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Multi-criteria sustainability assessment of water desalination and energy systems — Kuwait case

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ABSTRACT

The complexity expressed through the definition of sustainability notion and its application is a triple vision: preservation of energy resources and protection of environment, achievement of social values and justice within the present and for future generations, and as well as sustainable economic development. In order to reach this vision the multi-criteria assessment of water and energy systems is needed. Scarcity of water and energy resources implies the need for a new future strategy in the development of water and energy technologies. In particular the water desalination technology is important for regions with high shortage in natural water resources. Even in countries with abundant energy resources there is a need for evaluation of its use for the water production. Water desalination and power technologies have been closely related in the development of future energy strategy. Primary goal in this development was the economic validation of potential technologies. With new technologies in this field, it becomes of great interest to introduce multi-criteria evaluation in the assessment of different approaches. This implies the need to take into a consideration the environment, technological and social aspect of water and energy technologies. Demonstration of the multi-criteria evaluation of cogeneration electric power and desalting water plants is presented for the Kuwait case with attention to strategy development for the period 2010–2015. It is imminent to the development of new water and energy technologies to take into consideration different concepts of cogeneration systems. In this respect, we will focus the attention in this analysis to the following combined cycle's options: electricity and water production "as usual"; electricity and water production by natural gas; electricity and water production by nuclear energy; electricity and water production by solar energy. For each of these options different desalination technology is considered, including: multi stage flash (MSF), multi effect distillation (MED), and reverse osmosis (RO) desalting systems. The multi-criteria assessment method, based on the economic, environmental, technological and social criteria with respective indicators, is used in the evaluation of water and energy production options. It will comprise cases with economic, environmental, technological and social indicator priorities in comparison with others indicators. This aim of the analysis is to assist the decision makers in selecting appropriate option.

Keywords: Sustainability; Multi-criteria; Water desalination economic indicators; Environment indicators; Technological indicators; Social indicators; Electric power and water co-generation

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1. Introduction

Fresh water availability is essential commodity for any modern society to survive. It is a life support system commodity [1]. The evaluation of the available water resources, its geographical distribution, and forecasting its consumption are necessities in the planning process to satisfy the water needs for any country [2,3]. In Kuwait, there is almost no natural water resources. The country depends on desalting seawater to satisfy its major water demands, more than 93%, while the balance is obtained by mining non-renewable groundwater. The latter is diminishing in quantities and deteriorating in quality. In 2007, the renewable water resources in Kuwait were estimated by 8 cubic meters per year for each person (m^3/y.p), while 1000 m^3/y.p marks the water poverty line. Meanwhile, the municipal water consumption per capita is among the highest in the world, more than 500 litters/capita/d (l/d.p). Desalting seawater is an energy intensive process and it is very expensive especially with the increase of fuel cost, and inefficient use of energy in some desalination process. This creates interest into looking for a sustainable way to continue desalting seawater, and this is the subject of this paper.

1.1. Water scarcity

Natural water resources in Kuwait are very limited, and its water problem is predicted to increase significantly, mainly as a result of increases in population and standard of living. Desalination and reclaiming the waste waters are the only options Kuwait have, to satisfy its water needs. The desalting seawater cost is several times the cost of water obtained by the conventional means. The Gulf Cooperation Countries (GCC) are heavily subsidizing the water prices to render it affordable. However, in most of these countries, water is highly subsidized to the extent that the public have no incentives to curb their high water consumption. The water consumption would be greatly reduced if the charged prices are closer to the real cost of the water production.

1.2. Water and energy demand in Kuwait

Kuwait had a pioneering role, not only in using, but in the developing both the desalination technology and its combination with the power plants to form what is known as co-generation of power and desalting plants (CPDP). The first inland CPDP was built in Kuwait in 1953. The first ever multi-stage flash (MSF) desalting system, based on Professor Silver design, was built in Kuwait in 1960, and was developed in Kuwait to reach its status as most reliable desalting system. However, with the expansion of the CPDPs with their fuel consumptions became so high to the extent that in short time, say in less than 30 years, all the produced fuel oil (the main source of the country's income), can be consumed locally, if the same rate of expansion prevails [4]. The water problem in Kuwait is very serious, and can cause real crisis any time. The desalting plants, the main water resource available, are vulnerable to: any malfunction, the oil spill in the Gulf sea, the lack of enough fresh water storage capacity, and the continuous increase of water consumption and waste. Moreover, the existing daily desalting water plants capacity is less than the maximum daily water consumption, and if any one of the main five existing CPDP was forced to shut down; water cuts are to be forced. The groundwater extraction rate is at many folds of its replenishing rate, and its quality is becoming unacceptable even for agricultural and industrial uses. Although the waste water is treated to potable water quality, its use as the potable water is not considered due to the psychological and religious reasons.

