A TOPSIS Method to Evaluate Different Types of Power Plants in IRAN with Overview of the Clean Development Mechanism (CDM)

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Abstract: This paper aims to evaluate the most important factors in different types of power plants in order to identify the best option. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is used to perform the evaluation. The paper establishes the evaluation criteria from functional, performance, economic and also political aspect and international law and protection. TOPSIS method is proposed to ideal with linguistic evaluation information. Since the final ranking is the collective result, the bias in each single pre-ranking is eliminated & the selection is more objective and accurate. The data and below sample show the proposed model. The most dominant power plant proved to be natural gas power which ranked in the first place among 4 options. The research is helpful to evaluate the different alternatives.

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1. Introduction

In Power Generation Management System, based on the amount of pollutants, there are various options for its management addition to economic; there are also various time and environmental costs. Economic development is known as a key element in each country and energy is the most important and fundamental factor in development. Clean, low-cost power generation; these are the trends of energy market today, in a highly competitive environment with rising environmental concerns. Concepts like energy policy and greenhouse gas emissions reduction, that used exist in scientific discussions only, are now already a part of the national and international political scene. The warnings of the scientific community are now been taken into consideration and have a permanent place in conferences relevant to energy and the environment. The increasing world power consumption which is generated by means of fossil fuel consumption processes, has raised the CO2 concentration in the atmosphere. Considering this, the world community has already taken measures to reduce CO2 and other greenhouse gas emissions. Such reductions are possible by developing more efficient technologies, use renewable energy sources and utilizing new, cleaners fuels and implement supportive rules such as Clean Development Mechanism (CDM). Natural gas is a widely used fossil fuel that is cleaner than coal and petrol. It should be mentioned that there is abundance of natural gas and its utilization is constantly increasing in the last 50 years. Power plants that utilize natural gas have significantly lower emission than other fossil fuel plants.

The rational choice of power plant site, not only related to the quality, cost, schedule of the plant, and the source, economy of the construction of the plant, but also the problem of market competition and sustainable development. If you select the wrong site, it will increase the cost of electricity, and more critical, it will reduce competitiveness in the market to the plant. The potential influence of the irrationality site of the plant to the society and the environment imponderable. Therefore, the comprehensive evaluation and the optimizing site selection of any types of power plants practically important. In the feasibility study stage of any types of power plants, for sustainable development evaluation, must consider the combination of the social benefits, technical benefits and economical operation benefits. During the decision phase of each kind of power plant construction project, harmonization and coordination of the benefits must be weighed and these aspects of the comprehensive benefits must be considered.

There are many ways of evaluation for the site currently. Such as some qualitative evaluation methods. We can use the experience of experts, choose the right site, however, because this kind of method is not qualitative, and sometimes more difficult to rank the alternatives. This paper researches and establishes the model of comprehensive analysis that related to Gas Power Plant, Combined Cycle Power Plant, Diesel Power Plant and Steam Power Plant. This paper weighs the pros and cons of different kind of power plants in Islamic Republic of Iran since this issue is one of the most important pollutants in energy section (based on geographic areas)

2. TOPSIS Method

TOPSIS (Order Preference by Similarity to Ideal Solution) is proposed by Hwang and Yoon (Zadeh, 1965). It is assumed that the best alternative should have the smallest distance from the ideal solution and the farthest distance from negative solution. The comprehensive evaluation is being used by describing the various indicators of the object, if we regard index as variable, geometry will be formed in high-dimensional space. Each objects being evaluated by a number of indicators, the value of which reflect a point in the space. Therefore, from a geometric point of view, the object of evaluation are some points in the high-dimensional space, and the questions about comprehensive evaluation turn into the overall evaluation of cluster analysis is that, firstly. Identify the reference point, such as the optimal sample points, the worst such sample points, then, calculate the distance to the reference point from the optimal sample point as close as possible, the sample points from the worst as far as possible, and this is the basic idea of comprehensive evaluation method. The TOPSIS method could be presented as following steps (Hwang and Yoon, 1981).

Step 1. Calculate the normalized decision matrix.

The normalized value n_{ij} is calculated as:

(1) $$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}},$$

i = 1,2,..., m, j = 1,2,..., n

Step 2. Calculate the weighted normalized decision matrix.

