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ORIGINAL PAPER

Analysis of the impact of introduction of nuclear power plants on energy characteristics and environment in Egypt

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Abstract Most of electricity is produced by turbines, turned by steam from thermal generators that heating water to steam by burning different fuel, such as coal, natural gas and nuclear fuel. This paper proposed three scenarios to analyze the impact of nuclear power plant on the Egyptian electric grid from price, carbon dioxide emission, water consumption and fossil fuel consumption. The low scenario introduces the electricity generated without any nuclear plant. The basic scenario studies the expectation of the government program to 2030 that indicates the impact of first nuclear plant. We proposed the high scenario to study the impact of the nuclear power in 2030 as a double expectation of basic scenario. Wide applications of clean energy and those agreements for air environmental protection becomes an important target for the world. Analysis of the different energy resources and electricity generation fuels indicates that the nuclear energy is important for the poor fossil countries.

Keywords Nuclear energy · Cost of energy · Energy characteristics

1 Introduction

Since the world knew the effect of nuclear energy in 1945, where nuclear energy has been used regrettably for war purpose in the World War II before its distribution into the peaceful utilization and applications. The nuclear power plant was first applied in electricity generation at the fiftieth of last century in USA and few countries [1]. In 1954, the former soviet constructed the first universal's nuclear plant

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which connected to the power grid to produce about 5 MW of electricity [2]. Nuclear energy has seen concessions for nearly two decades until the late 1990 and due to nuclear accidents such as the Three Mile Island and Chernobyl subsequently. There is now a strong return of nuclear energy after the safety improvement and technological progress due to the shortage of fossil fuels and maintaining a clean environment by reducing carbon dioxide. Nuclear power reactors are still yet used safely around the world despite an incident occurs Fukushima mat Level 7 according to (INES, IAEA). In 1990s, the generation III recognized as an evolutionary design ranges of from 103 nuclear plants, and more advanced category within Gen III developed in 2000, which involved passive safety systems. Nuclear power is a mature technology with 434 nuclear reactors totaling around 349GWe operating in 32 countries in 1999. Worldwide, the majority of current nuclear power plants are competitive on a marginal generating cost basis in a deregulated market environment because of low operating costs and the fact that many are already fully depreciated [3]. To deal with the advantages of nuclear power, we can say that the nuclear power is clean, safe, reliable, compact, competitive and practically inexhaustible. Generation IV is now under intensive study, and is anticipated to be available within next 20 years [4].

Today over 400 nuclear reactors provide base load electric power in about thirty countries. Fifty years old, it is a relatively mature technology with the assurance of great improvement in the next generation.

Nuclear power has more advantages than power plants that use fossil fuel to generate power; it is safe, reliable, compact and clean, moreover, it is a source of power which is practically inexhaustible [5].

Nuclear energy has many advantages such as a low carbon transition energy, which contributes to stabilize the CO_2 level in the plant's atmosphere, and consequently minimizes

the climate change and global warming. High capital costs, high parasitic energy requirements, and additional environmental concerns over scrubbing chemicals have combined to limit the viability of CO_2 capture systems for fossil fuel power plants [6]. Nuclear fuel of most of the nuclear reactors is Uranium, which is still available worldwide. It is not predicted to deplete promptly as the fossil fuel which is expected to deplete after eight decades [7].

Nuclear power is safe, as proven by the record of half a century of commercial operation, with the accumulated experience of more than 12,000 reactor years. Nuclear reactors provide base load power and are available over 90% of the time; intervals between refueling have been extended and shutdown time for refueling has been reduced. On the other hand, the radioactive waste is correspondingly about a million times smaller than fossil fuel waste, and it is totally confined [8].

Egypt is the largest oil and natural gas consumer in Africa, accounting for more than 20% of total oil consumption and more than 40% of the natural gas consumption in Africa in 2013. Energy subsidies, which cost the government $26 billion in 2012, have contributed to raising energy demand and a high budget deficit. Egypt experiences frequent electricity blackouts because of raising demand, natural gas supply shortages, energy infrastructure aging, and inadequate generation and transmission capacity. Ongoing political and social unrest in Egypt delayed the government's plans to expand power generation capacity by 30 GW by 2020 [9]. The energy resources include the water which used for cooling to guarantee the safety of the electrical energy generation plants or for generation as the high dam plant (Egypt).

