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Economic (Cost-Benefit) Analysis of Power Generation from Commercial Reinforced Concrete Solar Chimney Power Plant Built in the Desert Regions of Iran

Farhad Saleki Baghban[1], Hosein Nasir Aghdam[2]

[1] Student of M.Sc., Department of Electrical Engineering. Ahar Branch, Islamic Azad University, Ahar, Iran Email: f_saleki_b@yahoo.com

[2] Department of Electrical Engineering. Ahar Branch, Islamic Azad University, Ahar, Iran

Email: h_nasir59@yahoo.com

ABSTRACT

This paper expands a model different from existing models to analyze the cost and benefit of a reinforced concrete solar chimney power plant (RCSCPP) built in the desert regions of Iran. Based on the model and some assumptions for values of parameters, this paper calculates total net present value (TNPV) and the minimum electricity price in each phase by dividing the whole service period into four phases. The results showed that the minimum electricity price in the first phase is higher than the current market price of electricity, but the minimum prices in the other phases are far less than the current market price. The analysis indicated that huge advantages of the RCSCPP over coal-fired power plants could be embodied in phases 2–4. In addition, the sensitivity analysis performed in this paper discovered that TNPV is very sensitive to changes in the solar electricity price and inflation rate, but responds only slightly to changes in carbon credits price, income tax rate and interest rate of loans. Our analysis predicts that RCSCPPs have very good application prospect.

KEYWORDS: Cost-benefit analysis, Power generation, Reinforced concrete solar chimney, Sensitivity analysis.

1. INTRODUCTION

In recent years, rapid developments of global economy and increase in population and living standards have been posing great pressure on natural resources (Fig. 1) and the environment. Fossil fuels are being exhausted at a fast rate, and utilization of fossil fuels together with net deforestation has induced considerable climate change in warming the atmosphere by releasing greenhouse gases (GHG) [1].

Stern estimated that the economic losses caused by global warming go beyond 20% of world GDP. For this reason, more and more countries begin to take measures to reduce the emission of greenhouse gases. One of these measures is to develop the technologies utilizing renewable and clean energy sources. As a renewable and clean energy, solar energy is carbon-free, inexhaustible, sustainable, cost free and practically unlimited. It is able to satisfy the power demand of mankind at present and in the future if some of the solar radiation radiating on the Earth's surface is utilized. In recent years, how to turn the abundant solar energy into the energy that human can directly utilize has become a popular and difficult problem. With the diminishing of fossil fuels and the exacerbation of greenhouse effect, many countries provide economic incentives for the development of solar power plants, including non-returnable subsidies, soft loans, favorable tax policies and so on [2].

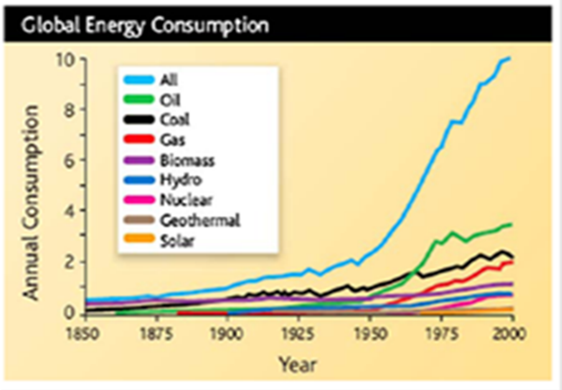


Fig.1. Annual global energy consumption during the time between 1850 and 2000

The solar chimney power plant (SCPP) combines three familiar components: a solar collector, a SC situated in the center of the collector, and power conversion unit (PCU) which includes one or several turbine generators. The turbines are driven by airflow produced by buoyancy resulting from greenhouse effect inside the collector (Fig. 2) [1].

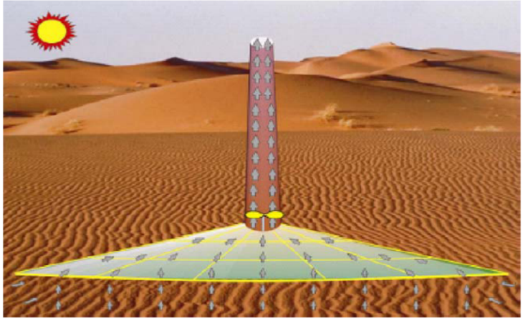


Fig. 2. Schematic diagram of SCPP

The most suitable construction sites of large-scale SCPPs are located in vast desert regions where land may be free. The technologies for the SCPP components are simple and reliable, accessible to the technologically less developed countries, which are sunny and often have limited raw material resources. Little maintenance and no combustible fuel and cooling water are needed for SCPPs [1].

By now, no one commercial SCPP have been built in the world. A comprehensive economic analysis is very necessary to show the competitiveness of the SCPP technology before its commercial application.

Recently, several economic models were developed to assess the economic competitiveness of the commercial SCPPs.

Schlaich and Bernardes estimated the component cost for various plant sizes, evaluated the levelized electricity cost (LEC), and analyzed the sensitivity of the LEC to some economic parameters. Besides, Bernardes derived a parametric cost model for the main plant components. Schlaich et al. estimated the cost of plants and the LEC with different power capacities. The collector roofs of the plants were assumed to be made of plastic membrane in the studies by Schlaich and Schlaich et al., and of glass in the study by Bernardes. Fluri et al. presented a more detailed cost model to estimate the cost of two commercial plants whose configurations were similar to the 100 MW plants, respectively proposed by Schlaich et al. and Bernardes. In their economic analysis, the impact of carbon credits on the LEC was also considered. These studies mentioned above considered commercial reinforced concrete solar chimney power plants (RCSCPPs).

By now, little work on economic analysis of SCPPs has been reported by taking into consideration the cash flows. Zhou et al. performed economic analysis of power generation from a 100 MW FSCPP by analyzing cash flows during their whole service period and compared the economics of the 100 MW FSCPP and a 100 MW RCSCPP. Later, Cao et al. performed economic analysis of conventional SCPPs and sloped-collector SCPPs with three power capacities of 5.1 MW, 35.1 MW, and 104.7 MW proposed in Northwest China by analyzing cash flows during their whole service periods. The service periods of the proposed plants were assumed to be 30 years. In Zhou et al's. and Cao et al's. views, the revenue of carbon credits need not be taxed, and the income tax cost has not been calculated.

In this paper, a detailed cost-benefit model is developed to estimate the cost and benefit of power generation from a 100 MW RCSCPP in the desert regions of Iran. There are several differences between this paper and the previous studies. Firstly, we develop a more comprehensive model than the ones built by others. Our model considers the benefit of carbon credits excluded by Schlaich and Bernardes, as well as the income tax cost omitted by Fluri et al., Zhou et al. and Cao et al. Secondly, we use risk-adjusted discount rate method for the first time to discount net cash flow. Compared to conventional discount method employed by Fluri et al, Zhou et al., Cao et al. and so on, risk-adjusted discount rate method can consider the huge risk of RCSCPPs whose service period exceed 100 years. Thirdly, we consider an RCSCPP which can be used for 120 years and divide the whole service periods into four phases to calculate total net present value of each phase. By doing so, we can compare RCSCPPs with coal-fired power plants which can usually serve 30 years. Finally, unlike previous studies, we use elasticity method to make sensitivity analysis. Accordingly, we can see the responsiveness of total net present value to many parameters [2].

2. PERFORMANCE OF REINFORCED CONCRETE SCPP

The working principle of SCPPs is simple: A huge chimney in an arid area with sufficiently high solar irradiation is surrounded by a large glass roof, the collector. The warm air collected under the roof flows towards the chimney. There, on its way, it drives turbines connected to generators which create electric power.

The high SCs for most commercial SCPP proposals were proposed to be built with reinforced concrete. The main advantage of RCSCPPs is that it has a long life span and can bring cash flows continually. Generally, RCSCPPs can be used for more than 100 years. Since the floating chimneys of FSCPPs need to be replaced every once in a while, RCSCPPs are more economic compared to FSCPPs owing to much less maintenance required.

An RCSCPP consists of three parts as shown in Fig. 3: chimney, collector and power conversion unit (PCU).

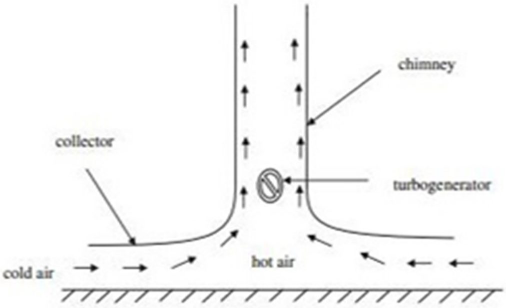


Fig.3. Schematic diagram of a solar chimney power plant.

