TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Industrial Engineering and Management

FEASIBILITY STUDY OF RENEWABLE ENERGY SOLUTIONS FOR FACTORIES

TAASTUVENERGEETIKA LAHENDUSTE OTSTARBEKUS TÖÖSTUSETTEVÕTETELE

MASTER THESIS

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Student code: 215462 MARM

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Tallinn 2023

(*On the reverse side of title page*)

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Hereby I declare, that I have written this thesis independently.

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THESIS TASK

Student: Syed Fakhir Ali 215462MARM

Study programme, main speciality: MARM06/18, Industrial Engineering and Management

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Thesis topic:

Implementation of renewable energy solution in textile industry due to energy crisis

Taastuvenergeetika lahenduste otstarbekus tööstusettevõtetele

Thesis main objectives:

1. To carryout a detailed overview of renewable energy solutions
2. Suggesting a renewable energy source to adopt
3. Calculating the energy output with the specific renewable energy source

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Technology overview, company overview	28.02.2023
2.	Current state analysis	15.03.2023
3.	Proposal for energy source	14.04.2023
4.	Energy output calculations, financial analysis and summary	05.05.2023

Language: English **Deadline for submission of thesis:** "22" May 2023

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PREFACE

The topic of this thesis came directly from the company named Ebrahim Textile Mills, located in Karachi, Pakistan. All of the suggestions made in this thesis were based on research available so that the best solution can be proposed.

I would like to thank Tallinn University of Technology for providing me the opportunity to study here and Mr. Meelis Pohlak for his continuous support and guidance throughout my thesis work. Secondly, Mr. Kristo Karjust for his consultation during entire study period. I want to dedicate my thesis to my late mother Mrs Rehana Sajid, who passed away in 2017 due to cancer. Since, living in Estonia far away from family is hard, my friend Syed Shahid Musvi always motivated me like a brother in tough times and with his continuous support I am able to complete graduation on time.

This thesis provides feasibility study of renewable energy sources for houses and small scale factories among wind, biomass and thermal energy sources. Wind energy is suggested in the light of literature and available resources. Based on this thesis ETM is going to make a trial with 10kW wind turbine on roof top and stand out in the market of Pakistan and also setting an example for other companies to adopt the same approach.

Keywords: renewable energy, wind energy, risk analysis, wind potential, master thesis

LIST OF ABBREVIATIONS AND SYMBOLS

GHG- Green House Gases

ETM- Ebrahim Textile Mills

RES- Renewable Energy Solutions

RE- Renewable energy

AEMO- Australian Energy Market Operator

CSIRO- Australia’s National Science Agency

HAWT- Horizontal Axis wind turbine

VAWT- Vertical axis wind turbine

PV- Photovoltaic

AC- Alternating current

DC- Direct current

KW- Kilo Watt

KWh- Kilo watt hours

MWh- Megawatt hour

PWh- Peta watt hours

LCOE- Levelized cost of energy

1 INTRODUCTION

The main objective of the thesis is to assess different renewable energy solutions for the production of electricity for small and medium-sized industries due to the hike in the price of electricity in Pakistan. For this purpose, Ebrahim Textile Mills based in Karachi, Pakistan, has offered this topic and based on this thesis conclusion they are planned for implementation of a renewable energy source. Moreover, a detailed solution will also be proposed in general for companies across the globe having same environmental and meteorological conditions who are willing to use renewable energy as possible energy source rather using fossil fuels. Solar energy is not considered as part of the study beside being the cheapest option as they have already installed in 2022 and generating 250 kW from it.

In this era, according to several economists energy plays role of a backbone in economic growth. It is not only part of economic growth but now considered as a way towards sustainable development [1]. Currently, renewable energy has become the hot topic for people as well as the subject matter experts across the globe. More and more studies have been developed pertaining to renewable energy sources. Being considered as clean energy sources and overcome the challenges of fossil fuel depletion and global warming people are also focused towards it and willing to make investment for electricity generation [2].

Globally, the textile market is valued at USD 1,032.1 billion (2022) with an anticipated forecast of USD 1,420.3 billion (2030). Analysis shows that demand for textiles is increasing with a growth rate of 4% by 2030 due to an increase in fashion trends and the development of e-commerce platforms [3]. In this context, industries require more energy to fulfill the demands of customers. With the passage of time, the world population is growing, causing a direct impact on demand for energy. Relying on fossil fuels creates problems such as reductions in fuel reserves, emissions of greenhouse gases (GHG), and hikes in fuel prices [4]. Unfortunately, catastrophic policies opted in the past led to different energy crises in Pakistan [5]. Pakistan's total energy supply is primarily based on the use of fossil fuels (75%), with renewable energy accounting for 22% and nuclear accounting for the remaining 3% [6]. According to FY 2022, there has been a decline of 0.6% in the industrial sector as compared to FY 2021, i.e. 7.8%[7]. Study shows that 98% fluctuation in the textile sector is observed due to the energy crisis, hike in prices, and rate of interest, which leads to a decrease in growth rate [8] but still, this sector has a lot of potential and provides opportunities for millions of people to work in this sector [7].

Currently, in Pakistan, the industrial sector accounts for 27.7% of electricity consumption [9], due to which there is a dire need for companies to transform themselves towards renewable solutions or their own electricity generation solutions to decrease dependency on furnace oil-generated electricity and move towards sustainable energy solutions to cause less impact on the environment as per the United Nations Development Goals. Moving towards renewable energy solutions will lead to a reduction of GHG, water scarcity, and affordable energy for consumers all over the globe [10].

2 COMPANY OVERVIEW

2.1 History

Orient Textile Mills Private Ltd. was established in 2000 and has three diverse business activities, including textiles, dairy, and crown corks. In textiles, there are two business units, namely Ebrahim Textile Mills and Orient Textile Mills. Ebrahim Textile Mills started operations in 2012 with a state-of-the-art wet processing facility with a capacity of 5 million meters per month and a stitching facility with a capacity of 1.5 million pieces per month. Ebrahim Textiles has been involved in the production of fabric for several years, beginning with cotton and ending with the finished product. They called themselves a one-stop solution in the textile industry, having customers throughout the globe. They are standouts in the Pakistani market because of their huge warehousing and production capacities, higher quality, and continuous investments in different projects [11].

2.2 Location

As previously stated, Orient Textile is a subsidiary of Ebrahim Textile Mills, which is located in Karachi, 4.54 kilometers (air to air) as shown in Fig 2.1 from the nearest seaport. Landhi is considered pioneers in industrial areas in Karachi and was established in 1949, soon after the independence of Pakistan. Industries such as glass, polymers, and textile manufacturing are the major ones in this area [12].

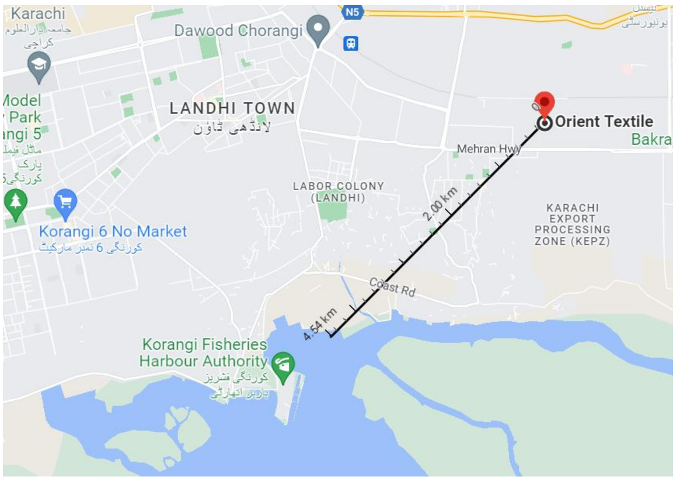


Figure 2.1 Distance from sea to ETM

2.3 Production Process

Ebrahim Textile is currently manufacturing bed sheets, comforters, curtains, quilt covers, and apparel. The process starts with grain folding, then goes through various operations before finally ending up in the warehouse. Below fig 2.2 describes the process flow followed to carry out the production process in ETM and it is acquired from company documents.

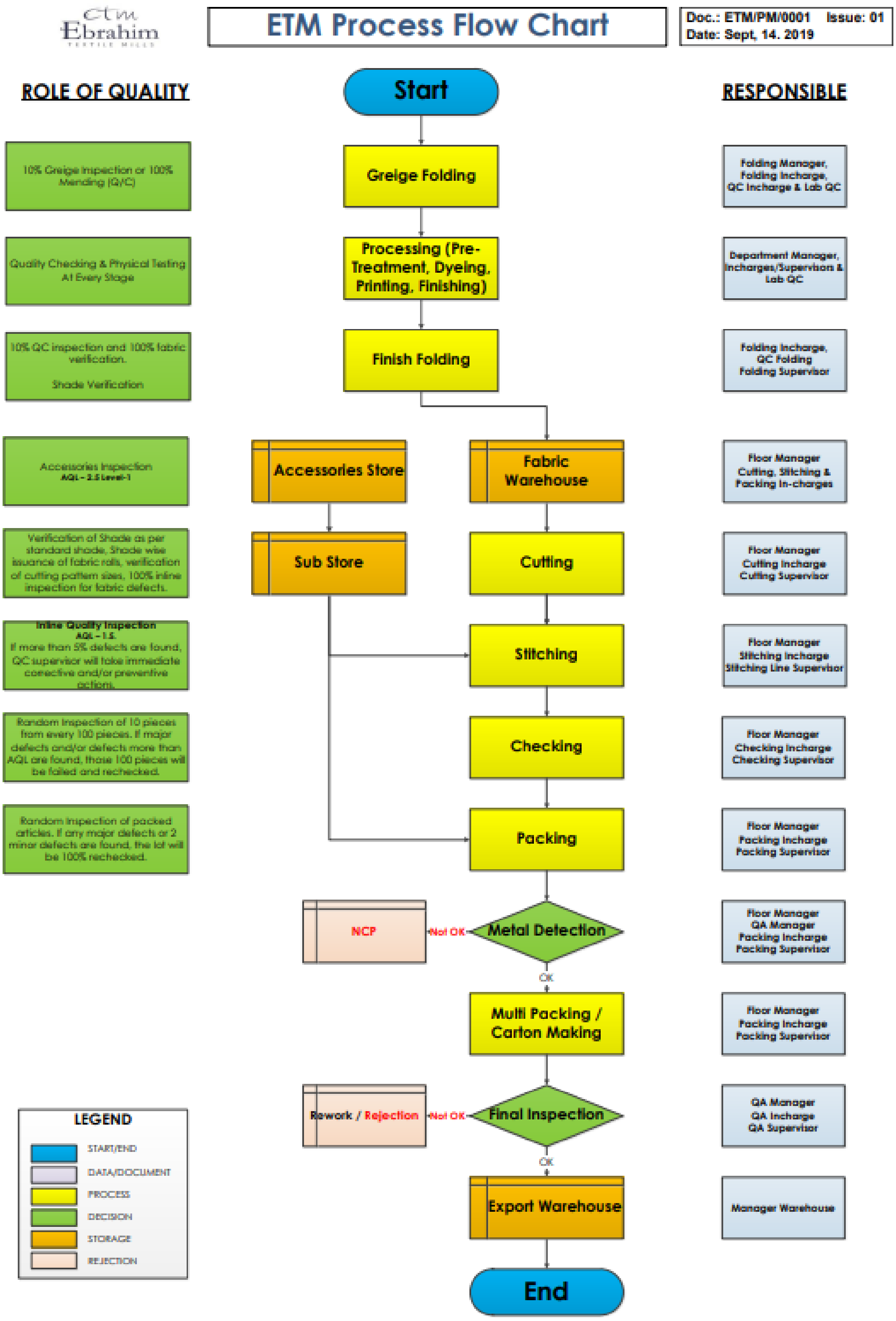


Figure 2.2 ETM Process Flow

The above operations are carried under a big production facility shown below in fig 2.3 to achieve maximum productivity of man, machine and material.

