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Realistic power and desalted water production costs in Qatar

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ABSTRACT

Water security in Qatar is of main concern. Low water pricing in Qatar does reflect the real value of water. The high cost of desalted seawater (DW) calculated in this paper calls for the use of more energy efficient desalting system such as the SWRO system in place of the multistage flash (MSF) and multieffect thermal vapor compression (METVC) methods presently used. Both MSF and METVC use thermal energy of about 270 kJ/m^3 and pumping energy of 2–4 kWh/m^3. In this paper, the mechanical energy equivalent to the thermal energy supplied to the MSF (or METVC) systems is calculated. When added to the pumping energy, it gives the specific consumed energy of more than 20 kWh/m^3, compared to 4–5 kWh/m^3 for SWRO system. Qatar's ground water (GW) is overexploited, depleted, and quality deteriorated, and thus the demand for DW is on the rise, with the more financial burden. Moreover, DW productions mean more air and marine environment deterioration. The water subsidization by the government should be reviewed, and water demand management should be applied. Wastewater should be treated for reuse to decrease the demand on both GW and DW. The calculated costs of DW at different natural gas price are calculated, and compared with the underestimated cost reported by the government.

Keywords: Power; Desalination; Cost; Qatar

1. Introduction

Qatar is an arid country that depends on desalted seawater (DW) to satisfy almost 99% of its municipal water needs. In Qatar and most Gulf Cooperation Countries (GCC), most seawater desalting plants (DP) are combined with power plants (PP) in what is called cogeneration power desalting plants (CPDP). The CPDP is adopted because of the used type of thermal DP, namely, multistage flash (MSF) and multieffect-thermal vapor compression (METVC). These plants require relatively low pressure (LP) steam (2–3 bar) as thermal energy input. This steam is either extracted from steam turbines (ST) or from a heat recovery steam generator (HRSG) connected to gas turbines (GT) existing in the PP. The use of steam generated by the fuel-fired boiler to directly operate these DP is very expensive. Besides thermal energy input, electric power (EP) is used for pumping by the MSF (about 4 kWh/m^3) and METVC (about 2 kWh/m^3). Both MSF and METVC consume much more energy than the Seawater reverse osmosis (SWRO) desalting method (about 4–6 kWh/m^3) pumping energy. Thus, SWRO is the most used desalting method worldwide, but not in the GCC where fuel cost is underestimated, and also due to the complexity of

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SWRO, pretreatment methods required to satisfy the Arabian gulf seawater conditions.

Qatar General Electricity and Water Corporation, known as KAHRAMAA, is the public sector company that regulates and maintains the supply of EP and DW to customers. KAHRAMAA is operated as an independent corporation on a commercial basis. It operated the transmission and distribution systems of the EP and DW to residential, commercial, and industrial consumers. The EP and DW are usually produced by private producers with a sizable government share through Independent Water and Power Project companies such as the Qatar Electricity & Water Company, the Ras Laffan B (EP and DW), the Ras Laffan C (EP and DW), and the Mesaieed Independent power project (IPP).

KAHRAMAA buys all the produced EP and DW from IWWP (or IPP) at production price, then resells it to the population at a subsidized rate. Kahramaa's published DW production cost is $1.64/m and distribution cost is $1.10/m, a total of $2.74/m; while the EP production cost is $0.07/kWh. Qatari nationals receive the EP and DW for free, while non-Qatari expatriate pays for the services at a subsidized rate; roughly 70% of production and distribution cost [1]. Qatar Petroleum supplies the fuel at its production cost, or a little higher. Table 1 outlines the production cost of water and electricity in Qatar, while Table 2 summarizes current tariffs for DW and EP for various customer categories. Table 2 also provides the percentage of the cost subsidized for the various customer categories. The Ministry of Municipal Affairs and Urban Planning is in charge of supplying water for agricultural and research purposes, while the Public Works Authority commonly known as "Ashghal" is in charge of sewage and drainage [1].

The reported EP cost of $0.07/kWh is less than the EP cost reported in many countries of the world. The costs of EP in countries worldwide are directly proportional to the used fuel cost. The cost of EP in countries extensively using nuclear power such as example US, Canada, and France is lower than those using natural gas (NG) [2].