The chimney is usually made of reinforced concrete. In order to improve the efficiency of SCPP, the chimney is needed to be as high as possible. With the development of construction technology, it is not very difficult to build more than 1000 m high chimneys. The collector is simply made up of collector cover, column system and support matrix. By and large, the collector cover is built with glass or plastic materials. The PCU includes turbines, generators, electronic control equipment and grid feed-in apparatus [2].

3. THE MODEL

3.1. Benefit analysis

The benefits of an SCPP include two parts: the benefit of electricity sale and the additional benefit resulted from carbon credits because of lessening GHG emissions.

3.1.1. Benefit of electricity sale

The benefit of electricity sale depends on the price of solar electricity (P_S) and annual electricity output (E_S). In order to promote the development of solar power plants, the government usually gives economic incentives by setting higher sale price than the market level of solar electricity. And the price goes up with the constant inflation rate (θ) every year. The electricity output is usually sold to the utility or used by the plant itself. Because the proportion of electricity used by the plant itself in the electricity output is very low, this paper supposes all the electricity is sold to the utility. Therefore, the benefit of electricity sale in the kth year (B_E^k) can be given by

$$B_E^k = E_S . P_S (1+\theta)^{k-1} \qquad (1)$$

Where n represents the life span of the plant and k=1, ..., n [2].

3.1.2. Benefit of carbon credits

One main advantage of a solar power plant over a conventional coal-fired power plant is that it never releases greenhouse gases. The data published by China Development and Reform Commission shows that burning one ton of standard coal can approximately generate 3000 kW of electricity and release 2.66–2.72 tons of carbon dioxide. Here takes the average value, namely 2.69. Then we can conclude the carbon dioxide released by coal-fired power plants is about 0.72 kg/kWh. We suppose that the price of carbon credits (P_c) annually increases with constant inflation rate (θ). Consequently, the benefit resulted from cutting down emissions of carbon dioxide in the kth year B_C^k can be expressed as [2]:

$$B_C^k = (0.72)\, E_s . P_c \, (1+\theta)^{k-1} \tag{2}$$

3.1.3. Total Benefits

Total benefits of a solar power plant are the sum of the benefit of electricity sale and the benefit of carbon credits. Let B^k denote total benefits in the kth year, then [2]

$$B^k = B_E^k + B_C^k \tag{3}$$

3.2. Cost analysis

Total costs of an SCPP in the whole service consist of the principal and interest of loans in the repayment period, the operation and maintenance cost, and the tax cost.

3.2.1. Initial investment

Let C_c denote the initial investment cost during the construction period. Suppose that all the investment cost is borrowed from banks and the loans will be repaid in the mth year. In general, there are two means of repaying loans, namely matching interest repayment law and equal principal repayment method. The former allows borrowers to repay the same amount of loans every period. However, the latter demands that borrowers repay equal principal and different amount of interest every period. Because borrowers repay constant principal every period, the interest cost becomes less and less. For this reason, total interest cost of equal principal repayment method is less than that of matching interest repayment law. Zhou et al. [3] adopt matching interest repayment law to evaluate the cost of solar power plants. In order to reduce the interest cost, this paper uses equal principal repayment method. Therefore, the principal repaid in the ith year (C_p^i) is given by:

$$C_p^i = \frac{C_c}{m} \tag{4}$$

And the debt after paying back the principal and interest in the ith year (C_D^i) becomes

$$C_D^i = C_c - (i-1)\, C_p^i \tag{5}$$

So the interest in the ith year (C_l^i) can be expressed as:

$$C_l^i = C_D^i . r \tag{6}$$

Where i=1, ..., m and r represents the interest rate of loans [2].

3.2.2. Operation and maintenance cost

The solar power plant need spend money to maintenance and repair the collector, chimney and PCU during the whole service period. All these costs are known as the operation and maintenance cost. Let C_o^1 denote the operation and maintenance cost in the first year and suppose that the cost increases with the constant inflation rate (θ). Then the operation and maintenance cost in the k^{th} year is given by

$$C_o^k = C_o^1 \left(1+\theta\right)^{k-1} \tag{7}$$

Where k=1, ..., n [2].

3.2.3. Tax cost

According to the tax law of China and Iran, depreciation and interest of loans can be excluded from the taxable benefit. In this work, the service period of the plant goes beyond 100 years. Therefore, the residual values approach zero when the plant comes to an end. In the case of proportional tax, it is favorable for the plant to use the accelerated depreciation method. Popular accelerated depreciation methods include the double-declining-balance method and the annual summation method of depreciation. Different from the depreciation method applied by Zhou et al. [3], this paper considers the latter. The depreciation rate in the kth year can be expressed as

$$d^k = \frac{n-\left(k-1\right)}{\frac{n\left(n-1\right)}{2}} = \frac{2\left(n-k+1\right)}{n\left(n+1\right)} \tag{8}$$

Consequently, the depreciation expense in the k^{th} year can be given by

$$D^k = C_c . d^k \tag{9}$$

Let t and C_T^k denote the income tax rate and the tax cost in the k^{th} year, respectively. Based on the above analysis, we have the following

$$C_T^k = \left(B_T^k - C_l^k - D^k\right)t \tag{10}$$

Where k=1, ..., n, and if k>m, then $C_l^k=0$ [2].

3.2.4. Total cost

Let C^k represent total costs of the solar power plant. Then

$$C^k = C_p^k + C_l^k + C_o^k + C_T^k \tag{11}$$

Where k=1, ..., n, and if k>m, $C_l^k=0$ and $C_p^k=0$ [2].

3.3. Cost-benefit analysis

In order to perform economic analysis of the solar power plant, it is necessary to discount the net cash flow of every year during the whole service period. Whether investment projects are profit-able partly depends on the choice of the discount rate. Zhou et al. [3] used the conventional discount method considering the inflation rate. One major shortcoming of this method is that it does not consider the risk of the project. In the light of huge risk of RCSCPPs whose service periods exceed 100 years, this work uses the risk-adjusted discount rate method (RADRM). By combining the net present value method with the capital asset pricing model, the RADRM adjusts the standard discount rate in term of the degree of risk. Let μ, b and Q denote the risk free discount rate, the risk return rate and the risk degree, respectively. Then the risk-adjusted discount rate (ρ) can be expressed as [2]

$$\rho=\mu+bQ \tag{12}$$

Where b is calculated by the difference between the investment return rate demanded by the project and the minimum return rate dividing the coefficient of medium risk, and Q is measured by the standard deviation of present value dividing total present value of benefits during the whole service period. Thus, the net present value (NPV) of RCSCPPs in the kth year can be given by [2]

$$NPV^k = \frac{B^k - C^k}{(1+\rho)^k} \tag{13}$$

Accordingly, total NPV(TNPV) becomes[2]

$$TNPV = \sum_{k=1}^{n} NPV^k \tag{14}$$

4. COST ESTIMATION OF AN RCSCPP BUILT IN THE DESERT REGIONS OF IRAN

Solar radiation varies in different parts of the world and in the sun belt of the earth is highest. Iran is located in areas of the High radiation and Studies show that the use of solar equipment in Iran is suitable and may provide part of the energy needed. Iran is a country which according to specialists wit more than two-thirds of its 300 days of sunshine and an average exposure of 4.5 - 5.5 kWh/m^2 per day, one of the countries with high potential in solar energy has been introduced. Some Solar experts step further and claim that the desert regions of Iran if fitted to the radiant energy system can satisfy the energy needed of a wide range of regional as well and be active in exporting electricity. So the SCPP system has large potential of application in the desert regions of Iran [4]. This paper considers a 100 MW RCSCPP whose dimension (chimney height is 1000 m, chimney diameter is 110 m and collector diameter is 4300 m) is similar to the configuration Weibing Li et al [2].

4.1. Initial investment estimation

Total initial investment of the RCSCPP consists of the investment on the collector, chimney and PCU.

4.1.1. Cost of the collector

The collector consists of transparent roof, column system and support matrix. Glass or plastic film is often used as collector cover material. Schlaich et al. and Bernardes evaluated the cost of different solar power plants which have plastic roofs. In comparison with a glass cover, a plastic film is easily age and readily destroyed in terrible environment. Here considers a glass cover. The collector cost includes the cost of materials, transportation cost and construction cost. In the estimation by Weibing Li et al. [2], construction cost and transportation cost were 20% and 2% of the cost of materials, respectively. This work employs the same in Iran. The prices of steel and 4 mm thick tempered glass are 23 million Rials/t and 185000 Rials/m^2, respectively. Here neglects the land cost because solar power plants are usually built in the vast wastelands or mountainous regions. Based on the estimation by Li et al. [2], we can easily calculate the cost of the collector presented in Table 1.

4.1.2. Chimney cost

The chimney cost consists of the cost of materials, construction cost, transportation cost and hoisting cost. Considering the height of the chimney and the weather conditions, here supposes the chimney is built with the high performance concrete (C80) whose price is 4.3 million Rials / m^3.