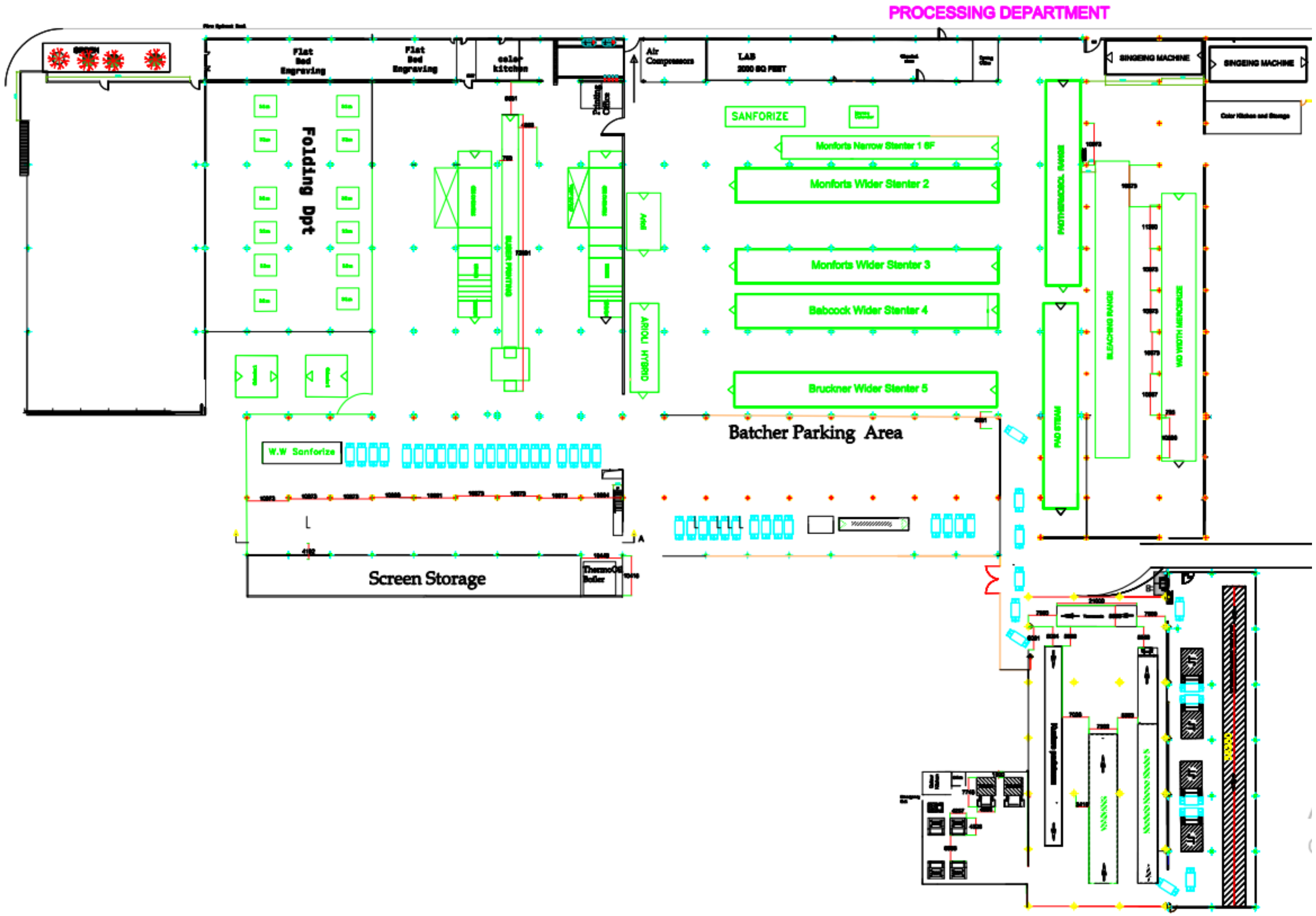


Figure 2.3 ETM production layout

2.4 ETM Energy consumption

Currently, is utilizing electricity and gas as an energy source to carry out production. Data taken from last year's electricity (fig 2.4) and gas bill (fig 2.5) reflects that ETM is consuming a massive amount of energy where there is a possibility to reduce and those costs can be utilized in reducing the amount of end product. The February 2023 electricity bill shows that total consumption was 1,347 KWh. However, these numbers are the lowest when compared to last year, when the highest number of units were consumed in August 2022, i.e., 6,089 KWh. Since most of the facility relies on gas, the gas bill is also accessed, where the numbers were even higher. The gas bill shows that in February 2023, 9,66,250 KWh were consumed. Upon interview, it was found that most of the production facility relies on steam, which requires the operation of a boiler and gas being supplied into it.

KE

Customer's Name: M/S EBRAHIM TEXTILE (PVT) LTD
Account Number: 0400009690180
Contract Number: 30555655

Please do not stamp on the bar code.

Invoice Number: 440014369251
Due Date: 23-Feb-23
Within Due Date: Rs. 146,980
After Due Date: Rs. 158,827

Bank Clearance / Signature

Your Current Bill Calculation آپ کے موجودہ بل کا حساب

Bill Charge Mode. NORM
Meter No. HTO-2618
Reading Date 07-Feb-23

The electricity you have used

	Previous Reading	Current Reading	MMF	Units (KWh)	MDI (KW)
Energy - Off Peak	913384	914347	1.000	963	2
Energy - Peak	190206	190590	1.000	384	2
Reactive Energy Off Peak	264796	264796	1.000	0	
Reactive Energy On Peak	58530	58530	1.000	0	

Your electricity charges for the period No. of Month(s): 1

	Units	Rate / Unit	Amount
Fixed Charges (kW)	**200.000**	**460**	**92,000.00**
Variable Charges			**35,269.11**
Off Peak	963.00	24.5300	23,622.39
On Peak	384.00	30.3300	11,646.72
Uniform Quarterly Adjustment ***			**5,985.25**
01-Nov-22 to 30-Nov-22	1343.58	4.4547	5,985.25
Fuel Charges Adjustment			**-14,783.01**
Dec-22	1369	-10.7984	-14,783.01
KE Charges			**118,471.35**
Electricity Duty			397.07
Sales Tax u/s 3(1)*			20,207.63
Income Tax U/S 235**			7,903.80
Government Charges			**28,508.50**
Your Electricity Charges for the Period			**146,979.85**

Customer Information صارف کی معلومات

Consumer No	BH000068	Sanc. Load	400
Account No	0400009690180	Conn. Load	400
Security Deposit	1156008.19	Tariff	B3-IH

Billing Statement بل کی تفصیل

Carry Forward Balance	**-0.37**
Payments/Adjustment	-178,434.00
Billing / Supplementary Bill ****	178,433.93
Your Electricity Charges for the Period	146,979.85
Outstanding Balance ****	**146,979.41**
Amount Payable within Due Date	**146,980**
Late Payment Surcharge	11,847.14
Amount Payable after Due Date	**158,827**

In case of any complaint, the consumers are advised to approach K-Electric in the first instance. If the complaint is not resolved, the consumers may file complaint at one of the following options:

NEPRA Regional Office, Karachi: Office No. 101, 1st Floor, Balad Trade Center, Block No. 3, Bahar Muslim Housing Society, Bahadarabad, Karachi.

OR

Consumer Affairs Department National Electric Power Regulatory Authority (NEPRA), Attaturk Avenue (East), Sector G-5/1, Islamabad.

EIK/POI Region-1 Mechanical & Soil Laboratory, Irrigation Building, Adjacent to City School PAF Chapter, Shaheed-e-Millat Road, Baloch Colony, Karachi.

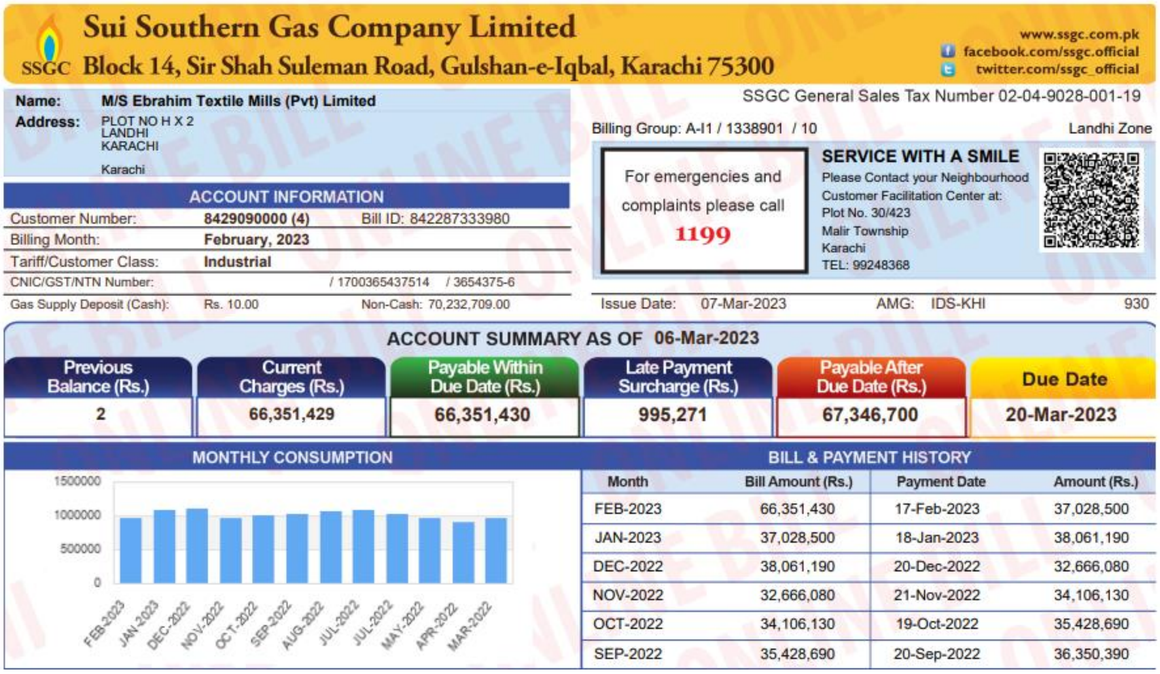
EIK/POI Region-2 Plot No. ST-02, Block-N, Main Sakhi Hasan Chowrangi, North Nazimabad, Karachi

EI/POI Hub, Balochistan Electric Inspectorate, Irrigation Building, Sakran Road, Hub, District Lasbela, Balochistan. Tel: 0853-310172

OR

Wafaqi Mohtasib (Federal Ombudsman) Wafaqi Mohtasib Secretariat, Block 4-B, Pakistan Secretariat, Saddar, Karachi
Website for online complaints: www.ombudsman.gov.pk www.mohtasib.gov.pk
Tel: 021-99202107
Fax: 021-99202121

Figure 2.4 Electricity Bill February 2023



Sui Southern Gas Company Limited
SSGC Block 14, Sir Shah Suleman Road, Gulshan-e-Iqbal, Karachi 75300

www.ssgc.com.pk
facebook.com/ssgc.official
twitter.com/ssgc_official

Name: M/S Ebrahim Textile Mills (Pvt) Limited
Address: PLOT NO H X 2
LANDHI
KARACHI
Karachi

SSGC General Sales Tax Number 02-04-9028-001-19
Billing Group: A-I1 / 1338901 / 10 Landhi Zone

For emergencies and complaints please call **1199**

SERVICE WITH A SMILE
Please Contact your Neighbourhood Customer Facilitation Center at:
Plot No. 30/423
Malir Township
Karachi
TEL: 99248368

ACCOUNT INFORMATION

Customer Number:	8429090000 (4)	Bill ID: 842287333980	
Billing Month:	February, 2023		
Tariff/Customer Class:	Industrial		
CNIC/GST/NTN Number:		/ 1700365437514	/ 3654375-6
Gas Supply Deposit (Cash):	Rs. 10.00	Non-Cash: 70,232,709.00	

Issue Date: 07-Mar-2023 AMG: IDS-KHI 930

ACCOUNT SUMMARY AS OF 06-Mar-2023

Previous Balance (Rs.)	Current Charges (Rs.)	Payable Within Due Date (Rs.)	Late Payment Surcharge (Rs.)	Payable After Due Date (Rs.)	Due Date
2	66,351,429	66,351,430	995,271	67,346,700	20-Mar-2023

MONTHLY CONSUMPTION

BILL & PAYMENT HISTORY

Month	Bill Amount (Rs.)	Payment Date	Amount (Rs.)
FEB-2023	66,351,430	17-Feb-2023	37,028,500
JAN-2023	37,028,500	18-Jan-2023	38,061,190
DEC-2022	38,061,190	20-Dec-2022	32,666,080
NOV-2022	32,666,080	21-Nov-2022	34,106,130
OCT-2022	34,106,130	19-Oct-2022	35,428,690
SEP-2022	35,428,690	20-Sep-2022	36,350,390

Figure 2.5 Gas Bill February 2023

2.5 Highlights of Solar Installation

In 2022, Ebrahim Textile Mills carried out the installation of a solar plant on the roof (fig 2.6) to generate electricity for industrial use, and due to their achievement, the United Nations Industrial Development Organization awarded them an award as the "Best Energy Performer" for sustainable energy initiatives for industries in Pakistan.

Figure 2.6 Solar units installed on roof top

Before the installation of the solar plant on the roof top, according to the data received, in the month of April 2021, total consumed units were 2,155,19 kWh (fig 2.7), which were the highest; however, in January 2021, they were the lowest, at 9,644 kWh.

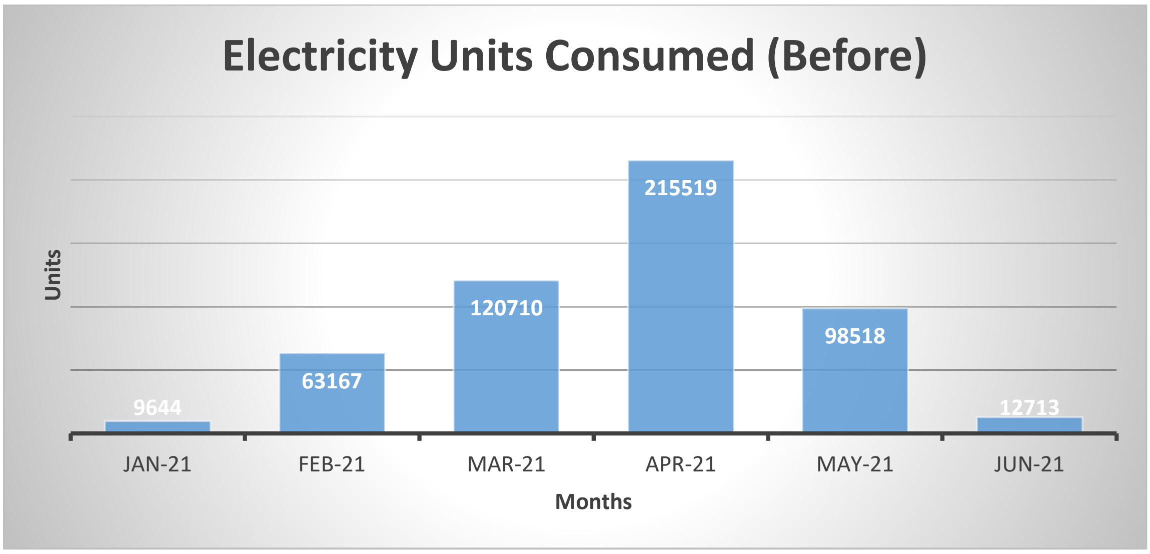


Figure 2.7 Electricity units consumed before solar installation

The project went well for ETM, as they are producing their own electricity, but a small amount is bought from the distribution company. Below fig 2.8 shows that now only 1,725 kWh were bought in the month of June 2022. However, it can seen that 7,085 kWh were consumed in June 2021 because the solar plant was operating at a lower efficiency at the time.