All newly built power plants in Qatar are using combined cycle (CC), due to good reasons, including low capital cost [3], less negative environmental impact when (NG) is used as fuel, and significantly higher efficiency (44–55% in the high-temperature environment in the GCC at full load). However, the cost of EP produced by the CC is very sensitive to the NG cost. It was noticed that 7–8% increase in Levelized energy cost with a 10% increase in the cost of NG [4]. The EP reported cost of $0.07/kWh is thought to be calculated by considering very low NG cost ($0.5–1.00/per million British thermal units (MMBtu)). When International cost is used, the EP cost will vary significantly.

Table 1
Production cost of water and electricity in Qatar [5]

Product cost	Cost (QR, before subsidies)	Cost (USD, before subsidies)
Electricity	≅0.24/kWh[a]	~0.07/kWh
Water	10/m^3	2.74/m^3

[a]Commercialand residential.

Table 2
Water & electricity tariffs in Qatar according to various customer categories [1]

Customer category	Tariffs (QR)	Tariffs (USD)	% Subsidized
Electricity			
Residential Flat	0.08–0.1 QR/kWh	0.02–0.03$/KWh	58.3–66.7
Residential Villa	0.08–0.1 QR/kWh	0.02–0.03$/KWh	58.3–66.7
Commercial	0.09–0.14 QR/kWh	0.02–0.04$/KWh	41.7–62.5
Industrial	0.07 QR/kWh	0.02 $/KWh	70.80
Government	0.15 QR/kWh	0.04 $/KWh	37.50
Water			
Residential Flat	4.4 QR/m^3	1.21$/m^3	55.80
Residential Villa	4.4 QR/m^3	1.21$/m^3	55.80
Commercial	5.2 QR/m^3	1.43$/m^3	47.80
Industrial	4.4 QR/m^3	1.21$/m^3	55.80
Government	7.0 QR/m^3	1.92$/m^3	29.90

2. Realistic EP cost

In GCC, the prices of NG and gasoline are set by each state, and can be marked as the lowest in the world. Most bulk NG in the GCC is sold at fixed prices of (more or less) US $1 MMBtu [6]. This is the reason for low reported EP cost ($0.07/kWh) and DW cost as $1.64/m^3 for production, $1.1 for transportation, or $2.74/m^3 for total cost reported in Qatar, and $0.07–0.09/kWh for EP and $2.48/m^3 for DW reported in United Arab Emirates (UAE) [1].

Recent NG sales provide further information on the value of NG in GCC. First among them is the so-called "interruptible supply" of between 1.2 and 3 billion cubic meters yearly of Qatari gas sold to Abu Dhabi via the spare capacity in the Dolphin Pipeline. That gas was reportedly priced near US$5/MMBtu. In 2011, Dolphin Energy resold Qatari gas in the UAE for between US $7 and US $10/MMBtu [6]. NG prices rose in Europe, but fell in North America, when rising US NG output pushed prices to record discount against both crude oil and international gas prices. The NG prices in the US Henry Hub in the US are the lowest in the world, but they started to increase from about $3.5/MMBtu to reach about $5.6/MMBtu in February 2014. So, at least $5/MMBtu is thought here as realistic price for NG in Qatar, and $10/MMBtu as NG price in the world. There is a trend of increasing the NG cost worldwide, especially in countries importing NG from Qatar such as Japan. This motivates Qatar to export more NG, decreasing NG consumption locally by raising its selling price in the country. This increases the cost of EP, and DW would be increased.

When a realistic price of NG equal to $5/MMBtu is considered, and not the very low cost considered in Qatar of $0.5–1.0/MMBtu, the costs of EP are considerably changed. When one MMBtu (=1,055.66 MJ) is supplied to PP having 0.36 efficiency, it would produce: 1,055.06 × 0.36 = 380 MJ of mechanical (electrical) energy. This 380 MJ is equal to 380,000 kJ or 380,000/3,600 = 105.66 kWh.

When NG cost is $5/MMBtu, the fuel cost for producing one kWh of the EP is (5/105.66=) $0.0473/kWh ($c 4.73). The EP and DW costs as a function of NG fuel cost are illustrated in Table 3. Note that this is only for fuel cost, which does not include capital cost, and operation and maintenance costs, which was estimated by $3.36/MWh [7] and capital cost. The capital cost/MWW can be roughly calculated by knowing that the capital cost is $1,500/kW, the actual capacity factor in Qatar is 50%, the average lifetime of the CC is 20 years, and this gives $17.12/MWh. The total cost/kWh would be the fuel cost plus $0.0205/kW. The percentage of the fuel cycle cost, capital cost, and the O&M cost of a CC PP are 65, 26, and 9%, respectively, which shows that for realistic average fuel cost of $4/MMBtu, the fuel cost is $c 3.79/kWh which is close to 35% of the total and EP cost is $c 5.84/kWh [8].

