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Research Paper

Investigation of Wind Energy to Generate Electric Power and its Role to Reduce Environmental Pollution in Iraq

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Abstract

Wind energy is one of the renewable energy that has been widely used round the world which is abundant, renewable, and generally available. The present paper established to study the possibility of generating electric power by wind turbines for three important cities in Iraq located in terms of altitude from sea level and climate, namely (Mosul in north, Baghdad in middle and Basra in the south of Iraq). The calculations depend on the hourly meteorology data's like wind speed, wind direction and air temperature taken from (Iraqi meteorological organization and seismology) since 2005 to 2015. Noting that, the calculations had been done for three variable types of wind turbine found in global markets which differ in capacity, cut-in velocity, cut-off velocity, blade diameter and initial cost. The main aims for present paper can be divide in three stages. First, it studies the possibility of using wind turbines for the selected cities. Then, it estimates the amount of annual electric power generation (EPG) and it's contribution to minimize the environmental pollution if the same power generated by gas turbine which regarded the diffuse method in Iraq. Finally, an economic analysis is also carried out for each turbine. Life cycle assessment software (SimaPro V 7.2) has been used to obtain the amount of emissions produced per kWh electricity power by gas power plant. (P1-P2) method has been used to estimate the economic data's for the project. The results of the research will decide the most appropriate zone to do the projects and the best turbine to give maximum EPG and its ability to reduce emissions with giving financial gain and payback period as an economic value to encourage the investors to apply like this project.

Keywords: *Environmental pollution, electric power generation, financial gain, life cycle assessment, payback period, wind turbine, wind speed.*

1. Introduction

The increasing demand for energy due to population growth and urbanization are led to an unexpected rise in fuel prices over the past decade. This does not affect to the fuel prices alone, but leads to increase air pollution and climate change also and it becomes one of the reasons that threaten the world. As expected future, energy consumption round the world will increase approximately by 56% in 2040s and most of these demands will met by fossil fuel (Gopalakrishnan et al., 2014). So, it was necessary to find alternative energy sources to reduce or eliminate the excessive greenhouse gas emissions. Therefore, many countries have encouraged the use of clean energy, like renewable energies (Bakos, 2000). Wind energy is one of the renewable energy that has been widely used round the world which is abundant, renewable, and generally available. It has been used before 4000 years ago to power sail boats, grain pump water for farms and recently generate electric power. The development of wind turbines happened as a result of the energy crises in the 1970s (Cengel and Boles, 2015). There are several classifications for wind turbine, but mainly it can be classified into two types depending on the axis of rotation namely horizontal axis and vertical axis wind turbines. The horizontal axis with propeller blades is the most common one which works more efficiently from other type (Saad and Asmuin, 2014). Iraq is one of the countries that intend to use wind turbine to eliminate its environmental pollution. Because of the availability of natural gas in this country, most of the power plants operate by gases. Gas turbines have lots of emissions of greenhouse gases from the chimney, the largest proportion of the gases emitted from these turbines are CO_2 which is responsible for the problem of global warming and H_2S which is considered a hazardous gas to human health (Ariyaratnam et al., 2013).Generally, the climate of Iraq is described as hot and dry in summer and cool and rainy in the winter season. The annual average variation in wind speed and air temperature are between (2-8 m/s) and (10-45 ^oC) respectively (Rasham, 2017). There are numerous studies about this feild. In Spain (Torres et al., 2005) used a model of autoregressive moving average process to forecast hourly wind speed and its relationship to topographic of earth surface and tilting to the persistence and its impact on the wind power. (Sedaghat et al., 2017) conducted a determination about wind speed for maximum annual energy production (AEP) of different speed wind turbines in Iran based on the relationship between AEP and the produced capacity value. They concluded that the suitable value for rated wind speed is higher than the natural value. (Qin et al., 2017) examined the offshore wind energy storage for the cost of rated power saving, based on investigation of compressed air energy stage (CAES) and hydraulic power transmission (HPT) system. They concluded that CAES+HPT can lead substantial saving about 21.6% for 20 years life time. (Akour et al., 2018) conducted a theoretical and practical study on the possibility of using micro wind turbine for the regions that have low wind speed. The study was based on design and implement new wind for two locations in UAE. The results showed that the new design is more cost effective and more wind energy is harnessed by using the swept area