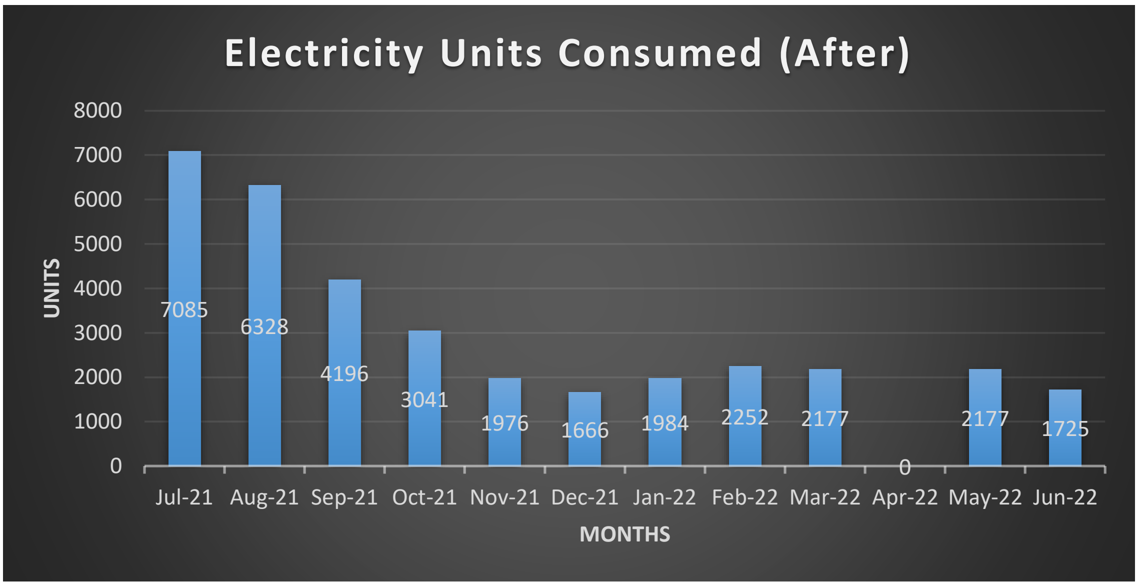


Figure 2.8 Electrcity units consumed after installtion of Solar

3 TECHNOLOGY OVERVIEW

Power and energy are two distinct terminologies, but they are often confused. Power can be defined as the amount of energy created or used. However, energy is the amount of work done or generated over time. Normally, residential or small generation facilities are measured in kW or watts; however, large generation facilities use MW [13]. Energy sources can be classified as fossil fuels, nuclear, and renewable energy sources.

Currently, methods for energy production using fossil fuels are causing a disastrous impact on the environment. Use of renewable energy can lower the impact, as research shows that it produces less carbon dioxide as compared to fossil fuels and nuclear energy [14]. By 2050 to reduce 80-95% green house gases, it is needed to improve energy efficiency [15].

3.1 Types of Renewable Energy

Renewable energy is a type of energy that is obtained from natural resources, e.g., the sun, wind, and water, or, in other words, from resources that cannot be exhausted. The most common types of renewable energy include

- Solar energy
- Wind energy
- Geothermal energy
- Hydro power energy
- Bio energy
- Ocean energy

3.1.1 Solar Energy

In solar energy, sunlight is transformed into electricity. Silicon is used to create photovoltaic cells, which convert sunlight into electricity. Normally, solar panels are installed on roof tops or on large fields close to residences or businesses. Solar farms also use mirrors to converge electricity and convert it for residential use. Solar energy is one of the least expensive RES and will grow at an exponential rate between 1992 and 2020.Solar cells were first developed in 1950, and since then many countries have used them, with the United States, China, Germany, and Japan being the top competitors at converting sunlight into electricity.

A solar PV panel consists of a DC/AC charge controller, battery, breaker, inverter, and power meter. PV panels produce DC output, which is managed by a charge controller and then stored in the battery. After storing energy in a battery, it is converted to AC using an inverter (fig 3.1). A power meter is normally used to monitor electricity flow. After installation of the plant, PVs are safe to use and there is no noise pollution, but toxic gases can be observed. PVs have a shorter payback time as compared to other REs, but they require more maintenance, such as cleaning due to dusty weather [16].

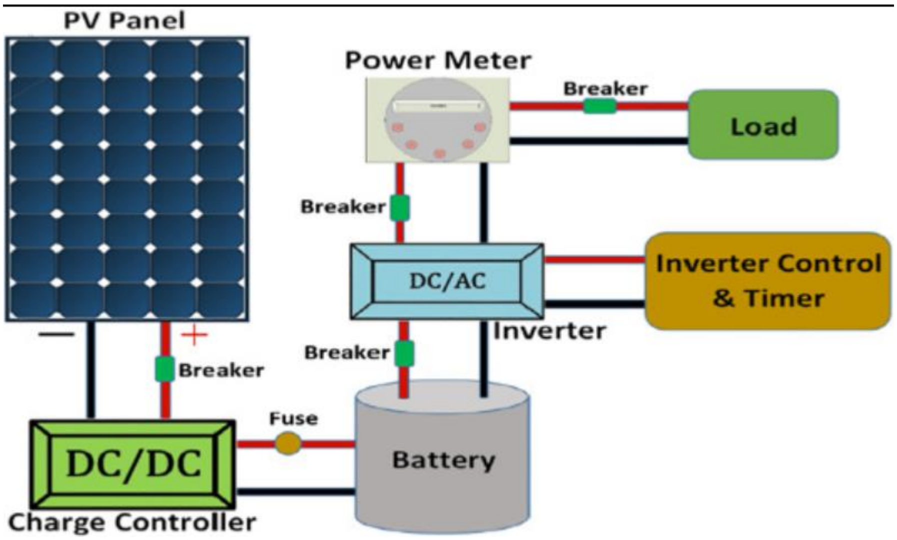


Figure 3.1 Schematic diagram of PV System [17]

There are three different types of PV’s availbale with differences in materials, manufacturing process and specifications [16].

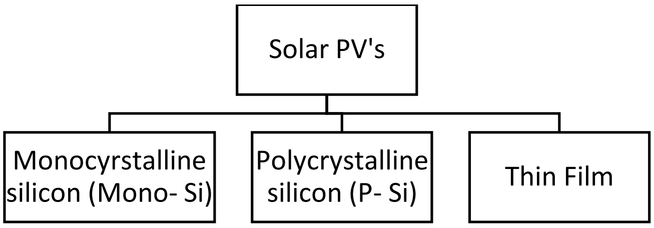


Figure 3.2 Types of PV

3.1.2 Wind Energy

In mid 1970’s NASA started working on wind turbines and developed 13 experimental wind turbines [18]. Normally, rotating a fan needs electricity, but in the case of a wind turbine, the working principle is the opposite, i.e., a rotating fan generates electricity. Wind spins the blades of the turbine, leading to the motor turning the generator and producing electricity. There are two basic types of wind turbines as shown in fig 3.3:

horizontal-axis and vertical-axis wind turbines. Horizontal wind turbines are fan-like blades that operate in the direction of the wind to generate energy. However, the vertical axis is an eggbeater-style Darrieus model invented by French scientist Georges Darrieus [19]

Figure 3.3 common type of turbines[19]

3.1.3 Geothermal Energy

In geothermal energy, thermal energy is taken from the crust of the earth. Geothermal reservoirs are heated using wells or reservoirs [20]. In geothermal resources, hot water reservoirs either made artificially or naturally under the earth are used for energy production [21]. The prerequisite for using geothermal energy is the availability of resources under the earth, i.e., geothermal resources are within seismic belts. Geothermal energy is one of the RES with low operating costs, less impact on the environment, and high reliability, but all of these things come with high installation costs and limited availability of reserves [22].

3.1.4 Hydro Power

Hydroelectric power is normally produced when water is transported from higher altitudes to lower altitudes. Major sources for generating hydropower are rivers, reservoirs, etc. Currently, hydropower is the largest source of renewable energy for electricity generation, as it is an environmentally friendly option and can be installed in remote locations. It is also a cheap solution to produce electricity as water is abundantly available, but the prerequisite must be a dam, river, canal, or flowing water on one side. In the United States, 31.5% of electricity is produced specifically from hydro, and 6.3% of total electricity generation [23]. Hydropower can be categorized on the basis of the output generated from it, i.e., large (>100 MW), medium (10–100 MW), small (1–10 MW), mini (100 KW–1 MW), micro (5–100 KW), and pico (5 KW). Since the availability of resources alone is not enough, an additional efficient system of generation is also important for that purpose. Generation depends upon head and flow, where head refers to the force per square area from where the water is flowing as elustrated in fig 3.4 and flow defines the rate at which water passes per unit time. Components used for generation include availability of water, penstock pipe, controller, turbine, distribution system, and load.

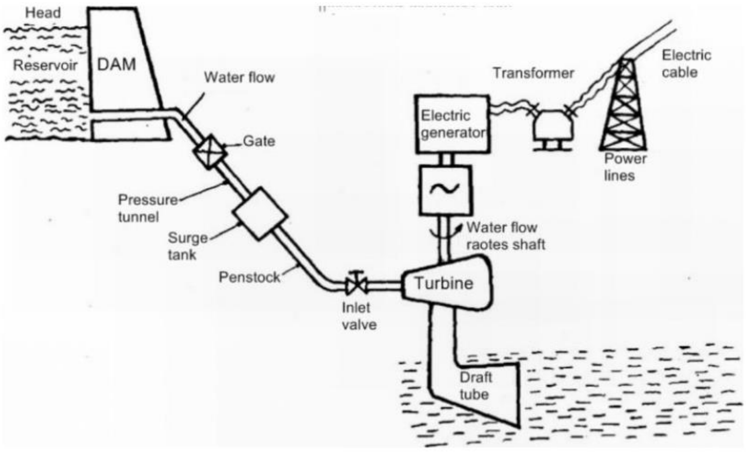


Figure 3.4 Schematic diagram of hydro power generation [24]

Above Schema 3.4, it is explained that, for the production of electricity, a dam is constructed after the reservoir. Water collects in the reservoir and reaches a certain height behind the dam. In this way, kinetic energy is converted into potential energy. Since, water is flowing from the dam (downward), and it is controlled by the help of the installed gate and flows through the penstock. Due to the high speed of the water flowing, it rotates a turbine. The turbine is connected to the generator through a shaft, which leads to drive the generator and produce electricity. But the installation costs of these have such a low rate of return. Secondly, projects estimated completion times are quite high—10 to 15 years—and ecological disturbance is also caused due to them [25].

3.1.5 Bio Energy

The remains of industrial waste, municipal waste, food crops, etc. can be used to produce bioenergy. Bioenergy can reduce Green House Gases (GHG) and also have the potential to reduce dependence on imported oil, landfills, etc [26]. Bioenergy is generally produced from crops, forest residues, wood energy crops, food waste, microalgae, etc. Energy can be extracted from these resources using three methods: burning, converting it to gas or liquid, or bacterial decay. This energy source can be used as a fuel for airplanes, traffic vehicles, the generation of electricity, and to generate heat [27]. Being widely used as an energy source, biomass energy has a direct impact on the economy as it creates employment opportunities for rural areas and reduces poverty in developing countries [28].

3.1.6 Ocean Energy

Earth consists of 70% oceans and is also called the world's largest powerhouse because energy is available and renewed anytime [29]. Ocean energy is considered one of the ample renewable energy sources, having the potential to produce 885 TWh of electricity annually [30]. Waves are created when wind passes over the ocean; the stronger the winds, the higher the waves that can be produced and the energy that can be harnessed through them [4]. There are four types of ocean energy technologies from which energy can be harnessed: wind, tides, waves, and thermal [31]. Out of these types, more focus has been given to tidal and wave technologies [32]. Winds are generated over oceans naturally, which produces waves, and due to the gravitational pull of the moon and sun, tides are produced. Turbines are used to generate electricity through the effect of wind on water surfaces, causing the turbine to rotate. The wave is initially transformed into mechanical energy and then converted to electrical energy [33].

3.2 Use of Energy Globally

The use of renewable energy depends on local resources being available and assessing the technology before installation so that the right solution can be proposed before making high investments. Different options are available in the market for transforming to renewable energy solutions depending upon city dynamics and geography. Wind, wave, solar, and geothermal are the most common solutions proposed [34].

According to the US Energy Information Administration, in 2021, the whole world consumed 177.02 petawatt hours (PWh) of energy against the generated energy of 177.84 PWh, but only 2.14 PWh were obtained from renewable energy, with China being the top contender in utilizing renewables as marked in Figure 3.5. In terms of only electricity, 7.802 PWh have been produced using renewables [35].

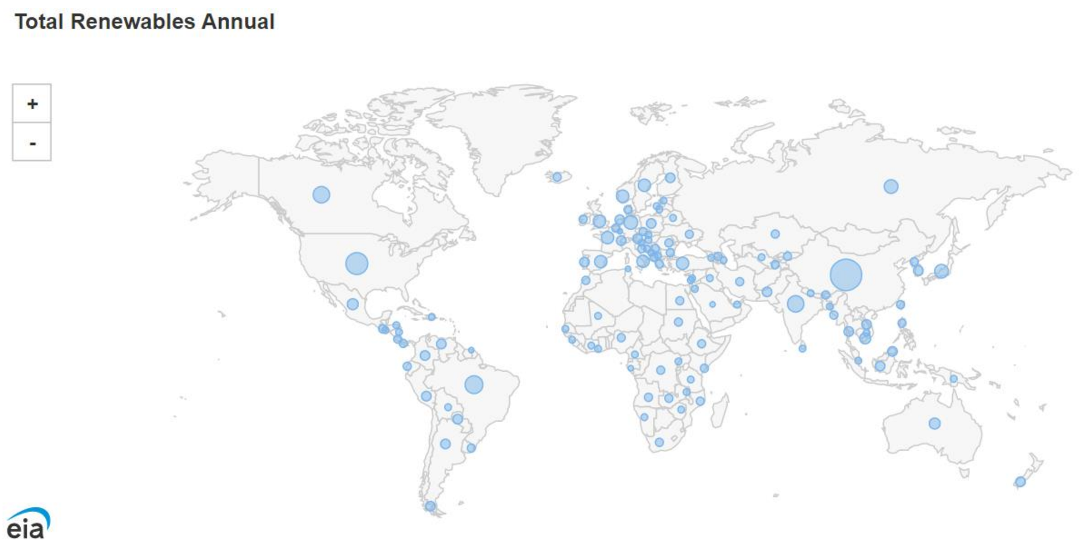


Figure 3.5 Countries using renewables (EIA)

According to the BNEF report, from 1970 to 2017, fossil fuels contributed the most to generation, but by 2050, this will decrease by 31%, and the use of renewable energy solutions will increase to 62%, with solar and wind accounting for 48% [36].