The price of the reinforcement used in the plant is 23 million Rials/t and every cubic meter needs 120 kg of reinforcements. The construction cost including the concrete cover and labor cost is assumed 10 million Rials / m^3 . The material hoisting cost of the high chimney is assumed to be 20% of the concrete and ring stiffener costs, excluding the transport cost. Based on the analysis of Weibing Li et al. [2] and the relevant prices in Iran, the cost of the chimney can be estimated in Table 2.

4.1.3. PCU cost

The PCU includes turbines, generators, electronic control equipments, grid-in apparatus and power plant infrastructure. At present, unit power investment of PCU is about 48 million Rials /kW. With a peak power of 66 MW this equals a total cost of 3168 milliard Rials for the PCU, which based on the analysis of Weibing Li et al. [2] unit equipment and infrastructure account for 75% and 20%, respectively. Table 3 presents the corresponding results.

Table 1. Cost of the collector (milliard Rials).

Component	Material cost	Construction cost	Transportation cost	Total cost
Glass	2686.57	537.31	53.73	3277.61
Column system	477.17	95.43	9.54	582.14
Support matrix	7015.91	1403.18	140.32	8559.41
Collector	10179.65	2035.92	203.59	12419.16

Table 2. Cost of the chimney (milliard Rials).

Component	Material cost	Construction cost	Hoisting cost	Transportation cost	Total cost
Chimney shell	1188.38	1683.25	574.33	23.77	3469.73
Ring stiffeners	118.47	23.70	23.70	2.37	168.24
Chimney foundation	449.41	636.55	0.00	8.99	1094.95
Chimney	1756.26	2343.50	598.03	35.13	4732.92

Table 3. Cost of the PCU (milliard Rials).

Component	Unit equipment	Infrastructure	Others	Total
Cost	2376	634	158	3168

Table 4. Cost structure of initial investment

Component	Cost (milliard Rials)	Percent of total cost (%)
Collector	12419.16	61.12
Chimney	4732.92	23.29
PCU	3168	15.60
Total	20320.1	-

Table.5.Values of economic parameters used in carrying out cost-benefit analysis.

Economic parameter	Value
Inflation rate, θ	20%
Interest rate of loans, r	4%
Income tax rate, t	25%
Repayment period of loans, m	30 years
The whole service period, n	120 years
Initial investment, C_c	20320.1 milliard Rials
Annual electricity output, E_s	255.2 GW h/a
Solar electricity sale price, P_s	6900 Rials/kW h
Price of carbon credit, P_c	284900 Rials/t
Risk free discount rate, μ	8%
Risk-adjusted discount rate, ρ	28.52%

4.1.4. Total investment

On the basis of the above analysis, total investment of the RCSCPP considered in this work amounts to 20320.1 milliard Rials, largely made up by the collector (61.12%) and the chimney (23.29%). The PCU makes a minor contribution (15.60%). Table 4 displays the cost of each component and its proportion of totalcost.

4.2. Operation and maintenance cost

Weibing Li et al. [2] specified the operation and maintenance cost of a 100 MW RCSCPP to be 1.9 million Euros in the first year of operation. Similar with Li et al., this paper employs the cost of 1.9 million Euros, namely 70.3 milliard Rials and supposes this cost increases with inflation rate.

5. COST-BENEFIT ANALYSIS OF THE RCSCPP BUILT IN THE DESERT REGIONS OF IRAN

5.1. Parameter value

The cost and benefit of the RCSCPP are determined by many parameters, including the inflation rate, the interest rate of loans, the income tax rate, the life span, the initial investment, the operation and maintenance cost and so on. Iran’s average inflation rate in recent 10 years is about 20%. Therefore, this work takes 20% of inflation rate. Also here supposes that the RCSCPP can get a 4% interest rate loan whose repayment period is 30 years. Similar with Weibing Li et al. [2], this paper supposes the RCSCPP is legal entity to an income tax rate of 25% according to article 105 of Iran's direct taxes (income tax for legal entities) [5]. The base rate approved by the Ministry of Energy to buy electricity from renewable power plants in 1393 under Article 4, paragraph B of Article 133 of the law of the Fifth Development Plan of the Islamic Republic of Iran (Act No. 100/37732 dated 91/05/08 Economic Council) determined the equivalent of 4628 Rials per kWh [4]. This paper will calculate the NPV of the RCSCPP according to the price of 6900 Rials/kW h. Similar with Weibing Li et al. [2], here takes a electricity output of 320 GW h/a.

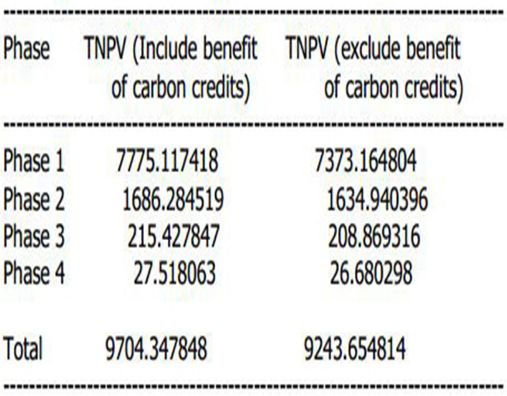
The minimum attractive rate of return (MARR) of the solar power industry is usually 8% [2]. Here supposes that the risk free discount rate ( ) is equal to MARR. When the price of solar electricity ( ) is set to 6900 Rials/kW h, it is easy to calculate the present value of benefits during the whole service period and its combined standard deviation, respectively 8845.73 and 22689.31 milliard Rials. Accordingly, the risk degree (Q) is 2.565. If the investment return rate demanded by the RCSCPP is set to 12%, and the coefficient of medium risk is 0.5, then the risk return rate (b) amounts to 0.08. Using Eq. (12), we can get the 28.52% of the risk-adjusted discount rate ( ). At present, the price of carbon credits pre tone is 7.7 Euros, namely 284900 Rials [2]. In the light of the above references and analysis, the values of economic parameters used in carrying out cost-benefit analysis are given in Table 5.

5.2. Cost-benefit analysis

Based on the economic model developed in this paper and relevant data, the detailed cost and benefit of the 100 MW RCSCPP are presented in Table 6. Conventional coal-fired power plants are assumed to serve 30 years. To compare with coal-fired power plants, the whole service period of the RCSCPP is divided into four phases and TNPV of each phase is calculated and shown in Table 6. Because of the influence of the discount rate, TNPV decreases from 7775.1 milliard Rials in the first phase to 27.52 milliard Rials in the last phase. It is necessary to evaluate TNPV of the RCSCPP excluding the benefit of carbon credits. From Table 7,it can be seen that if the benefit of carbon credits is not included in the total benefit, TNPV will decrease from 9704.34 to 9243.65 milliard Rials, namely a 4.7% drops. The reason why the benefit of carbon credits has little influence on the TNPV is because the price of carbon credit is too low at present. TNPV estimated here shows the RCSCPP is economical under the strict assumptions.

price can reflect the advantages of the RCSCPP over coal-fired power plants. By analyzing the cost and benefit of the RCSCPP, we can derive the minimum solar electricity sale price which can make TNPV of the RCSCPP equal zero.

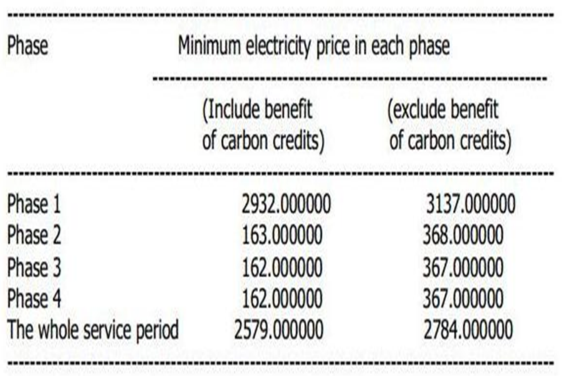
Table 7. TNPV of different phase (milliard Rials).