3. Realistic DW cost

A similar approach can be used to determine the DW cost when the realistic cost of NG is considered. The main SW desalting methods used in Qatar and other GCC are the MSF and METVC systems. Evaluation of fuel energy charged to the DP using

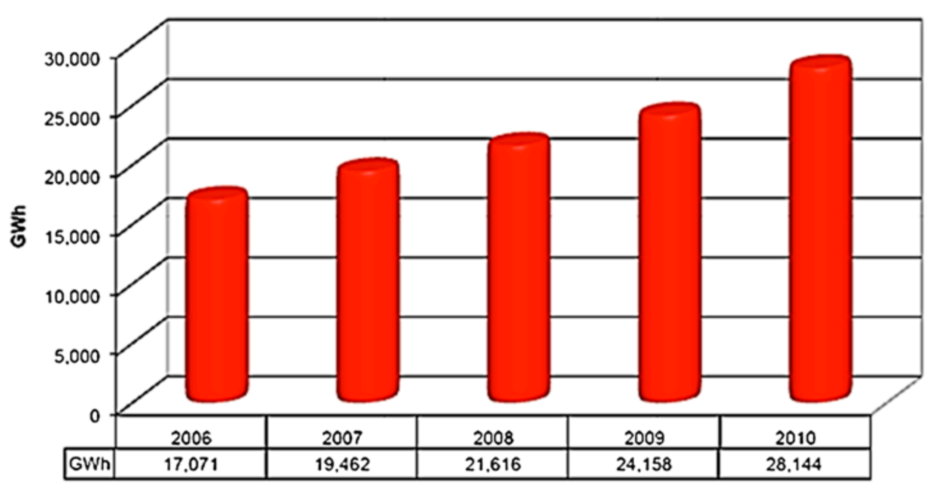

Fig. 1. Qatar electric power production [14].

Table 3
The cost of EP and DW at varying NG prices

NG cost ($/MMBtu)	EP fuel cost (c/kWh)	EP cost (c/kWh)	DW (MSF) production ($/m^3)	DW (SWRO) energy ($/m^3)	DW (SWRO) production ($/m^3)
0.75	0.71	2.76	1.04	0.14	0.62
1	0.95	2.99	1.10	0.15	0.63
2	1.90	3.94	1.33	0.20	0.68
3	2.84	4.89	1.57	0.24	0.72
4	3.74	5.83	1.81	0.29	0.77
5	4.73	6.78	2.04	0.34	0.82
6	5.68	7.73	2.28	0.39	0.87
7	6.63	8.67	2.52	0.43	0.91
8	7.57	9.62	2.75	0.48	0.96
9	8.52	10.57	2.99	0.53	1.01
10	9.462	11.51	3.23	0.58	1.06
11	10.41	12.46	3.46	0.62	1.10
12	11.36	13.41	3.70	0.67	1.15
13	12.30	14.35	3.94	0.72	1.20
14	13.25	15.30	4.17	0.76	1.24
15	14.20	16.24	4.41	0.81	1.29
16	15.14	17.19	4.65	0.86	1.34
17	16.09	18.14	4.88	0.91	1.39
18	17.04	19.08	5.12	0.95	1.43
19	17.98	20.03	5.36	1.00	1.48
20	18.93	20.98	5.59	1.05	1.53

Notes: EP fuel cost = NG cost × 100/105.66; EP total cost = EP fuel cost + 0.336 (by O&M) + 1.712 (by capital cost); DW (MSF) cost = [(20 * EP cost)/100]/0.8 + 0.348 (by capital + O&M); DW (SWRO) energy cost = 5 × EP (cost); DW (SWRO) production cost = 0.48 (by capital and O&M) + DW energy cost.

these plants is not straightforward, as the DPs are combined with PP. The DW in Qatar and GCC is mostly produced in the recently built CPDP using GT, HRSG, and MSF or METVC DP. In these plants, steam is generated in HRSGs using the exhaust hot gases leaving the GT. This steam operates a steam turbine (ST) from which steam can be extracted (or discharged) to the MSF units. At low electric load, the ST can be stopped, and the DP is directly supplied with steam from the HRSG after being throttled and desuperheated. A typical CPDP using CC, the Shuaiba, Kuwait plant use three GT, and each GT is combined with one HRSG. The steam generated from three HRSGs is supplied to one ST. Similar CC cycles are used in several plants in Qatar such as: Ras Abu Fontas (A, B, and B2), Ras Laffan (A, B, and C), Ras Girtas Power, and Mesaieed PP. A list of PP in Qatar is given in Table 4. When the MSF units are combined with the GTCC, two types of STs can be used. The first type is extracted-condensing steam turbine, where part of the expanding steam is extracted to the MSF units, while the other part continues its expansion to a condenser. The other type is the back pressure steam turbine, where the entire expanding steam is exhausted to the MSF units at the pressure required by these units.

