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The IAEA DEEP desalination economic model: A critical review

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ABSTRACT

The IAEA DEEP software has been used worldwide for the economic evaluation of desalination plants (thermal or electrical) coupled with various energy sources (nuclear, fossil fueled or renewable). Throughout the years, the software was updated constantly. Such updates included the user interface and model structure but not the economic models. Previous continuous development was culminated in the development of the DEEP 3.2 version which has been recently released in 2009.

This paper presents a step forwards in the continuous effort to maintain high standards and reliability of DEEP. It also scrutinizes methods used, assumptions made, and constants or default values originally used. The validity of calculations as well as the identification of the most important parameters is presented. Sensitivity analysis is used to identify the most important parameters in the DEEP model.

Overall, the review proves that both the DEEP economic model and software implementation are solid for economic evaluation of dual purpose plants. Based on results presented and recommendations made, a new version of DEEP is expected to be released in 2010 which will address minor issues and improvements.

1. Introduction

Technological advances of the last decade have succeeded in making desalination spreading faster and becoming a reliable source for the supply of water, and consequently for sustainable development. Yet, minimizing the cost of seawater desalination is recognized as one of the most important technology challenges. With the rising energy costs and water demands, the energy consumed and subsequently the costs involved in any desalination plant may play an important role in any economic feasibility and optimization studies of desalination systems.

In the last decade, the total contracted desalination capacity has almost tripled (see Fig. 1). The desalination technology with the greatest share is 60% for RO, 30% for MSF and 10% for MED [1]. The average capacity per project has also dramatically increased (see Fig. 2). Consequently, the energy needs of each project have become significantly larger creating the necessity for larger and more reliable energy sources. Moreover, the increase in energy costs and the uncertainty in fossil fuel prices have multiplied the expenditures of constructing and operating a desalination plant [2].

The economics of desalination could be enhanced further through cogeneration i.e. the use of dual purpose plants (e.g. for electricity generation and water production). Sustainability, environmental considerations, and large-scale economic aspects have made nuclear energy a promising energy source candidate for desalination, based on previous experience with nuclear desalination (see Table 1) [1,3].

Currently, there is a growing interest in the use of nuclear energy for various non-electrical applications such as desalination, hydrogen production, and process heat applications [4]. Among other drivers for this interest are cheaper energy, less uncertainty on energy costs, higher load factor of the desalination plant, better load factor of the nuclear unit, utilization of nuclear plant's free land, and reduction of the desalination carbon footprint [5–7].

The attractiveness of using nuclear energy for seawater desalination on large scale [8,9] has led the International Atomic Energy Agency (IAEA) to develop and distribute freely the Desalination Economic Evaluation Program (DEEP). DEEP was originally derived from the desalination cost evaluation package developed in the eighties by General Atomics on behalf of the IAEA [10]. The old version, named "Co-generation and Desalination Economic Evaluation" Spreadsheet, (CDEE) which was used for feasibility studies related to nuclear desalination in the IAEA and other Member States. Subsequently, with its increasing popularity, a user-friendly version was issued by the Agency towards the end of 1998 under its current name of "Desalination Economic Evaluation Program" (DEEP).

The DEEP software is usually used for the following [11]:

- Calculation of the levelized cost of electricity and desalted water as a function of quantity, site specific parameters, energy source, and desalination technology.
- Side-by-side comparison of a large number of design alternatives on a consistent basis with common assumptions.
- Quick identification of the lowest cost options for providing specified quantities of desalted water and/or power at a given location.

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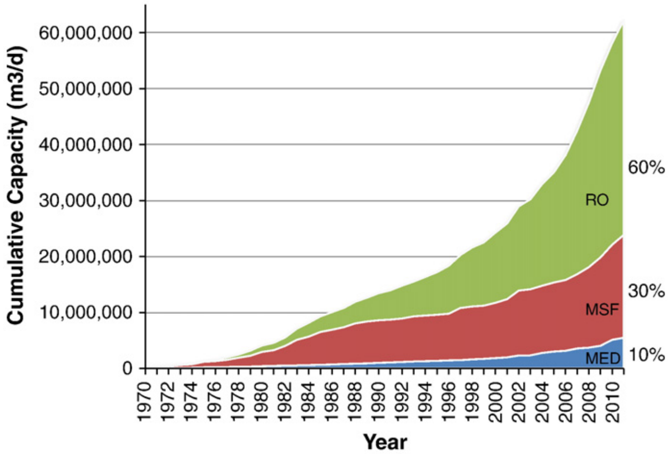

Fig. 1. Cumulative contracted capacity of desalination plants.

Despite the fact that DEEP is not a design code, it has been used worldwide for the economic evaluation of desalination plants (thermal or electrical) coupled with various energy sources (nuclear, fossil fueled or renewable) for site specific project feasibility analysis [12–14], what-if analysis [15,16] or even for conceptual research studies [17]. Throughout the years, the software was updated constantly. Such updates included the user interface and model structure but not the economic models. One of the most salient features of DEEP was the complete modularization of various cases. As the user group enlarged, new ideas as well as criticisms of the DEEP models appeared. Some of them were implemented gradually in different working versions (versions 2.0 [11], 2.1, 2.2, 2.3, 2.4, 2.6, 3.0 [18], 3.1). The previous continuous development culminated in the development of the DEEP 3.2 version which has been recently released in 2009. The DEEP main calculation sheet supports both nuclear and fossil power options. It considers heating and power plants as well as heat-only plants, distillation processes MSF and MED and membrane process reverse osmosis.