Both of these systems withdraw and consume water through cooling, raw water from a reservoir, river, ocean, or other body of water located in the plant zone through the plant cooling loops included heat exchangers and condensate the other phase of water through the condensation loop and return back into the body of water. Water consumed due to the effect of highly temperature of the coolant, and consequently by loss of water. The heat is dissipated through the cooling tower by evaporation to the atmosphere and maintains the temperature of the cooling loop. The quantity of water that consumed in the cooling process can be calculated as the summation of water evaporated plus water losses due to drift (unelaborated cooling water droplets that are entrained in the air passing though the cooling tower) and quantity of blow down. The losses of that quantity must be re-feeded by freshwater withdrawals from the plant water supply [10].

The interdependency between water and energy, sometimes called the water-energy nexus, is growing in importance as demand for both water and energy increases. Energy is required for water treatment, while virtually all processes for energy production requires significant amount of water. Many areas of the world are already underwater and energy constraints. Moreover, the world's population is expected to grow, which boost water and energy demand substantially in the feature, especially in developing countries. In addition, climate changes are accelerating the problem of shortages of energy; due to extreme weather conditions, the water withdrawal will raise due to more energy consumption [11]. Water management has recently become a major concern for many countries. During the last century, consumption of water and energy has been increased in the world. This trend is anticipated to continue for decades to come. One of the greatest reasons is the unplanned industrial activities deteriorating environment in the name of rising standard of life [12].

In this paper, an analysis of three scenarios is proposed to study the impact of nuclear power plant on the Egyptian electric grid. The low scenario introduces the electricity generated without any nuclear plant. The basic scenario studies the expectation of the government program to 2030 that indicates the impact of first nuclear plant. We proposed high scenario to study the impact of the nuclear power in 2030 as a double expectation of basic scenario. The main contribution is providing an analysis for three scenarios form point of view for price, carbon dioxide emission, water consumption and fossil fuel consumption. The obtained results confirm that the nuclear energy is important for the poor fossil countries.

The paper is organized as follows. Section 2 indicates the using of water resources in electricity generation. Section 3 shows the carbon dioxide emission, while Sect. 4 introduces the Egyptian electrical grid. Section 5 studies the levelized cost of energy and Sect. 6 gives the analysis of the results. Section 7 summarizes the concluded remarks.

2 Water resources for electricity generation

A large nuclear power plant that utilizes a once-through cooling system may withdraw 800 million to 1 billion gallons of water a day; these plants are usually built next to rivers, lakes, or oceans. As the name implies, once-through cooling uses water a single time to cool and condense steam produced for electricity generation. Water which is produced from the condensed steam is reused in the generation process, but water used for cooling is discharged back into the river, lakes or ocean, with high temperature which increase up to 30°. The temperature increase in the bodies of water can have serious adverse effects on aquatic life. Warm water holds less oxygen than cold water, thus discharge from once-through cooling systems can create a "temperature squeeze" that elevates the metabolic rate for fish. Additionally, suction pipes that are used to intake water can draw plankton, eggs and larvae into the plant's machinery, while larger organisms can be trapped against the protective screens of the pipes. Blocked intake screens have led to temporary shut downs of the plants [13].

Hydropower plants use water directly to generate power. These power plants represent the single largest consumer of water among any industrial, governmental or residential activity. Water used is a measure of the amount of water that is withdrawn from an adjacent water body, such as lakes, streams, rivers, and estuaries, passes through various components of a plant, and ultimately discharged back into the water body [14].

Consumption is a subset of withdrawal, with water consumption mathematically equal to the difference between water withdrawal and return flow. Both withdrawal and consumption are relevant for the power generation industry. Water consumption factors for electricity generating technologies vary substantially within and across technology categories. The highest water consumption factors for all technologies result from the use of evaporative cooling towers. With the exception of hydropower, pulverized coal with carbon capture and CSP technologies utilizing a cooling tower represent the upper bound of water consumption, at approximately 3.78 m^3/MWh of electricity production. The lowest operational water consumption factors result from wind energy, PV, and CSP solar technologies and natural gas combined cycle facilities that employ dry cooling technologies. Water withdrawal is defined as water diverted from a surface water or groundwater source that might or might not be returned. Water consumption is water that is not directly returned to the original source, often due to evaporation [15].

Water withdrawal factors for electricity generating technologies show a similar variability within and across technology categories. The highest water withdrawal values result from nuclear technologies, whereas the smallest withdrawal values are for non-thermal renewable technologies. Consistent with the literature, withdrawal factors for CSP, wind, geothermal, and PV systems are assumed to be equivalent to consumption factors. Table 1 provides a comparison of withdrawal and consumption of water relative to fuel, cooling type in cubic meters per megawatt hours (m^3/MWh).