3.3 Selection of renewable energy alternative

There are certain factors on which the selection of a renewable energy source usually depends, which includes [37]

1. Economic: depends upon R & D, operation maintenance, installation cost, generation cost
2. Technical: depends upon available technical resources, reliability, efficiency, resources, deployment time
3. Environmental: Stress on the Eco system, land requirement
4. Social: social benefits such as job creation
5. Political: National energy security

Data acquired from a literature review shows that for urban environments, ocean and hydro are not good options because the resources are unavailable or significant changes to the layout of the city are needed to acquire this type of energy, and ETM is also not ready to face those challenges. The remaining three options—wind, biomass, and geothermal—can be considered as these resources can be found. Since, according to the geographical location of Pakistan, it lies on tectonic plates, there is a possibility of geothermal energy according to some research, but as of date, no experiment has been carried out specifically in Karachi to ensure the presence of geothermal energy. Wind and biomass could be good options, but ETM is a textile-based company, and textile leftovers cannot be used as an energy source. Either they need to buy the biomass or establish a plant to acquire this type of energy. Below table 3.1 is the weighted scoring model that has been used to further analyze some factors to make the decision-making process more efficient.

		Raw scores			**Weighted Score**		
Factors	**Weight**	**Wind**	**Biomass**	**Geo**	**Wind**	**Biomass**	**Geo**
Available resources	30%	10	0	5	3	0	1.5
Cost	20%	8	6	8	1.6	1.2	1.6
Energy demand	15%	10	10	0	1.5	1.5	0
Sustainable	15%	10	8	10	1.5	1.2	1.5
Environmental impact	5%	8	7	9	0.4	0.35	0.45
Reliability	10%	9	8	10	0.9	0.8	1
Legal	5%	10	10	10	0.5	0.5	0.5
	1				**9.4**	**5.55**	**6.55**

Table 3.1 Weighted score model of renewable resources

The European Wind Energy Association shared the opinion of the public (table 3.2) towards renewable energy solutions, and below are the results, which equate to the fact that, with the EU as a hub of industrialization, Pakistan can also replicate these numbers to come out of the electricity crisis.

Power plant Type	Public opinion
Solar photovoltaic	80%
Solar thermal	80%
Wind	71%
Biomass	55%

Table 3.2 Public opinion towards renewable

Above data also shows less interest in biomass due to its lack of green energy, hazardous impact on the environment, and high price for processing [38]. Secondly, CSIRO and AEMO made a cost comparison with respect to generation costs in Australia, and the results show that the cheapest solution will be either wind or solar PV [39]. Based on the above results, the feasibility of wind energy installation for industries to install onshore wind turbines to produce electricity for industrial use will be assessed

4 WIND ENERGY

Wind energy is the abundantly available resource being used by more than 80 countries throughout the world with increase in growth on competitive cost [40]. According to Global wind energy council (GWEC) in 2021 more than three times volume of wind turbine has been installed as compared to 2020 with 850GW of installations worldwide. IRENA and IEA predicts 8000GW more capacity of energy by 2050 which seems central pillar of global energy system but still there is a shortfall of two third wind energy capacity by 2030 required for 1.5°C and net zero pathway [41].

Wind turbine operates on the principle of converting kinetic energy into electrical energy considering the fact like costless wind, pollution free environment and large distributions [42]. For this purpose, considerations must be made to have adequate choice wind turbine for best economical, efficient and energy results [43]. Another important factor to consider is geographic location including distance to roads, energy infrastructures and economic activities [44].

Wind is one of the natural resources which is abundantly available in Pakistan, Karachi is blessed with this resource and located on the coast line of Pakistan with a possibility to install wind turbine and generate electricity. As wind is the cheapest and cleanest solution to produce electricity according to IEA there is a possibility to install onshore wind turbines and electricity can be generated for residential and industrial use.

4.1 Important factors in site selection

Before installation of wind turbine several factors must be considered to ensure succesful installation. The aim to carryout efficient and eco system with less impact on environment. Site is also important as durability of wind tubines on average is 20 years and it is quite expensive to make these investments and get higher return on investment [45].

4.1.1 Environmental

Environmental impact plays a vital role in the installaion of wind power plant. It is recommended to consider limitation of forests, governmental zones, wild life [46]. Secondly while turbine is running it produces noice pollution causing the impact on people’s health and scaring wild life [47]. Whenever installing wind turbine loaction must be selected having less impact on environment.

4.1.2 Location

Second factor is analyse location where plant needs to be installed. In this regard distance to main roads, rail roads, ports, urban areas, substations, power lines must be considered to carryout smooth logistics process for machinery and lowering the cost of project. Moreover, If the distance will be shorter from power grids less energy will be lost and connection cost will also be lower [48].

4.1.3 Economic

Economics is the backbone of any project while carrying out feasibility analysis construction cost, cost of land, skilled labor, operation and maintenance, government support must be considered to carryout efficient utilization of resources. Often, it has been seen that natural disasters cause direct impact on operation. For that purpose cost should be estimated before carryout installation [48].

4.1.4 Meteorological

Meteorological factor point towards area where there is potential of available wind speed, direction and density. For carrying out calculation of four factors must be calculated:

1) Wind speed-rate at which the wind moving towards a location. Normally it is calculated in m/s by taking an annual average of available winds [49] [50]. Research shows that different seasons are having different speed of wind [51].

2) Wind density-For evaluating the availability of wind energy in a certain area, wind speed and density are combined indicators [52]. It is the density of wind energy above the surface on a yearly average. It calculates the kinetic energy of the wind per square meter for a specific period of time (W/m) [53].

3) Wind hours- it defines the total number of hours of effective wind is produced in a year, measured in hours [50].

4) Turbulence leads to direct impact on performance of wind turbine, decreasing production and even disastrous to generators [52] in this regard turbulence must be less than the load on generator [54].

4.1.5 Orographic

Geological and topographic characteristics of a site are included in the orographic category. While selecting a location for wind farms, slope, geographical direction, soil roughness, plant elevation and geological suitability must be considered [48].

4.1.6 Society

Society plays an important role in terms of acceptance. Before installing public acceptance, electricity demand, employment opportunities, stroboscopic effect must be taken into account to benefit society [48].

4.2 Potential for wind installation in Karachi

According to a feasibility analysis [55] made along the coast line of Pakistan, Karachi (Zone 1) seems to have more potential as compared to Ormara, Pasni and Gawadar. Study reveals that in summer, winter, autumn and spring average 6.7m/s, 3.1m/s, 5.5m/s and 4.4m/s wind speeds were observed. Below table 4.1 shows the seasonal months of Pakistan.

Summer	May, June and July
Winter	November, December and January
Autumn	August, September, October
Spring	February, March, April

Table 4.1 Seasonal months of Pakistan

4.3 Types of wind turbines

Since wind turbine installation totally depends on available resources and the factors discussed above, Currently, there are two types of wind turbines: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). Further, VAWT can be divided into two types: Savonius and Darrieus. The Darrieus model comes in three shapes, namely the Darrieus rotor, the H-darrieus, and the H-shape as presented below in fig 4.1 and 4.2.

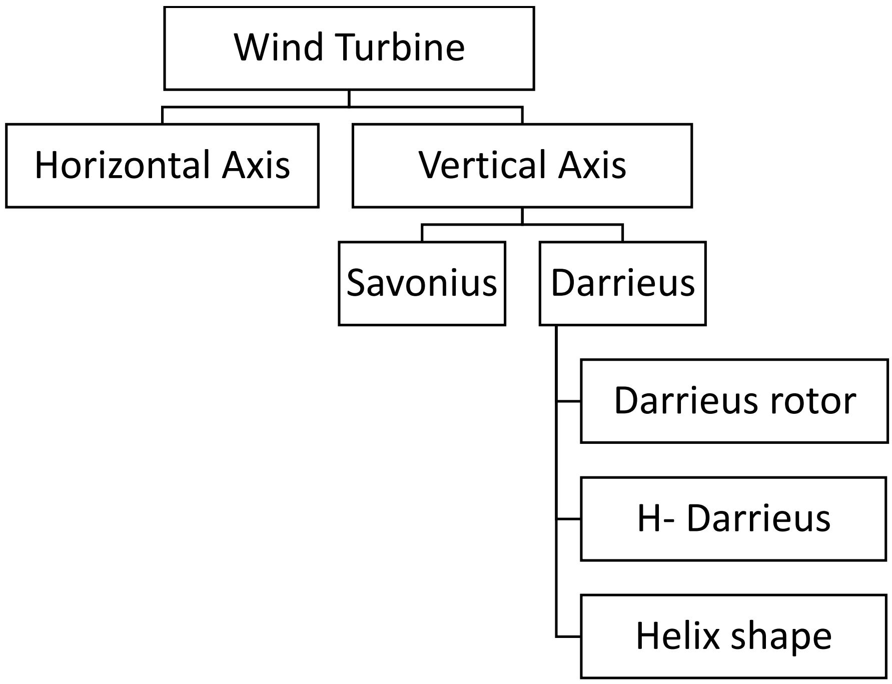


Figure 4.1 Types of wind turbine

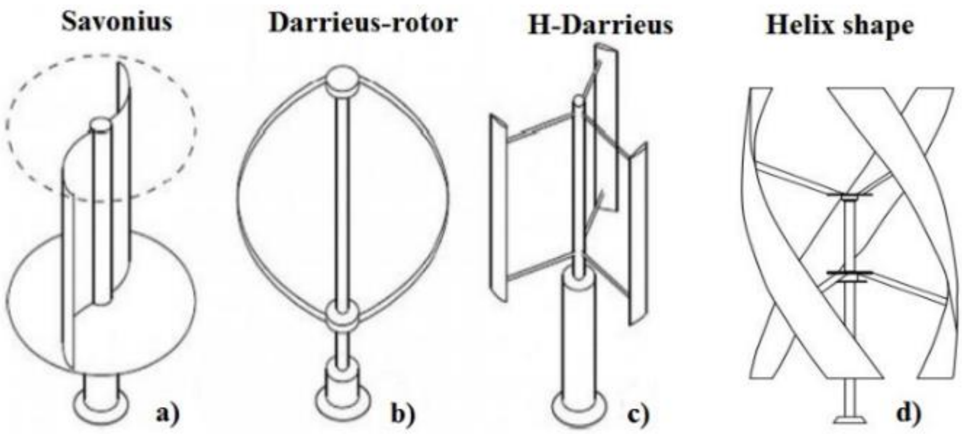


Figure 4.2 Types of vertical axis wind turbine[56]

HAWT is the most popular type of wind turbine as they are more efficient than VAWT. Three blades face the wind perpendicularly, by which aerodynamic lift is generated under consistent wind. However, this model has a significant disadvantage in that it must always be pointed in the direction of the wind. If the wind is turbulent and the direction of the wind keeps changing, then the efficiency will be lower [57].

HAWT is a conventional type of wind turbine normally used offshore or onshore to generate energy. Normally, more recognition is given to HAWT, as people think they are more efficient than VAWT. But a recent study shows that VAWTs are more efficient in urban installations because of unique design and potential benefits over HAWT. Moreover, VAWTs are preferred due to their lower noise, no need to change the direction as the wind direction changes, and effectiveness in turbulent or distributed winds.

Savonius-type wind turbines use drag force to rotate the vertical shaft and generate power with the available wind. Savonius types have various advantages, such as their simple design, low installation and maintenance costs, less impact on urban areas, independence from wind direction, and ability to generate high torque. Despite having several advantages, the efficiency of Savonius turbines is lower than that of other conventional types. For that reason, Savonius turbines are normally preferred for very small-scale generation.

The Darrieus type uses lift force to rotate the vertical shaft in all shapes. In comparison to the Savonius model, the Darrieus is more efficient due to its high rotational speed but has less torque. Since there are advantages and disadvantages to both HAWT and VAWT, as research shows, the results are varied. But depending on the resources and factors available, a model can be chosen to seek the best possible results [57]. Below table 4.2 is the analysis carried out between HAWT and VAWT using the factor rating model in the urban area where the plant location lies.

Evaluating Factors	**Factor Rating**	**HAWT**	**Product Factor**	**VAWT**	**Product Factor**
Environmental	7	3	21	5	35
Location	6	4	24	4	24
Economic	8	5	40	4	32
Meteorological	9	3	27	5	45
Orographic	4	3	12	3	12
Society	3	5	15	3	9
Sum			**139**		**157**

Table 4.2 Factor rating model between HAWT and VAWT

Above analysis shows that on the basis of the factors provided, VAWT would be the best option to install in Karachi. Since noise pollution will be less as compared to HAWT, less space is required, and climatic conditions suit VAWT, but economically, VAWT will be costly, and skills will need to be developed among people to overcome issues if faced in operational use. But in the end, it can be said that VAWT will be more efficient than HAWT as per the factors analyzed. Lastly, among all types of vertical axis wind turbine H type can be choosen due to ability to generate energy on smaller scale, low noise and finally having characterstick of operation in turbulent winds.

4.4 Wind Rose

The wind direction is one of the most important factors in wind farm positioning. The wind direction is substantially influenced by the geographical characteristics of the study region and the movement of the atmosphere; as a result, wind direction variation may be seen. A wind rose diagram is a helpful diagram that combines an illustration of wind direction, wind speed, and frequency [58]. The below wind rose diagram (fig 4.3) shows that in Karachi, most of the wind blows from the south-west (54.7%), with heavy winds observed from March until September. Data shows that from May until August, the wind blows at a speed of 28 km/hr for more than 10 days in a month, while the rest of the days it blows at a speed of 19 km/hr. While rest of the month, wind speed lies between 12 and 19 km/hr.