1.3. Electricity and water production in Kuwait

The first steam power plant (PP) was built in Shuwaikh, Kuwait in 1952. It had three steam turbine (ST) units of 750 kW each, (expressed here as 3 × 750 kW ST). Besides the power production, these steam turbines supplied steam (by extracting from the turbines) to desalting units built on the same site, in what is known as the first in-land co-generation power desalting plant (CPDP), producing both electric power and desalted seawater. More steam turbines ST (and desalting units) were built in the Shuwaikh PP later as follows: 4×7.5 MW ST in 1955, 4×10 MW ST in 1958, and 4×30 MW ST in 1962. Several power plants (PP), other than the Shuwaikh PP, were built later but with steam turbines (ST) as the main working horse for power production, and with steam extracted from the ST to the desalting multi-stage flash (MSF) units. So, all these plants are working as the cogeneration power desalting plants (CPDP) as shown in Table 1.

In 2003, the CPDP in Kuwait consisted of ST having 8970 MW total installed capacity and small capacity units of gas turbines (GT) of 219 MW total capacity. The latter GT are used for peak load operation and with the blackout starting within 10 min, while this takes about five hours for ST.

The use of ST for the power production in Kuwait followed the 1980's general world trend of using ST in the PP, when the share of gas/steam turbines combined cycle (CC) plants was very limited. In the 1990's, the share of CC increased very rapidly in the world due to extensive improvements in the GT. These improvements in GT resulted in the reliable CC technology and low capital cost of the CC plants compared to ST cycle of the same capacity. The natural gas availability at low cost in many parts of the world and the high efficiency of the CC, (and thus the use of less fuel with less impact on the environment) promoted the share of the CC all over the world. Today the CC type PP becomes the preferred choice of power plants in most areas in the world, particularly in the Gulf region. The CC equipment costs are less than that of the

Table 1
Steam and gas turbine power plants in Kuwait

Date commissioned	Capacity of the gas turbine	Date commissioned	Capacity of the steam turbine	Plant
1965–1968*	2 turbines × 25 MW	1965–1968	5 turbines × 70 MW	Shuaiba North
		1970–1974	6 turbines × 134 MW	Shuaiba South
1981	6 turbines × 18 MW	1977–1979	7 turbines × 150 MW	Doha East
		1983–1984	8 turbines × 300 MW	Doha West
1987–1988	4 turbines × 27.75 MW	1987–1989	8 turbines × 300 MW	Azzour South
		1998–2000	8 turbines × 300 MW	Sabbiya

*This plant was destroyed during Iraqi invasion

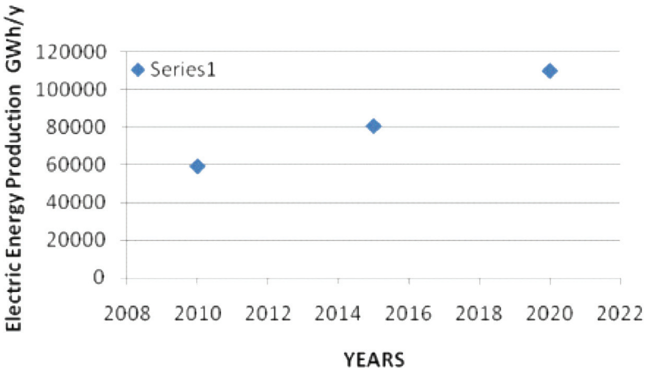


Fig. 1. Development of installed capacity of the power plants in Kuwait [4].

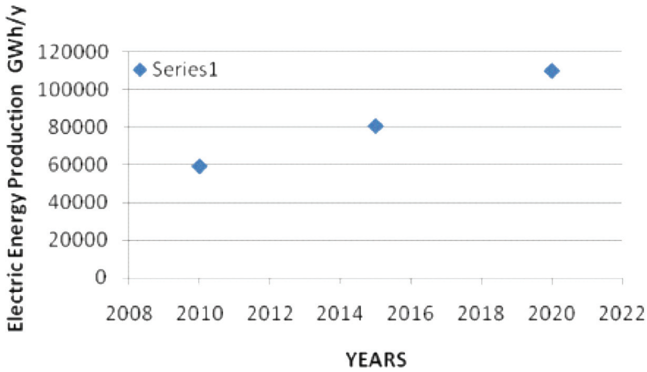


Fig. 2. Development of water production capacity in Kuwait [4].

conventional ST plants. The combined cycle CC plants are operating in several parts of the world with net efficiencies over 55%, whereas the best efficiency reported for the ST plants is in the range of 40%.