3 Carbon dioxide emission

The idea behind global warming is simple enough. Earth's atmosphere retains some of the heat that Earth receives from the Sun. The amount of heat retained depends upon the chemical composition of the atmosphere. If the chemical properties of Earth's atmosphere are changed, then the thermal properties of the atmosphere, that is, its heat retention properties change as well. Burning fossil fuels releases carbon dioxide into the atmosphere. The combustion reaction in which fossil fuels are consumed produces, mainly, two products: carbon dioxide and water. At ordinary temperatures and pressures, carbon dioxide is a gas, so burning fossil fuels releases carbon dioxide gas into the air. There is ample evidence that carbon dioxide levels in the atmosphere have increased as a result. Consequently, the thermal properties of the atmosphere have changed. More CO_2 in the atmosphere means more of the energy that Earth receives from the Sun is retained.

As a result of human activities and large usage of contaminated energy of the environment, the use of greenhouse gases is on the rise, according to the UN 2005 [16]

The changes observed over the last several decades are mostly due to human activities. The global temperature of land and ocean surface was 0.561ċ higher than the twentieth century average, tying with 2006 as the fifth warmest since 1850. The continuation of the increasing heat of climate change, the vast tracts of land will sink due to sea level rise and the loss of fertile land are many, according to studies of physics and environmentalists. This will encourage the migration of agricultural inhabitants who will, therefore, seek to alternative safe land. Electricity generated by fossil fuels is the source for almost half of the country's emissions. Keeping with the Kyoto Protocol the carbon dioxide is produced per kilowatt hour when generating electricity with fossil fuels. We can calculate the amount of carbon produced per kilowatt/hour (kWh) for specific fuels and specific types of electricity generators by multiplying the CO_2 emissions factor for the fuel (in kg of CO_2 per million Btu) by the heat rate of a generator (in Btu per kWh generated), and dividing the result by 1,000,000. The quantity in kg of CO_2 produced from different fuel types used in energy generation, the average heat rates for steam-electric generators in 2013 using those fuels, and the resulting amount of CO_2 produced per kWh is illustrated in reference [17,18].

The nexus between nuclear energy consumption, CO_2 emissions and economic growth have been recently discussed in the economics literature. The overall results showed that there is a strong relationship between nuclear energy use

Table 1 Water used in electricity generation with different primary energy

Fuel type	Cooling type	Withdrawal (m^3/MWh)	Consumption (m^3/MWh)
Nuclear	Tower recalculating	4.2	2.5
	Once-through	167.9	1.0
Natural gas	Tower	1.0	0.7
	Once-through	43.1	0.4
Oil	–	1.03	0.80
Cool	Tower	2.31	1.9
	Once-through	85.5	0.4
Hydropower	–	792	16.2
Solar photovoltaic	–	0.1	0.1
Wind	–	0.0	0.0

Table 2 Forecasted of electricity generation for mix energy GW's in Egypt (2016–2030) [22]

Year	Oil	Gas	Nuclear	Hydro	Wind	Solar
2016	4.8	34.388	0	2.83	2.7	0.132
2018	5.028	38.57	1	2.83	4.315	0.132
2020	5.47	42.511	2	2.83	5.85	0.132
2022	6.03	46.2	3	2.83	6.75	0.132
2024	6.7	51.15	4	2.83	6.87	0.132
2026	7.66	55.79	4	2.83	7.03	0.132
2028	8.69	63.2	4	2.83	7.23	0.132
2030	9.53	69.17	4	2.83	7.33	0.132

and economic growth, between CO_2 emissions and economic growth, and between renewable energy consumption and economic growth. Nevertheless, there is a great concern about environmental challenge, since the energy consumption can cause economic growth but it is the key reason of environmental degradation [19,20].

4 Egyptian electrical grid

Egypt has a rapidly expanding economy that is dependent on the availability of reliable and low cost electric power. The annual average rate of growth of electricity demand in Egypt is expected to range between 6 and 7% during this decade and beyond. Peak demand is expected from 25.705 MWe in 2011/2012 to 42.000 MWe by 2016 and installed capacity is expected to increase from 27 MWe to 33.200 MWe during the same period. In 2016, about 99% of the population was served by the Egyptian electricity grid. A demand of 367.9 TWh on the interconnected system, about 9.25% was met by hydropower, principally the High Dam and Aswan units 1 and 2, and the remaining was met with thermal power plants, of which around 68.24% were supplied from natural gas and 31.76% heavy fuel oil [21].