Phase	TNPV (Include benefit of carbon credits)	TNPV (exclude benefit of carbon credits)
Phase 1	7775.117418	7373.164804
Phase 2	1686.284519	1634.940396
Phase 3	215.427847	208.869316
Phase 4	27.518063	26.680298
Total	9704.347848	9243.654814

The service period of the RCSCPP is three times longer than that of coal-fired power plants. For this reason, one RCSCPP is equivalent to four coal-fired power plants. After the RCSCPP pays off the loans in the first phase, it only incurs the operation and maintenance cost, depreciation cost and tax cost which are very low. At the same time, when a coal-fired power plant comes to an end after 30 years, there is a need to invest again to build a new plant which costs a lot. Under the circumstances, RCSCPPs can show huge advantages over coal-fired power plants. Applying similar method, we can calculate the minimum electricity sale prices of each phase which are displayed in Table 8. Table 8 shows the minimum electricity sale price in the whole service period is 2579 Rials/kW h if the benefit of carbon credits is included in thewhole benefits. Even though the benefit of carbon credits is excluded, the minimum price is still 2784 Rials/kW h. Both of the minimum prices are less than on-grid price of solar renewable power generation (4628 Rials/kW h), which shows the electricity from RCSCPPs is competitive with solar renewable power generation. The minimum electricity sale price of the first phase (2932 or 3137 Rials/kW h) is very close to 4628 Rials/kW h whether the benefit of carbon credits is included or not. The price maybe exceed the current market price of electricity (560 Rials/kW h), but if looking at the minimum price of the other phases, we will find that it (below 368 Rials/kW h) is far less than the current market price.

Table 8. Minimum electricity sale price of each phase (milliard Rials).



Phase	Minimum electricity price in each phase	
	(Include benefit of carbon credits)	(exclude benefit of carbon credits)
Phase 1	2932.000000	3137.000000
Phase 2	163.000000	368.000000
Phase 3	162.000000	367.000000
Phase 4	162.000000	367.000000
The whole service period	2579.000000	2784.000000

The above analysis indicates that the huge advantages of the RCSCPP over coal-fired power plants can be embodied in phase 2–4. The reason is that the RCSCPP need not make initial investment after the end of phase 1 and only incurs a low cost, but coal-fired power plants need cost a lot to invest again so as to build a new plant after 30 years. The above estimation is based on a very low price of carbon credits. We expect the price of carbon credits will rise rapidly in the future, thus the competitiveness of RCSCPPs with coal-fired power plants will be more and more remarkable.

From Table 8, we also find that the minimum electricity price during the whole service period is very close to that of phase 1. The reason is that the RCSCPP need additional cost to repay huge loans in the first phase, but only incur a low cost in other phases. This analysis suggests that the government should set a higher price than the market electricity price for the RCSCPP in the first phase, but appropriately lower the price in other phases.

5.3. Sensitivity analysis

It can be seen from the above analysis that many parameters have effects on TNPV of the RCSCPP, such as the price of solar electricity, the price of carbon credits, the inflation rate, the interest rate of loans, and the income tax rate. To examine the effect of a certain parameter on TNPV, we will estimate TNPV by changing the value of one parameter in turn and keeping the values of other parameters unchanged.

5.3.1. Effect of the solar electricity price on TNPV

TNPV displayed in Table 6 is calculated at the solar electricity price of 6900 Rials/kW h. To make a sensitivity analysis, here supposes the maximum price of solar power electricity is 25 times as the market price of electricity (560 Rials/kW h) in Iran, namely 14000 Rials/kW h. Fig. 4 presents the computing result when the price ranges from 4628 to 14000 Rials/kW h.

From Fig. 4, it can be seen that a 103% increase in the price of electricity (from 6900 to 14000 Rials/kW h) causes TNPV during the whole service period to increase by 164.3% (from 9704.34 to 25650.1 milliard Rials). We can calculate the electricity price elasticity of TNPV is 1.59. This elasticity is greater than 1, so that TNPV responds substantially to changes in the price. To put it different, a slight change in the solar electricity price will lead to a big change in the TNPV.

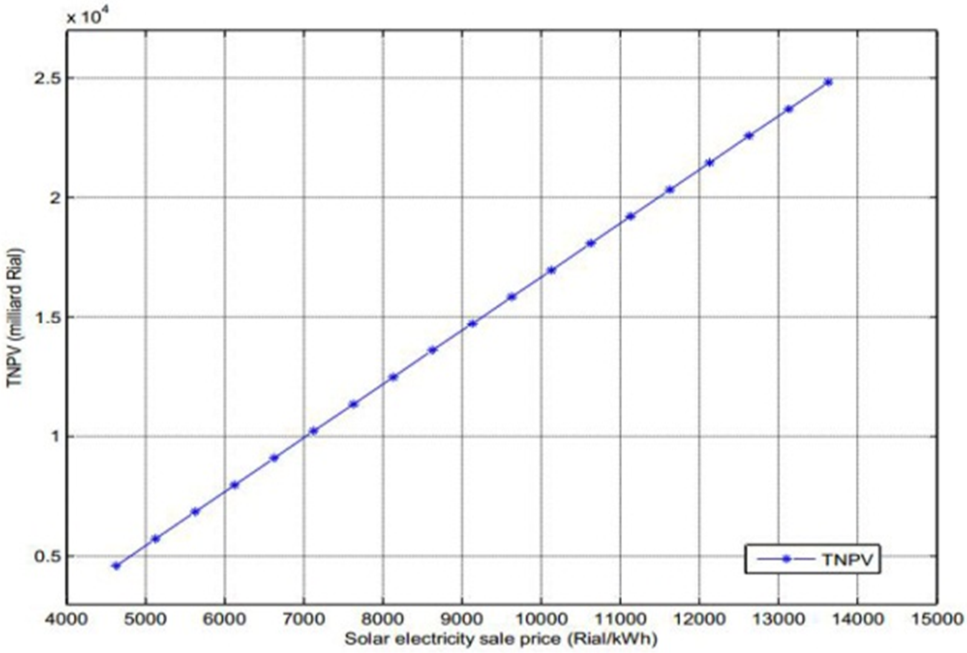


Fig. 4. Relation between TNPV with the solar electricity price.

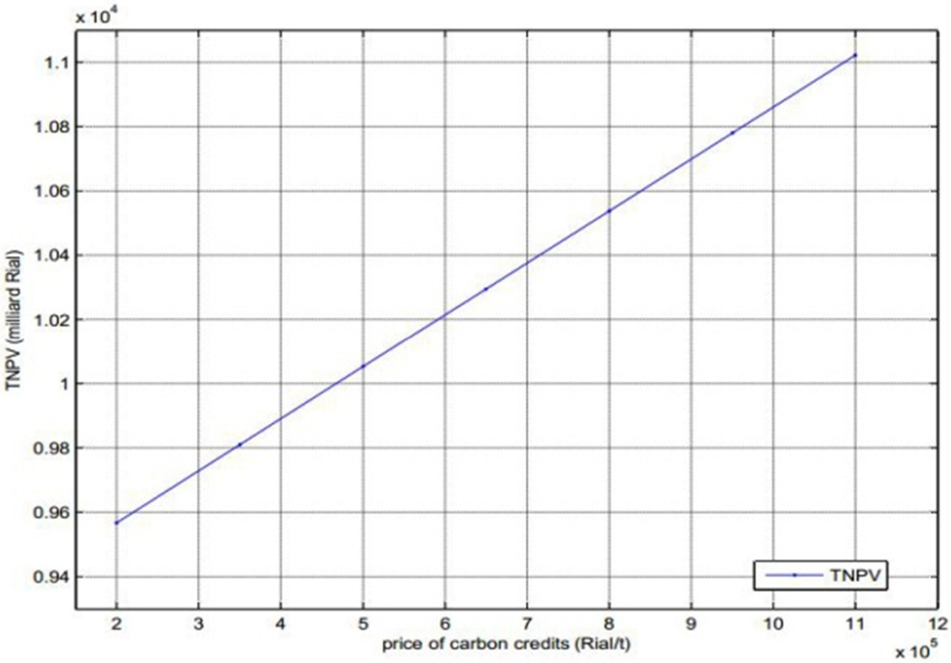


Fig. 5. Relation between TNPV with the prices of carbon credits

5.3.2. Effect of the price of carbon credits on TNPV

Faced with the reduction of the price of carbon credits, the European Union started to take measures to reduce the supply of carbon emission permit. A report issued by European Commission predicts that the price of carbon credits during 2013–2020 will reach 30 Euros/t (namely 1200000 Rials/t). Seeing that the European carbon trading volume accounts for more than 85%of global carbon trading volume, this work uses this price to make sensitivity analysis. Fig. 5 shows the corresponding result under the condition that the price of carbon credits ranges from 200000 to 1200000 Rials/t.As can be seen from Fig. 5, a 140% increase in the price of carbon credits (from 500000 to 1200000 Rials/t) gives rise to a 11.26% increase in TNPV (from 10052.17 to 11184.09 milliard Rials), which means a carbon credits price elasticity of TNPV of 0.08. This elasticity is far less than 1, thus TNPV responds only slightly to changes in the price of carbon credits. In other words, a big change in the price of carbon credits only result in a slight change in TNPV.