The weighted normalized value v_{ij} is calculated as:

(2) $$v_{ij} = w_j n_{ij},$$

i = 1,2,..., m, j = 1,2,..., n

Where w_j is the weight of the ith criterion, and $\sum_{j=1}^{n} w_j$=1.

Step 3. Define the positive ideal solution (PIS) A^+ and negative ideal solution (NIS) A^- as:

(3) $$A^+ = (v_1^+, \dots, v_n^+)$$

$$A^- = (v_1^-, \dots, v_n^-)$$

Where for benefit criterion:

$v_j^+ = \max_i (v_{ij})$, j = 1,2,..., n

$v_j^- = \min_i (v_{ij})$, j = 1,2,..., n

For cost criterion:

$v_j^- = \max_i (v_{ij})$, j = 1,2,..., n

$v_j^+ = \min_i (v_{ij})$, j = 1,2,..., n

Step 4. Calculate the distance d_i^+ and d_i^- of each alternative from PIS and NIS using the following equations, respectively:

(4) $$d_i^+ = \sum_{j=1}^{n} dis\ (v_{ij} - v_j^+),$$ i = 1,2,..., m

$$d_i^- = \sum_{j=1}^{n} dis\ (v_{ij} - v_j^-),$$ i = 1,2,..., m

Where, $dis\ (vij - v_j^+)$ is the distance between evaluation value of alternative I and FPIS on the j criterion, $dis\ (vij - v_j^-)$ is the distance between evaluation value of alternative I and NPIS on the j criterion.

Step 5. Calculate the relative closeness to the ideal solution. The relative closeness Ri of the alternative Ai with respect to A^+ is defined as:

(5) $$R_i = \frac{d_i^-}{d_i^+ + d_i^-},$$ i = 1,2,..., m

According to the relative closeness degree Ri, the ranking order of the alternatives can be determined. If any alternative has the highest Ri value, then, it is the most describable alternatives.

3. Related literature

Past researchers have already applied TOPSIS in selection problem for different manufacturing facilities using various mathematical models, heuristics and MCDM techniques. The merit of MCDM techniques is that they consider both qualitative parameters as well as the quantitative ones. MCDM includes many solution techniques such as simple additive weighting (SAW), weighting product (WP) (Hwang and Yoon, 1981). The personnel selection problem, from the multi-criteria perspective, has attracted the interest of many scholars as in Saremi et al. (2009) and Seol and Sarkis (2005). Wang et al. (2006) present a model to select the exact web service based on user's preference Sun (2002) presented a logical and systematic procedure to evaluate the computer numerical control (CNC) machines in terms of system specifications and cost by using the technique for order preference by the (TOPSIS) method, which is observed to be quite capable of solving such type of multi-criteria decision-making (MCDM) problems

3.1. Description of Options

Four different types of options were selected for evaluation. It should be noted that there are differences in the levels of maturity of the technology of these options. Therefore, the data on emerging technologies may be preliminary and less reliable than the data of more mature technologies. However, it is interesting to see how upcoming and developing technologies perform compared to mature and established ones. Below follows a brief description of these types;

3.2. Open Gas-Turbine Power Plant (Single Cycle); A_1:

The use of gas turbines for generating electricity dates back to 1939. Today, gas turbines are one of the most widely-used power generating technologies. Gas turbines are a type of internal combustion (IC) engine in which burning of an air-fuel mixture produces hot gases that spin a turbine to produce power. It is the production of hot gas during fuel combustion, not the fuel itself that the gives gas turbines the name.

Fresh air enters the compressor at ambient temperature where its pressure and temperature are increased. The high pressure air enters the combustion chamber where the fuel is burned at constant pressure. The high temperature (and pressure) gas enters the turbine where it expands to ambient pressure and produces work.

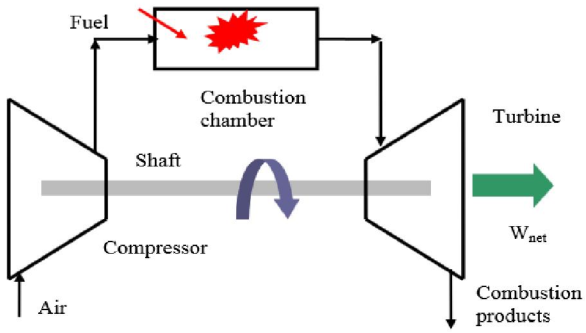


Fig.1: Schematic for an open gas-turbine cycle.