Currently, the Egyptian Electrical National Grid (EENG) is divided into six geographical regions, which include Alexandria, Delta, Cairo, Canal, Middle Egypt, and Upper Egypt. The Egyptian Electricity Transmission system is composed of 500, 400, 220, 132, and 66 kV [22].

Table 2 summarizes the base scenario of the Egyptian national grid with mixed energy GW until 2030 and indicate the forecasted electricity generation for mixed energy in GWs in Egypt to 2030.

5 Levelized cost of energy

Power plants are classified as conventional and nonconventional; the conventional power plants include the following:

steam engines power plants, steam turbine power plants, diesel power plants, gas turbine power plants, hydroelectric power plants and nuclear power plants. The type of nonconventional power plants are thermoelectric generator, thermionic generator, fuel cells power plants, photovoltaic solar cells power system, fusion reactors, power system biogas, biomass energy power system, geothermal energy and wind energy power system. Actually, the levelized cost of electricity depends on many parameters such as the type of plant and type of fuel. The levelized cost of electricity is a constant unit price ($/MWh) for comparing the costs of power plants that have different technology, use different fuels, different capital expenditure paths, different annual costs, such as operating, maintenance, taxes, carbon prices, different net outputs, and different economic lives. Escalation of dollar value relative to the local currency, it does not have a clarified image to calculate the real cost. Generally, the levelized cost of electricity can be defined through the following equations [23–25].

$$\sum_t \frac{(\text{electricity sold})_t * \left(P_{\text{electricity}}\right)}{(1+r)^t}$$
$$= \sum_t \frac{\text{capital expenditure}}{(1+r)^t} + \frac{\text{O\&M}_t}{(1+r)^t} + \frac{\text{fuel}_t}{(1+r)^t} \quad (1)$$

where electricity sold is the net electricity produced in (MWh) and sold in 1 year. $P_{\text{electicity}}$ is a constant price of electricity that illustrated in Eq. 2, (LOCE), while r is the annual rate that used to discount the values taken to be fraction a predefined rate of return required to cover equity and debt cost; Capital expenditure is the expenditure in year (t), associated with construction of the plant in $;

O & M_t: Total nonfuel operating and maintenance in $;
fuel$_t$: Total fuel costs in year t, (time, t).

The left side of Eq. 1 represents the present value of all received income from electricity sales over the plant life. This amount must balance with the present value of the following costs for building, operation and maintenance of the plant over its life. Since fuel cost is the dominant component of operating costs, this item is commonly called out separately from other nonfuel operating costs.

The annual O&M costs also may include such items as taxes, carbon dioxide values, or any other costs incurred through time. In case of fossil fuel technologies, any decommissioning costs at the end of the plant life are usually ignored. The rule of thumb is that the plant salvage value will cover these costs.

Taking $P_{electricity}$ in Eq. 1 to be defined as the constant levelized cost of electricity (LCOE) and it is defined mathematically by Eq. 2 as follows:

$$LCOE = \sum_T \frac{(\text{capital expenditure})_t}{(1+r)^t} \Bigg/ \sum_t \frac{(\text{electricity sold})_t}{(1+r)^t} \tag{2}$$

The levelized term arises from the recognition that the calculations in Eq. 2 establish a single present value of overall cost that can be transformed into a series of uniform level, annual values through the use of the so-called levelization factors. By common practice in LCOE calculations, the levelization factors are termed differently when applied to different cost elements, as elaborated below.

If the operating condition, maintenance, fuel costs, the net electricity produced and the net output of the plant are constant over the plant life then Eq. 2 can be reduced to Eq. 3 as follows:

$$\text{LCOE} = \frac{(\text{TCR})(\text{FCF}) + \text{FOM}}{(\text{MW})(\text{CF} \times 8766)} + \text{VOM} + (\text{HR})(\text{FC}) \tag{3}$$

where:

TCR is the total capital requirement in the base $ year of the analysis;
FCF is the fixed change factor (fraction);
FOM is the fixed O&M costs ($/year);
MW is the net power output of the plant (Mw);
CF is the capacity factor (fraction)
VOM is the variable O&M costs ($/MWh);
HR is the net power plant heat rate (MJ/MWh);
FC is the fuel cost per unit of energy ($/MJ);