5.3.3. Effect of income tax rate on TNPV

The income tax rate of an individual in article 131 of direct taxes in Iran (income tax of businesses) is to 35%. In the previous analysis, we suppose the RCSCPP is regarded as a legal entity and taxed according to the income tax rate of 25%. Using the model developed earlier, we can calculate TNPV at the two income tax rates (Table 9). Table 9 shows TNPV decreases with increases in the income tax rate because the tax is one cost of the RCSCPP. The income tax rate elasticity of TNPV is -0.45, which means a big increase in the income tax rate only leads to a small decrease in TNPV.

5.3.4. Effects of inflation rate and interest rate of loans on TNPV

This work supposes the values of many parameters increase with the inflation rate. So TNPV will increase with the inflation rate. Fig. 6 depicts the relation between TNPV during the whole service period with the inflation rate from 10% to 35%. The interest rate is the opportunity cost of loans. The annual interest payment of loans depends on the interest rate. Therefore, TNPV will decrease with the increase in the interest rate of loans in theory. Fig. 7 displays the variations of TNPV during the whole service period with different interest rates from 1% to 9%. Fig. 6 shows that TNPV is very sensitive to the change of inflation rates. For example, TNPV increases from 2378.4 to 90111.42 milliard Rials with increase in the inflation rate from 12% to 28% which means an elasticity of 27.67. Meanwhile Fig. 7 shows that TNPV responds only slightly to changes in the interest rate of loans, which can be proved by the fact that TNPV decreases from 10176.29 to 8760.46 milliard Rials with increase in the interest rate of loans from 3% to 6%.

Table 9. TNPV during the whole service period at different income tax rates.

	At the income tax rate of 25%	At the income tax rate of 35%	Percentage change (%)	Income tax rate elasticity of TNPV
TNPV (milliard Rial)	9704.347848	7983.958410	-17.728027	
The income tax rate (Percentage)	25	35	40.000000	
				-0.443201

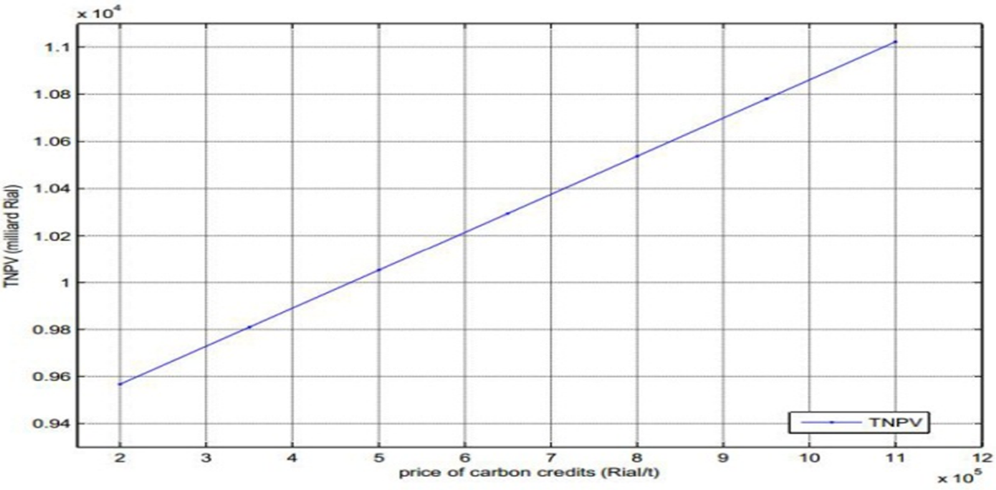


Fig. 5. Relation between TNPV with the prices of carbon credits.

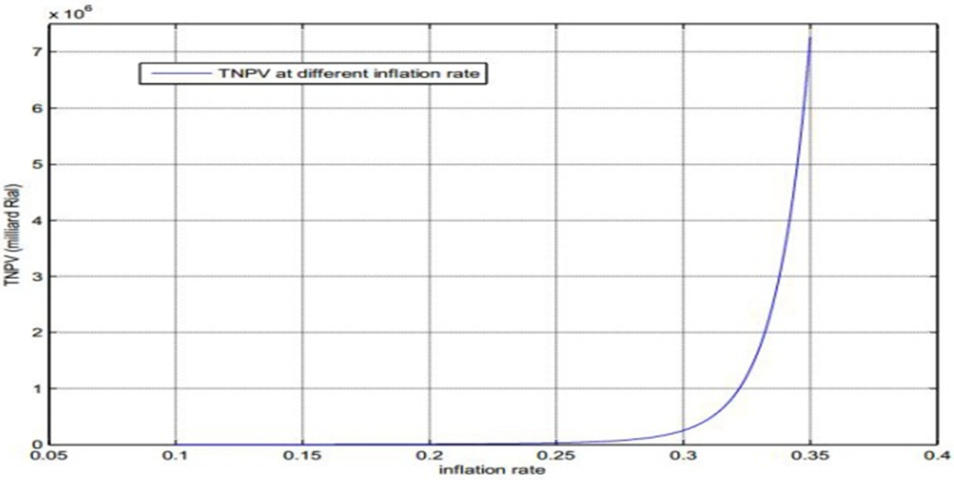


Fig. 6. Relation between TNPV with the inflation rate.

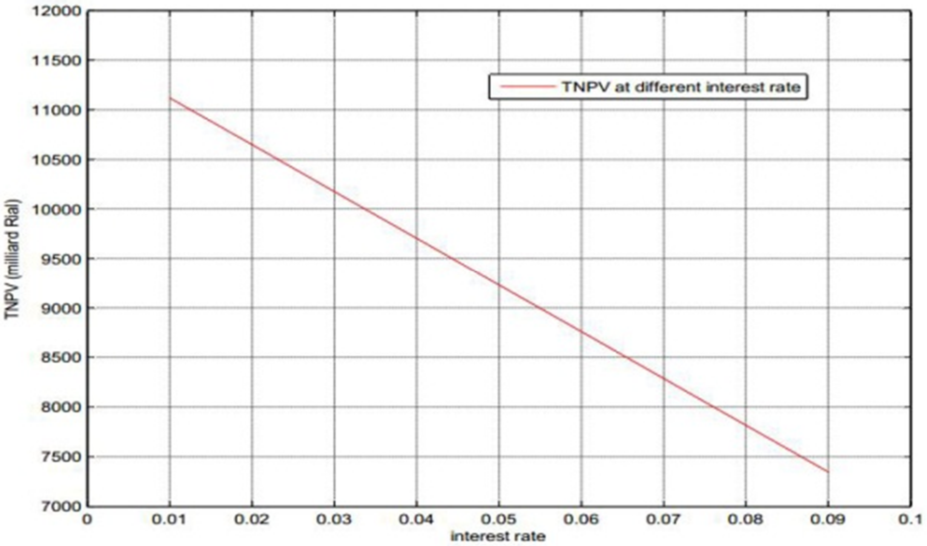


Fig. 7. Relation between TNPV with the interest rate.

6. CONCLUSIONS

This paper develops an economic model to analyze the cost-benefit of the RCSCPP built in the desert regions of Iran. The model uses risk-adjusted discount rate method which considers the huge risk of SCPPs. Another feature of this model is that it applies equal principal repayment method which can save the interest cost, but existing studies usually use annuity method. In addition, this model considers the annual summation method of depreciation which is different from existing studies. The initial investment estimated in this paper is 20320.1 milliard Rials. Based on the model presented in this work, we calculate that TNPV during the whole service period is 9704.34 milliard Rials under some assumptions on parameter values including loans at an interest rate of 4%, an income tax rate of 25%, and collection of additional benefit generated from carbon credits. By dividing the whole service period into four phases and calculating the minimum price of electricity, we find the minimum price of phase 1 is very close to 4628 Rials/kW h which is higher than the current market price of electricity. But if looking at the minimum price of the other phases, we become aware of that it is below 368 Rials/kW h which is far lower than the price of coal-fired power generation. The analysis predicts that huge advantages of the RCSCPP over coal-fired power plants can be embodied in the phase 2–4. The policy implication here is that the government should provide subsidy for RCSCPPs by setting higher electricity price in the first phase, then lower electricity price in the other phases. By sensitivity analysis, this paper discovers TNPV is very sensitive to changes in the electricity sale price and inflation rate, but responds only slightly to changes in carbon credits price, income tax rate and interest rate of loans. The cost-benefit analysis of the RCSCPP built in the desert regions of Iran shows that the RCSCPP has very good application prospect.