The scope of this work is to review the overall economic model and parameters used in DEEP, and evaluate the validity and reliability of DEEP through comparative results. The review scrutinizes methods used, assumptions made, and constants or default values originally used. As a part of the review process, concepts and methodologies of the economic sub-models used in DEEP are presented, and the model

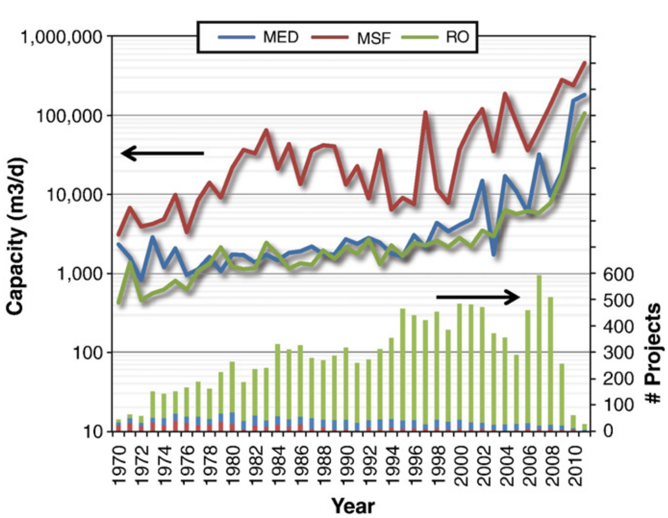

Fig. 2. Average capacity per project and number of projects contracted for each type of desalination plant.

results are discussed comparatively. Moreover, the sensitivity of the models to its parameters is examined for various characteristic cases. As an important goal of the review is to verify that the model expressions have been encoded correctly into the computer software. For the sake of clarity, the detailed model equations are not presented here and are available in the DEEP computer manual [11]. This paper presents a step forwards in the continuous effort to maintain high standards and reliability of DEEP.

2. DEEP economic models

DEEP includes models for 9 power plants (3 nuclear, 5 fossil and one renewable), and 5 desalination plants (2 thermal, one electrical and 2 hybrid) (see Table 2). There are 37 possible configurations between energy sources and desalination plants as formulated on equal numbered DEEP templates. DEEP input variables are split in the following categories:

- User input data: Case specific input such as power and desalination plant capacity, discount rate, interest, fuel escalation etc.
- Technical parameters: Technology specific parameters such as efficiencies, temperature intervals etc. which depend only on the technology used
- Cost parameters: specific costs of various components (e.g. construction, fuel etc.), cost factors and other operational parameters (lifetime, availability … etc.).

As this work elaborates on the economic module of DEEP, only the latter category is going to be presented. DEEP output is presented in terms of cost per unit product (\$/kWh for energy and \$/m^3 for water) broken down in its cost components.

2.1. DEEP economic model of energy source

The cost breakdown of a single purpose power plant annual costs and its calculation flow is presented in Fig. 3. The default operation and cost parameters are specified along with their default values for each kind of power plant on Table 3. Economics of a single purpose nuclear or fossil fueled plant can be evaluated in DEEP using the well known constant money levelized cost methodology. The levelized cost of energy is the discounted cost of all expenditures associated with the design, construction, operation, maintenance, fuel cycle costs divided by the discounted values of the quantities of energy produced [8]. This is also known as total revenue requirement method, which is the revenue that must be collected in a given year through the sales of all products to compensate the system operating company for all the expenditures incurred in the same year and to ensure sound economic plant operation [19].

The capital costs of the plant are calculated in DEEP as follows: Based on a given plant capacity (depending on the plant type, electric or thermal), the construction cost (overnight cost) is estimated. This later cost consists of the engineering, procurement and construction costs (EPC), the owners' costs, and contingency costs to keep the design at the safe side. Then, the interest during construction is calculated with an approximate formula. For the approximation, it is assumed that the total construction costs are spent at mid-time of the construction period and that payments are equally apportioned throughout the construction period. The interest is then added to the total construction cost for obtaining the total plant investment. The capital recovery factor is calculated from the discount rate and the plant economic life. This fixed charge rate is multiplied by the total plant investment to obtain the annualized capital cost. In case of nuclear power plant decommissioning costs are added to the plant annualized capital cost.

The annual energy produced is calculated in DEEP based on a given availability factor. For the estimation of the operating costs, it is assumed, that all costs except fuel costs change annually with the

Table 1
Operating nuclear desalination plants.

Site	Country	Reactor data					Desalination plant data					
		Reactors coupled	Type	Net capacity (MW)	Outlet temp (°C)	Grid date	Type	Capacity (m^3/d)	Cost (USD)	Online date	El. equivalent (GWh) (2008)	Production (m^3) (2008)
Kalpakkam	India	2	PHWR	2×202	293	1979	RO+MSF	6300	11M	2003	N/A	N/A
Genkai	Japan	2	PWR	2×1127	325	1993	MED	1000	2.61M	1993	9.35	384,552
Ikata	Japan	3	PWR	2×538 1×846	323	1996	MSF	2000	5.21M	1996	15.1	656,750
Ohi	Japan	2	PWR	2×1120	325	1979	RO	2600	6.7M	1979	24.22	1,052,995
Takahama	Japan	2	PWR	2×830	321	2004	MED	2000	5.21M	2004	11.64	506,198
Karachi	Pakistan	1	PHWR	1×125	293	1971	MED	1600	1.88M	1971	N/A	N/A

average inflation rate. Fuel costs (both fossil and nuclear) are expected over a long period of future years to increase on the average faster than the assumed inflation rate. For that reason, cost escalation is applied to that expenditure over the whole lifetime of the plant. The constant-escalation levelization factor is used to levelize the expenditure at the beginning of the first year i.e. to convert it to an equivalent annuity. Operating costs also include Operation & Maintenance and carbon tax costs (for fossil fueled plants).