Typical energy consumed by the MSF system is pumping energy of 4 kWh/m^3 (14.4 kJ/kg work or electrical energy), and 270 kJ/kg of thermal energy obtained by condensing the supplied steam to the MSF brine heaters. This steam is usually supplied at 2–3 bar pressure and at saturation temperature of 120°C.

4. Real value of thermal energy supplied to the MSF system

The real value of the 270 kJ/kg thermal energy supplied as steam to the MSF units be specified based on its ability to produce work (or EP). If this steam was expanded in a LP turbine to the condenser pressure, it would produce more power. So, supplying steam to the MSF is considered as work (or EP) loss, that can be calculated, and it would be equivalent to the thermal energy supplied to the MSF unit.

The case considered here is for a real plant, having three MSF desalting units of 15 MIGD capacity each

Table 4
List of PP in Qatar (limited to 200), PP [9]

Title	Capacity (MW)	Fuel types	Output (MWh)	CO_2 (kg)	Intensity (kg/MWh)
Ras Laffan-a Power plant	756	NG	3,711,940	1,276,890,000	344
Ras Abu Fontas B1 Power plant	985	NG	3,490,870	1,549,430,000	444
Ras Abu Fontas A Power plant	626	NG	1,850,900	861,200,000	465
Ras Laffan-b Power plant	1,025	NG	1,688,810	790,364,000	468
Umm Said Refinery Power plant	128	NG	734,945	365,480,000	497
Al-wajbah Power plant	301	NG, Oil	723,120	360,025,000	498
Ras Laffan Ras Gas Power plant	330	NG	718,016	357,669,000	498
Qafco Works Power plant			563,471	285,693,000	507
Ras Laffan Qatar Gas Power plant	187	NG	396,416	206,216,000	520
Ras Abu Aboud Power plant			369,993	193,442,000	523
Saliyah Power plant	134	NG, Oil	310,524	164,438,000	529
MesaieedQvc Power plant			286,768	152,743,000	533
Doha South Super Power plant	67	NG, Oil	149,590	83,551,700	558
Umm Said Qapco Power plant			136,098	76,541,900	562
Dukhan Field Power plant	44	NG	90,051	52,194,000	580
Maersk Qatar Power plant			40,943	25,135,400	614
Halul Terminal Power plant			25,319	16,098,000	636
Abu-Samra Power plant			10,503	6,033,690	575
Mesaieed Qatalum Power plant	1,350	NG	0	0	0
Ras Abu Fontas B2 Power plant	567	NG	0	0	0
Qstp Solar Power plant		SP	0	0	0
Pearl Gtl Plant Power plant			0	0	0
Doha Qafco Power plant			0	0	0
Ras Laffan-c Power plant	2,730	NG	0	0	0
Ras Laffan Dolphin Power plant			0	0	0
Mesaieed Power plant	2,007	NG	0	0	0
Qatar Biogas Power plant			0	0	0
Al Ali Hospital Power plant			0	0	0
Doha Dswmc Power plant			0	0	0

(or 2,638 kg/s total capacity). The steam leaves the turbine at the rate of 1,050.6 ton/h (291.83 kg/s), 2.8 bar pressure, 159.4°C temperature, and 2,782.8 kJ/kg of enthalpy. If this steam was expanded in the LP turbine to a condenser pressure at 8 kPa, its enthalpy at the LP turbine exit would be 2,330 kJ/kg and the work output would be ($W_{\text{heating steam}}$ = 291.83 * (2,782.8–2,330) = 132.1 kW). This represents the work loss due to the steam supplied to the three MSF units. Another small amount of steam is extracted from the ST, but at higher pressure, to operate the steam ejectors of the three MSF plants, at 19.9 ton/h (5.53 kg/s) flow rate, 30.1 bar pressure, 448.1°C temperature, and 3,342.5 kJ/kg enthalpy. If this steam was expanded in a turbine to the condensing pressure of 8 kPa, its enthalpy would be 2,330 kJ/kg and the work output would be (W_{ejector} = 5.53 * (3,342.5–2,330) = 5,599 kW), W_{ejector} represents the work loss due to the steam supplied to three MSF ejectors. So, the total work loss by the steam supplied to the 45 MIGD (2,368 kg/s) is 137,741 kW or 58.2 kJ/kg (16.16 kWh/m^3). Since the pumping energy of the MSF is in the range of 4 kWh/m^{3,} the total equivalent mechanical energy (counting for pumping and thermal energy) to produce one m^3 of DW is about 20 kWh/m^3.