The levelization factor for the total capital requirement is commonly called the fixed charge factor, FCF. This factor converts the total capital value to a uniform annual amount (also called an annuity); the FCF is given by the following equation:

$$\text{FCF} = \frac{r(1+r)^t}{(1+r)^t - 1} \tag{4}$$

where, r is the interest rate or discount rate, and T is the economic life of the plant relative to the base year of analysis used in the study. Note that the assumption of constant values for all terms in Eq. (3) is, explicitly or implicitly, an analysis of electricity cost in real (or constant) dollars. On the other hand, a modified version of Eq. (3) is needed if annual plant costs change through time as occurs, for example, when using nominal (current dollar) costs that include an assumed inflation rate, or when assuming "real escalation rates" for

fuel or other O&M costs, or when the level of plant output varies over time (reflected by different capacity factors). In such cases, the LCOE can be expressed as:

$$\text{LCOE} = \frac{(\text{TCR})(\text{FCF}_L) + L_1(\text{FOM})}{(\text{MW})(\text{CF}_L \times 8766)} + L_2(\text{VOM}) + L_3(\text{HR})(\text{FC}) \tag{5}$$

Here, l_1, l_2 and l_3 are levelization factors applied to the initial (first year) value of fixed and variable operating costs and total fuel cost, respectively. (Additional factors can be applied to any sequence of other annual costs, or to the individual components of FOM and VOM). These factors serve as "multipliers" that effectively convert all first-year O&M and fuel costs to annuity values over the plant life, expressed in the base year of the analysis. In discrete terms, these various levelization factors, l_i ($i = 1, 2, 3$) are given by [26]:

$$L_i = \frac{K_i(1 - K_i^T)}{A_T(1 - K_i)} \tag{6}$$

where: $K_i = \frac{1 + e_{a,i}}{1 + \gamma^n} \tag{7}$

$$e_{a,i} = (1 + e_{a,i})(1 + e_{\inf}) - 1 \tag{8}$$

Here, r and T are as defined earlier. The additional term A_T represents the present value of an annuity payment, and $e_{a,i}$ is the apparent escalation rate of the relevant cost component, i, resulting from real annual escalation rate, $e_{r,i}$, and a general inflation rate, $e_{\inf}$ (in the case of a current dollar analysis). In the case of constant-dollar analysis with no real cost escalations, the value of e_a is zero and the levelization factors, l_i, are equal to 1.0.

6 Analysis and application results

6.1 Power generation cost

The cost of generating electricity, as defined within the scope of this study, is expressed in terms of a unit cost (dollar per kWh) delivered at the boundary of the power station site. Therefore, this cost value includes the capital cost of the generating plant and equipment; the cost of fuel burned (if applicable); and the cost of operating and maintaining the plant in keeping with optimal operation [27]. The amount of annual cost of electricity supply (Billion $/year) is shown in Table 3 for the three scenarios until 2030. Table 4 gives the electricity generation cost ($/KWh) for the three scenarios of nuclear energy in Egypt until 2030. The difference of price of kilowatt hour between three scenarios is very small and can be neglected.

Table 3 Annual cost of electricity supply in Egypt [billion $/year]

Years	Low scenario	Based scenario	High scenario
2016	41	41	41
2018	48	48	48
2020	58	58	58
2022	65	64	64
2024	75	74	74
2026	96	95	94
2028	112	111	110
2030	118	117	116

Table 4 Annual power generation cost in Egypt LOCE [$/kWh]

Years	Low scenario	Based scenario	High scenario
2016	0.105	0.105	0.105
2018	0.105	0.105	0.105
2020	0.113	0.113	0.112
2022	0.114	0.113	0.112
2024	0.119	0.118	0.117
2026	0.141	0.14	0.138
2028	0.145	0.144	0.143
2030	0.144	0.143	0.142

6.2 Carbon emission

Comparing the nuclear energy scenarios with the case of traditional scenario may help or consider that the scenario provides one way of estimating the potential carbon emissions reductions that could be attributed to nuclear energy. This scenario assumes that the conventional generation mix is allowed to expand while optimizing total costs without any carbon regulation policy [28].