2. Water and energy strategy development for Kuwait

2.1. Option selection

The options of cogeneration power-desalting plants CPDP types considered here to produce the electric power and desalt seawater in Kuwait are evaluated to see which is more sustainable compared to the others. The conducted analysis concerns the period of 2010–2015. The forecasted installed capacities required for electric power and desalting plants are given in Figs. 1 and 2. In Kuwait, the crude oil fuel production is much higher than that of natural gases. This forces the Ministry of Electricity and Water, MEW to depend heavily on the crude fuel oil in the operation of CPDP, compared to natural gases. Table 2 shows the country's crude oil and natural gas productions and consumptions. This table indicates that the consumed natural gas is much higher than its Kuwaiti production and as a result natural gas is imported from abroad.

Table 2
Kuwait crude oil and natural gas productions and consumptions in equivalent 1000 barrel/d

Year	Crude oil production	Natural gas consumption	Crude oil consumption	Natural gas production
2001	1947	79.4	248.12	4.34
2002	1746	68.3	278.39	8.04
2003	2107	73.2	299.06	7.12
2004	2288	79.2	327.76	6.54
2005	2573	82.2	343.27	5.67
2006	2646	86	364.16	6.21

In this analysis, the attention is focused on the number of options for the combined power and water desalted water production.

It is assumed that in the period of 2010–2015, the production increase will be 20000 GWh for electric power and 250 Mm^3 for desalted water [6]. The potential options of the CPDP for electric power and desalted water production, are to be chosen based on the following considerations.

2.1.1. Electricity and water production "as usual"

The electricity and water production "as usual" is focused on the presently used pattern based on the cogeneration of power and water desalting plant CPDP using steam turbines with typical efficiency of 36%. It is anticipated that this system can be taken "as usual" pattern for future Kuwait strategy development. In these CPDPs, heavy oil is used as fuel to operate steam generators. The generated steam is supplied to extraction-condensing steam turbines (ST). In this ST, part of the expanded steam is extracted to MSF desalting units, as at 2–3 bar, while the balace continues to expand to the condenser say at 10 kPa. The extracted steam to the MSF units supplies these units with its thermal energy requirements, in the range of 260 kJ/kg of desalted water. The MSF units consume mechanical energy to operate their pumps, at the rate of 4 kWh/m^3. The specific equivalent energy, counted for both mechanical and thermal energy, (SEE), consumed by the MSF desalters is in the range of 20 kWh/m^3. The MSF desalting system is known by its high energy consumption.

2.1.2. Using natural gas for electricity and water production

Recently, it has become very attractive, and economically and ecologically justified to use natural gas (NG), compared to heavy oil, as the energy source for the electricity and water production in CPDP. Natural gas utilization is used to operate combined cycle (CC) of gas turbine (GT) as upper cycle and steam turbine (ST) as bottoming cycle. The efficiency of the CC is in the range of 48–52% (depending on the environment temperature), which is much higher than that of ST cycle of 36%. In this analysis, low temperature multi effect distillation (MED) desalting system is anticipated to be combined with ST of the bottoming cycle. The MED consumes thermal energy by steam at temperature (in the range of 70°C), lower than that used by the MSF units (of 120°C), and thus the steam consumed by the MED has lower availability (exergy). Also, the pumping energy of the MED is in the range of 2 kWh/m^3. This makes the SEE of the MED in the range of 10 kWh/m^3. Also, seawater reverse osmosis (RO) desalting system can be operated by the electric power output of the CC cycle. The RO is the most efficient, energy wise, desalting system. It consumes only mechanical energy with SEE in the range of 4 kWh/m^3 for seawater when energy recovery system is used [7–9].

2.1.3. Electricity and water production by nuclear energy, nuclear power desalting plants (NPDP)

For a long time nuclear energy (NE) was considered as the potential option for electricity and water production [10,11]. Recently, it has been shown attractive to consider NE for the electricity and water production, i.e. nuclear combined power-desalting plants (NCPDP). In this analysis, the anticipated nuclear power plant is based using pressurized water reactor. This is the most used type of reactors in power plants with more than 50 years experience in design, operation and maintenance. There are different combinations of desalting systems with NCPDP. The NCPDPs are characterized by its high capital cost (in the range of $3000/kW installed capacity (compared with $850/kW for CC), and low nuclear fuel cost (compared with the NG cost used in the CC. The MED desalting system can be combined with the steam turbine of the NCPDP; and/or the NCPDP can operate seawater RO desalting system.