Fig. 4 presents a comparison of the power cost of all power plants examined in DEEP, broken down to its components, as compared to their default values which are presented in Table 3.

2.2. DEEP economic model of desalination plant

All desalination processes require heat and electricity according to their technology, capacity and operation. In dual purpose plant, the energy needed is supplied from the power plant. Costing these energy flows is sometimes debatable and several methods have been reported in the literature, such as apportioning, calorific, exergetic etc. [8,20]. However, DEEP uses the so called 'power credit' method [13]. This method is based on the comparison between the proposed dual purpose plant and an imaginary reference single purpose plant. The cost of electricity delivered to the desalination plant, is valued based on the cost of that product from alternative imaginary power plant. The cost of heat is taken to be the revenue that would have accrued from lost electricity generation (due to the delivery of heat). As a result, water is credited with all of the economic benefits associated with the plant being dual purpose. For dual purpose heat-only plants that are coupled with a thermal desalination process, the levelized (heat) energy costs are calculated with the same procedure as for single purpose electricity only plants [8]. An option for fossil fueled-backup heat is also available so that heat can be provided for desalination even if the power plant is unavailable.

The detailed economic model of desalination plants is presented in Fig. 5. For the sake of clarity a more generic model is used which describes both thermal and electric desalination plants with the same variable names. Table 4 presents the default operation and cost parameters as specified along with their default values for each kind of desalination plant. DEEP includes energy requirements (heat and power) of desalination plant and lost electricity of the power plant caused by the partial extraction of heat to a higher temperature which is proper for the plant operation.

The estimation of desalination capital costs in DEEP is similar to that of power plants. The biggest portion of capital costs refers to construction costs, which also include in/outfall costs, backup heat costs if needed and intermediate loop costs (needed for nuclear plants as an extra safety barrier). Based on this cost owners and contingency costs and finally the interest during construction are estimated. Operating costs are split in two categories:

1. Energy costs: heat and electricity, which can either be produced from the power plant or imported from an auxiliary load when higher availability is desired (grid electricity, heat from boiler etc.).
2. Operation & Maintenance costs: staff costs (management and labor), insurance costs and material costs which consist of spare parts costs, chemicals for pre- and post-treatment, tubing replacement costs (only for low temperature MED) and membrane replacement costs (for RO).

Water cost of hybrid plants i.e. the combination of one thermal plant with RO, is calculated as the sum of the cost if the plants worked independently. The only synergy considered is that only one infall/outfall is needed in the case of hybrid plant. Fig. 6 presents a comparison between the water cost of all the available configurations of dual purpose plants that are available in DEEP, and the default values as stated in Table 4. The cost components of each plant can also be compared using Fig. 6.

Table 2
Power and desalination plants formulated in DEEP.

		Power	Heat
Energy sources			
NSC	Nuclear Steam Turbine (PWR, PWHR, and SPWR)	✓	✓
NBC	Nuclear Gas Turbine (GTMHR)	✓	✓
NH	Nuclear Heat (HR)		✓
COAL	Steam Cycle — Coal (SSB)	✓	✓
OIL	Steam Cycle — Oil	✓	✓
GT	Gas Turbine/HRSG	✓	✓
CC	Combined Cycle (Steam Turbine — Gas Turbine)	✓	✓
FH	Fossil Heat (Boiler)		✓
RH	Renewable Heat		✓
Desalination plants			
MED	Multi Effect Distillation	✓	✓
MSF	Multi Stage Flash	✓	✓
RO	Reverse Osmosis	✓	
MED+RO	Hybrid: Multi Effect Distillation+Reverse Osmosis	✓	✓
MSF+RO	Hybrid: Multi Stage Flash+Reverse Osmosis	✓	✓

3. Results and discussion

The inputs and results of the model are presented and compared with common practice, in order to see if DEEP methodology, model and parameters are valid for the economic evaluation of desalination plants. Moreover, the most important parameters are justified by using sensitivity analysis.

3.1. Model overview and results

The economic models are formulated according to conventional economic analysis methods and are appropriate for feasibility analysis of dual purpose plants. Costs that are considered in DEEP for the estimation of levelized power and water costs include major components of power and desalination plants and found to be sufficient for preliminary comparative analysis (see Figs. 4 and 6).