Features:

- Gas-turbine is used in aircraft propulsion and electric power generation.
- High thermal efficiencies up to 44%.
- Suitable for combined cycles (with steam power plant)
- High power to weight ratio, high reliability, long life
- Fast start up time, about 2 min, compared to 4 hrs. for steam-propulsion systems
- High back work ratio (ratio of compressor work to the turbine work), up to 50%, compared to few percent in steam power plants.

3.3. Combined Cycle Power Plant (C.C. Power Plant); A_2:

Combined cycle power plants feature gas and steam turbines. The gas turbine generates electricity using natural gas fuel, while the steam turbine generates electricity using waste heat from the gas turbine. The process is extremely efficient since exhaust heat is re-used that would otherwise be lost through the exhaust stack.

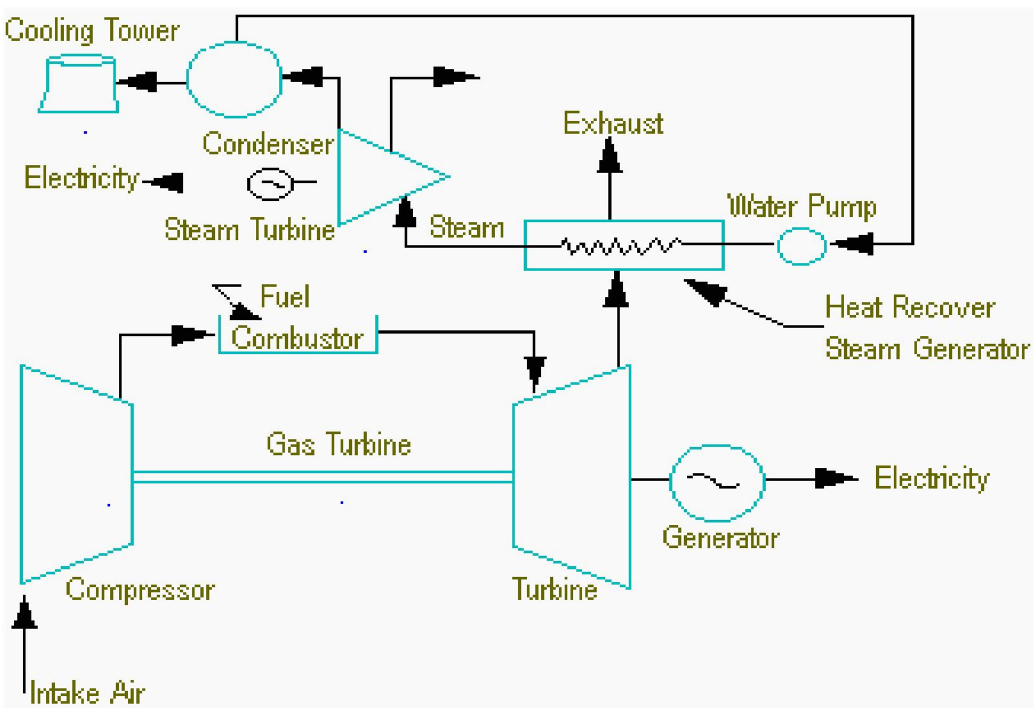


Fig.2: Combined cycle power plant scheme

A gas turbine compresses air and mixes it with fuel. The fuel is burned and the resultant hot air-fuel mixture is expanded through turbine blades, making them spin about a shaft. The spinning turbine drives a generator that converts the spinning energy into electricity.

- Fuel is burned in a combustor
- The resulting energy in the gas turbine turns the generator drive shaft
- Exhaust heat from the gas turbine is sent to a heat recovery steam generator (HRSG)
- The HRSG creates steam using the gas turbine exhaust heat and delivers it to the steam turbine
- The steam turbine delivers additional energy to the generator drive shaft
- The generator converts the energy into electricity

3.4. Steam Turbine Power Plant; A_3:

A steam-electric power station is a power station in which the electric generator is steam driven. Water is heated, turns into steam and spins a steam turbine. After it passes through the turbine, the steam is condensed in a condenser. The greatest variation in the design of steam-electric power plants is due to the different fuel sources.