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correctly. (Wang et al., 2017) estimated amount of wind energy produced when constructed on a building with canopy roof. CFD parameter was conducted and tested by wind tunnel experiment before start of the simulation. The results showed that the double pitched canopy roof with a pitch angle of 20° has been the best one in wind concentration. (Lombardi et al., 2017) submitted a study about the environmental impacts of electricity production by vertical axis micro wind turbines in Italy. Environmental impact was estimated when using wind turbines, taking into account the effect of turbine manufacturing on the environment negatively. The estimation was conducted a comparison between two type of turbines that differs in capacity (1 and 3 kW). They found out that 3 kW turbine has lower environmental impacts than 1 kW turbine which has 27% lower global warming and 75% lower abiotic depletion. An Iraqi researches had share about this regard too. (Al-Jurane, 2009) presented statistical study about the ability to generate electricity by wind turbines in Iraq based on the monthly and yearly data's for ten stations. He concluded that wind speed during warm season of a year has maximum value from others that give the possibility to generate electricity especially in the south cities. The wind power potential has been statistically analyzed for the Bakrajo region in suleymanya city (Ahmed et. al, 2011). Depending on the weibull function and the monthly measured data's for four years (2004-2007). It shows that this region has a poor wind power resource where the maximum wind speed was 2.4 m/s at 50 m height. In the other study, (Al-ahmed, 2017) examined the capability of watering plant and trees from watering project by wind turbines in AL-Hawija region which regarded an agriculture area in north of Iraq. The study turned out that the wind speed is not appropriate for this topics up to a height of 10 m, but at 50 m height be appropriate where the wind speed becomes higher than 3.5 m/s. The content of this research is characterized by studying the possibility of using wind turbines to produce electric power, the calculations based on the hourly values (8760 data's in a year) of the wind speed with their direction as well as the hourly temperature of the air which has a significant impact on the change in the air density. The data's taken from Iraqi meteorological organization and seismology (seismology, 2017) for long time period science (2005-2015) to deal with values as accurate as possible, leading the results to be very close to reality as well as reducing the error. The present paper conducted for three important cities that have high population density, located in terms of altitude from sea level and climate, namely (Mosul in north, Baghdad in middle and Basra in the south of Iraq). A statistical results of wind speed have been applied on three variable types of turbine found in the global markets to obtain the annual EPG. The turbines were selected depending on its capacity as well as its cut-in velocity (The wind speed that the turbine starts to run), cut-off velocity (The maximum wind speed that the turbine stop running) and its availability in global markets at an appropriate price. The amount of CO_2 and H_2S emitted per kWh electricity produced by gas power plant is obtained from life cycle assessment software SimaPro V 7.2 (Consultants, 2013), it can be able to see the role of wind turbines to reduce CO_2 and H_2S emissions if the same value of EPG are produced by gas turbines that regarded the most widespread units in this country. Furthermore, an economic analysis has been undertaken for each turbine. When the capacity of the turbine increases, the cost per (kWh) will decrease. For example, the cost of a turbine with a capacity of 1000 kW is less than the cost of two turbines of 500 kW. On the other hand, large turbines have a high cut-in velocity that means, it does not work at low wind speed while the small turbines work at this state. Therefore, the optimal turbine should be selected to suit the characteristics of each city, taking into account the cost of the project to obtain the largest EPG and lowest cost.

Nomenclature:

Symbols		
$\dot{W}$	Ideal power generation.	(W)
$\dot{m}$	Mass flow rate.	(kg/s)
A	Swept area.	(m^2)
C_e	Electric cost.	($/kW.h)
C_t	Total cost.	($)
D	Blade diameter.	(m)
d	Discount rate.	
i	Interest rate.	
M_s	Ratio of annual transportation, maintenance cost.	
N_r	Payback period.	(yr)
P	Atmospheric pressure.	(Pa)
R	Universal gas constant.	(kJ/kg.K)
S_m	Financial gain.	($/25yr)
T	Air Temperature.	(K)
V	Wind speed.	(m/s)
y_p	Annual profit from electricity.	($/yr)
η	Overall wind turbine efficiency.	(%)
ρ	Density.	(kg/m^3)
EPG	Actual electric power generation.	(MWh)
PWF, P_1	present worth factor.	
S	South direction.	
E	East direction.	
W	West direction.	
N	North direction.	
R_v	Ratio of resale value to the first cost	

2. Materials and Methods

Before beginning the calculation, the hourly wind speed for each city must be processed by subjecting it to three steps. First, it should be classified to four main directions as shown in Fig. 1. Assuming that the north direction is a reference angle (0°), the wind that coming from;

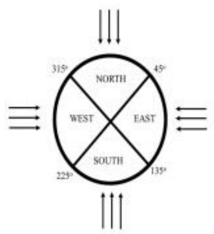

Fig. 1: Classification of wind direction.