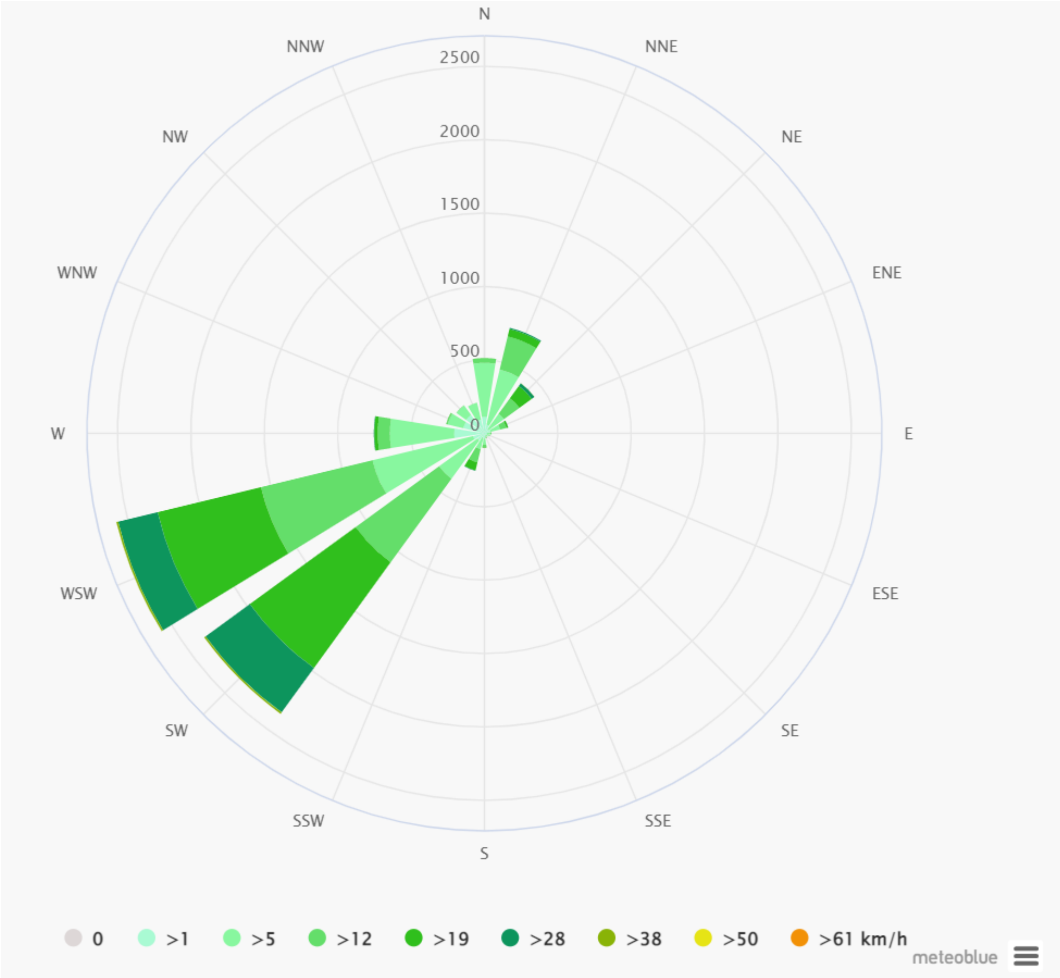


Figure 4.3 Wind rose diagram of Karachi [59]

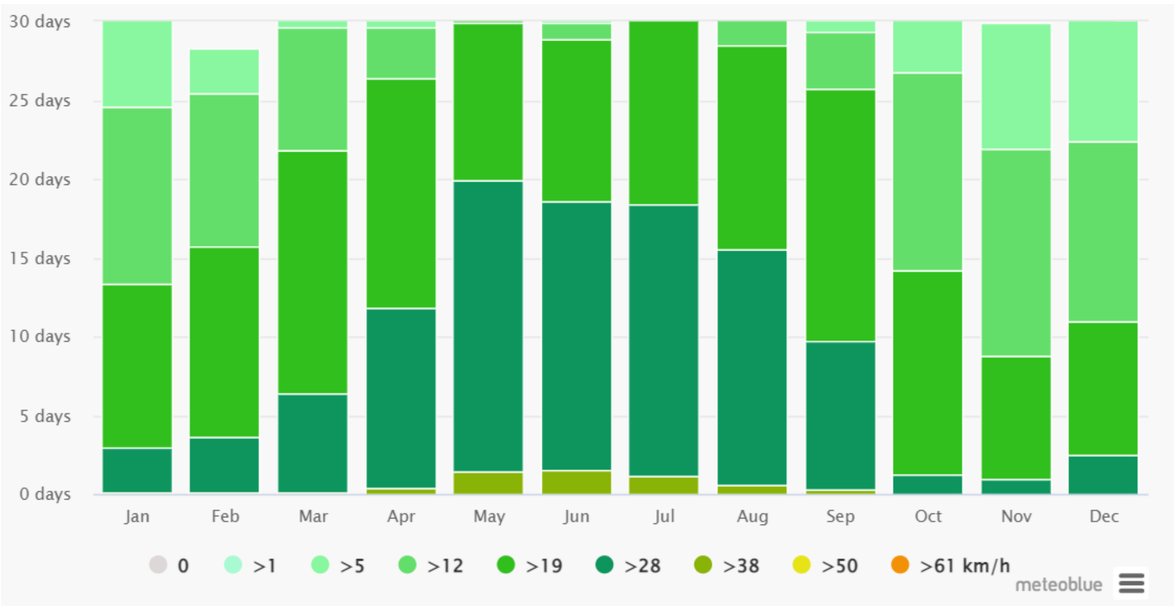


Figure 4.4 Wind speed with respect to months [59]

Force	Strength	km/h	Effect
0	Calm	0-1	If smoke will generate it will go upwards
1	Blaze wind	1-5	Smoke drifts slowly
2	Light wind	6-11	Wind feels on human body
3	Gentle wind	12-19	Small branches of trees move
4	Moderate wind	20-29	Dust moves and feels in air
5	Fresh wind	30-39	Movement of small trees
6	Strong wind	40-50	Large tree branches move

Table 4.3 Wind classification

4.5 ETM and Energy Department

From literature review and data sources some power generation approaches are easier to implement than the others. In case of ETM they first went for easiest and cheapest solution on the basis of resources available i.e Solar. But before implementing any of the renewable energy solution, one should make a longer plan what is the order of implementation, e.g. first solar, then wind, next biogas, etc. And all implementation plans should consider the possibility of adding next level later (so after solar panels it would be possible to install also wind turbines into the same system and even onto the same roof).

Currently, as per point 1.1.4 of the electricity bill, it can be seen that 1,348 units (KWh) have been bought from the electricity-providing company at a cost of 1,46,980 rupees, which is almost equivalent to 500 € a month. As per inflation and other economic factors in Pakistan, the cost of electricity is increasing, and the government is putting more taxation and fuel adjustment charges in electricity bills, which is causing a burden on companies to operate. As per the meeting held with ETM, ETM is willing to install the proposed wind turbine as a trial for any effective result to eliminate dependency on an electricity provider and set an example for other industries to move towards sustainable solutions. Upon searching for possibilities where installation can be carried out, different options were explored, including on the ground and roof. The roof-top option seems to be more effective as compared to ground due to less hindrance in wind due to infrastructure. For this purpose, a dedicated energy department is working on possibilities and a pre-study for installation on a roof-top pillar. Since there are challenges, they are still searching for possibilities to make things happen that can reduce the cost of energy in ETM. Below is the roof-top layout of ETM, where installation can be carried out for wind turbines. Since the roof layout (fig 4.5 and 4.6) is taken from ETM, the total area shown is in millimetres.

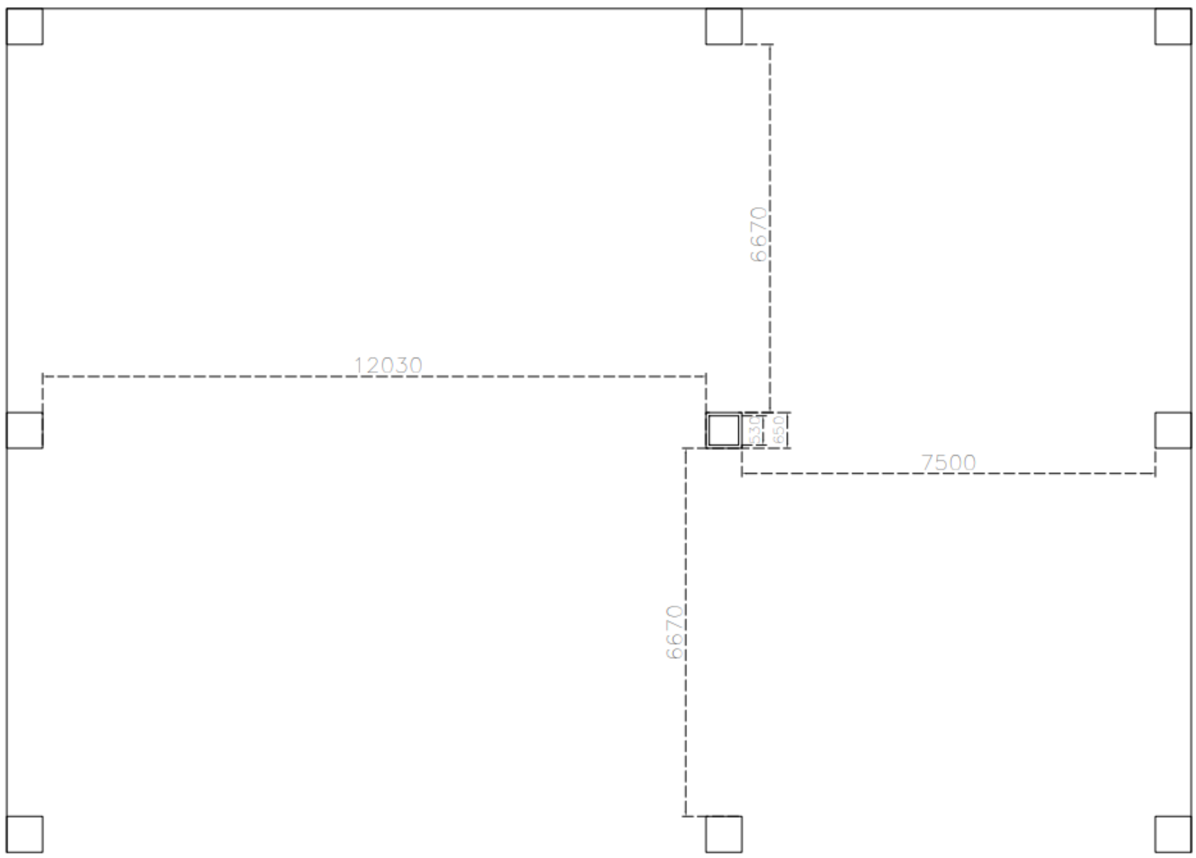


Figure 4.5 Roof top layout

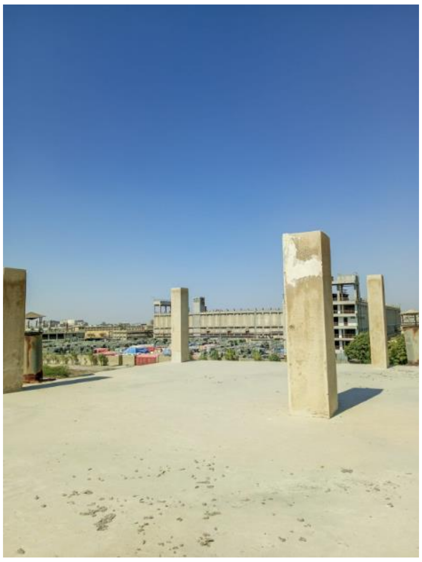


Figure 4.6 View of roof top

Karachi is situated 10 meters above sea level, and the height of buildings where installation can be carried out is 11 meters. To make it more efficient, according to research data collected at a height of 10 m, a pillar can be constructed, and installation can be carried out. Below is the schematic diagram of the pillar as shown in fig 4.7.

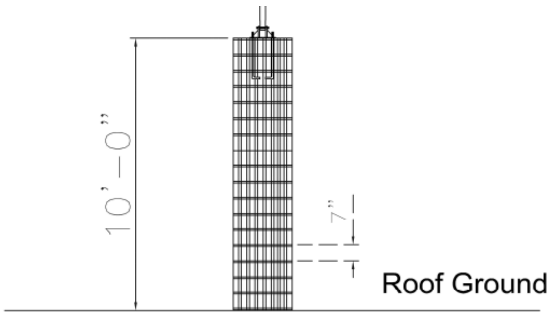


Figure 4.7 Proposed installation plan on pillar

5 RISK ANALYSIS ON BUILDING

The installation of a vertical axis wind turbine (VAWT) on a roof can have several risks on the building, including:

5.1 Structural considerations

The weight and size of the wind turbine need to be considered in relation to the building's structure. The roof and the building's support structure should be able to handle the additional weight and forces imposed by the wind turbine. Vibration is the most important factor while installing roof top wind turbine as they may cause impact on people working in the facility and weakens the structure with the peiod of time. There are three factors needs to be considered before installation

- Wind turbine itself is the source of vibration
- Mounting system can cause vibration in structure
- Act of building itself

According to a reseach [60] am experiement was made with 3 blades rotating at an speed of 250 rev/min. Accelerometer were installed on flat and H frame with wind conditions of 6m/s. Following results (fig 5.1) were obtained which shows negligible impact in terms of vibrations.