Almost all coal, nuclear, geothermal, solar thermal electric power plants, waste incineration plants as well as many natural gas power plants are steam-electric. Natural gas is frequently combusted in gas turbines as well as boilers. The waste heat from a gas turbine can be used to raise steam, in a combined cycle plant that improves overall efficiency.

The electric efficiency of a conventional steam-electric power plant, is typically 33 to 48% efficient, limited as all heat engines are by the laws of thermodynamics.

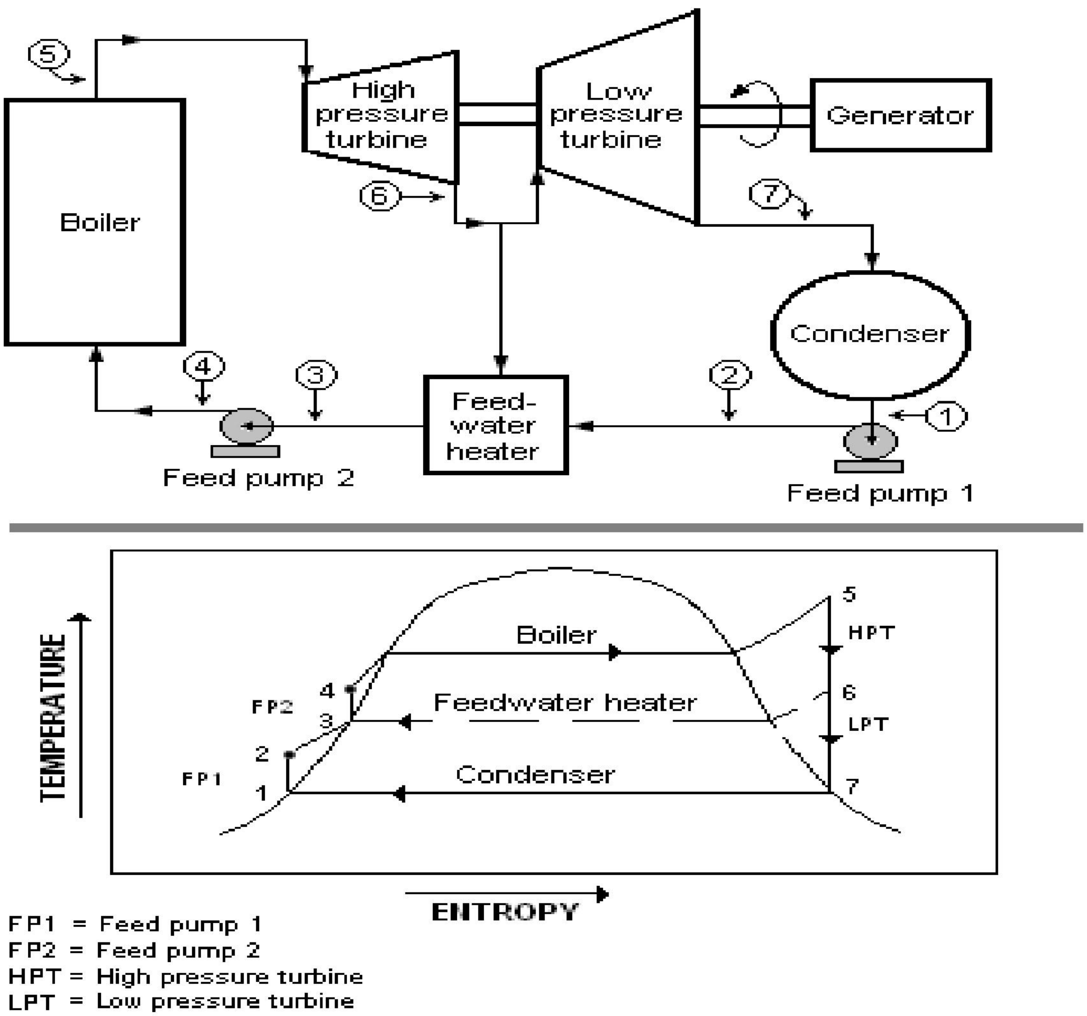


Fig.3: Steam power plant scheme

3.5. Diesel Turbine Power Plant; A_4:

Diesel power plants are divided into two main classes: stationary and mobile. Stationary diesel power plants use four-stroke diesel engines (less frequently, two-stroke diesel engines), with power ratings of 110, 220, 330, 440, and 735 kilowatts (kW). Stationary diesel power plants are classed as average in their power rating if the rating does not exceed 750 kW; large diesel power plants can have a power rating of 2,200 kW or more. The advantages of a diesel power plant are favorable economy of operation, stable operating characteristics, and an easy and quick start-up. The main disadvantage is the comparatively short interval between major overhauls. Diesel power plants are used mainly for servicing areas remote from transmission lines or areas where sources of water supply are limited and where the construction of a steam power plant or of a hydroelectric power plant is not feasible. Stationary diesels are usually equipped with synchronous generators.

4. Methodology Used (Description of criteria)

The criteria used for the evaluation of the selected power plants are:

1. Nominal Capacity; x_1
2. Operational Capacity; x_2
3. Gross Power Generation; x_3
4. Net Power Generation; x_4
5. Efficiency; x_5
6. N_2O Emission; x_6
7. CH_4 Emission ; x_7
8. SO_2 Emission; x_8
9. NO_x Emission; x_9
10. SO_3 Emission; x_{10}
11. CO_2 Emission; x_{11}
12. SPM Emission; x_{12}
13. CO Emission; x_{13}

Efficiency

The efficiency criterion is the quality measure of the system. It represents the percentage of the fuel's lower heating value (LHV) that is converted to useful electrical energy. Gas turbines in the simple cycle mode, only Gas turbines running, have an efficiency of 32 % to 38 %. The most important parameter that dictates the efficiency is the maximum gas temperature possible. The latest Gas Turbines with technological advances in materials and aerodynamics have efficiencies up to 38%. Diesel engines, large capacity industrial engines, deliver efficiencies in the range of 30 – 38 %. Combined Cycle power plant has an efficiency of 50 % and this range for steam turbine power plant is about 40%

Nominal Capacity