1. (0°<wind<45° and 315°<wind<360°) will be north direction.
2. (45°<wind<135°) will be east direction.
3. (135°<wind<225°) will be south direction.
4. (225°<wind<315°) will be west direction.

Then, the average wind speed of ten years should be calculated for each direction. Finally, choose the highest wind speed between the values obtained from the second step considering that the modern turbines able to change its direction according to wind direction. It is important to understand the principle of turbine work which leads us to make calculations accurately where Fig. 2 shows this mechanism. The turbine does not start working before cut-in velocity, after this velocity the EPG increases significantly by increasing the wind speed up to rated velocity which regarded a velocity that turbine works at maximum capacity. When increasing the wind speed too, the EPG remains constant until it reaches to cut-off velocity at which the turbine stops working for fearing from failure and destruction because it did not design to operate above this speed.

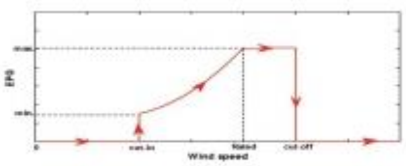

Fig. 2: Behavior of EPG when increasing wind speed.

When studying the wind speed of Basra city in Fig. 3 as a model, we note that there is 8760 black nodes distributed throughout a year which represent the values of hourly wind speed, the lower and the upper lines represent cut-in and cut-off velocities respectively. The nodes between these two lines are only entered in the calculations and the others are considered to be outside the operating limits. However increasing the distance between these two lines leads to be the operating hours more. So, the wind speed that obtained by applying these three steps (which explained above) must be undergo to the conditions of the turbine properties like;

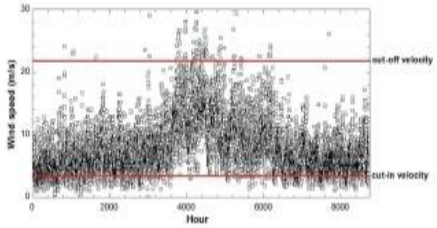

Fig. 3: Hourly wind speed during a year for Basra city.

- It must be greater than cut-in velocity and less than cut-off velocity which are the boundary speed that turbine stay running.
- When the wind speed overcomes the rated speed, the turbine capacity remains constant at maximum capacity.

Three types of turbine have been selected from online global markets (Engineering w.t.m, 2018) which differs in capacity. Where the first one (T_1), the second (T_2) and the third turbine (T_3) have 1000, 250 and 100 kW capacity respectively. Also, these turbines have different other properties too like cut-in velocity, cut off velocity, blade diameter which have significant effect to the results. The properties of the selected turbines are tabulated in Table 1. Wind turbine works according to the kinetic energy principle by influence of wind speed. If the wind is blowing at a velocity of V, the wind power generated ($\dot{W}$) will be;

$$\dot{W} = \frac{1}{2}\dot{m}V^2 \quad (1)$$

This value is the maximum power generation (ideal state) of wind turbine for the given velocity (V). The mass flow rate (m) of the air can be converted to volume flow rate that is the result of multiplication the velocity to the area (A);

$$\dot{m} = \rho A V \quad (2)$$

Where ρ is the density of the air. Because the air is regarded as an ideal gas, thus its density can be calculated from the general ideal gas law as described below;

$$\rho = \frac{P}{RT} \quad (3)$$

Hence, P is atmospheric pressure, R is universal gas constant for air (0.287 kJ/kg. K) and T is the hourly air temperature taken from meteorological station too. The disk area calculates from equation $A=\pi D^2/4$, where D is the blade diameter. Substituting Eq.(2) and Eq.(3) into Eq.(1), gets