Similar results were obtained for some of the Saudi Arabia DP. The equivalent mechanical energy for the consumed thermal energy, and pumping energy are given, respectively, as: AlKhober 2 (18.3 and 5.1 kWh/m^3), Jeddah 2 (13.7 and 6.8 kWh/m^3), Jeddah 3 (16.8 and 5.3), and Alkhober 3 (15.2 and 4.9 kWh/m^3 [10]. So, the fuel energy cost to produce 1 m^3 of DW, based on the energy cost reported by Qatari's authorities of \$0.07/kWh is: Fuel energy cost/m^3 of DW = \$0.07/kWh × 20 (equivalent kWh of EP consumed by DW) = \$1.4/m^3.

The fuel cost to produce 1 m^3 of DW is a major part of production cost, and can be considered as 80% of the total cost. So, then the total production cost of 1 m^3 DW is (\$1.4/0.8=) \$1.75/m^3, which is even higher than the reported value of \$1.64/m^3. So, the calculated total water cost is \$1.75/m^3 for energy production and

$1.1/m^3 for transportation, or total cost of $2.85/m^3. The total water cost per m^3 DW is calculated for different costs of NG, as the production cost plus the transportation of $1.1/m^3, and accordingly the cost of DW is [(20 × $/kWh/0.8) + $1.1]. This (in $/m^3) is equal to 2.14, 2.198, 2.895, 3.14, 3.62, and 4.33 for NG cost (in $/MMBtu) of 0.75, 1.0, 4.0, 5.0, 7.0, and 10.0/ MMBtu, respectively, as shown in Table 2.

Qatar yearly DW production increased from 178 in 2004 to 373 Mm^3/year in 2010 (almost doubled in 6 years or 18% annual increase) and is expected to reach 480 Mm^3/year in 2014. This is based on 5.4% annual increase by Qatari's people and 7% for expatriates as expected by National Strategy [11] and by taking 6.5% as an annual average increase, or 1.32 Mm^3/d. This means that the annual DW cost is ranging (in billion US dollars/year) between 1.059 when the NG cost is in the range of $1.0/MMBtu to 1.51 when NG cost of $5/MMBtu (the most realistic cost) to 2.08 when NG cost is $10/MMBtu is used.

It may be interested here to see how the cost of producing DW using SWRO and compare it with those of MSF by assuming the pumping energy consumed by the SWRO is equal to 5 kWh/m^3, and the both capital and constant operating and running cost are $0.48/m^3. At the NG cost of $4/MMBtu, the energy cost represents about 50%. Table gives the cost of DW produced by both MSF and SWRO as a function of the NG cost.

5. Energy and DW subsidization in Qatar

The percentages of energy subsidization for EP and DW given in Table 2 are underestimated, since it is based on the low NG cost of, say $1/MMBtu, while the real cost is about $5/MMBtu. At this cost, the EP cost is estimated by $0.1123/kWh, and the DW cost is $3.9/m^3. When the EP's tariff is at the average of $0.025/kWh, the subsidization percentage is 78%, and not 62.5% as reported in Table 2. Meanwhile, when the DW tariffs is at $1.21/m^3, the subsidization percentage is 66%, and not 55.8%.

The objectives behind the introduction of energy subsidies in Qatar are: protecting low-income people, promoting industrial development, and avoiding inflationary pressures. Clearly, the consumed EP and DW are inversely related with those utilities' tariffs. As an example, it was reported by the Qatari Water Strategy [14], that studies in 2009 showed Qataris consumed 1,200 liters per capita per day (l/d Ca) of water because of the free water's tariff, while expatriates consumed 150 l/d Ca because they pay about 30% of the water cost. The most disadvantage of subsidizing the water prices is the impression left to the public that the water has no value, with no real incentives to conserve. This is not reflected only on DW, but on Groundwater (GW) as well. The GW replenishment rate is 58 Mm^3/year, while the GW abstraction in 2012 reached 400 Mm^3/year [12].