Figure 1 illustrates the cumulative carbon emissions reduced from 389 to 364 million tons of carbon attributed to producing high and base scenario receptivity due to the significant nuclear energy expansion period, 2016 to 2030. The figure shows the benefit of the nuclear energy and how it
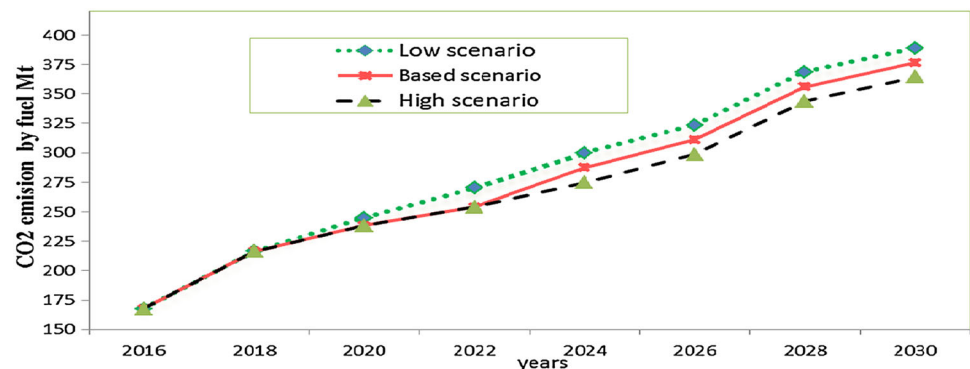
can be used to reduce the effect of global warming and save the earth plant compared with the traditional energy systems.

6.3 Water using with energy mix

Figure 2 shows the annual estimated water withdrawal for mix energy scenarios for installations in the Egyptian electrical grid until 2030. The expected water withdrawal annually by mix energy in case of basic and high scenarios for the period of 2016–2030 is more than 75 and 150 million cubic meters form low scenario, respectively. Figure 3 shows the estimated annual water consumption by mix energy in case of basic and high scenarios from 2016 to 2030 is more than 34 and 68 million cubic meters form low scenario, respectively.

6.4 Analysis of fossil fuel consumption and cost

Table 5 gives the annual estimation of oil fuel consumption by mixing energy scenarios that installed in the Egyptian electrical grid until 2030. The annually expected value of gas saved in case of base and high scenarios during the period from 2016 to 2030 is around 3 million tons from oil and 4 millions of gas, respectively. Table 6 indicates that the fossil fuel annual cost is around one billion dollars and summarizes the difference between all scenarios. It is important to reconsider nuclear energy, which reduces the consumption of fossil fuels and save about three billion dollars.

The study of the consumption and the relative cost of each type of fuel have the following remarks:

1. The price difference of kilowatt hour for the three scenarios is small and the annual cost of electricity (billion dollars$/year) with the three scenarios of nuclear energy generation is reduced from 118 to 116 billion dollars per year.
2. Annual expected water withdrawal by mix energy of both based and high scenarios from 2016 to 2030 is greater than 74 and 147 million cubic meters, respectively. The expected water consumption of both based and high sce-

Fig. 1 Annual CO_2 emission with million tons by mix energy scenarios (2016–2030)

Fig. 2 Annual water withdrawal in billion cubic meters for mix energy scenarios (2016–2030)
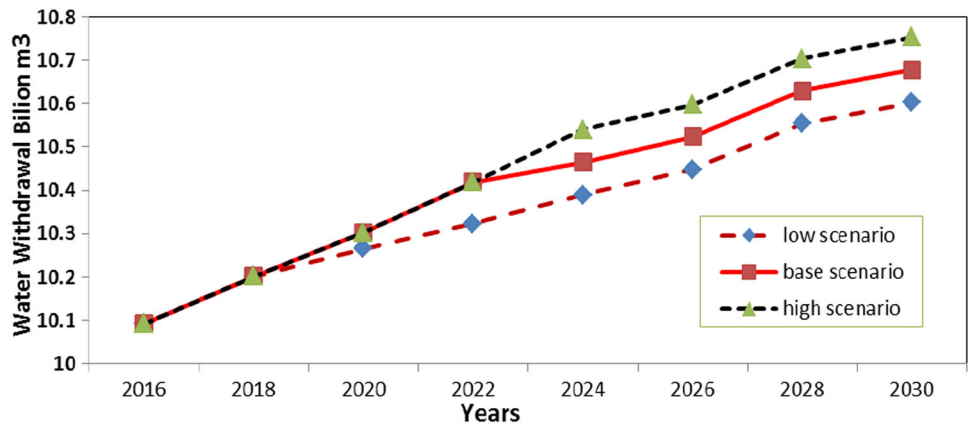