$$\dot{W} = \frac{\pi P D^2 V^3}{8RT} \quad (4)$$

At the ideal state, the velocity of the exit air from the turbine assumed to be zero, this is not possible for practical state, because air must be go away from the turbine blades to maintain the air flow through it, this theory was first calculated by Albert Betz who concluded that the maximum efficiency of the wind turbines does not exceed (59.26%) of the ideal power which called BITZ LIMIT. Furthermore, the gearbox-generator has an efficiency about (80%) approximately. In actual state, the overall wind turbine efficiency usually ranges between 30 and 40 percent (Mathew, 2007). So, the actual value of EPG by the wind turbine can be calculated by;

$$EPG = \dot{W} * \eta \quad (5)$$

Where, η is the overall wind turbine efficiency. The equations and their details had written depending on (Mathew, 2007) as well as the details of BITZ LIMIT.

Table 1: The properties of chosen turbines

Property	T_1	T_2	T_3
Power capacity (kW)	1000	250	100
Total cost ($)	1 180*10^3	377*10^3	195*10^3
Hub height (m)	105	40.5	30.5
Blade diameter (m)	55	32	20
Cut-in velocity (m/s)	3	2.5	2
Cut-off velocity (m/s)	24	24	24
Rated velocity (m/s)	12.6	10	10.5
Number of blades	3	2	2

Because of the availability of natural gas in Iraq, most of the power plants currently are based on this source. Gas turbines emit a large amount of pollutants especially CO_2 and H_2S, which have the largest portion of this pollution and play a significant role in global warming and significantly affect in human health. A life cycle assessment software SimaPro V 7.2 (Consultants, 2013) has been used to estimate the amount of CO_2 and H_2S emitted per kWh electricity produced by gas power plant.

Economic analysis: The preparation of economic analysis is one of the most important way to success the projects. The convenient planning of projects ensures the success and effectiveness of these projects, in addition to make the projects more profitable. Therefore, before starting any project, the economic analysis must be done first. Economic analysis is very necessary to estimate the total cost for this project (C_t), which includes the cost of the device, transportation and installation. As well as the amount of financial gain from the investment during the lifetime of the device (S_m) in addition to the period required to pay the total cost back that spent to the project (N_r). In engineering economic, life-cycle cost analysis regards the most common analysis and the best way of it is (P_1–P_2) method. It is a practical and well-known method. P_1 or PWF is the present worth factor of a series of N_r future payments with interest rate (i) per period accounting for the time value of money with a market discount rate (d) per period (A. Duffie and Beckman, 1980). The equation for P_1 is defined as;

$$P_1(N_r,i,d)=\sum_{j=1}^{N_r}\frac{(1+i)^{j-1}}{(1+d)^j}=\begin{cases}\frac{1}{d-i}\left[1-\left(\frac{1+i}{1+d}\right)^{N_r}\right] & \text{if } i\neq d\\ \frac{N_r}{1+i} & \text{if } i=d\end{cases} \quad (6)$$

Hence, P_2 is the ratio of life cycle expenditures incurred as a result of the investment to the total cost. A high value of P_2 refers to that the investment has a low first cost but higher costs over the life of the equipment. It can be calculate by

$$P_2=1+P_1M_s - R_v(1+d)^{-N_r} \quad (7)$$

Where, M_s is the ratio of the annual maintenance, transport and installing cost to the original first cost, R_v is the ratio of the resale value to the first cost. The purchasing of the selected turbines depends on the offers in the international markets and the facilities that provide by the company like transporting and installation and maintenance the device in addition to training the workers to operate it. The most current offers are in which the transport, installation and maintenance for one years is the responsibility of the selling company. In general, M_s is estimated about 10% to 30% of the total cost of the turbine (Nguyen and Chou, 2018), in this study, M_s assumed to be %20 of the first cost. The amount of financial gain during the lifetime of the turbine can be formulated by (P_1-P_2) method as

$$S_m = P_1\ y_p - P_2 C_t \qquad (8)$$

Where y_p is the amount of annual financial gain from the sale of EPG to the state at the low domestic price, it can be calculated by applying equation

$$y_p = EPG * C_e \qquad (9)$$

Where, C_e is the price of 1 kWh electric power. Payback period of the project cost can be calculated by setting S_m in Eq. (8) to zero, where

$$N_r = \begin{cases} ln\left[1 - \dfrac{P_2 C_t}{y_p}(d-i) - \left(\dfrac{1+i}{1+d}\right)\right] & if\ i \neq d \\ \dfrac{P_2 C_t\,(1+i)}{y_p} & if\ i = d \end{cases} \qquad (10)$$

The equations of economic analysis was written depending on (A. Duffie and Beckman, 1980). The parameters which used in this study and their corresponding values are listed in Table 2.