Nominal capacity, also known as the rated capacity, nameplate capacity, installed capacity or maximum effect, refers to the intended technical full-load sustained output of a facility such as a power plant.

Nameplate capacity is the number registered with authorities for classifying the power output of a power station usually expressed in megawatts (MW).

Nominal Capacity

The maximum output of power generators installed considering the environmental conditions.

Gross Power Generation

Total gross electricity generation covers gross electricity generation in all types of power plants. The gross electricity generation at the plant level is defined as the electricity measured at the outlet of the main transformers, i.e. the consumption of electricity in the plant auxiliaries and in transformers is included.

Net Power Generation

Net generation is the amount of electricity generated by a power plant that is transmitted and distributed for consumer use. Net generation is less than the total gross power generation as some power produced is consumed within the plant itself to power auxiliary equipment such as pumps, motors and pollution control devices.

Net Generation = Gross Generation - Usage within the plant

NO_X Emission

The NO_X emissions criterion represents the amount of nitric oxides (NO) and nitrogen dioxides (NO_2) that is released from the power plant in the atmosphere as a byproduct of the energy conversion process. It is measured in g/kWh. The option with the highest NO_X emissions is the natural gas turbine.

CO_2 emissions

The CO_2 emissions criterion represents the amount of carbon dioxide that is released from the power plant in the atmosphere as a byproduct of the energy conversion process. It is measured in ton CO_2 emissions for power plants.

Other Emissions

Based on manual balance sheet which approved and published by Department of the Environment (DOE) of Iran, all emissions from power plants measured with high measurement accuracy for each kind of power plants.

5. TOPSIS Evaluations

First, there are some points based on governmental law of IRAN should be mentioned as follow;

Data;

All data are gathered from official websites, Statistics and Information which have been released officially in year 2011- 2012.

Benchmark for Investment;

The national benchmark for investments in power plants as confirmed by the Ministry of Energy (MoE) in Iran is used for investment for power plants. It is equal to 25% for a pre-tax project IRR. The financial analysis is done over the period of conversion or operation of the power plant.

Lifetime;

Since there is different kind of agreement in order to investment such as B.O.O (Build, Own, Operation), B.O.T (Build, Operation, Transfer), B.O.O.T (Build, Own, Operation, Transfer); the lifetime for power plant normally is considered about 20 years.