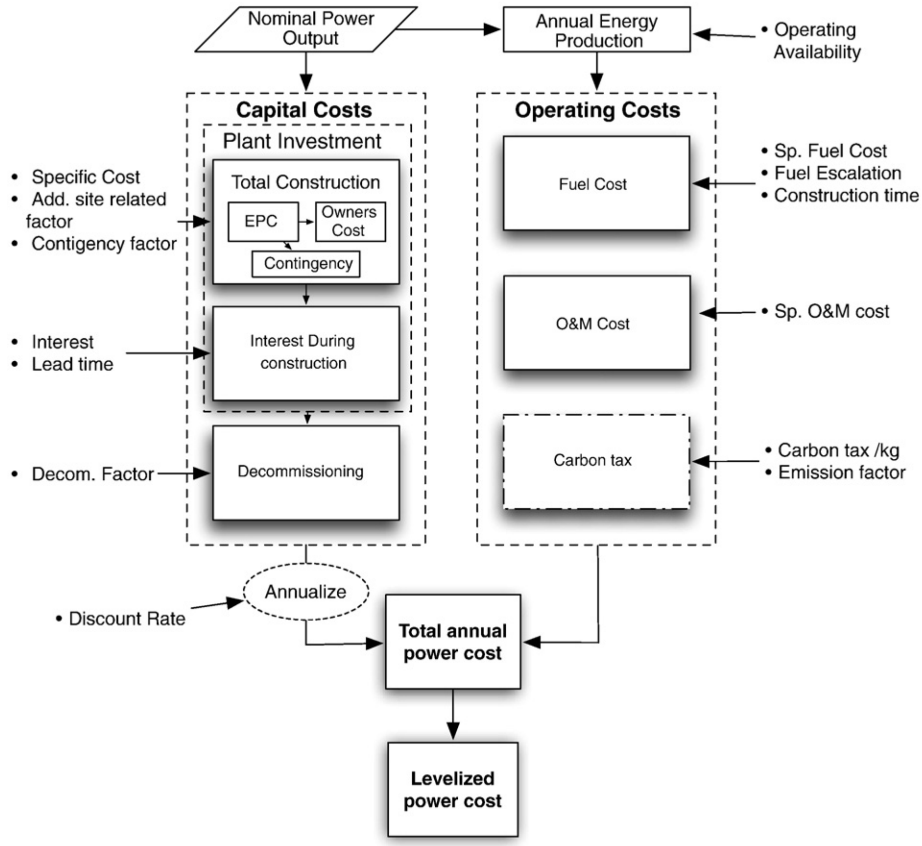

Fig. 3. Cost breakdown of power plant economic model.

The default parameters presented in Tables 3 and 4 constitute the core of the model and can be used for generic comparative estimations of conceptual plants. Overall, the parameter values seem realistic, depicting the analogy between the different configurations. Some single parameter values especially those related with fuel prices or construction times need to be updated on a regular basis in order to reflect the technological advances and fluctuations of energy prices. Major concerns have been raised on specific costs that are mentioned to underestimate the real cost of the water and power. It was found that some values that currently have no value (e.g. contingency factor) need to be revised. In addition, terminology used among models need to be revised in order to be consistent with the international practice (e.g. construction–base cost–adjusted base cost–EPC cost etc.).

Fig. 6 presents the water costs break down for all configurations available. The base case considered refers to large-scale seawater desalination plants with a discount rate of 5% and a fuel escalation (where applicable) of 2%. In general, RO is cheaper than thermal desalination methods for both fossil and nuclear options. The ideal energy source is a nuclear power plant due to the very cheap power that it provides, followed by coal plants and CC. Gas turbine based plants have also an advantage due to the virtual cost free thermal

Table 3
Power plant default model parameters.

Power plant model parameters			Fossil					RH	Nuclear		
			OIL	COAL	FH	CC	GT		NH	NSC	NBC
Operation and performance parameters											
Construction lead time	*Le*	m	36	48	18	24	24	18	40	60	24
Lifetime of energy plant	*Lep*	yr	35	35	35	25	25	35	60	60	40
Op availability	*App*	%	85%	85%	85%	85%	85%	85%	90%	90%	90%
Planned outage rate	opp	%	10%	10%	5%	10%	10%	5%	10%	10%	10%
Unplanned outage rate	oup	%	11%	11%	5%	11%	11%	5%	11%	11%	11%
Specific CO_2 emissions	*CO2e*	kg/kWh	0.5	0.5	0.5	0.5	0.5	0	0	0	0
Cost parameters											
Specific construction cost	*Ce*	\$/kW(e) or (t)	1200	1300	50	700	500	50	200	1700	1500
Specific fuel cost	*Csf*	\$/MWh(e) or (t)	75.89	25.44	30.4	57.0	89.89	7.87	6.00	6.00	6.00
Primary fuel price	*Cff*	\$/(bbl or tn)	50	75	50	50	50	30			
Specific O&M cost	*Ceom*	\$/MWh(e) or (t)	3.3	3.5	1	5.5	6.6	1	2	8.8	12
Carbon tax	*ct*	\$/t	20	20	20	20	20	0	0	0	0
Additional site related construction cost factor	*DCr*	%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Energy plant contingency factor	*kec*	%	0	0	0	0	0	0	0	0	0
Nuclear plant decommissioning cost factor	*kdcopp*	%							30%	30%	30%