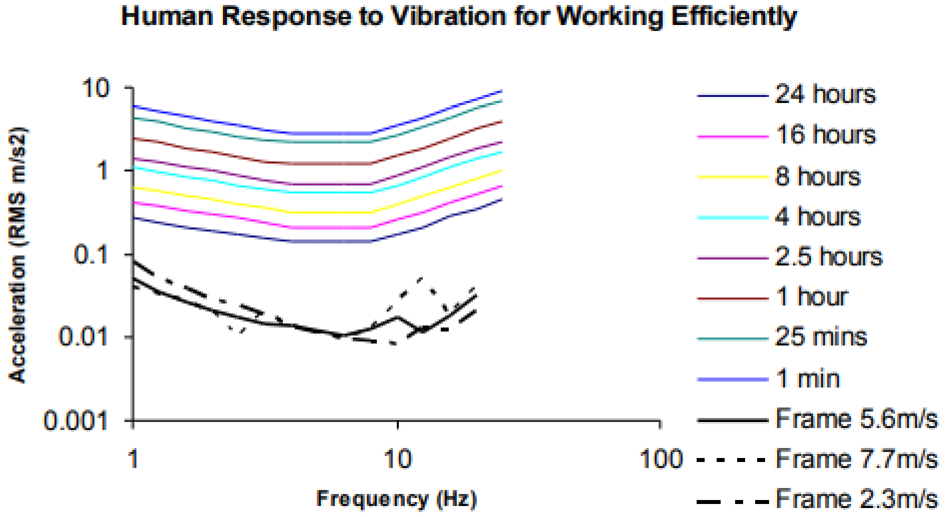


Figure 5.1 Vibration response

But precautionary measures can be taken such as installing damper between mount and turbine, making structural analysis, avoid installing turbine on corners or edges, contruction of foundation and mounting system and regular inspection will be made to avoid any disastor. From above data it can be assumed that vertical axis wind turbines causes less impact on building structure if these precautionary measures will be taken into account. Moreover, before installing a wind turbine on a roof, it is important to consult with a structural engineer locally and other experts to evaluate the feasibility and potential impacts of the installation on roof and building.

5.2 Noise and vibration

VAWTs can produce some noise and vibration during operation, which may affect the building's occupants. The level of noise and vibration can depend on the design and quality of the wind turbine, as well as the wind speed and direction. But in our case turbine needs to be installed in industrial areas where factories are running almost 24/7 and no habitant living in homes causing impact on lives.

5.3 Wind loading

The wind turbine can increase the wind loading on the building and the roof, which can affect the structural integrity and stability of the building. This can be particularly important in areas with high wind speeds or exposure to strong winds. According to wind rose diagram shown in point 2.4 fig 16 Karachi is having maximum of 10.5 m/s wind speeds which cannot cause severe demage on buidling and roof.

5.4 Maintenance

The wind turbine will require regular maintenance and inspection, which may involve accessing the roof or other parts of the building. This can be challenging and may require specialized equipment and expertise.

5.5 Aesthetics

The wind turbine can affect the appearance of the building and may not be visually appealing to everyone. But building and turbine can be painted in a colorful way to appeal the people and increase beauty of building facade. Additionally as the blades of turbine are flat and can be seen from a distance so they can be used for company marketing by outting sticker or LED lights to enhance beauty and appeal people.

6 TURBINE AND CONTROL SYSTEM

6.1 Turbine

The turbine is the primary component in a wind energy system, responsible for converting the kinetic energy of wind into mechanical energy that can be used to generate electricity. Since, as per energy requirements of ETM it is suggested to install 10kW wind turbine on the roof top to generate electricity. Wind turbines typically consist of a rotor with blades that are connected to a shaft, which is connected to a generator. As the wind blows, it causes the blades to rotate, which in turn rotates the shaft and generator, producing electricity. There are various option available in market for vertical axis wind turbine. For this thesis a supplier has been engaged in China for costing of total wind turbine setup. According to data analysed above if the column can support as per recommendation of structural engineer 10kW wind turbine can be installed on the roof top. Below in figure 6.1 and 6.2 are the pictorial and disection overview of VAWT and figure 6.3 shows details of turbine which shows starup wind speed, rated wind speed and other parameters having suitable wind conditions.

Figure 6.1 Actual H shape vertical axis wind turbine

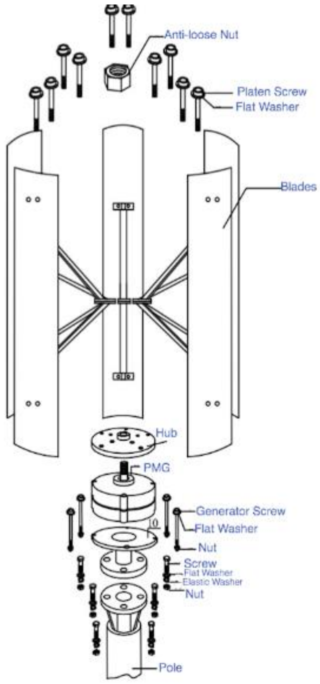


Figure 6.2 Disection view of VAWT

Model	SW-2000H	SW-3000H	SW-5000H	SW-10KH
Rated Power(W)	2000	3000	5000	10000
Maximum power(W)	2100	3200	5200	11000
Rated voltage(V)	48v/96v/120v/220v/240v		96v/120v/220v/240v	120v/220v/240v/380v
Start-up wind speed(m/s)	2.5	2.5	2.5	2.5
Rated wind speed(m/s)	11	11	11	11
Survival wind speed(m/s)	45	45	45	45
Wheel diameter(m)	1.55	2	2.2	3.9
Blades height	2.4m	3m	4.2m	5m
Number of blades	5			
Blades material	Aluminum alloy			
Generator type	Outer rotor generator			
Magnet material	NdFeB			
Control system	Electromagnet			
Speed regulation	Automatically windward			

Figure 6.3 Specifications of VAWT

6.2 Wind Controller

The wind controller coordinates the operation of the individual wind turbines to optimize the performance of the wind farm as a whole. It receives information about the wind speed and direction from various sensors and uses this information to adjust the speed and pitch of the turbines' blades, ensuring that each turbine is operating at maximum efficiency. The controller also manages the flow of electricity from each turbine and directs it to the substation for transmission to the grid.

The wind controller is responsible for maintaining the stability and reliability of the wind farm by managing the power output of the turbines. It can ramp up or ramp down the output of the turbines in response to changes in wind speed or grid demand, ensuring that the wind farm is operating within safe and stable limits. It can also shut down individual turbines or the entire wind farm in the event of severe weather or other safety concerns.

Overall, the wind controller is a critical component of a wind farm, ensuring that the energy generated by the wind turbines is delivered to the grid in a reliable and efficient manner. It plays a key role in maximizing the performance of the wind farm and minimizing downtime or interruptions in power delivery.

6.3 Off Grid single phase inverter

Off-grid single-phase inverters are an essential component of a standalone renewable energy system, where the system is not connected to the utility grid. Their main role is to convert the DC (Direct Current) electricity produced by renewable energy sources such as solar panels, wind turbines, or hydroelectric systems, into AC (Alternating Current) electricity that can be used to power AC loads like household appliances, lights, and electronics.

Off-grid single-phase inverters are designed to work with battery storage systems, which store the energy produced by the renewable energy sources during times when the energy demand is low or when the system is producing more energy than is currently being used. During times of high energy demand, the battery system provides energy to the inverter, which in turn converts the DC electricity stored in the batteries into AC electricity that can be used by the loads.

Off-grid single-phase inverters come in different sizes and capacities to suit different system sizes and loads. They are usually compact and lightweight, making them easy to install and transport. They also include features such as protection from overvoltage, under voltage, overcurrent, short-circuit, and over-temperature to ensure that the system operates safely and efficiently.

Overall, the role of an off-grid single-phase inverter in a standalone renewable energy system is critical. It is responsible for converting the DC electricity produced by renewable energy sources into usable AC electricity and managing the flow of electricity between the batteries, loads, and renewable energy sources. By doing so, it enables households, businesses, and communities to access clean, reliable, and sustainable electricity in areas where grid electricity is not available.

6.4 Batteries

To calculate how much batteries are required to store energy for wind turbine several facrtors are considred which includes

Power Output: Determine the power output of the wind turbine in watts. This information depends upon specification of turbine which a company is planning to buy to store energy

Battery Capacity: Determine the capacity of the battery in watt-hours (Wh). This information can usually be found in the battery specifications.

Battery Voltage: Determine the voltage of the battery. This information can also usually be found in the battery specifications.

Average Wind Speed: Determine the average wind speed in the area where the wind turbine will be installed. This information can be obtained from a local weather station or through a wind rose diagram of potential location.

A 12V-100AH Gel battery plays a crucial role in a variety of applications, from backup power systems to off-grid renewable energy systems. Its main role is to store electrical energy produced by a renewable energy source or from the grid during periods of low demand, and then release it when demand is high or when the primary power source is not available.

In off-grid renewable energy systems, the 12V-100AH Gel battery acts as an energy storage bank that stores excess energy generated by solar panels or wind turbines during periods of high production. During periods of low production, such as at night or during low-wind periods, the battery supplies stored energy to the loads, allowing them to continue operating.

In backup power systems, the 12V-100AH Gel battery provides a reliable source of energy during power outages or emergencies. It can provide power to critical systems such as lighting, communication systems, medical equipment, and security systems.

The 12V-100AH Gel battery is a type of deep-cycle battery, which means that it is designed to be discharged and recharged repeatedly over a long period. It is also maintenance-free and resistant to leaks, making it a safe and reliable option for energy storage.

Overall, the 12V-100AH Gel battery plays a critical role in providing reliable and efficient energy storage for a variety of applications. By storing excess energy and releasing it when needed, it helps to ensure a stable and reliable supply of electricity, both in off-grid renewable energy systems and in backup power systems.

7 CALCULATION FOR WIND TURBINE

Based on meteorological data [59] available calculations can be made for wind energy potential. The important factors to consider are wind speed, air density and power curve. In the case of Karachi assumption has been made with 5 m/s and Cp 0.3 as Cp lies between 0.2 and 0.5 and some data shows that in case of vertical axis wind turbine 0.3 Cp has been taken as assumption to make calculations. Where standard air density can also be represented as ρ, Since ρ can be 1.23kg/m^3 at 1 atm and 15C, swept area is the area of turbine, C_p is coefficient of performance and V is the monthly mean wind speed.

The power input of a wind turbine is the power that is extracted from the wind by the turbine's rotor blades. It is the power that is used to turn the turbine's generator to produce electrical power.

The power output of a wind turbine, on the other hand, is the electrical power that the turbine generates and delivers to the electrical grid.

Here, power output can be calculated as

$$P_{Output}=\frac{1}{2} \text{ x air density x swept area x } C_p \text{ x } V^3 \qquad \text{Eq.1}$$

And power input can be calculated as:

$$P_{input}=\frac{1}{2} \text{ x air density x swept area x } V^3 \qquad \text{Eq.2}$$

The swept area of a wind turbine is the area swept by its rotor blades as they rotate through the air. It is a key factor in determining the amount of power that can be extracted from the wind.

The swept area (A) of a wind turbine can be calculated using the following formula:

$$\text{Swept area=A= } \pi r^2 \quad \text{Eq.3}$$

Where, r is the radius of the rotor blades.

Suppose vertical axis wind turbine is taken as mentioned in point 4 with diameter of the wind turbine 3.9 meters, then the radius (r) is half of the diameter, which is:

$$r = \frac{3.9}{2} = 1.95 \text{ m}$$

Substituting this value into the formula, we get:

$$A=\pi 1.95^2$$

$$A= 11.95\ m^2$$

Therefore, the swept area of a wind turbine with a diameter of 3.9 meters is approximately $11.95m^2$

Now, power input can be calculated by substituting values in equation 2

$$P_{input} = \frac{1}{2} \times 1.23 \times 11.95 \times 5^3$$

$$P_{input} = 918.65 \text{ W}$$

Now, power output can be calculated by substituting values in equation 1

$$P_{output} = \frac{1}{2} \times 1.23 \times 0.3 \times 11.95 \times 5^3$$

$$P_{output} = 275.5 \text{ W}$$

The role of efficiency is to ensure that energy is used in the most effective and sustainable way possible. Efficiency is a measure of how well a system or process converts energy inputs into useful outputs. In general, higher efficiency means that less energy is wasted and more of it is used to perform useful work.

Efficiency is important for several reasons:

Cost savings: By improving efficiency, we can reduce the amount of energy consumed, which can result in cost savings. For example, a more efficient heating system can reduce energy bills, and a more efficient vehicle can reduce fuel costs.

Resource conservation: By using energy more efficiently, we can conserve natural resources such as fossil fuels, which are finite and non-renewable. Improving efficiency can also reduce the demand for energy, which can help to preserve natural habitats and ecosystems.

Environmental impact: Energy consumption is a major contributor to greenhouse gas emissions and other forms of pollution. By improving efficiency, we can reduce the environmental impact of energy consumption and help to mitigate the effects of climate change.

Energy security: Improving efficiency can also help to enhance energy security by reducing our dependence on foreign sources of energy and reducing the risk of energy supply disruptions.

Overall, the role of efficiency is to promote sustainable and responsible energy use, and to ensure that we can meet our energy needs in a way that is environmentally, economically, and socially sustainable.

Efficiency can be calculated as:

$$\text{Efficiency}= \frac{Power\ output}{Power\ input} \times 100 \qquad \text{Eq.4}$$

By substituting above results of power output and input in equation 4, efficiency will be,

$$\text{Efficiency} = \frac{275.5}{918.65} \times 100$$

$$\text{Efficiency}= 30\%$$

The above results shows that turbine is able to operate at 30 % of efficiency and capable to generate 87.6 Wh. But as per nature's effect there is no constant speed, however it changes over a specific period of time. Below is the power output curve fig 7.1 drawn with different wind speeds as per wind rose data available ranging from 0 to 9 m/s.