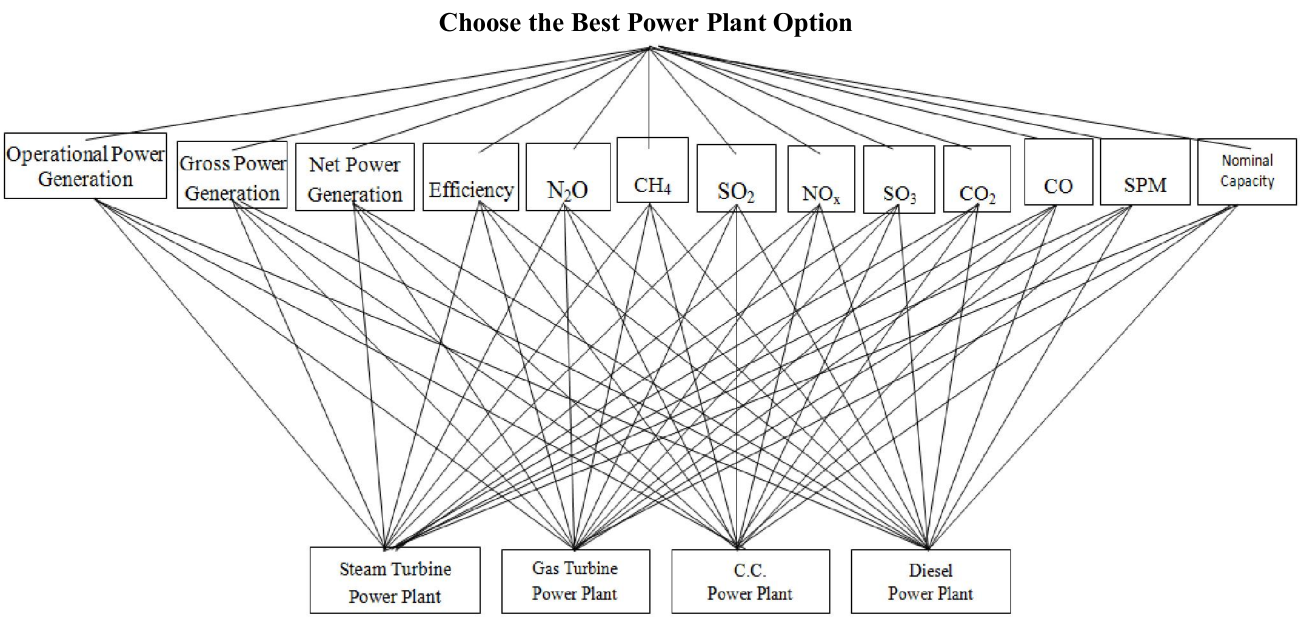
Electricity Price;

Accordance with paragraph (b) of Article (133) of the five-year development of the Islamic Republic of Iran, electricity cost per kWh should be 591.1 Rails with subsidy fuel and 1240.1 Rails with non-subsidy fuel. These amounts will be approved for each year by parliament and then impart to MoE.

The decision matrix made from the available information and data sources are made as follows and represented in Table I. The hierarchy of analytical hierarchy process is shown in Figure

Table1. The Decision Matrix, Available from Data Source.

	Nominal Capacity	Operational Capacity	Gross Power Generation	Net Power Generation	Efficiency	N2O	CH4	SO2	NOx	SO3	CO	SPM	CO2
Steam Turbine	14973	14568	92554	86243	0.4	350	1980	628400	235426	2911	134918	15025	76637541
Gas Turbine	12261	9809	30413	30180	0.3	98	627	30411	96063	738	3752	4782	26649450
Combined Cycle	14780	12166	72749	71389	0.5	139	933	24483	217797	960	5309	6954	35832456
Diesel	408	262	128	58	0.4	0.4	2	273	90	4	0.1	17	46073
Total	**42422**	**36805**	**195844**	**187870**	**1.6**	**587.4**	**3542**	**683567**	**549376**	**4613**	**143979.1**	**26778**	**139165520**