2.1.4. Electricity and water production by solar energy (SE)

Abundant solar energy (SE) resource has been always considered as a potential option for desalting seawater [12,13]. As the solar energy conversion directly to electricity by photovoltaic PV has become commercially available, it is of great challenge to consider it for desalting seawater. The PV power plant is characterized by its intermittent power output, with capacity factor in less than 20%, compared to 90% for NCPDP or CC. This means that the nominal capacity of PV power plant should be 4–5 times the capacity of NCPDP or the CC to produce the same amount of electricity. Moreover, the conversion efficiency of the PV from solar to electricity is in the range of 15%. The practicality of using PV for large power plants of more than 50% is very questionable. As the output of the PV power plant is only electric power, the use of desalting system is limited to mechanical operated desalting systems. These include, besides, the seawater RO, the mechanically operated vapor compression desalting system (MVC). The MVC is characterized by its low capacity/per unit (less than one million imperial gallons per day MIGD or 4546 m^3/d). The MVC energy consumption is in the range of 8–10 kWh/m^3. So, its SEE is in the range of the MED. Also the high capacity units use multi effect arrangement similar to the MED system, but with no thermal energy consumption. Since the MVC has almost the same SEE, and using multi effect arrangements as the MED system, both system will be referred as MED system.

So, the following options are specifically considered for CPDP:

- Option 1: As usual using ST, fuel oil with MSF desalting.
- Option 2: Using NG with MED for desalting
- Option 3: Using NG with RO for desalting

- Option 4: Using (NE) with MED for desalting
- Option 5: Using NE with RO for desalting
- Option 6: Using Solar PV in CPDP and MVC for desalting
- Option 7: Using Solar PV in CPDP and RO for desalting

2.2. Criteria for evaluation of water and energy cogeneration systems

The quality of systems under consideration is defined by the specific criteria used for the evaluation of the system under consideration [14–16]. Criteria for the assessment are quantified by the respective indicators. The quality assessment of energy and water cogeneration systems strongly depends on the selection of indicators to be used in the evaluation of options under consideration. There are several groups of indicators which are relevant for the assessment of quality of options. In general, the quality can be defined by different indicators defining the specific quality of the options under consideration. Among those indicators there are groups of sub-indicators comprising sub-quality of the system.

2.3. Indicators

Evaluation of different options of energy and water cogeneration plants is based on the respective criteria [17]. The assessment of specific option comprises the selection of criteria to be used in the procedure. The criteria define the specific quality of the system and are numerically defined by the respective values of the indicators. In this analysis, the following indicators are used for electric power and desalted water production systems: economic indicator, environment indicator, technological indicator and social indicators. Each of this group of indicators is linked to the definition of specific criteria. In this evaluation the following indicators: economic indicator defined with sub-indicators such as efficiency, water cost, electricity cost and investment cost; environment indicator has sub-indicators such as CO_2 emission, NO_x emission and SO_2 emission; technological indicator defined by sub-indicators of market and development capital, and social indicator sub-indicators include new job opening, in water and energy system area and health.

As shown in Table 3 numerical values for all sub-indicators are defined. Using these data we can compare options under consideration and obtain specific rating among them.

This type of evaluation will lead us to the single parameter analysis which has limited domain in the assessment energy and water cogeneration systems. In order to overcome this limitation we can calculate economic indicator, environment indicator, social indicator and technological indicators.

2.3.1. Economic indicator

As given before, the economic indicator includes the sub-indicators of electricity cost, water cost and investment [18]. The electricity cost is defined as the unit cost for power production of the respective power plant. Definition of the water cost indicator is obtained from the following reference [19] as desalting water cost per m^3 of desalted water. Investment indicator is obtained as the total amount to be used in the construction of CPDP of total capacity for the period 2010–2015 [20,21].

2.3.2. Environment indicator

Environment indicator includes total emission of the CO_2, NO_x and SO_2 due to the power and water production for the period 2010–2015 [18] by the respective CPDP. In this analysis, it is assumed that nuclear and solar PV plants are having zero emission. Oil and gas fired power plants emission is defined as shown in [20]. Emission of CO_2, NO_x and SO_2 from water production plants is taken from [18].