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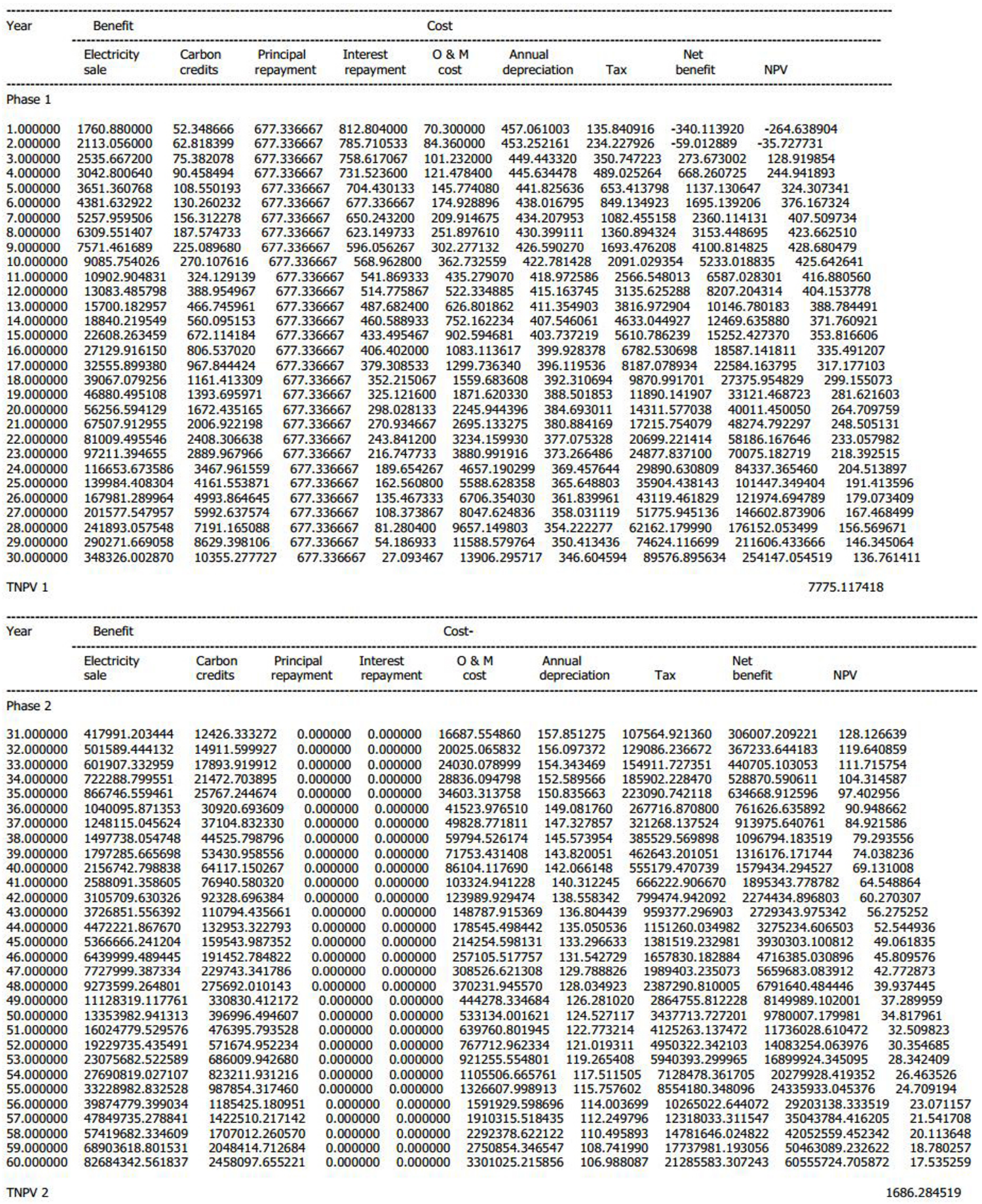
Table 6. Detailed cost and benefit of the RCSCPP (milliard Rials).



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Year        Benefit                                       Cost
            ------------------------------------------------------------------------------------------------------------------------------------
            Electricity    Carbon       Principal     Interest      O & M         Annual                         Net
            sale           credits      repayment     repayment     cost          depreciation    Tax            benefit        NPV
--------------------------------------------------------------------------------------------------------------------------------------------------
Phase 1

1.000000    1760.880000    52.348666    677.336667    812.804000    70.300000     457.061003    135.840916    -340.113920    -264.638904
2.000000    2113.056000    62.818399    677.336667    785.710533    84.360000     453.252161    234.227926    -59.012889     -35.727731
3.000000    2535.667200    75.382078    677.336667    758.617067    101.232000    449.443320    350.747223    273.673002     128.919854
4.000000    3042.800640    90.458494    677.336667    731.523600    121.478400    445.634478    489.025264    668.260725     244.941893
5.000000    3651.360768    108.550193   677.336667    704.430133    145.774080    441.825636    653.413798    1137.130647    324.307341
6.000000    4381.632922    130.260232   677.336667    677.336667    174.928896    438.016795    849.134923    1695.139206    376.167324
7.000000    5257.959506    156.312278   677.336667    650.243200    209.914675    434.207953    1082.455158   2360.114131    407.509734
8.000000    6309.551407    187.574733   677.336667    623.149733    251.897610    430.399111    1360.894324   3153.448695    423.662510
9.000000    7571.461689    225.089680   677.336667    596.056267    302.277132    426.590270    1693.476208   4100.814825    428.680479
10.000000   9085.754026    270.107616   677.336667    568.962800    362.732559    422.781428    2091.029354   5233.018835    425.642641
11.000000   10902.904831   324.129139   677.336667    541.869333    435.279070    418.972586    2566.548013   6587.028301    416.880560
12.000000   13083.485798   388.954967   677.336667    514.775867    522.334885    415.163745    3135.625288   8207.204314    404.153778
13.000000   15700.182957   466.745961   677.336667    487.682400    626.801862    411.354903    3816.972904   10146.780183   388.784491
14.000000   18840.219549   560.095153   677.336667    460.588933    752.162234    407.546061    4633.044927   12469.635880   371.760921
15.000000   22608.263459   672.114184   677.336667    433.495467    902.594681    403.737219    5610.786239   15252.427370   353.816606
16.000000   27129.916150   806.537020   677.336667    406.402000    1083.113617   399.928378    6782.530698   18587.141811   335.491207
17.000000   32555.899380   967.844424   677.336667    379.308533    1299.736340   396.119536    8187.078934   22584.163795   317.177103
18.000000   39067.079256   1161.413309  677.336667    352.215067    1559.683608   392.310694    9870.991701   27375.954829   299.155073
19.000000   46880.495108   1393.695971  677.336667    325.121600    1871.620330   388.501853    11890.141907  33121.468723   281.621603
20.000000   56256.594129   1672.435165  677.336667    298.028133    2245.944396   384.693011    14311.577038  40011.450050   264.709759
21.000000   67507.912955   2006.922198  677.336667    270.934667    2695.133275   380.884169    17215.754079  48274.792297   248.505131
22.000000   81009.495546   2408.306638  677.336667    243.841200    3234.159930   377.075328    20699.221414  58186.167646   233.057982
23.000000   97211.394655   2889.967966  677.336667    216.747733    3880.991916   373.266486    24877.837100  70075.182719   218.392515
24.000000   116653.673586  3467.961559  677.336667    189.654267    4657.190299   369.457644    29890.630809  84337.365460   204.513897
25.000000   139984.408304  4161.553871  677.336667    162.560800    5588.628358   365.648803    35904.438143  101447.349404  191.413596
26.000000   167981.289964  4993.864645  677.336667    135.467333    6706.354030   361.839961    43119.461829  121974.694789  179.073409
27.000000   201577.547957  5992.637574  677.336667    108.373867    8047.624836   358.031119    51775.945136  146602.873906  167.468499
28.000000   241893.057548  7191.165088  677.336667    81.280400     9657.149803   354.222277    62162.179990  176152.053499  156.569671
29.000000   290271.669058  8629.398106  677.336667    54.186933     11588.579764  350.413436    74624.116699  211606.433666  146.345064
30.000000   348326.002870  10355.277727 677.336667    27.093467     13906.295717  346.604594    89576.895634  254147.054519  136.761411

TNPV 1                                                                                                                      7775.117418

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Year        Benefit                                           Cost-
            ------------------------------------------------------------------------------------------------------------------------------------
            Electricity       Carbon          Principal   Interest    O & M            Annual                           Net
            sale              credits         repayment   repayment   cost             depreciation    Tax              benefit           NPV
--------------------------------------------------------------------------------------------------------------------------------------------------
Phase 2