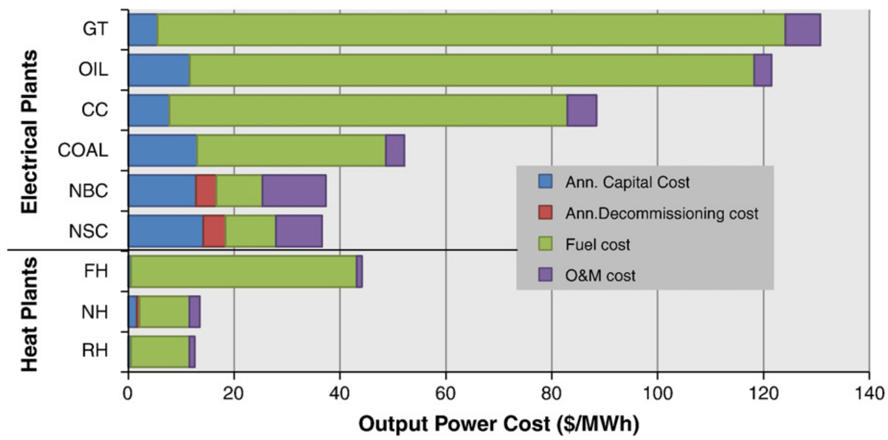

Fig. 4. Power costs for each kind of plant (sorted from least to most expensive).

energy but the high power costs do not allow it to be more competitive. As seen in Fig. 6, other fossil fuel options are more expensive due to the higher cost of steam. Water from heat-only plants is not competitive in any case. The model results, as summarized above, seem to be consistent with current practice as the water costs fall into the expected range found in literature [21,22].

DEEP economic models are formulated in such a way that the investment size does not affect the levelized water or energy cost, meaning that the economy of scale effect is poorly implemented. The fact that DEEP is applicable to large-scale desalination and power plants is reflected to the default parameter values. Users are advised to have sufficient experience to understand the uncertainty of these values and to modify the parameters if smaller scale plants are considered. Therefore, if DEEP were to be used for smaller capacity plants an underestimation of the costs should be expected. This is reflected especially in the power plant construction costs and construction time values. Hence, the total specific construction costs for a large-scale RO desalination plant (150,000 m^3/d) are approximately \$900/(m^3/d) but for a small plant they can rise even to \$2000/(m^3/d) [1]. It is therefore suggested that a more generic approach should be considered where the specific costs would be a function of the size of the plant by incorporating an economy of scale exponent. Moreover, more synergies of dual purpose plants and hybrid plants should be formulated in order to stress their benefits in terms of cost savings compared to single purpose/standalone plants.

The formulation of time value of money in DEEP is also discussed. Discount factor is a very important variable which involves a great degree of uncertainty. Contradictory opinions do exist among the model developers and users on the effect of different escalations and discount ratios on fuel costs. In general, high discount rates reflect the belief that a large profit can be made from an alternative investment.

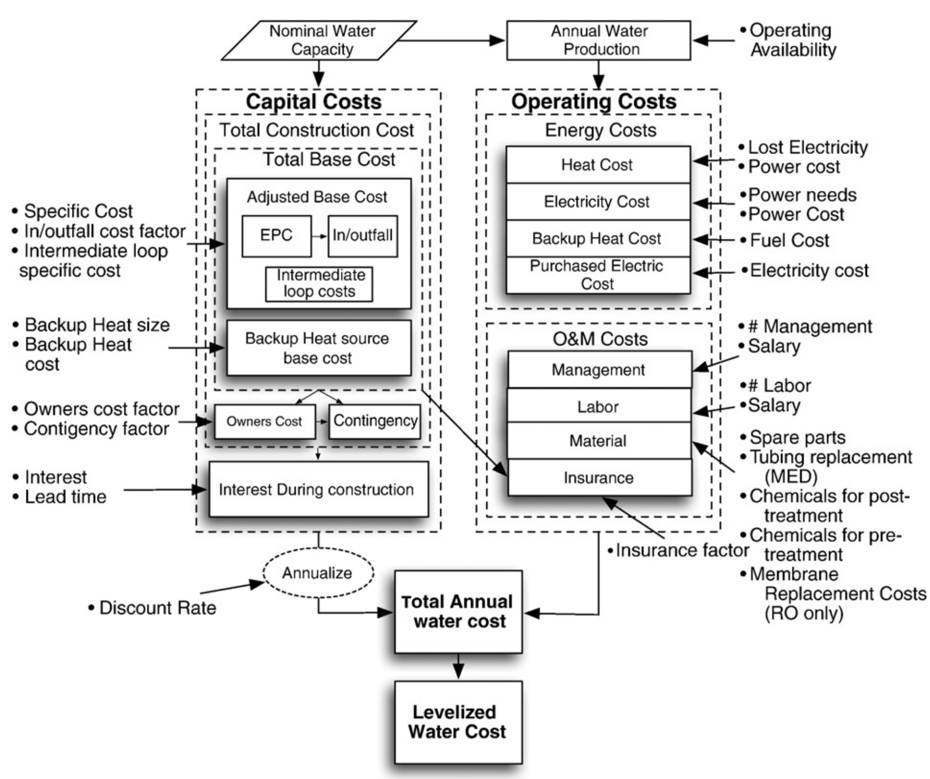

Fig. 5. Cost breakdown of desalination plant economic model.

Table 4
Desalination plant default model parameters.