2.3.3. Technological indicator

Technological indicator is defined by the market [20] and development capital sub-indicator [21]. It is anticipated that total market for the period 2010–2015 is 46 billion USD [22]. Division among the options under consideration is introduced by the subjective assessment of authors. Development capital is defined as the amount defined as 4% of total market price divided among options by the technology forecast expectation defined by the author.

2.3.4. Social indicator

Social indicator comprises new job opening and health sub-indicators. New job opening sub-indicator defines the men-power obtained by respective operation and maintenance cost for the total power and water capacity for the specific option [21]. Health sub-indicators is defined as the health cost caused by the NOx emission for the respective option under consideration [22].

Table 3 presents the numerical values of indicatos as specified.

3. Multi-criteria assessment of water and energy cogeneration systems

The next step is the evaluation of the agglomeration of sub-indicator. In doing this, specific procedure is adopted in order to obtain the values of indicators reflecting priority of the sub-indicator in definition of the agglomerated value for all indicators. The procedure for formation of the agglomerated indicators is based on the multi-criteria method for the assessment of the systems under consideration.

Table 3
Indicators

Option	Technological indicator	
CPDP	Market US$×10⁹	Development capital US$×10⁶
As usual, ST and fuel oil	9.6	25
Using NG and MED	9.6	50
Using NG and RO	4.8	75
Using NE and MED	7.2	100
Using NE and RO	7.2	160
Using solar PV and MED	4.8	75
Using solar PV and RO	4.8	75

Option	Environmental indicators		
CPDP	CO_2 emission 10^6 kg	NO_x emission 10^6 kg	SO_2 emission 10^6 kg
As usual using ST and fuel oil	24850	63.80	47.07
Using NG and MED	16300	43.33	106.62
Using NG and RO	12095	38.97	102.50
Using NE and MED	4650	5.35	6.62
Using NE and RO	445	0.967	2.5
Using solar PV and MED	4650	5.35	6.65
Using solar PV and RO	445	0.97	2.5

Option	Economic indicator		
	Electricity cost	Water cost	Investment 109
CPDP	€/kWh	€/m³	€
As usual ST and fuel oil	0.035	0.40	2.48
Using NG and MED	0.067	0.46	2.06
Using NG and RO	0.067	0.42	2.65
Using NE and MED	0.046	0.46	3.53
Using NE and RO	0.046	0.65	4.02
Using solar PV and MED	0.11	0.75	15.49
Using solar PV and RO	0.11	0.65	15.78

Option	Social indicator	
CPDP	New job opening	Health
	103	€×10⁹
As usual using ST and fuel oil	8.00	2.47
Using NG and MED	7.35	1.67
Using NG and RO	4.35	1.50
Using NE and MED	4.45	0.21
Using NE and RO	4.55	0.037
Using solar PV and MED	61.9	0.21
Using solar PV and RO	61.0	0.037

3.1. Multi-criteria method

The multi-criteria assessment is based on the decision making procedure [23] reflecting combined effect of all criteria under consideration and is expressed in the form of General index of sustainability. Selected number of indicators is taken as measure of the criteria comprising specific information of the options under consideration [24]. The procedure aim is to evaluate the selected options by the respective set of indicators.

The next step in the preparation of data for the multi-criteria sustainability assessment is getting an arithmetic weighting factors of the indicators.

This step consists of formation of particular membership functions $q_1(x_1), \ldots, q_m(x_m)$. For every indicator x_i we have: (1) to fix two values MIN $_{(i)}$, MAX $_{(i)}$; (2) to indicate is the function $q_i(x_i)$ is decreasing or increasing with the increase of argument x_i; (3) to choose the exponent's value λ in the formula

$$q_i(x_i)=\begin{cases} 1,\ \text{if } x_i \le \mathrm{MIN}(i), \\ \left(\dfrac{\mathrm{MAX}(i)x_i - x_i}{\mathrm{MAX}\ (i)-\mathrm{MIN}\ (i)}\right),\ \text{if } \mathrm{MIN}(i) < x_i \le \mathrm{MAX}(i), \\ 0,\ \text{if } x_i > \mathrm{MAX}(i) \end{cases} \quad (1)$$

for the deceasing function $q_i(x_i)$.

The functions $q_1(x_1), \ldots, q_m(x_m)$ formation process being finished with a matrix $(q_{i(j)})$, $i = 1, \ldots, m$, $j = 1, \ldots, k$, where $q_1(x_1), \ldots, q_m(x_m)$ are used. For q_1, q_2 and q_4 membership function the decreasing function are adapted.