31.000000   417991.203444     12426.333272    0.000000    0.000000    16687.554860     157.851275    107564.921360     306007.209221     128.126639
32.000000   501589.444132     14911.599927    0.000000    0.000000    20025.065832     156.097372    129086.236672     367233.644183     119.640859
33.000000   601907.332959     17893.919912    0.000000    0.000000    24030.078999     154.343469    154911.727351     440705.103053     111.715754
34.000000   722288.799551     21472.703895    0.000000    0.000000    28836.094798     152.589566    185902.228470     528870.590611     104.314587
35.000000   866746.559461     25767.244674    0.000000    0.000000    34603.313758     150.835663    223090.742118     634668.912596     97.402956
36.000000   1040095.871353    30920.693609    0.000000    0.000000    41523.976510     149.081760    267716.870800     761626.635892     90.948662
37.000000   1248115.045624    37104.832330    0.000000    0.000000    49828.771811     147.327857    321268.137524     913975.640761     84.921586
38.000000   1497738.054748    44525.798796    0.000000    0.000000    59794.526174     145.573954    385529.569898     1096794.183519    79.293556
39.000000   1797285.665698    53430.958556    0.000000    0.000000    71753.431408     143.820051    462643.201051     1316176.171744    74.038236
40.000000   2156742.798838    64117.150267    0.000000    0.000000    86104.117690     142.066148    555179.470739     1579434.294527    69.131008
41.000000   2588091.358605    76940.580320    0.000000    0.000000    103324.941228    140.312245    666222.906670     1895343.778782    64.548864
42.000000   3105709.630326    92328.696384    0.000000    0.000000    123989.929474    138.558342    799474.942092     2274434.896803    60.270307
43.000000   3726851.556392    110794.435661   0.000000    0.000000    148787.915369    136.804439    959377.296903     2729343.975342    56.275252
44.000000   4472221.867670    132953.322793   0.000000    0.000000    178545.498442    135.050536    1151260.034982    3275234.606503    52.544936
45.000000   5366666.241204    159543.987352   0.000000    0.000000    214254.598131    133.296633    1381519.232981    3930303.100812    49.061835
46.000000   6439999.489445    191452.784822   0.000000    0.000000    257105.517757    131.542729    1657830.182884    4716385.030896    45.809576
47.000000   7727999.387334    229743.341786   0.000000    0.000000    308526.621308    129.788826    1989403.235073    5659683.083912    42.772873
48.000000   9273599.264801    275692.010143   0.000000    0.000000    370231.945570    128.034923    2387290.810005    6791640.484446    39.937445
49.000000   11128319.117761   330830.412172   0.000000    0.000000    444278.334684    126.281020    2864755.812228    8149989.102001    37.289959
50.000000   13353982.941313   396996.494607   0.000000    0.000000    533134.001621    124.527117    3437713.727201    9780007.179981    34.817961
51.000000   16024779.529576   476395.793528   0.000000    0.000000    639760.801945    122.773214    4125263.137472    11736028.610472   32.509823
52.000000   19229735.435491   571674.952234   0.000000    0.000000    767712.962334    121.019311    4950322.342103    14083254.063976   30.354685
53.000000   23075682.522589   686009.942680   0.000000    0.000000    921255.554801    119.265408    5940393.299965    16899924.345095   28.342409
54.000000   27690819.027107   823211.931216   0.000000    0.000000    1105506.665761   117.511505    7128478.361705    20279928.419352   26.463526
55.000000   33228982.832528   987854.317460   0.000000    0.000000    1326607.998913   115.757602    8554180.348096    24335933.045376   24.709194
56.000000   39874779.399034   1185425.180951  0.000000    0.000000    1591929.598696   114.003699    10265022.644072   29203138.333519   23.071157
57.000000   47849735.278841   1422510.217142  0.000000    0.000000    1910315.518435   112.249796    12318033.311547   35043784.416205   21.541708
58.000000   57419682.334609   1707012.260570  0.000000    0.000000    2292378.622122   110.495893    14781646.024822   42052559.452342   20.113648
59.000000   68903618.801531   2048414.712684  0.000000    0.000000    2750854.346547   108.741990    17737981.193056   50463089.232622   18.780257
60.000000   82684342.561837   2458097.655221  0.000000    0.000000    3301025.215856   106.988087    21285583.307243   60555724.705872   17.535259

TNPV 2                                                                                                                          1686.284519
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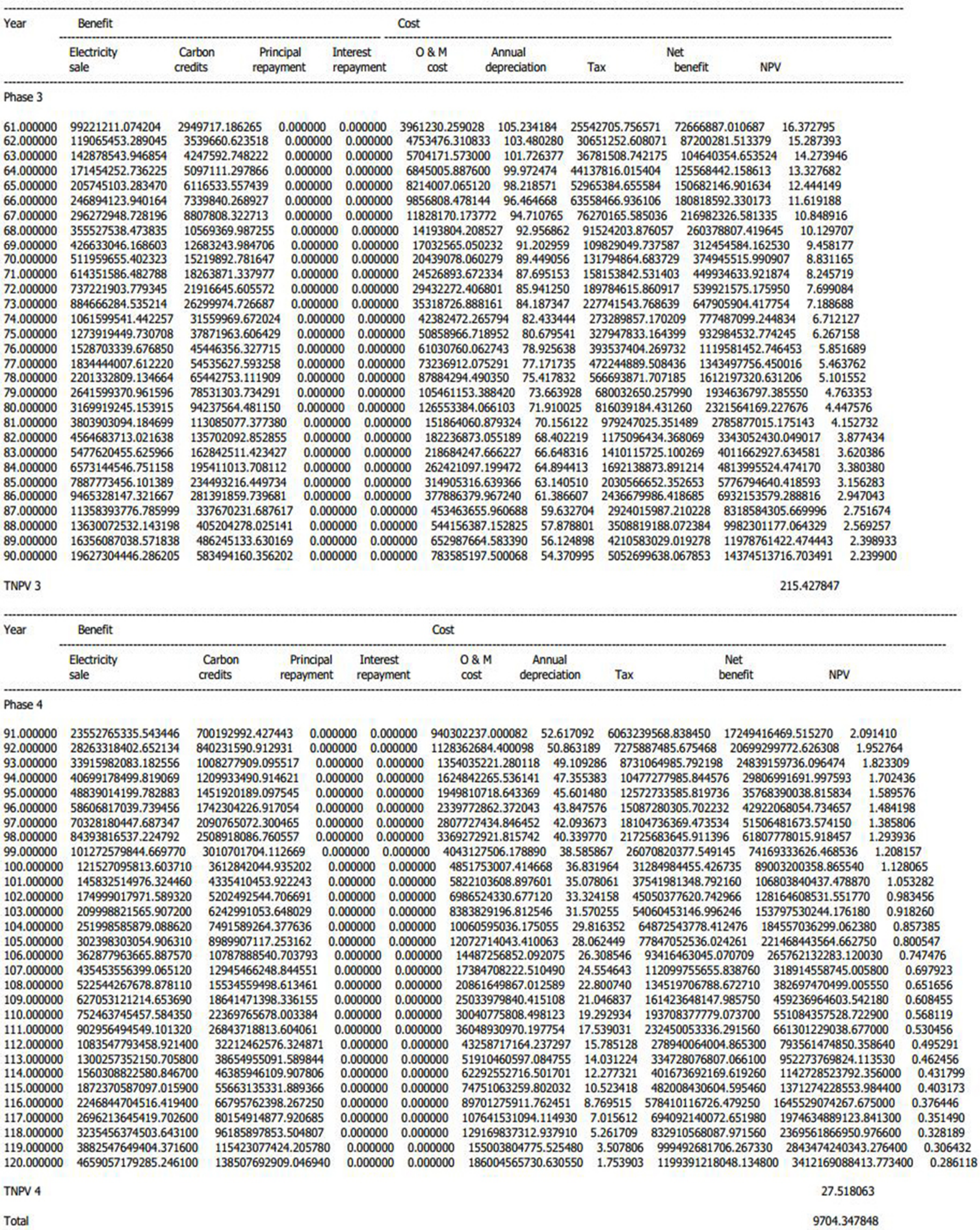
Table 6 (continued). Detailed cost and benefit of the RCSCPP (milliard Rials).