K=1/Ln m = 0.721

	Nominal Capacity	Operational Capacity	Gross Power Generation	Net Power Generation	Efficiency	N2O	CH4	SO2	NOx	SO3	CO	SPM	CO2
Steam Turbine	0.3530	0.3958	0.4726	0.4591	0.2500	0.5958	0.5590	0.9193	0.4285	0.6310	0.9371	0.5611	0.5507
Gas Turbine	0.2890	0.2665	0.1553	0.1606	0.1875	0.1668	0.1770	0.0445	0.1749	0.1600	0.0261	0.1786	0.1915
Combined Cycle	0.3484	0.3306	0.3715	0.3800	0.3125	0.2366	0.2634	0.0358	0.3964	0.2081	0.0369	0.2597	0.2575
Diesel	0.0096	0.0071	0.0007	0.0003	0.2500	0.0007	0.0006	0.0004	0.0002	0.0009	0.0000	0.0006	0.0003

Table2. The weight of Criteria.

	Nominal Capacity	Operational Capacity	Gross Power Generation	Net Power Generation	Efficiency	N2O	CH4	SO2	NOx	SO3	CO	SPM	CO2
Ej	0.8207	0.8078	0.7326	0.6684	0.9881	0.6873	0.7118	0.2438	0.6838	0.6608	0.2002	0.7114	0.7189
1-Ej	0.1793	0.1922	0.2674	0.3316	0.0119	0.3127	0.2882	0.7562	0.3162	0.3392	0.7998	0.2886	0.2811
Wj	**0.0411**	**0.0440**	**0.0613**	**0.0760**	**0.0027**	**0.0716**	**0.0660**	**0.1733**	**0.0725**	**0.0777**	**0.1833**	**0.0661**	**0.0644**

$\sum w_j = 1$

Table3. Weighted normalized decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
Steam Turbine	0.025	0.03	0.047	0.057	0.001	0.064	0.057	0.173	0.051	0.072	0.183	0.058	0.056
Gas Turbine	0.021	0.02	0.015	0.02	0.001	0.018	0.018	0.008	0.021	0.018	0.005	0.018	0.019
Combined Cycle	0.025	0.025	0.037	0.047	0.002	0.026	0.027	0.007	0.047	0.024	0.007	0.027	0.026
Diesel	0.001	0.001	0	0	0.001	0	0	0	0	0	0	0	0

In order to determining factor for a positive ideal and negative ideal solutions. The separation measures are stated in table 4;

Table 4. Positive ideal and negative ideal of each Criteria.

Criteria	Positive Ideal	Negative Ideal
C1	0.025	0.001
C2	0.03	0.001
C3	0.047	0
C4	0.057	0
C5	0.002	0.001
C6	0	0.064
C7	0	0.057
C8	0	0.173
C9	0	0.051
C10	0	0.072
C11	0	0.183
C12	0	0.058
C13	0	0.056

Calculating the distance from the positive and negative ideal solution and also the distance and proximity from the ideal positive and negative of each option are shown in Table 5.

Table 5. The distance from the positive and negative ideal solution & CL.

Row	Options	The Proximity to Positive Ideal	The Proximity to Negative Ideal	CL	Rank
1	A1	0.2920	0.0830	0.2210	4
2	A2	0.0680	0.2660	0.7950	1
3	A3	0.0770	0.2640	0.7760	3
4	A4	0.0830	0.2920	0.7790	2

5. Result

In the process of evaluation, TOPSIS method reflects the idea of the combination of quantitative analysis and qualitative analysis better. This method is simple and can transform complex Decision-Making Problem into clear and simple one. Throughout the evaluation process, this method not only eliminates the influence of subjective factors, and the results of the evaluation can be more objective. The results of ranking of the options by using TOPSIS method indicate that the third option is the top priority in comparison to other options as each option has a higher value will get a better rank.

6. Clean Development Mechanism (CDM)

3.1. What is the CDM?

Under the Clean Development Mechanism, emission-reduction projects in developing countries can earn certified emission reduction credits. These saleable credits can be used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol. The *CDM* allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tone of CO2. These CERs can be traded and sold, and used by industrialized countries to a meet a part of their emission reduction targets under the Kyoto Protocol. The mechanism stimulates sustainable development and emission reductions, while giving industrialized countries some flexibility in how they meet their emission reduction limitation targets. The CDM is the main source of income for the UNFCCC Adaptation Fund, which was established to finance adaptation projects and programs in developing country Parties to the Kyoto Protocol that are particularly vulnerable to the adverse effects of climate change. The Adaptation Fund is financed by a 2% levy on CERs issued by the CDM. The UNFCCC secretariat is mandated to support the Conference of the Parties and the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol and their associated bodies. In the case of the clean development mechanism (CDM), the secretariat is responsible for supporting the work of the CDM Executive Board, the decision-making authority on all CDM project activities.