The next step in this evaluation is the determination of the agglomerated indicators. The procedure for the determination of the agglomerated indicators is based on the statistical validation of contribution of individual sub-indicators [25]. The individual contribution of sub-indicators is difficult to determine with sufficient accuracy. In this respect the weighting coefficients are used to determine importance of individual indicator to the general object index. In order to overcome this deficiency, the agglomeration procedure is adopted which will lead to the aggregation of individual sub-indicators in the main group of indicators defined to the specific economic indicator, environment indicator, technological Indicator and social indicator. As it is shown individual sub-indicators are subset of the set of indicator reflecting attributes in the description of objects. Under constrain that the subset of sub-indicators belong to the set of general indicators as defined by the attributes, it is allowed to use the linear agglomeration function represented as follows

$$I_{\mathrm{agg}} = \sum_{i=1}^{m} w_i q_i \quad (2)$$

where I_{agg} — aggregated indicator, w_i — weighting coefficient for sub-indicator i, q_i — normalized value of sub-indicator i.

Table 4
Agglomerated indicators

	Economic indicator	Environment indicator	Technological indicator	Social indicator
	(Electricity cost > water cost = investment)	(CO_2 emission> NO_x emission= SO_2 emission)	(Market > development capital)	New job (opening > health)
As usual using heavy oil	0.827	0.0667	0.7625	0.1749
Using NG and MED	0.644	0.0584	0.7906	0.1807
Using NG and RO	0.632	0.2488	0.1036	0.1571
Using NE and MED	0.806	0.7964	0.6258	0.3261
Using NE and RO	0.798	0.9401	0.6841	0.35
Using solar PV and MED	0.12	0.7963	0.1036	0.9678
Using solar PV and RO	0.183	0.9801	0.1036	0.9902

Table 4 shows agglomerated values for economic, environmental, technological and social indicators under specific constrains.

3.2. Evaluation of options under consideration

In order to obtain priority list of the of the options under consideration, the agglomerated indicators: economic indicator, environment indicator, technological indicator and social indicator are used to form the general index defined as follows.

General index comprises formation of an aggregative function with the weighted arithmetic mean as the synthesizing function defined as

$$Q\left(I_{\text{agg}}, w\right) = \sum_{i=1}^{m} w_i I_{\text{agg}\,i} \tag{3}$$

where w_i — weight-coefficients elements of vector w, I_{agg} — aggregated indicators of specific criteria.

In order to define weight-coefficient vector the randomization of uncertainty is introduced. Randomization produces stochastic with realizations from corresponding sets of functions and a random weight-vector. It is assumed that the measurement of the weight coefficients is accurate to within a steps $h = 1/n$, with n a positive integer. In this case the infinite set of all possible vectors may be approximated by the finite set $W_{(m,n)}$ of all possible weight vectors with discrete components. In our case, we will use $m = 5$, and $n = 40$ so that the total number of elements of the set $W_{(m,n)}$ is $N_{(m,n)} = 92251$.

The nonnumeric, inexact and incomplete information is used for the reduction of the set $W_{(m,n)}$ of all possible vectors w to obtain the discrete components set $W_{(i,n,m)}$ it is defined as a number of constrain reflecting nonnumeric information about mutual relation among the criteria under consideration. The method has been demonstrated in the evaluation of number of system [25].

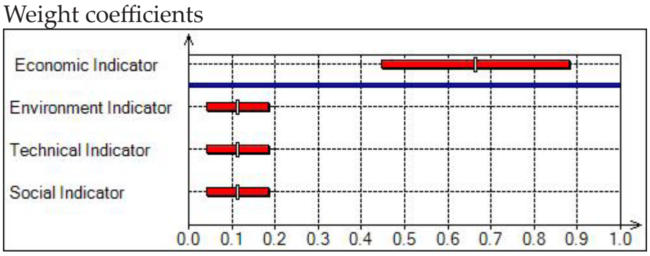
3.3. Selection of evaluation cases

In the evaluation of the potential options, we will take into consideration several cases which are examples to prove validity of the method. Following procedure for the assessment, the following cases are evaluated:

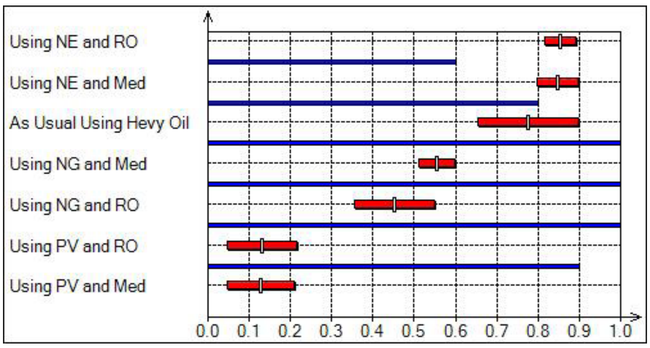
- CASE 1 – Priority given to the economic indicator
- CASE.2 – Priority given to the environment indicator
- CASE 3 – Priority given to the technological indicator
- CASE 4 – Priority given to the social indicator

CASE 1 - GENERAL INDEX with economic indicator (Electricity cost > Efficiency = Water cost = Investment) priority

Weight coefficients



General index



Red — General index and weight coefficients standard deviation
Blue — Probability of the dominancy among successive pars

Fig. 3. Weight coefficient and general index for Case 1.

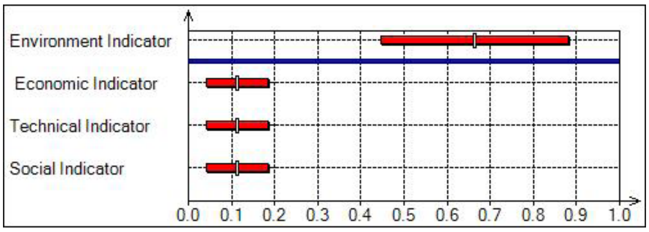
Case 1 is designed with economic indicator priority. It is anticipated that the economic indicator is calculated under constrain reflecting priority of electricity cost sub-indicator.

As it can be noticed from Fig. 3, options CPDP using NG with RO, CPDP using NG with MED, and NPDP as usual with heavy oil, are having marginal difference in general index rating. This proves that electricity cost sub-indicator is having positive effect on the general index rating and adds equalization among the options under consideration. Other options are having deceasing values general index with substantial change.

CASE 2 - GENERAL INDEX with environment indicator (CO_2) emission

NO_x emission = SO_2 emission) Priority

Weight coefficients



General index

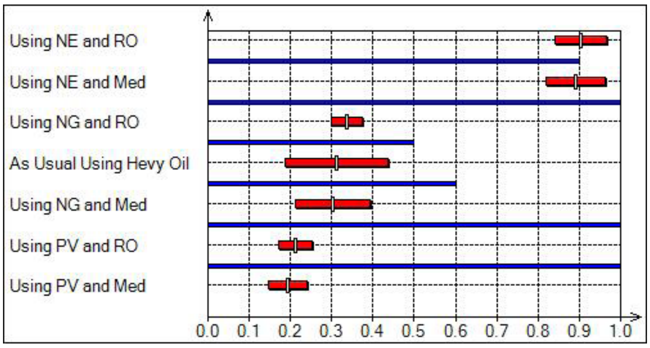
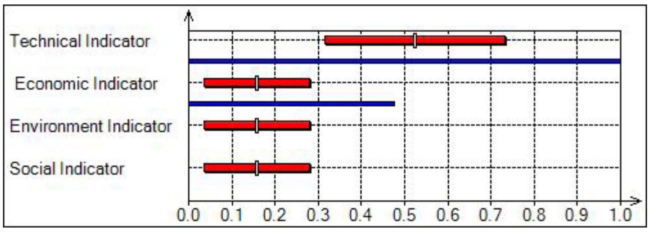


Fig. 4. Weight coefficient and general index for Case 2.

Case 2 reflects the effect of environment indicator with CO2 emission sub-indicator priority on the general index rating under this constrain. As it can be noticed in Fig. 4 for this case, there are two groups of options with substantial difference in the priority list rating. First group includes NE with-RO, solar PV with RO, NE with MED and solar PV with MED options. It obliviously reflects the options including reverse osmoses as the desalination technology with nuclear and solar energy electricity production options. Second group are options with natural gas and oil fired power plants

CASE 3 — GENERAL INDEX with technological indicator (Market > Development capital) priority