Year	Benefit		Cost						
	Electricity sale	Carbon credits	Principal repayment	Interest repayment	O & M cost	Annual depreciation	Tax	Net benefit	NPV
Phase 3									
61.000000	99221211.074204	2949717.186265	0.000000	0.000000	3961230.259028	105.234184	25542705.756571	72666887.010687	16.372795
62.000000	119065453.289045	3539660.623518	0.000000	0.000000	4753476.310833	103.480280	30651252.608071	87200281.513379	15.287393
63.000000	142878543.946854	4247592.748222	0.000000	0.000000	5704171.573000	101.726377	36781508.742175	104640354.653524	14.273946
64.000000	171454252.736225	5097111.297866	0.000000	0.000000	6845005.887600	99.972474	44137816.015404	125568442.158613	13.327682
65.000000	205745103.283470	6116533.557439	0.000000	0.000000	8214007.065120	98.218571	52965384.655584	150682146.901634	12.444149
66.000000	246894123.940164	7339840.268927	0.000000	0.000000	9856808.478144	96.464668	63558466.936106	180818592.330173	11.619188
67.000000	296272948.728196	8807808.322713	0.000000	0.000000	11828170.173772	94.710765	76270165.585036	216982326.581335	10.848916
68.000000	355527538.473835	10569369.987255	0.000000	0.000000	14193804.208527	92.956862	91524203.876057	260378807.419645	10.129707
69.000000	426633046.168603	12683243.984706	0.000000	0.000000	17032565.050232	91.202959	109829049.737587	312454584.162530	9.458177
70.000000	511959655.402323	15219892.781647	0.000000	0.000000	20439078.060279	89.449056	131794864.683729	374945515.990907	8.831165
71.000000	614351586.482788	18263871.337977	0.000000	0.000000	24526893.672334	87.695153	158153842.531403	449934633.921874	8.245719
72.000000	737221903.779345	21916645.605572	0.000000	0.000000	29432272.406801	85.941250	189784615.860917	539921575.175950	7.699084
73.000000	884666284.535214	26299974.726687	0.000000	0.000000	35318726.888161	84.187347	227741543.768639	647905904.417754	7.188688
74.000000	1061599541.442257	31559969.672024	0.000000	0.000000	42382472.265794	82.433444	273289857.170209	777487099.244834	6.712127
75.000000	1273919449.730708	37871963.606429	0.000000	0.000000	50858966.718952	80.679541	327947833.164399	932984532.774245	6.267158
76.000000	1528703339.676850	45446356.327715	0.000000	0.000000	61030760.062743	78.925638	393537404.269732	1119581452.746453	5.851689
77.000000	1834444007.612220	54535627.593258	0.000000	0.000000	73236912.075291	77.171735	472244889.508436	1343497756.450016	5.463762
78.000000	2201332809.134664	65442753.111909	0.000000	0.000000	87884294.490350	75.417832	566693871.707185	1612197320.631206	5.101552
79.000000	2641599370.961596	78531303.734291	0.000000	0.000000	105461153.388420	73.663928	680032650.257990	1934636797.385550	4.763353
80.000000	3169919245.153915	94237564.481150	0.000000	0.000000	126553384.066103	71.910025	816039184.431260	2321564169.227676	4.447576
81.000000	3803903094.184699	113085077.377380	0.000000	0.000000	151864060.879324	70.156122	979247025.351489	2785877015.175143	4.152732
82.000000	4564683713.021638	135702092.852855	0.000000	0.000000	182236873.055189	68.402219	1175096434.368069	3343052430.049017	3.877434
83.000000	5477620455.625966	162842511.423427	0.000000	0.000000	218684247.666227	66.648316	1410115725.100269	4011662927.634581	3.620386
84.000000	6573144546.751158	195411013.708112	0.000000	0.000000	262421097.199472	64.894413	1692138873.891214	4813995524.474170	3.380380
85.000000	7887773456.101389	234493216.449734	0.000000	0.000000	314905316.639366	63.140510	2030566652.352653	5776794640.418593	3.156283
86.000000	9465328147.321667	281391859.739681	0.000000	0.000000	377886379.967240	61.386607	2436679986.418685	6932153579.288816	2.947043
87.000000	11358393776.785999	337670231.687617	0.000000	0.000000	453463655.960688	59.632704	2924015987.210228	8318584305.669996	2.751674
88.000000	13630072532.143198	405204278.025141	0.000000	0.000000	544156387.152825	57.878801	3508819188.072384	9982301177.064329	2.569257
89.000000	16356087038.571838	486245133.630169	0.000000	0.000000	652987664.583390	56.124898	4210583029.019278	11978761422.474443	2.398933
90.000000	19627304446.286205	583494160.356202	0.000000	0.000000	783585197.500068	54.370995	5052699638.067853	14374513716.703491	2.239900
TNPV 3									215.427847

Year	Benefit		Cost						
	Electricity sale	Carbon credits	Principal repayment	Interest repayment	O & M cost	Annual depreciation	Tax	Net benefit	NPV
Phase 4									
91.000000	23552765335.543446	700192992.427443	0.000000	0.000000	940302237.000082	52.617092	6063239568.838450	17249416469.515270	2.091410
92.000000	28263318402.652134	840231590.912931	0.000000	0.000000	1128362684.400098	50.863189	7275887485.675468	20699299772.626308	1.952764
93.000000	33915982083.182556	1008277909.095517	0.000000	0.000000	1354035221.280118	49.109286	8731064985.792198	24839159736.096474	1.823309
94.000000	40699178499.819069	1209933490.914621	0.000000	0.000000	1624842265.536141	47.355383	10477277985.844576	29806991691.997593	1.702436
95.000000	48839014199.782883	1451920189.097545	0.000000	0.000000	1949810718.643369	45.601480	12572733585.819736	35768390038.815834	1.589576
96.000000	58606817039.739456	1742304226.917054	0.000000	0.000000	2339772862.372043	43.847576	15087280305.702232	42922068054.734657	1.484198
97.000000	70328180447.687347	2090765072.300465	0.000000	0.000000	2807727434.846452	42.093673	18104736369.473534	51506481673.574150	1.385806
98.000000	84393816537.224792	2508918086.760557	0.000000	0.000000	3369272921.815742	40.339770	21725683645.911396	61807778015.918457	1.293936
99.000000	101272579844.669770	3010701704.112669	0.000000	0.000000	4043127506.178890	38.585867	26070820377.549145	74169333626.468536	1.208157
100.000000	121527095813.603710	3612842044.935202	0.000000	0.000000	4851753007.414668	36.831964	31284984455.426735	89003200358.865540	1.128065
101.000000	145832514976.324460	4335410453.922243	0.000000	0.000000	5822103608.897601	35.078061	37541981348.792160	106803840437.478870	1.053282
102.000000	174999017971.589320	5202492544.706691	0.000000	0.000000	6986524330.677120	33.324158	45050377620.742966	128164608531.551770	0.983456
103.000000	209998821565.907200	6242991053.648029	0.000000	0.000000	8383829196.812546	31.570255	54060453146.996246	153797530244.176180	0.918260
104.000000	251998585879.088620	7491589264.377636	0.000000	0.000000	10060595036.175055	29.816352	64872543778.412476	184557036299.062380	0.857385
105.000000	302398303054.906310	8989907117.253162	0.000000	0.000000	12072714043.410063	28.062449	77847052536.024261	221468443564.662750	0.800547
106.000000	362877963665.887570	10787888540.703793	0.000000	0.000000	14487256852.092075	26.308546	93416463045.070709	265762132283.120030	0.747476
107.000000	435453556399.065120	12945466248.844551	0.000000	0.000000	17384708222.510490	24.554643	112099755655.838760	318914558745.005800	0.697923
108.000000	522544267678.878110	15534559498.613461	0.000000	0.000000	20861649867.012589	22.800740	134519706788.672710	382697470499.005550	0.651656
109.000000	627053121214.653690	18641471398.336155	0.000000	0.000000	25033979840.415108	21.046837	161423648147.985750	459236964603.542180	0.608455
110.000000	752463745457.584350	22369765678.003384	0.000000	0.000000	30040775808.498123	19.292934	193708377779.073700	551084357528.722900	0.568119
111.000000	902956494549.101320	26843718813.604061	0.000000	0.000000	36048930970.197754	17.539031	232450053336.291560	661301229038.677000	0.530456
112.000000	1083547793458.921400	32212462576.324871	0.000000	0.000000	43258717164.237297	15.785128	278940064004.865300	793561474850.358640	0.495291
113.000000	1300257352150.705800	38654955091.589844	0.000000	0.000000	51910460597.084755	14.031224	334728076807.066100	952273769824.113530	0.462456
114.000000	1560308822580.846700	46385946109.907806	0.000000	0.000000	62292552716.501701	12.277321	401673692169.619260	1142728523792.356000	0.431799
115.000000	1872370587097.015900	55663135331.889366	0.000000	0.000000	74751063259.802032	10.523418	482008430604.595460	1371274228553.984400	0.403173
116.000000	2246844704516.419400	66795762398.267250	0.000000	0.000000	89701275911.762451	8.769515	578410116726.479250	1645529074267.675000	0.376446
117.000000	2696213645419.702600	80154914877.920685	0.000000	0.000000	107641531094.114930	7.015612	694092140072.651980	1974634889123.841300	0.351490
118.000000	3235456374503.643100	96185897853.504807	0.000000	0.000000	129169837312.937910	5.261709	832910568087.971560	2369561866950.976600	0.328189
119.000000	3882547649404.371600	115423077424.205780	0.000000	0.000000	155003804775.525480	3.507806	999492681706.267330	2843474240343.276400	0.306432
120.000000	4659057179285.246100	138507692909.046940	0.000000	0.000000	186004565730.630550	1.753903	1199391218048.134800	3412169088413.773400	0.286118
TNPV 4									27.518063
Total									9704.347848