Desalination plant model parameters			MED	MSF	RO
Operation and performance data	Vars	Units			
Water plant lead time	*Ld*	m	12	12	12
Lifetime of water plant	*Lwp*	yr	20	20	20
Lifetime of backup heat	*LBK*	yr	20	20	–
Water plant operating availability	*Adp*	%	90%	90%	90%
WP planned outage rate	*opd*	%	3.0%	3.0%	3.2%
WP unplanned outage rate	*oud*	%	6.5%	6.5%	6.0%
Cost data					
Base unit cost	*Cdu*	$/(m^3/d)	900	1000	900
Backup heat source	*Cbu*	$/MW(t)	55,000	55,000	–
Fossil fuel price for backup heat	*Cffb*	$/bbl	20	20	–
Purchased power cost	*Cpe*	$/kWh	0.06	0.06	0.06
Management salary	*Sdm*	$/yr	66,000	66,000	66,000
Labor salary	*Sdl*	$/yr	29,700	29,700	29,700
Specific O&M spare parts cost	*csds*	$/m^3	0.03	0.03	0.04
Tubing replacement cost (LT— MED)	*cdtr*	$/m^3	0.01	–	–
Specific O&M chemicals cost for pre-treatment	*cdcpr*	$/m^3	0.03	0.03	0.03
Specific O&M chemicals cost for post-treatment	*cdcpo*	$/m^3	0.02	0.02	0.01
O&M membrane replacement cost (RO)	–	$/m^3	–	–	0.07
In/outfall sp. cost factor	*Csdo*	%	7%	10%	7%
Water plant owners cost factor	*kdo*	%	5%	5%	5%
Water plant cost contingency factor	*kdc*	%	10%	10%	10%
Water plant O&M insurance cost	*kdi*	%	0.5%	0.5%	0.5%

Thus, money today is very valuable and future money is less valuable. As a result, an increasing discount raise causes a raise in total costs. However, it is observed in DEEP that levelized fuel costs and consequently operating costs are getting lower with the raise of discount rate (Fig. 7). This behavior is completely normal and can be explained by understanding the effect of discount rate and cost escalation. Levelized cost means average cost including capital/finance and operation over a plants lifetime. Fuel costs will be more increased towards the end of the plant lifetime (due to their escalation). Since a higher discount rate would made future money less valuable, the average levelized fuel cost and consequently the operating costs would be reduced. The behavior of total power costs depends on the share of fuel costs to the levelized power cost; fuel cost has a smaller share in nuclear power sources compared to fossil power sources. Therefore, it is common for fossil fueled energy plants to benefit a high discount rate, lowering their total costs. On the contrary, the total cost of water plants tend to rise with the discount rate due to the fact that the share of power plants fuel costs to the total water cost is usually so small that it does not affect the behavior of the total cost.

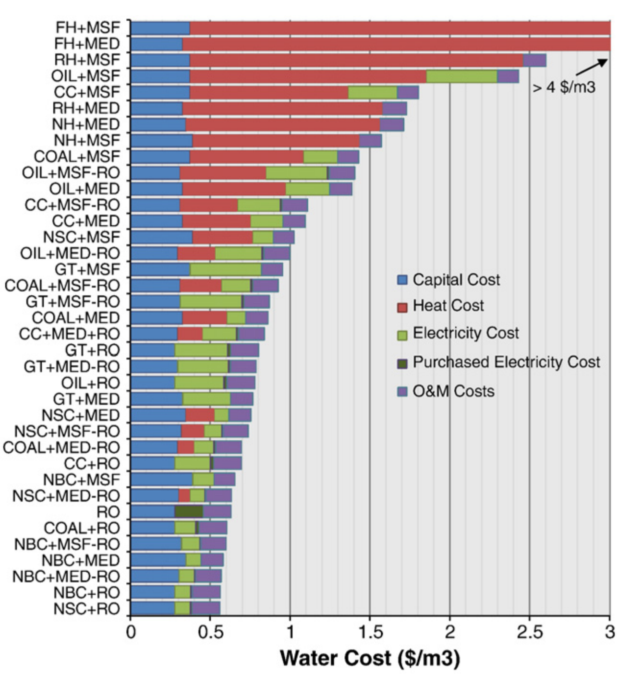

Fig. 6. Water costs for each kind of configuration (sorted from most to least expensive).

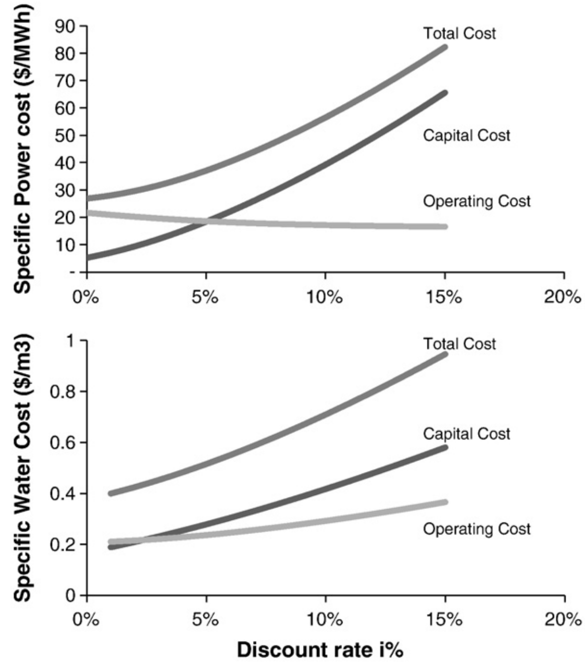

Fig. 7. Effect of discount rate in power and water costs (case of NSC + MED).