This is severely exploited and deteriorated the GW, and resulted in that the total area under which fresh water (TDS < 1,000) has reduced by nearly 80% between 1982 and 2008 (from 1,278 to 275 km^2). Based on current withdrawal, GW fresh water will completely disappear within four years from now [13].

The same argument applies to EP. In 2011, the consumed EP per capita in Qatar was among the highest in the world at 15,755 kWh/y Ca, World Bank, EP consumption [12]. This is to be compared with 8,161 kWh/y Ca in Saudi Arabia, and 9,389 in UAE. Part of this EP high consumption EP is due to the air-conditioning load, besides the low EP tariff. Electricity heavy subsidization leads to inefficiency, and overuse as well as waste of national resources.

The Qatar EP production was increased from 17.071 in 2006 to 28.144 GWh in 2010, with an increasing percentage of 18.6, 14.0, 11.1, 11.8, and 16.5% in 2006, 2007, 2008, 2009, and 2010, respectively, as shown in Fig. 1. If the rate of increase is held at 6%, the 2014 EP production would reach 35.53 GWh. Then, the government subsidization for EP in 2014 would be $B3.1 if the cost/ kWh is $0.1123/kWh, while it is sold at $0.025/kWh. The 2014 production 480 Mm^3/year of DW would be subsidized with $B1.13. So, the EP and DW subsidization in one year, only of 2014, would be $B 4.33.

Besides this economic burden on the government, the air and marine environmental burden are increasing. In 2014, the Qatar productions of EP and DW were estimated as 35.53 GWh and 480 m^3/year (1.32 Mm^3/d), respectively. The calculation pertaining to the consumed fuel energy and its resultant CO_2 emission to generate the EP and DW can be calculated. The equivalent consumed EP per m^3 of DW by the MSF desalting system was given before as 20 kWh/m^3. So, the consumed equivalent EP to desalt 480 Mm^3/ year is 9.8 GWh/year in 2014. So, the total equivalent EP output of both electricity and DW as 45.13 GWh, (35.513 for EP + 9.6 for DW), with a DW share of 21%. By assuming a 36% average efficiency due to part-time operation that prevails most of the time with low efficiency, the consumed fuel energy by the CPDP is 451.3 MGJ which is equivalent to 75.22 million barrels of oil (bbl) or 430 billion cubic feet (BCF) of NG. The heat content of one bbl is assumed equal to be 6 GJ, and of 1,000 cubic feet (CF) of NG is 1,050 kJ.

The mass of fuel burned in the CPDP (430 BCF) is equal to 430 × 0.0208 = 12.03 M-tons of NG, with the contribution of 2.56 M-tons by the DW. The CO_2

produced due to burning 12.03 M-tons of NG is: $12.03 \times 0.75 \times 44/12 = 33.1$ M-tons. The contribution of DW to this amount stands at 7.04 M-tons, indicating that the production of 1 m^3 of DW causes an emission of 14.67 kg of CO_2. In brief, desalting of 480 Mm^3 in 2014 (1.32 Mm^3/d) causes the burning of 2.56 M-tons of NG and an emission of 7.04 M-tons of CO^2. So, energy subsidization inflates EP and DW consumption, besides ruining the environment. The desalination negative effect on marine environment was given by Darwish et al. [14].

6. Conclusion

Water security in Qatar is of main concern. Low water pricing in Qatar does not reflect the real value of water. The high cost of DW shown in this paper calls for the use of more energy efficient desalting system such as the SWRO system in place of the MSF and METVC methods presently used in Qatar. It calls also for efficient use of water. The Groundwater is overexploited, depleted, and quality deteriorated. More DW productions mean more air and marine environmental deterioration, and more economic burden on the government. The water subsidization by the government should be reviewed, and water demand management should be applied. The cost of NG of less than \$1/MMBtu as used by Qatar's authorities is far less than the real value considered in either NG producing countries like SA or UAE or worldwide. It gives very low production costs of EP (less than \$c3/kWh) and DW (\$1.1/m^3 by MSF and \$0.63/m^3 by SWRO). These very low prices do not motivate people to conserve, but to waste. The realistic low cost of \$5/MMBtu for NG in Qatar and UAE gives a production cost of EP as \$c 6.78/kWh, and DW produced by MSF is \$2.04/m^3 or \$0.82 for SWRO. The international cost of \$10/MMBtu gives almost the known worldwide production cost of EP as \$c 11.51/kWh, and DW produced by MSF is \$3.23/m^3 or \$1.06 for SWRO.

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