3. Results and Discussions

The statistical results as shown in Fig. 4 indicates that the prevailing winds in Baghdad and Basra cities are southern and western which come from the Arabian Desert and be warm and dry. While in Mosul the prevailing winds is northern and western which coming from the Mediterranean Sea and be cold and wet. We note that the winds are differ in relative humidity and temperature in these cities, this observation confirms the need to deal with the density of air accurately because it influence by these two properties.

Table 2: The parameters and assumptions used in the calculations.

Parameter	unit	value
Atmospheric pressure (P)	N/m^2	101.325
Universal gas constant (R)	kJ/kg. K	0.287
Efficiency (η)	%	35
Interest rate (i)	%	6
Discount rate (d)	%	5
Lifetime of turbine (N_r)	yr	25
Electric price (C_e)	$/kWh	0.05

In this study, the comparison between turbines in the following diagrams has been done for 1000 kW capacity. This means that when a unit of T_1 is used for a particular city it must be met by 4 units of T_2 and 10 units of T_3 to be the power capacity of each type equal to 1000 kW. Fig. 5 presents (for the selected cities and turbines) the change in hourly EPG during a year as well as the contribution of wind turbine in reducing CO_2 and H_2S if used instead of the gas turbine. Because of the availability of wind speed in the summer at higher value than required, the EPG in this season will be more than the others but differ from a country to another. Where these values are close in Baghdad and Basra because they have convenient value of wind speed. While the Mosul city has lower EPG although it has the highest altitude from sea level. The emissions of CO_2 and H_2S depend on the amount of EPG in the power plants by a linear relation, this explains that these gases have the same behavior if compared with the demeanor of EPG. Fig. 6 presents annual emissions for CO_2 and H_2S that can be reduced as well as the annual EPG. The comparison between the turbines in terms of maximum value of EPG, CO_2 and H_2S found that in Baghdad and Basra cities, T_3 is ranked first followed by T_1 then T_2. In general, the results obtained for the two cities are very close to each other because of the convergence of wind speed values. In Mosul city, this sequence differs, where T_3 is ranked first followed by T_2 then T_1 which be the minimum EPG. Generally, the results in Mosul have been reduced by almost half if compared with other two cities. The results of the economic analysis indicates to a different point of view. Where, Fig. 7 shows the estimated values of S_m during the lifetime of the turbine and N_r for each turbine and city. It shows that the turbine capacity is directly proportional to the S_m and vice versa with N_r. Where, T_1 has the largest S_m and lowest N_r. The values of S_m for Mosul appear to be significantly lower than the other two cities especially T_3, where its value is negative which means that during the lifetime of the device, the financial gain does not fill the money that will be spent on it. For this reason, the value of N_r became greater than the lifetime of the device.

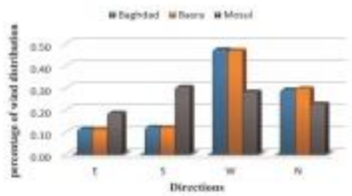

Fig. 4: Percentage of wind distribution according to directions

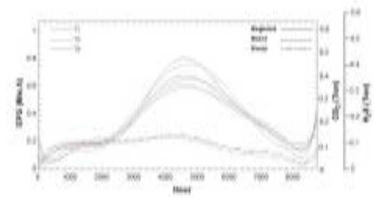

Fig. 5: Variation of EPG, CO2 and H_2S during a year.

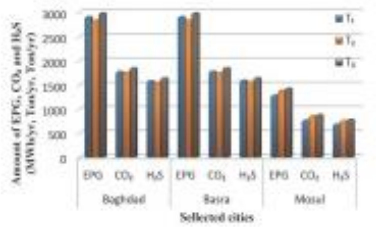

Fig. 6: The annual reducing of CO_2 emission, H_2S emission and EPG.

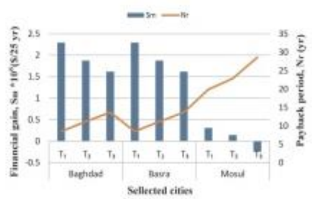

Fig. 7: Financial gain and payback period for chosen turbines and cities.