As far as decommissioning costs are concerned, it has been debated that they have been overestimated. As they are expected to be disbursed at the end of the plant lifetime, a different estimation of the present value of this cost should be used, which would conclude that in present value terms it is not a major component of levelized energy cost. At the present, they are considered to be disbursed at the beginning of the lifetime and are discounted just as capital costs. Moreover, they consist only of a 10–15% of the initial cap cost and when discounted they contribute a few percent to the total power costs. It is agreed that in present value terms this term is negligible [23]. This false assumption leads to an overestimation of power costs of nuclear power plants, reducing thus the estimated benefits of nuclear desalination.

Overall, it is evident that DEEP methodology, assumptions and parameters of economic models are appropriate for the preliminary economic evaluation and comparison of both desalination and power plants. The analysis involves the calculation of major cost components of both power and desalination plants. It is based on user-adjusted parameters that are appropriate for any examined case. A more analytical cost breakdown could be used especially for the construction costs of the desalination plant. However, this would not improve the uncertainty of the results and the precision of the model which is used only for preliminary analysis. Overestimation of the results will keep always the design on the safe side. Based on previous issues and concerns, minor corrections may improve the precision of the model.

3.2. Sensitivity analysis

An important aspect of this review is to evaluate the effect of changes in input values and assumptions made in DEEP and to justify weighting of importance of parameters during the calculation of the energy/water cost. Despite its uncertainties and limitations, such evaluation is intended to determine whether DEEP model can be

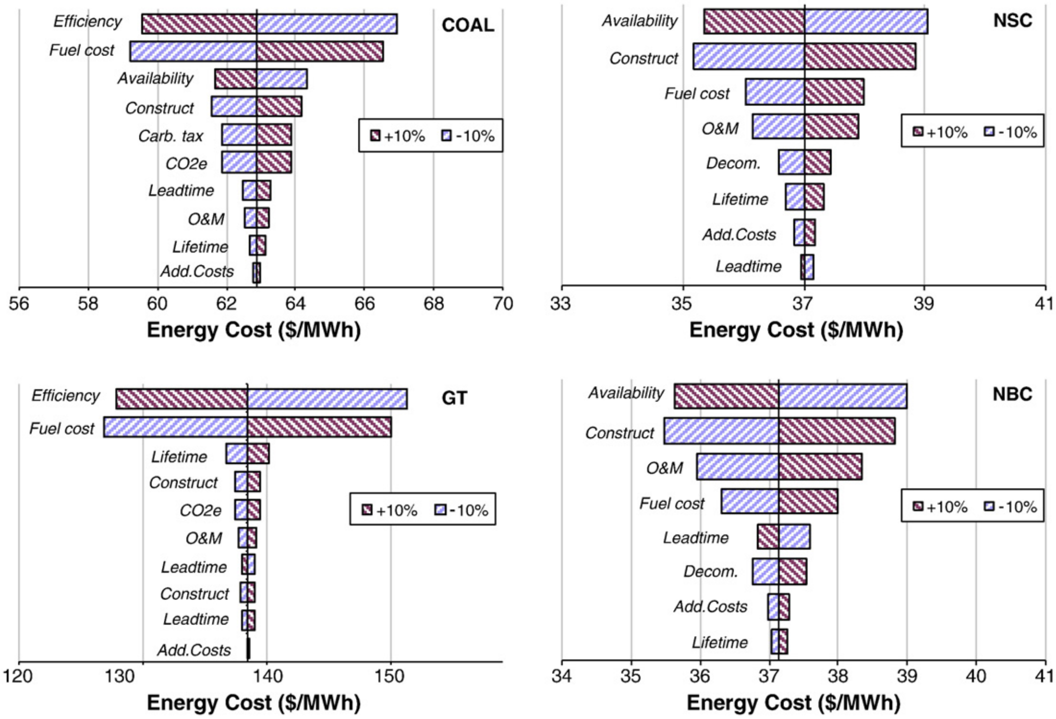

Fig. 8. Sensitivity analysis of power plants model parameters (2 nuclear and 2 fossil fueled).

appropriately used to support the decision-making process on nuclear desalination. Uncertainties in the reliability of plant construction and operation as well as unforeseen escalation of costs are important criteria which always have to be taken into account. For example, a technically unproven plant design may result in higher outage rates, higher capital and O&M costs as well as in shorter economic life than considered in the economic assessment.

Sensitivity analysis is being conducted on the default parameters of each plant formulated in DEEP in order to justify their importance and its impact on the power and water costs. A common approach of the sensitivity analysis is that to change one-factor-at a time. The key concept is to choose a base case scenario of input values and to perturb each input variable by a given percentage away from the base value while holding all other input variables constant. This method provides quick information about the most crucial parameters. The most crucial parameters for two nuclear and two fossil fueled plants are presented in the form of a tornado plot: steam cycle (NSC, COAL) and gas cycle (NBC, GT) plants (see Fig. 8). In Fig. 8, all parameters are modified by $\pm 10\%$ and are sorted by their influence on the output. As seen in Fig. 8, the power cost in fossil fueled plants is very sensitive to fuel prices due to the fact that fuel cost is the biggest component of power cost. On the contrary, the fuel contribution to the overall cost of the electricity produced by a nuclear power plant is relatively small, as expected, so even a large fuel escalation will have a relatively little effect. It is also clear from Fig. 8 that the most sensitive parameter in nuclear power plants is its availability and construction cost.