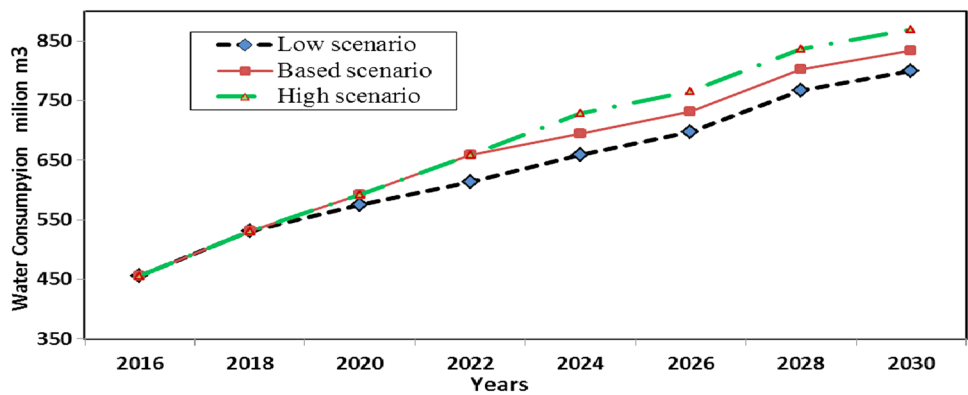**Fig. 3** Annual water consumption in billion cubic meters for mix energy scenarios (2016–2030)

Table 5 Annual fossil fuel consumption in million tones in Egypt (2016–2030)

Year	Low scenario		Based scenario		High scenario	
	Gas	Oil	Gas	Oil	Gas	Oil
2016	34	28	34	28	34	28
2018	39	32	38	31	38	31
2020	44	36	43	35	42	34
2022	49	40	47	38	45	36
2024	54	44	52	42	50	41
2026	60	47	57	45	55	43
2028	69	52	66	51	64	49
2030	73	55	71	53	68	51

Table 6 Annual fossil fuel cost in billion dollars in Egypt (2016–2030)

Years	Low scenario	Based scenario	High scenario
2016	15	15	14
2018	23	23	23
2020	26	25	26
2022	29	28	28
2024	32	31	31
2026	47	46	46
2028	54	52	50
2030	56	55	53

narios are more than low scenario by 34 and 69 million cubic meter

3. Carbon emission reduction of about 12 and 25 million tons of carbon attributed to producing high and base scenario receptivity during the significant nuclear energy expansion period, 2016 to 2030. In based on high scenarios, the fossil fuel consumption oil and gas are decreased [29].

7 Conclusion

This paper introduced a specific study to investigate the effect of nuclear energy used on electricity generation parameters, such as price, carbon dioxide, water consumption and saving fossil fuel. The relationship between power generation, carbon dioxide, water consumption and saving fossil fuel has important implications for sustainable resource management. Our analysis demonstrates that the difference in the price of kilowatt hour for three scenarios is small. The change of annual cost of electricity supply with the three scenarios is around 2 billion $/year for high scenario.

Our results include the following:

1. The nuclear generation for high scenario the carbon emissions reduction of more than 25 million metric tons.

2. The difference of water withdrawal between high and low scenario from 2016 until 2030 is 7.1 to 14.7 million cubic metric.

3. The difference of water consumption between high and low scenario from 2016 until 2030 is 34 to 69 million cubic metric

This work assists the decision makers to choose the high scenario for the energy generation because it is able to minimize the emission of CO_2, price of electricity (KWs) and only it consumes more water than the other scenarios.

References

1. Martín AD (2012) Water footprint of electric power eneration: modeling its use and analyzing options for a water-scarce future. Massachusetts Institute of Technology

2. Macknick J, Newmark R, Heath Robin, Hallett KC (2011) A review of operational water consumption and withdrawal factors for electricity generating technologies, Technical Report NREL/TP-6A20-50900, Task No. DOCC.1005

3. Sim Ralph EH, Rogner Hans-Holger, Gregory Ken (2003) Carbon emission and mitigation cost comparisons between fossil fue, nuclear and renewable energy resources for electricity generation. Elsevier Sci Energy Policy 31:1315–1326

4. Fencl A, Clark V, Mehta V, Purkey D, Davis M, Yates D (2012) Water for electricity: resource scarcity, climate change and business in a finite world, Stockholm Environment Institute, Kräftriket 2B, 106 91 Stockholm, Sweden