6.2. What is validation?

Validation is the process of independent evaluation of a CDM project activity (or program of activities) by a Designated Operational Entity (DOE) against the CDM rules and requirements. It is a prerequisite for submitting a request for registration. Proposed CDM projects are validated in line with CDM rules and regulations based on the information contained in a project design document (PDD) which, at the beginning of the validation process, has to be published on the UNFCCC CDM website inviting comments from the general public.

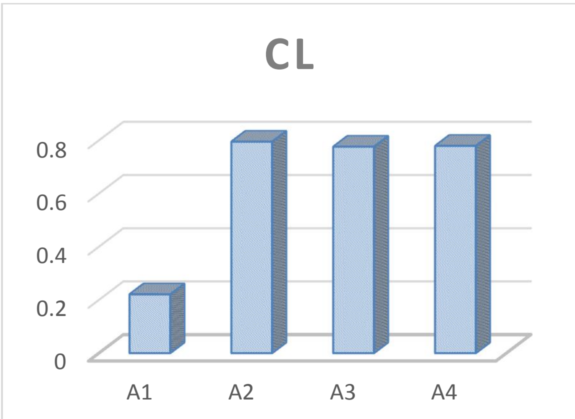


Fig.5: shows the ranking of the options.

6.3. What is the role of the UNFCCC secretariat in implementing CDM projects?

The UNFCCC secretariat does not provide individual project developers assistance in:

(a) Pre-appraising project ideas/proposals;

(b) Sourcing financing or expert help;

(c) Preparing required documents.

6.4. Clean Development Mechanism (CDM) and the position of Iran

One of the important mechanism use to monitor and reducing emissions is Clean Development Mechanism (CDM). The mechanism includes those projects which implement in developed countries in order to fulfill their commitment emission reduction and contributing to sustainable development in developing countries. So far, 76 developing countries have attempted to define and register CDM projects. Based on TOPSIS method and as result shows and with reference to distance between Gas Turbine Power Plant and Combined Cycle Power Plant, C.C. is not the first beneficial option but as UNFCCC supporting developing countries by this mechanism, this type of power plant can be economical and also in terms of environmental benefits is appropriate. Iran have already registered many projects based on Kyoto protocol in UNFCCC. Since combined cycled power plants will bring revenue by reducing the amount of greenhouse gases based on methodologies which are approved by UNFCCC. Moreover, by converting open cycle power plant (Gas Turbine power plant) to combined cycle, the efficiency and operational capacity will increase obviously.

The largest project (registered) in Iran up to now, is Jahrom combined cycle power plant with 897,000 CER per year.

It should be noted that the largest project with a 1'364'761 CERs is for MAPNA Pareh Sar combined cycle power plant (greenfield) is being reviewed and certified by Designated Operational Entities (DOE) which is located in north of Iran that Arian Jahan Energy Co. is working on it as consultant. It should be mentioned that at this step, we can name another 4 large scale projects which are being reviewed and certified by DOE are important for Iran, South Isfahan C.C. power plant and Genaveh C.C. power plant (MAPNA & Arian Jahan Energy Co.) and also Yazd C.C. power plant and Islam Abad C.C. power plant (FARAB Co. & Arian Jahan Energy Co.).

The national benchmark for investments in power plants as confirmed by the Ministry of Energy in Iran is used. It is equal to 25% for a pre-tax project IRR. The financial analysis is done over the period of conversion and operation of the power plant.

The sensitivity analysis confirms the outcome of the benchmark analysis, since under all scenarios the IRR remains below the benchmark. Only with unrealistic variations in the parameters will the project activity hit the benchmark. The result that combined cycle power plants are not an attractive investment in Iran without CDM is confirmed by the results of the World Bank Iran Power Sector Note. This shows that combined cycle power plants without CDM are not cost competitive in Iran, mainly because of the very low price of natural gas. This confirms the outcome of benchmark analysis.

In short, Combined Cycle Power Plant with CDM can bring more revenue than other types.

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