Fig. 9 shows the parameters of desalination plant that affect the water cost sorted by their importance. Fuel costs are a major component in non-nuclear power plants as expected. This fact gives an advantage compared to fossil fueled solutions as it provides a safety barrier to the unexpected fluctuations of fossil fuel prices. Nuclear fuel costs amount to only a small percentage of total electricity cost and consequently to water cost, hence it is less sensitive to the fluctuations of fuel prices. The benefit of using a nuclear source will be even more pronounced when the carbon tax is going to be enforced [16]. The most sensitive components of all water plants are also the availability, the construction cost, and the lifetime of plant. Variables from the technical module (lost electricity, power requirements etc.) that mostly express the benefit of a dual purpose plant and its technological efficiency have a major impact on the water cost. The overall results show that the desalination

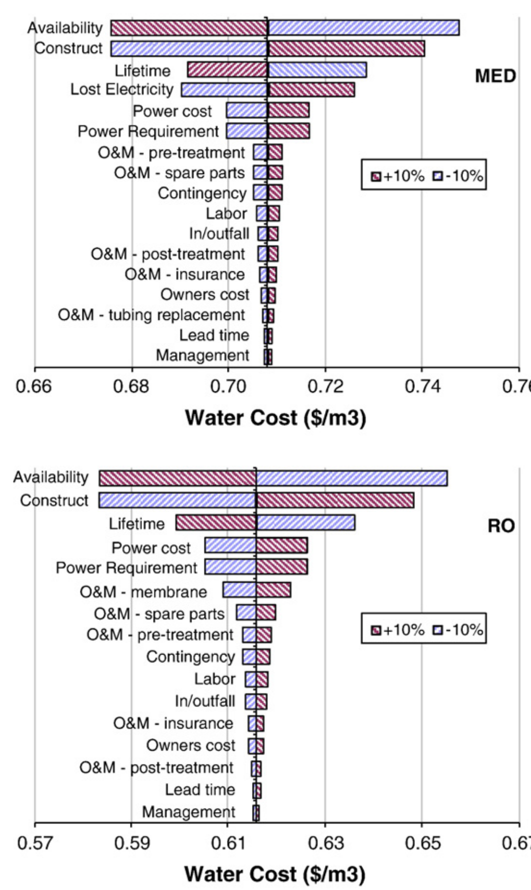

Fig. 9. Sensitivity analysis of desalination plants coupled with a NSC power source.

economic model is over-parameterised. As indicated from the sensitivity analysis (see Fig. 9), less important parameters can be unified, thus simplifying the model without increasing its uncertainty limits. Parameters related to most O&M costs are barely affecting total costs. For example there are four different specific costs used for the estimation of the material costs that barely affect the energy costs that could be unified. As a result, the allocation of costs for both energy and water in DEEP is found to be realistic. However it is over-sensitive in some specific parameters in which data entry should be more cautious. Some less important parameters could be unified in order to simplify the model and to focus on the most important effects.

3.3. Implementation of the economic models in DEEP

The described economic models are implemented on MS Excel spreadsheet enhanced with Visual Basic methodology and connected with the thermodynamic/technical models. During the continuous updates and the maintenance of the 37 different templates, some minor inconsistencies and continuity errors have been caused between the connections of different modules. Moreover, some variables have become obsolete but were not removed from the spreadsheet causing confusion to the users. Most indicative errors fall into the following categories:

- Some formulas break down due to the lack of conditional clauses that check for specific values, e.g. when discount rate equals fuel escalation the fuel levelization factor is not defined.
- Model of similar plants formulated in different templates is not consistent with the described methodology, e.g. water plant insurance costs for RO plants are calculated in a different way compared to MSF or MED. More specifically, the latter do not consider owner and contingency costs.
- Factors are sometimes used in a different way than intended, e.g. for the estimation of backup heat fuel costs, the lifetime of the power plant is used instead of the lifetime of the desalination plant. Backup heat load factor is used for the purchased electricity cost, instead of a grid load factor, resulting to not charging heat-only power plants for their electrical needs.
- Existence of two variables referring to the same figure, inadvertently caused by an update, e.g. lead time is used in interest during construction calculation, and reference year of construction and operation used in fuel levelization factor.

It is suggested that DEEP code could well be revised in order to eliminate minor deficiencies and to ensure the proper implementation of the models. The introduction of modern programming concepts in DEEP will make the maintenance of the code easier, emphasizing the user friendliness while keeping the open philosophy of the application. Moreover, to enhance the economic evaluation of desalination plants with more information, more detailed cash flows presentation, various cost/benefit profitability analyses and estimation of various economic indices, could be introduced in DEEP in order to make it usable for bankable feasibility analysis.

4. Conclusion

DEEP is a powerful tool for comparative economic evaluation of various configurations for desalination plants. The review revealed that overall DEEP economic methods and software implementation are still solid for the economic assessment of dual purpose plants. It was found that minor deficiency in DEEP does not affect greatly the results and the overall value of DEEP code. Results derived from DEEP should be used as an additional tool for improving judgment and enhancing the decision-making process. However, users still need to be knowledgeable about DEEP models, its assumptions and the range of applicability of all parameters, and evaluate results based on such knowledge. It should be pointed that improvements based on this review are currently under consideration in the new release of DEEP version. The new version, expected to be released in 2010, will have some peculiar advantages which will help: a) experts to perform comparative evaluation in an easy, friendly and transparent way, and b) new users to quickly learn the aspects of a desalination plant and their assessment techniques.

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