As is known, the interest rate and the discount rate are not constant throughout the life cycle of the turbine and the values that used in the equation are assumptions for the next 25 years depending on previous data's. Therefore, the interest rate and the discount rate should be assumed well to get results close to reality. Fig. 8 presents the changing in the S_m and N_r if the interest rate and the discount rate are equal and changes from 0 to 12 percent for Basra city as a model of the selected cities. The purpose of this figure is to indicate the changes that occur in economic results if the financial value of the country changes during the life span of the turbine It states that increasing in interest rate and discount rate leads to increase in N_r and decrease in S_m slightly. It tells us that when changing in interest rate and discount rate from 0 to 12 percent during lifetime of turbine doesn't affected to economic results significantly.

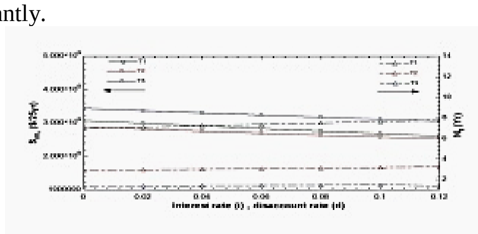

Fig. 8: Variation of S_m and N_r with respect to interest and discount rate for Basra city.

4. Conclusions

Wind turbine is the most environmentally friendly type in renewable energy that has the potential to produce electricity from wind energy without the use of fossil fuel. The main purpose of this study is to know the possibility of using these types of turbines in Iraq and to estimate the amount of electrical energy that can be produced. With the help of a life cycle assessment software SimaPro, the contribution of these turbines can be seen in reducing the environmental pollution in this country. In addition to conducting an economic analysis for the selected turbines. The main results for the selected cities and turbines are shown in Table 3 which can be concluded as follows:

Table 3: Annual EPG, CO_2, H_2S emissions, financial gain and payback period.

		T_1	T_2	T_3
Baghdad	EPG (MWh/yr)	2918.5	2840.8	2996.1
	CO_2 (Ton/yr)	1780	1752	1855
	H_2S (Ton/yr)	1588	1560	1647
	S_m ($/25yr) $*10^6$	2.294	1.874	1.617
	N_r (yr)	8.49	11.2	13.7
Basra	EPG (MWh/yr)	2919.1	2842.1	2997.2
	CO_2 (Ton/yr)	1785	1760	1858
	H_2S (Ton/yr)	1600	1566	1650
	S_m ($/25yr) $*10^6$	2.295	1.875	1.618
	N_r (yr)	8.48	11.14	13.66
Mosul	EPG (MWh/yr)	1248.9	1386.7	1432.9
	CO_2 (Ton/yr)	770	858	888
	H_2S (Ton/yr)	685	760	787
	S_m ($/25yr) $*10^6$	0.307	0.143	-0.244
	N_r (yr)	19.84	22.84	28.58

- The amount of EPG in Baghdad and Basra cities are very close to each other, and the reason is the convergence of wind speed values between them throughout a year. While these values are estimated to be less than half in the Mosul city because of the lack of suitable wind speed during a year which leads to work the turbine shorter periods of time.

- The comparison between the selected turbines in terms of maximum EPG indicates that T_3 is ranked first for the selected cities. While the second one is T_1 for Baghdad and Basra and T_2 for the Mosul city. This disparity in Mosul city is due to the low value of wind speed which enhances the small turbines work more efficiently. Because the values of CO_2, H_2S that can be reduced depend on the amount of EPG directly, the relationship of these values between the selected cities are the same as well as the sequence of the turbines.
- The comparison according to the results of the economic analysis presents that the turbine sequence for a largest S_m and lowest N_r for all cities, T_1 ranked first, followed by T_2 finally T_3 as worst on, especially in Mosul city where the value of S_m is negative, referring to the failure and loss of the project if used in this city, where its N_r is greater than the lifetime of the turbine.

- By looking at the results, it shows that the cities of Basra and Baghdad are the best in implementing the project and T_1 regarded the most suitable turbine in terms of maximum EPG and maximum quantity of CO_2 and H_2S which can be reduced in addition to the amount of S_m and N_r which encourage the investor to apply these type of turbine in these cities.

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