Wind Speed (m/s)	Wind ouput
0	0
1	0
2	0
3	60
4	141
5	276
6	476
7	756
8	1129
9	1607
10	2205
11	2935

Table 7.1 Wind speed vs power output

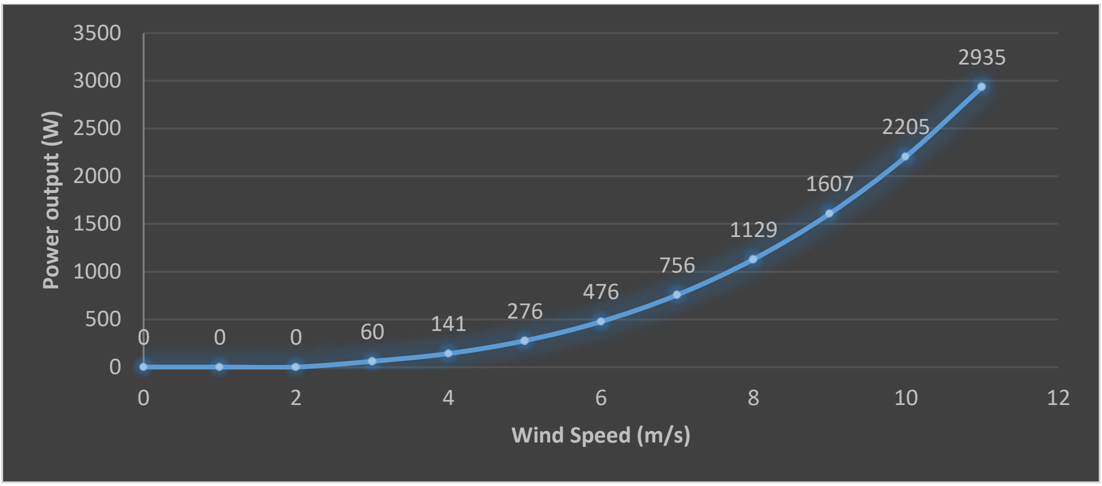


Figure 7.1 Power output curve

8 ECONOMIC ANALYSIS

8.1 Project Costing

Project costing refers to the process of estimating and tracking the costs associated with a specific project. It involves identifying the various costs involved in the project, including labor, materials, equipment, and other expenses, and then developing a budget and cost management plan to ensure that the project stays within its financial constraints. Effective project costing is essential for ensuring that a project is financially feasible and that it delivers the desired outcomes within the available resources

Item	**Quantity**	**Cost €**
10kW wind turbine	1	2155
Wind controller	1	808
Off grid single phase inverter	1	1311
Wiring	100m	182
Gel battery	20	1638
Import duty	17% of import bill	1004
Freight	One container	700
Custom cleareance	5 % of import bill	295
Base construction	-	227
Total		**8,320€**

Table 8.1 Project costing

It is estimated that in total project will account for approximately 8,320 €. But according to supplier results, a battery life is approximately 5 years. So, after every 5 years an investment will be made as per prices available in the period of time. Secondly, for operation and maintenance 2 person will be working on call basis for any unwanted situations or malfunctionting in the system. These 2 person are a skilled resource available in the company already responsible for installation of wind turbine.

Note: Above prices are taken are accoding to labor charges in Pakistan but it may vary depending upon the region

8.2 Cost of Energy

Wind energy is one of the most promising forms of renewable energy, but it is important to assess its economic viability before investing in wind energy projects. By calculating the cost of energy generation from wind turbines, we can determine if wind energy is a cost-competitive alternative to other forms of energy generation, such as fossil fuels.

$$\text{Levelized cost of energy} = \frac{A+B+C+D+E}{Fx\ Gx\ H} \qquad \text{Eq.5}$$

Where,

Symbol	Description	Cost	Justification
A	Initial investment	8,320	Refer to point 9.1
B	Fixed operation and maintenance cost	0	Labour cost
C	Variable operation cost	0	For initial five years its 0
D	Fuel cost	0	In case of wind and solar it is zero
E	Taxation	0	In house generation
F	Annual electricity production	2,413 kW/ year	Energy output = 275.5x8760hrs
G	Capacity factor	0.3	A capacity factor of 0.3 is a typical assumption for a wind turbine installed at a good wind site. This means that the wind turbine is expected to produce 30% of its maximum possible energy output over the course of a year
H	Life of project	20	As provided by supplier

Table 8.2 Levelized cost of energy

Substituting values in equation 7 we get,

$$\text{Levelized cost of energy (LCOE)} = \frac{16314+1200+0+0+0}{2413*0.3*20}$$

$$\text{Levelized cost of energy (LCOE)} = \frac{8320}{14478}$$

Levelized cost of energy (LCOE) = 0.57 € / kW

This means that the cost of energy generation from the VAWT is 0.57 € per kW. However, we have made assumption if plant is running at an efficiency of 30% and generating 275.5 Wh of electricity. Secondly, all the calculations are made with low winds but with high winds more energy can be generated resulting a lower cost but it is vice versa in the case when wind are more turbulent and unable to rotate the turbine. Since, above cost may seems non- ideal following cost comparison has been carried out with same technical specifications but different wind speeds.

Wind Speed (m/s)	Wind Output	Yearly Output (kW)	Cost/ kWhr (€)
0	0	0	0
1	0	0	0
2	0	0	0
3	60	521	2.66
4	141	1236	1.12
5	276	2414	0.57
6	476	4172	0.33
7	756	6625	0.21
8	1129	9889	0.14
9	1607	14080	0.1
10	2205	19314	0.07
11	2935	25707	0.05

Table 8.3 Wind speeds Vs cost of generation

8.3 Payback period

The payback period is a useful metric for evaluating the financial feasibility of an investment project. Generally, the shorter the payback period, the better the project is from a financial standpoint, as it indicates that the investment will generate returns more quickly.

$$\text{Payback period is given by} = \frac{\textit{Initial investment}}{\textit{annual cash flow}} \qquad \text{Eq. 6}$$

Suppose, annually 2,413 kWh will be generated over a year with a cost of 0.57 € per kWh. So, total annual cash flow will be 2413x 0.57= 1375.41 €

$$\text{Payback} = \frac{8320}{1375}$$

Payback Period= 6 Years

Result shows that payback period of 6 years for this project is very good. The payback period is the amount of time it takes for a project to generate enough cash flows to recover the initial investment. A shorter payback period indicates that the project is able to recover the investment quickly and start generating positive returns. Therefore, this payback period of 6 years is an indication that the project is able to recover its initial investment quickly, which can be seen as a positive indicator of the project's financial viability. Here, we need to remember that we have made calculation on a constant wind speed to of 5 m/s. If we suppose the wind blows ranging between 0 to 9 m/s, then payback period will be much lower.

8.4 Depreciation

Depreciation plays a crucial role in project evaluation and analysis. It is a non-cash expense that reflects the gradual decrease in the value of an asset over time due to wear and tear, obsolescence, or other factors. Depreciation affects the project's financial statements, particularly the income statement and balance sheet, by reducing its taxable income and increasing its after-tax cash flow. It is used to calculate the project's net income, cash flow, payback period, and net present value, and its duration and method can significantly impact the project's financial performance and viability. As such, understanding and properly accounting for depreciation is essential in evaluating the feasibility and profitability of a project

$$\text{Depreciation can be given by}= \frac{Cost\ of\ assest - savage\ value}{useful\ life\ of\ asset} \quad \text{Eq. 7}$$

$$\text{Depreciation}= \frac{8320-0}{7}$$

Depreciation= 1188.5 €

9 CONTINIOUS IMPROVEMENT FRAMEWORK

9.1 Hybrid Solution (Solar + Wind)

Hybrid renewable energy systems that combine wind and solar power are becoming increasingly popular as a way to increase the reliability and efficiency of renewable energy generation. These systems can be designed on roof tops utilizing the space to complement each other, with wind turbines producing electricity during periods of high wind speed, and solar panels producing electricity during periods of high sunlight intensity. By combining the two, the system can produce more reliable and consistent electricity output throughout the day and year.

Wind power is one of the most established forms of renewable energy, with wind turbines being used to generate electricity for over a century. Wind turbines work by converting the kinetic energy of wind into mechanical energy, which is then converted into electrical energy. Wind turbines are typically mounted on tall towers to take advantage of higher wind speeds at higher altitudes. They can be either horizontal-axis or vertical-axis, with horizontal-axis turbines being the most common.

Solar power is another popular form of renewable energy, with solar panels being used to generate electricity for several decades. Solar panels work by converting the energy from sunlight into direct current (DC) electricity. This electricity can then be converted into alternating current (AC) electricity using an inverter. Solar panels are typically mounted on rooftops or on the ground and can be connected to a grid-tied system or an off-grid system.

In a hybrid renewable energy system that combines wind and solar power, the wind turbines and solar panels are connected to a common power distribution system. The power output from both sources is combined, and a battery bank is used to store excess electricity produced by either the wind turbines or solar panels. This stored energy can be used during periods of low wind or sunlight, ensuring a constant and reliable power supply.

Hybrid renewable energy systems can be designed for both on-grid and off-grid applications. In on-grid systems, excess energy produced by the wind turbines and solar panels can be fed back into the grid, reducing energy costs and providing a revenue stream for the system owner. In off-grid systems, the hybrid system can provide a reliable source of electricity for remote communities or industries that are not connected to the grid.

One of the main advantages of a hybrid renewable energy system that combines wind and solar power is that it can provide a more reliable and consistent supply of electricity. Wind and solar power are both intermittent sources of energy, with wind turbines producing more electricity during periods of high wind speed and solar panels producing more electricity during periods of high sunlight intensity. By combining the two, the system can produce more reliable and consistent electricity output throughout the day and year. This can help to reduce the need for backup generators and improve the overall efficiency of the system.

Another advantage of a hybrid renewable energy system that combines wind and solar power is that it can help to offset the intermittency of both wind and solar power. When the wind is not blowing, solar panels can continue to produce electricity, and vice versa. This can help to ensure a constant and reliable power supply, even during periods of low wind or sunlight.

Hybrid renewable energy systems that combine wind and solar power can also help to reduce greenhouse gas emissions and provide a more sustainable and eco-friendly energy source. By reducing the dependence on fossil fuels, these systems can help to reduce the carbon footprint of homes, businesses, and communities.

When designing a hybrid renewable energy system that combines wind and solar power, several factors must be taken into consideration. These factors include the local climate, the availability of wind and sunlight, the size of the system, and the energy demand of the system. The system must be sized to meet the energy demand of the users while also taking into account the variability of wind and solar power. Battery storage must also be carefully considered to ensure that the system can provide a reliable and consistent power supply. Below is the simple pictorial overview of hybrid system.

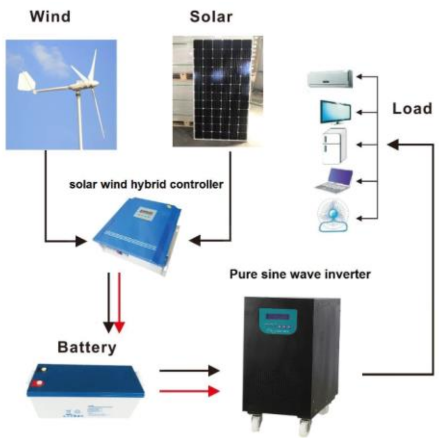


Figure 9.1 Solar and wind hybrid system[61]

CONCLUSION

In conclusion, the thesis aimed to provide a feasible and sustainable solution for energy needs in the industrial sector. For this purpose, wind energy has been proposed as the most viable option based on the availability of wind resources in the region, considering the fact that solar is already installed but other options can be considered. We have provided an equipment guide, wind energy calculations, and an economic analysis to support the proposal. The thesis has the potential to not only reduce operational costs but also contribute to a cleaner and greener environment in Karachi, Pakistan.

Recommendations:

- Based on the findings and analysis, solar is considered the cheapest solution, but thinking from a global perspective where solar energy is less available, wind energy can be taken into account

- It is the second cheapest option with less maintenance and operational cost. It is recommended that small and medium-scale industries in Karachi consider adopting wind energy as a renewable energy solution,

- If there is availability of solar and wind, hybrid systems can also be taken into consideration to lower the cost with high efficiency.

- It is suggested that factories conduct further feasibility studies to determine the most suitable wind turbine model and the best location for installation.

- It is also recommended that the government provide more incentives and policies to encourage the adoption of renewable energy solutions, including wind energy, to promote sustainable economic growth and reduce the country's dependency on non-renewable sources of energy.

SUMMARY

This thesis provides a feasible study for renewable energy solutions for small-scale factories by which they can reduce dependency on fossil fuels that have a negative impact on the environment through the emission of greenhouse gases and move towards the cheapest solutions. For this purpose, the author of this thesis has carried out research among renewable energy sources, including solar, wind, thermal, ocean, biomass, and hydroelectric energy types.

A technology overview has been carried out among all energy sources, and based on the weighted score model, wind energy is selected among thermal and hydroelectric. Solar, hydroelectric, and ocean energy were not considered as part of the research as solar was already implemented by the company, and ocean and hydro energy require huge investments and several changes in the layout of the city to implement. According to several studies, solar is considered the cheapest energy source in terms of available resources. However, after that, wind energy is the most viable option due to the fact that wind is naturally available, depending on wind speed and other environmental factors. Initially, in this thesis, important factors are assessed, such as environmental, location, meterological, economic, orographic, and social, with the potential of wind turbine installation in Karachi on factory roof tops.

Among the two types of wind turbines, horizontal and vertical axis, the vertical axis wind turbine has been chosen based on the factor rating model. VAWT has the potential to generate energy in urban environments with turbulent winds. With the available data, among all types of vertical axis wind turbines, the H type can be chosen due to its ability to generate energy on a smaller scale, low noise, and finally, its characteristics of operation in turbulent winds. The wind rose diagram of Karachi shows that the wind in Karachi lies between 0 and 9 m/s on average, showing potential to consider for electricity generation. However, people see that installing wind turbines on roof tops could be dangerous, but taking precautions and with the help of structural analysis, it is recommended to install and generate energy in an efficient manner.

In the context of the wind rose diagram, calculations have been carried out with an average wind speed of 5 m/s to determine what power output can be generated from it. The result shows that with this wind speed, around 275 W can be generated per hour if the plant is running at an efficiency of 30%. Based on financial feasibility and economic calculation, the cost of energy with a 5 m/s wind speed will be 0.57 euros per kWh, and the project can be paid back in a span of 6 years with a depreciation of 1188.5 euros per year. This number of payback years does not happen in an ideal situation, as winds

are constantly changing. If we consider more wind, our payback period will be much shorter, and even the cost of energy will be lower.

