and rechargeable way at the required temperature. 6. Isothermal and higher storage capacity per unit weight.	TES is large system requird to build the initial infrastructure.	0-60 Mw	Minutes to months

(Oberhofer, 2012 ; Chen et al., 2009 ; Ibrahim et al.,2008)

APPINDIX B

B.HDPE pipe dimension

HDPE pipe dimensions

SABS APPROVED 4427

Nominal Working Pressure HDS 5 mpa PE 63									(CLASS 6) PN 6.3				(CLASS) PN 8			
Nominal Working Pressure HDS 6.3mpa PE 80					(CLASS 6) PN 6.3				(CLASS) PN 8				(CLASS) PN 10			
Nominal Working Pressure HDS 8 mpa PE 100					(CLASS) PN 8				(CLASS) PN 10				(CLASS) PN 12.5			
Standard Diameter Ratio					SDR 21				SDR 17				SDR 13.6			
Norm Size mm	Mean Outside Diameter		Ovality Outside Dameter		Wall Thickness		Pipe ID & Mass		Wall Thickness		Pipe ID & Mass		Wall Thickness		Pipe ID & Mass	
	Min	Max	Min	Max	Min	Max	ID	Kg/m	Min	Max	ID	Kg/m	Min	Max	ID	Kg/m
16	16	16.3	15.55	16.75												
20	20	20.3	19.4	20.6									1.6	1.75	16.65	0.09
25	25	25,3	24,4	25,6					1,6	1,8	21,65	0,12	2,0	2,15	20,85	0,14
32	32	32,3	31,4	32,7	1,7	1,8	28,50	0,16	2,0	2,2	27,85	0,18	2,4	2,60	27,00	0,22
40	40	40,4	39,3	40,7	2,0	2,2	35,85	0,23	2,4	2,6	35,00	0,28	3,0	3,25	33,75	0,34
50	50	50.5	49.3	50.7	2.4	2.6	45.00	0.35	3.0	3.2	43.80	0.43	3.7	3.95	42.35	0.52
63	63	63.4	62.2	63.8	3.0	3.2	56.80	0.55	3.8	4.1	55.15	0.69	4.7	5.00	53.30	0.84
75	75	75.5	74.2	75.8	3.6	3.9	67.55	0.79	4.5	4.8	65.70	0.97	5.6	5.95	63.45	1.19
90	90	90.6	89.1	90.9	4.3	4.6	81.10	1.13	5.4	5.8	78.85	1.40	6.7	7.10	76.20	1.70
110	110	110,7	108,8	111,1	5,3	5,7	99,05	1,70	6,6	7,0	96,40	2,08	8,1	8,60	93,30	2,52
125	125	125,8	123,8	126,3	6,0	6,4	112,65	2,18	7,4	7,9	109,75	2,65	9,2	9,75	106,05	3,25
140	140	140,9	138,6	141,4	6,7	7,1	126,20	2,72	8,3	8,8	122,90	3,33	10,3	10,90	118,80	4,07
160	160	161.0	158.4	161.6	7.7	8.2	144.15	3.57	9.5	10.1	140.45	4.35	11.8	12.45	135.75	5.32
180	180	181.1	178.2	181.8	8.6	9.1	162.30	4.49	10.7	11.3	158.00	5.51	13.3	14.05	152.65	6.75
200	200	201.2	198.0	202.0	9.6	10.2	180.25	5.57	11.9	12.6	175.55	6.81	14.7	15.50	169.80	8.28
225	225	226.4	222.8	227.3	10.8	11.4	202.80	7.04	13.4	14.2	197.45	8.63	16.6	17.50	190.90	10.51
250	250	251,5	247,5	252,5	11,9	12,6	225,55	8,62	14,8	15,6	219,60	10,58	18,4	19,40	212,20	12,95
280	280	281,7	275,1	284,9	13,4	14,2	252,45	10,88	16,6	17,5	245,90	13,30	20,6	21,70	237,70	16,24
315	315	316,9	309,5	320,6	15,0	15,8	284,20	13,68	18,7	19,7	276,60	16,84	23,2	24,45	267,35	20,57
355	355	357.2	348.8	361.3	16.9	17.8	320.30	17.37	21.1	22.3	311.65	21.43	26.1	27.50	301.40	26.09
400	400	402.4	393.0	407.0	19.1	20.2	360.75	22.14	23.7	25.0	351.35	27.10	29.4	30.95	339.65	33.10
450	450	452.7	442.1	457.9	21.5	22.7	405.85	28.01	26.7	28.1	395.25	34.31	33.1	34.85	382.05	41.92
500	500	503.0	491.3	508.8	23.9	25.2	450.95	34.58	29.7	31.3	439.05	42.44	36.8	38.80	424.40	51.81
560	560	563,4	550,2	569,8	26,7	28,2	505,15	43,32	33,2	35,0	491,85	53,15	41,2	43,35	475,45	64,91
630	630	633,8	619,0	641,1	30,0	31,6	568,45	54,69	37,4	39,4	553,25	67,33	46,3	48,70	535,00	82,06
710	710	716,4	See Note		33,9	35,7	640,45	69,64	42,1	44,3	623,60	85,43	52,2	54,90	602,90	104,25
800	800	807,2	See Note		38,1	40,1	721,80	88,23	47,4	49,9	702,75	108,35	58,8	61,80	679,40	132,28
900	900	908.1	See Note		42.9	45.1	812.00	111.70	53.3	56.1	790.65	137.07	66.2	69.60	764.20	167.56
1000	1000	1009.0	See Note		47.7	50.2	902.15	138.00	59.3	62.4	878.35	169.41	72.5	76.20	851.30	204.10

APPINDIX C

C. Transportation Phase:

C.1 Turbine Transportation:

	Distance .Km	unit
Turbine transportation	70.95	km*kg

C.2 Sheet Transportation:

	Distance .Km	unit
Sheets transportation	1015.86	km*kg

C.3 Pipe Transportation:

	Distance .km	Unit
Pipe transportation	247.0194	km*kg

جامعة النجاح الوطنية

كلية الدراسات العليا

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إعداد

الاء محمود القب

اشراف

د .عبد الرحيم أبو الصفا

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة وترشيد الاستهلاك، بكلية الدراسات العليا، في جامعة النجاح الوطنية في نابلس- فلسطين.