Weight coefficients



General index

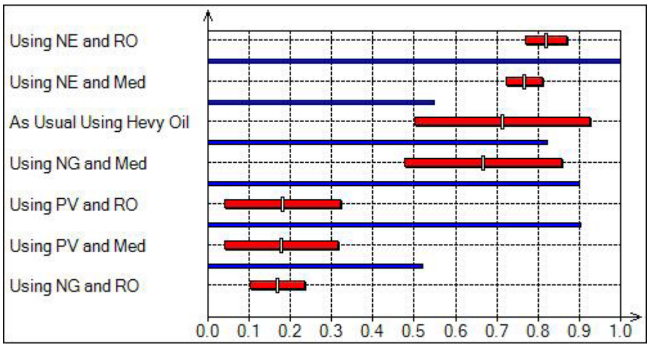


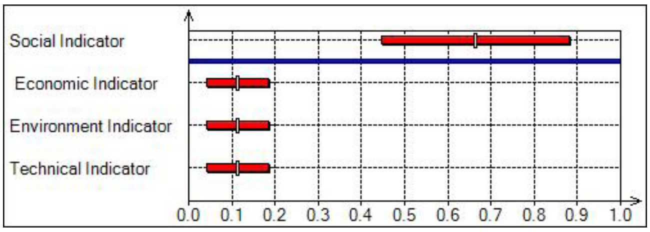
Fig. 5. Caption ????

Case 3 is designed to investigate the effect of the technological indicator with priority given to market sub-indicator Fig. 5. The market priority strongly effects division among the options under consideration. First group on the rating list includes NE with RO, as usual case wit ST with MSF desalting, NE with MED, option followed by solar PV with RO, solar PV with MED and NG with RO. This proves that the market sub-indicator within the technology indicators is having substantial role on the formation of the priority list.

CASE 4 — GENERAL INDEX with social indicator (New job opening > Health) priority

Case 4 is designed to show the effect of the social indicator based on the priority of the New job opening sub-indicator on the rating list among options under consideration. Since solar energy utilization requires high manpower, it expected that options with energy production by solar energy will have priority on the rating list. .In this case other options are having position on the rating list in accordance with the desalination technologies used for water production.

Weight coefficients



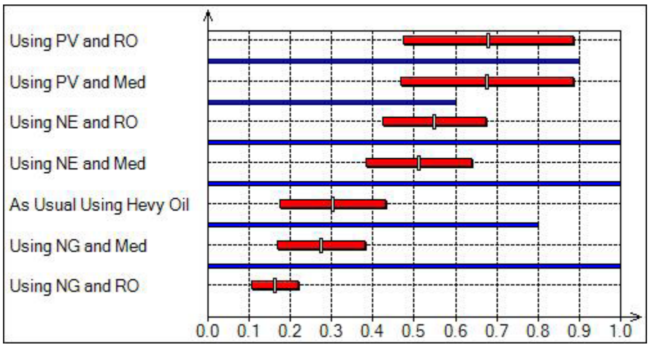


Fig. 6. Weight coefficient and general index for Case 4.

3.4. Sustainability index rating

The general index rating is the result of evaluation of the cases, reflecting constraints introduced in assessment procedure. It is of interest to notice the effect of different constraints to the final priority list. In this analysis we have taken into a consideration only limited number of cases so that the final conclusion can be obtained within this constraint. If it is assumed that we put together all cases we have taken into consideration and adding their general index we will obtain agglomerated rating list as shown in Table 5.

It should be emphasized the rating list obtained in this analysis is based on the data collected from the references given in the reference list. Also, it is of interest to mention that the result obtained is subject the reconsideration if the method should be applied to the specific cases. If this method of evaluation will be used in any specific cases special attention has to be devoted to the evaluation and selection of the specific indicators.

Table 5
Agglomerated rating list

Cogeneration power desalting CPDP rating options	
1	NE with RO
2	NE with MED
3	As usual with ST and MSF
4	NG with MED
5	Solar PV with RO
6	Solar with MED
7	NG with RO

4. Conclusions

It is of interest for this evaluation to investigate to what extend of the multi-criteria analysis can contribute to the appropriate assessment of the potential option for the strategic development and selection of the cogeneration options. In this respect, from this analysis we have learned that nuclear energy as the energy resource for the cogeneration power desalting plants CPDP is promising route to be used in the future strategic development of energy and water production. Also, solar energy is one of the promising resources for the energy and water cogeneration option under multi-criteria assessment. It should be mentioned that present technology based on the oil-fired steam production coupled with multi-stage flashing desalination is one of the options to be considered as the promising choice.

Demonstration example for the Kuwait selection of the appropriate energy and water cogeneration option is used as the exercise of the procedure for the multi-criteria assessment of the potential options to be used into a consideration for the decision making in selection of the appropriate cogeneration system.

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