5. Faeth P, Benjamin K, Zoë Thorkildsen S, Rao A, Purcell D, Eidsness J, Johnson K, Thompson B, Imperiale S, Gilbert A (2014) Water adequacy and electric reliability in China, India, France, and Texas. CNA Analysis and solution

6. Allama RJ, Palmer MR, Brown GW Jr, Fetvedt J (2013) High efficiency and low cost of electricity generation from fossil fuels while eliminating atmospheric emissions, including carbon dioxide. Energy Procedia 37:1135–1149 (Published by Elsevier)

7. Wilson W (2012) A river network report "the water footprint of electricity". Published by River Network, Portland, Oregon

8. Varagani RK, Châtel-Pélage F, Pranda P (2005) CO_2 avoidance. In: Fourth Annual conference on carbon sequestration, May, 2005, Alexandria, VA Performance simulation and cost assessment of oxy-combustion process for CO_2 capture from coal-fired power plants

9. US Energy Information Egypt International energy data and analysis full report. Last Updated: June 2 (2015)

10. Mielke E, Anadon LD, Narayanamurti V (2010) Water consumption of energy resource extraction, processing, and conversion. Belfer Center for Science and International Affairs. Harvard Kennedy School, Cambridge

11. Komiyama R, kotb S (2012) Nuclear energy management school project. Tokai University of Tokyo and IAEA

12. Yuksel I (2015) Water management for sustainable and clean energy in Turkey. Sci Direct Energy Rep 1:129–133

13. Palo Alto CA (1993) Technical assessment guide, electricity supply, Electric Power Research Institute, revision 7, V.1

14. Cambell M (2008) The Drivers of the levelized cost of electricity for utility-scale photovoltaics. Sunpower

15. DeNooyer Tyler A, Peschel Joshua M, Zhang Zhenxing, Stillwell Ashlynn S (2016) Integrating water resources and power generation: the energy-water nexus in Illinois. Sci Direct Appl Energy 162:363–371

16. United Nations (2005) Framework greenhouse gas emissions data for 1990–2003 submitted to the convention on climate change

17. (1991) Modeling of integrated environmental control systems for coal-fired power plants, Report No. DE-AC22-87PC79864, Prepared by Center for Energy and Environmental Studies, Carnegie Mellon University, for U.S. Department of Energy, Pittsburgh Energy Technology Center, Pittsburgh, PA, May 1991

18. Saidi Kais, Mbarek Mounir Ben (2016) Nuclear energy, renewable energy, CO_2 emissions, and economic growth for nine developed countries: Evidence from panel Granger causality tests. Science Direct Progress Nucl Energy 88:364–374

19. Tokimatsu K, Kosugi T, Asami T, Williams E, Kaya Y (2006) Evaluation of lifecycle CO2 emissions from the Japanese electric power sector in the 21st century under various nuclear scenarios. Elsevier 34(7):833–852

20. Suto M (2016) Importance of nuclear generation in the struggles to reduce CO2 emission at Kansai Electric Power Co. Dosclide

21. Stacy TF, Taylor GS (2015) The levelized cost of electricity from existing generation resources, Institute for energy research (IER)

22. (2011) International Energy Outlook, DOE/EIA 0484, September 2011

23. Amin Shabanpour Haghighi, Seifi Ali Reza, Niknam Taher (2014) A modified teaching–learning based optimization for multi-objective optimal power flow problem. Energy Convers Manag 77:597–607m

24. De Roo Guillaume, Parsons John E (2011) A methodology for calculating the levelized cost of electricity in nuclear power systems with fuel recycling. Energy Econ 33:826–839

25. Thoisenniklas, Kost C, Johannes N, Mayerjessica (2013) Levelized cost of electricity renewable energy technologies study

26. Weiner AM, McGovern RK, John H, Lienhard V (2015) A new reverse electro dialysis design strategy which significantly reduces the levelized cost of electricity. J Membr Sci 493:60–614

27. Singh Nirala, McFarland Eric W (2015) Levelized cost of energy and sensitivity analysis for the hydrogen-bromine flow battery. Power Sources 288:187–198

28. Díaz Guzmán, Gómez-Aleixandre Javier, Coto José (2015) Dynamic evaluation of the levelized cost of wind power generation. Energy Convers Manag 101:721–729

29. Boubault Antoine, Ho Clifford K, Hall Aaron, Lambert Timothy N, Ambrosini Andrea (2016) Levelized cost of energy (LCOE) metric to characterize solar absorber coatings for the CSP industry. Renew energy 85:472–483