In the end, the result shows that the strategy and calculations made in this can have a bigger impact on a larger audience, especially houses and small-scale factories, depending on whether the location has ideal conditions worldwide and spaces available on roof tops.

KOKKUVÕTE

See lõputöö pakub väikeste tehaste jaoks teostatavusuuringut taastuvenergia lahenduste kohta, mille abil saab vähendada sõltuvust fossiilkütustest, mis mõjutavad keskkonda negatiivselt kasvuhoonegaaside heitmete kaudu, ja liikuda odavamate lahenduste poole. Selleks on lõputöö autor uurinud taastuvenergiaallikaid, sealhulgas päikese-, tuule-, soojus-, ookeani-, biomassi- ja hüdroenergia tüüpe.

Tehti ülevaade kõigist energialiikidest, ning kaalutud skoorimudeli alusel valiti soojus- ja hüdroenergia asemel tuuleenergia. Päikesepaneelid, hüdroenergia ja ookeanienergia ei olnud uurimuse osa, kuna päikesepaneelid olid juba ettevõtte poolt kasutusele võetud ning ookeani- ja hüdroenergia nõuaksid suuri investeeringuid ja linna kujunduse olulisi muudatusi rakendamiseks. Mitmete uuringute kohaselt peetakse päikeseenergiat odavaimaks energiallikaks, võttes arvesse olemasolevaid ressursse. Pärast seda on tuuleenergia kõige elujõulisem valik, kuna tuul on loomulikult olemas, olenevalt tuule kiirusest ja teistest keskkonnateguritest. Alguses hinnatakse olulisi tegureid, nagu keskkond, asukoht, meteoroloogiline, majanduslik, orograafiline ja sotsiaalne, tuulegeneraatorite paigaldamise potentsiaal Karachis tehaste katustele.

Horisontaal- ja vertikaaltelje vahel valiti faktorite hindamismudeli alusel vertikaaltelje tuulegeneraator. Vertikaaltelje tuulegeneraatoritel on potentsiaal energiat toota linnakeskkonnas turbulentses tuules. Saadaolevate andmete põhjal võib kõikidest vertikaaltelje tuulegeneraatoritest valida H-tüübi, kuna see suudab toota energiat väiksemas mastaabis, tekitab vähem müra ja töötab hästi turbulentses tuules. Karachis asuv tuuleroosi diagramm näitab, et tuul liigub Karachis keskmiselt 0-9 m/s, näidates potentsiaali elektrienergia tootmiseks. Kuigi inimesed võivad pidada tuulegeneraatorite paigaldamist katustele ohtlikuks, on soovitatav võtta ettevaatusabinõusid ja teha struktuurianalüüs, et paigaldada ja energiat tõhusalt toota.

Tuuleroosi diagrammi kontekstis on tehtud arvutused keskmise tuulekiirusega 5 m/s, et välja selgitada, milline võimsus sellest genereerida saab. Tulemus näitab, et selle tuulekiiruse korral saab tunnis toota umbes 275 W võimsust, kui seade töötab 30% efektiivsusega. Finantsilise teostatavuse ja majandusarvutuste põhjal oleks 5 m/s tuulekiiruse korral energiakulu umbes 0,57 eurot kilovatt-tunni kohta ning projekt saaks tagasi tasutud 6 aasta jooksul, kusjuures aastane kulum on 1188,5 eurot. Selline tasuvusperioodi arv ei saa ideaalses olukorras tekkida, kuna tuuled muutuvad pidevalt. Kui arvestame rohkem tuult, oleks tasuvusperiood märksa lühem ja energiakulu veelgi madalam.

Kokkuvõttes näitab tulemus, et sellel strateegial ja arvutustel võib olla suurem mõju suuremale sihtrühmale, eriti majadele ja väikestes mahus tehastele, sõltuvalt sellest, kas asukoht pakub ülemaailmselt ideaalseid tingimusi ja kas katustel on ruumi paigaldamiseks.

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APPENDICES

Appendix 1

SUNWAYTECH

OFFICIAL QUOTATION SHEET

Date: 2023/4/18

To:

From: Sunway Solar Co., Ltd
Attn.: Chloe
Add.: Huguang Road, New Industrial Park, Shushan District, Hefei City, China
Tel: 13024033237
E-mail: sales26@sunwaypv.com

10Kw Wind Power system Quotation

Item	Article	Picture	Description	Quantity	Unit Price	Amount (USD)
1	10Kw Wind Turbine		Power: 10Kw Warranty: 3 years Output voltage:Single phase 220v	1	$2,369	$2,369
2	Wind Controller		System Voltage:240v Power:10Kw	1	$888	$888
3	Off-grid Single-phase Inverter		System voltage: 240v Output power:10kw	1	$1,441	$1,441
4	12v-100AH Gel battery		Maintenance-free DOD:70% Warranty: 3years	20	$90	$1,800
			Total EXW price			**$6,498**

Payment term: Payment term: 100% in advance (T/T,Alibaba Trade Assurance,Western Union, Credit Card,etc.)

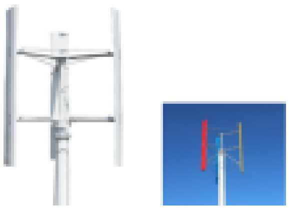
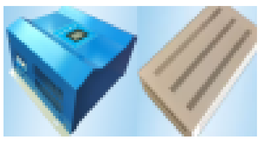
Quote Validity: 5days, sea freight valid in 5days.

Lead time: 15 working days after receiving deposit

SUNWAY-Your Professional PV Supplier

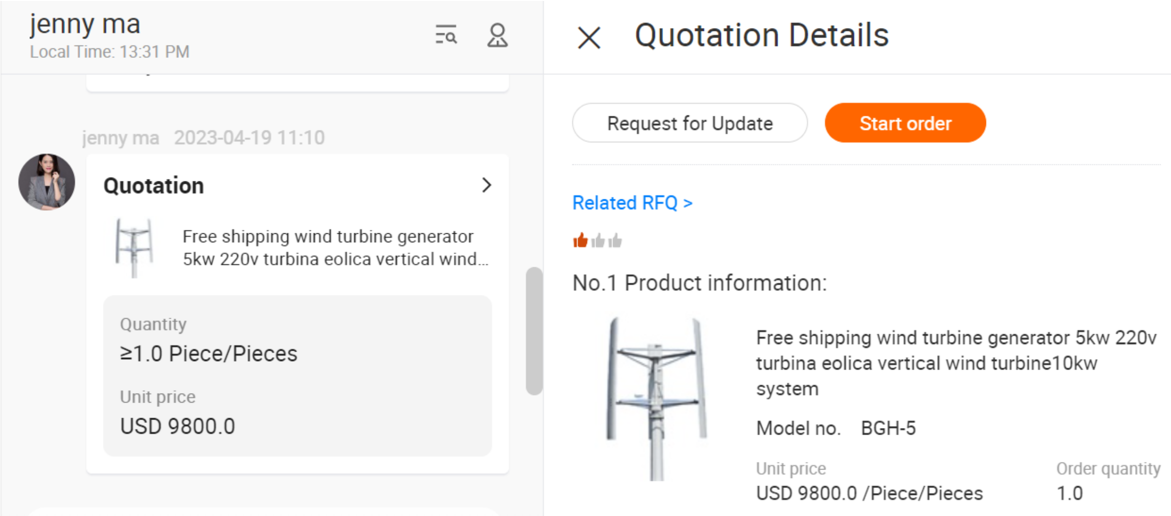
Quotation 1

Appendix 2

	Des/Model: FH-2000 Rated Power: 2000W maximum power: 2100W Rated voltage: 48V/96V Start up wind speed: 1.5m/s Rated wind speed: 12m/s Security wind speed: 40m/s Blades height: 2.8m wheel Diameter: 2m Gross weight: 188kg Packing size: 155*45*56cm 135kg 286* 26*53cm 53kg	$1,771
	Model: H-3000 Generator power: 3000w Maximum power: 3500w Rated voltage: 48V-220v Rated wind speed: 10m/s Rated RPM: 300 Net weight: 200kg Blades height: 3.2m Wheel diameter: 2m	$2,376
	ABDP- 3kw off grid controller	$355
	Model: FH-5000 Generator power: 5000w Maximum power: 5500w Rated voltage: 96V-380v Rated wind speed: 10m/s Blades height: 3.6m Wheel diameter: 2.4m Package Size: Generator: 161*45*76cm 140kg Blades :365*26*53 77kg	$3,131

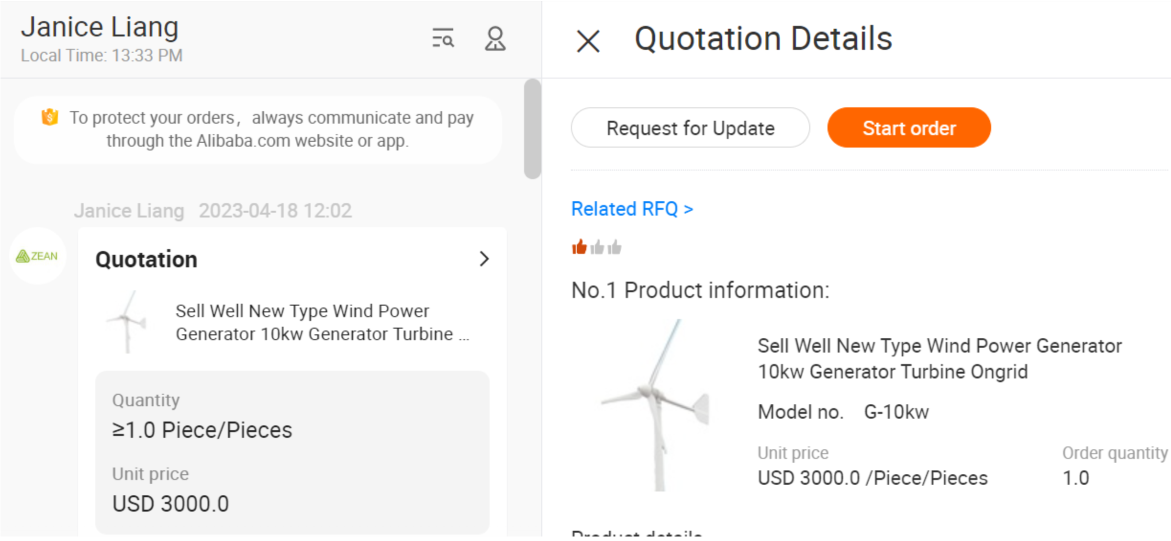
Quotation 2

Appendix 3



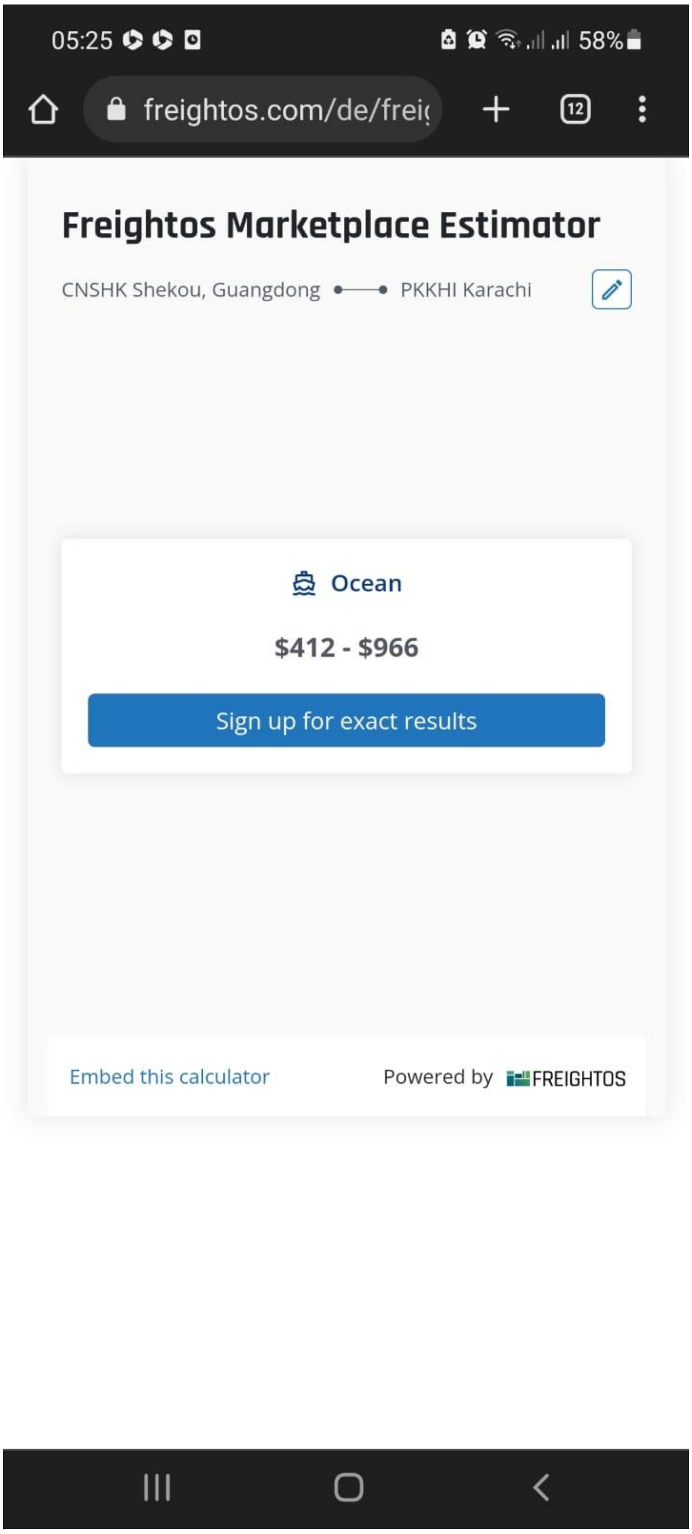
Quotation 3

Appendix 4



Quotation 4

Appendix 5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Ocean
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