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الملخص

التزايد المستمر في عدد سكان الكون والتطور الصناعي والتكنولوجي ادى الى ازدياد متسارع وملحوظ في استخدام الطاقة. وعليه توجب البحث عن طرق لتوليد الطاقة من اجل تخفيف استهلاك الوقود المسبب لتلوث البيئة .

انظمة الطاقة النظيفة ذات طبيعة متقطعة ويتحتم استخدامها بشكل مثالي الى انظمة تخزين، انظمة تخزين الطاقة لها اهمية ايضا لتخفيف احمال الكهرباء في اوقات الذروة.

تهدف هذه الدراسة الي تصميم نظام تخزين طاقة هيدروكهربائي خاص بمحطة معالجة المياه العادمة الغربية في مدينة نابلس– دير شرف، حيث تمتاز محطات تنقية المياه بالاستهلاك العالي للكهرباء تستهلك محطة التنقية في نابلس – دير شرف ما يقارب 2,261,762 kWh في السنه وقد تم تصميم نظام التخزين ليقوم بتخزين طاقة خلال ساعات النهار(10 ساعات) وتزويد المحطة بالطاقة ليلا لمدة (14 ساعه).

ويتطلب ذلك وجود خزانين علوي وسفلي بسعة 24000 متر مكعب للخزان الواحد، بالإضافة الى انبوب بلاستيكي بطول 310 متر وقطر خارجي 630 مليمتر؛ والعنصر الاساسي في هذا النظام هو توربين منعكس (حيث يقوم بعمل المضخة والتوربين حسب الحاجة) بقدرة 563 كيلو وات .

ولمعرفة اثار هذا النظام التخزينية على البيئة وتكلفته، اخترنا ان ندرس دورة الحياه لهذا النظام باستخدام اسلوب جامعة ليدن، حيث يتم تقسيم الأثار البيئية المترتبة الى 10 أثار رئيسية .تطرقت الدراسة كذلك إلى حساب التكلفة الإجمالية للنظام ومقارنته بنظام تخزين اخر الا وهو بطاريات الرصاص الحمضية.

ولتحليل دورة حياة نظام تخزين الطاقة الكهرومائية تم تقسيم مرحلة حياة النظام الي خمس مراحل هي مرحلة الحفر، مرحلة الانتاج، مرحلة النقل، مرحلة الصيانه و مرحلة التخلص او التدوير. ومن ثم تقييم أثر كل مرحله لها. وفقا لهيكلية المنظمه الدولية للمعايير (الايزو 14040). باستخدام برنامج openLCA.

وبعد دراسة هذه النظام عن طريق دورة الحياة تبين لنا النتائج التالية:

ان مرحله الانتاج ومرحلة التخلص تعتبر الاكثر اثرا على البيئه، ويتبع ذلك مرحلة الصيانة. بينما مرحلتي النقل والحفر فهي تكاد ان تكون معدومة مقارنة بما ذكر من مراحل.

اما من ناحية التكلفة الاقتصادية فان تكلفة المشروع الإنشائية قدرت ب (651765.4$). وتم حساب ايضا التكلفة السنوية للمشروع على مدى خمسين عاما –عمر النظام المفترض–ومن خلالها تم حساب سعر kWh لنجد انها تساوي (0.0317 $/kWh).

ومن ناحية اخرى قد تمت المقارنة بين نظام التخزين الكهرومائي ونظام بطاريات الرصاص الحامضية.

ولقد اشارت النتائج بان نظام تخزين الطاقة الكهرومائية هو الاقل تكلفة خلال فترة حياته بواقع (651765.4$) بينما تكلفة البطاريات خلال نفس فترة الحياة تقدر ب (3,077,044.2 $).

اما من ناحية الاثار البيئيه فتمت مقارنة الاثار فقط في مرحلة الانتاج لكلا النظامين نظرا لما لهذه المرحلة من اثرا واضح على البيئة.– واستندت المقارنة هنا ايضا وفقا للمنظمة الدولية للمعايير–.

حيث تبين بمقارنة دورة حياة كل من النظامين في مرحلة الانتاج: ان نظام الطاقة الكهرومائية اقل أثر في فئة الاختباس الحراري ((global warming potential وفئة الامطار الحمضية(Acidification). بينما سجلت نسبة اعلى في تأثيرها على البيئه في فئة سمية الانسان (human toxicity) مقارنه بنظيرتها بطاريات الرصاص الحامضية.

ومن هنا فان انظمة تخزين الطاقة هي انظمة مكملة لنظام الطاقة المتجددة لإمدادها بالاستمرارية طوال النهار والليل .

ومن دراستنا هذه نستنتج ان نظام تخزين الطاقة الكهرومائي نظام مفيد ومجدي اقتصاديا لمحطة دير شرف نابلس حيث يسد احتياجاتها للطاقة الكهربائية . ونظرا لتوفر العوامل الجغرافيه (المساحه والارتفاع والماء) فان هذا خيار مناسب لدعم تخزين الطاقة المتجددة في هذه المحطة . وكما انه صديق للبيئة لما له ن اثر قليل في عملية الاحتباس الحراري.

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