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Sensitivity and effectiveness analysis of incentives for concentrated solar power projects in Chile

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ABSTRACT

Northern Chile has excellent conditions to develop concentrated solar power projects. Although solar irradiation makes a significant contribution to production in the region, solar thermal projects need some support mechanisms. This study focuses on the best combinations of solar incentives and financial parameters to have lowest government cost and maximum levelized cost of electricity reduction. Key findings of this paper showed that debt fraction and discount rate illustrated meaningful sensitivities on both LCOE and government cost. ITC, PTC, and DM as tax credit and PBI as cash incentives had the best effectiveness, and reduced LCOE better than IBI and STR. The effectiveness of ITC, PTC, PBI, and DM was independent of financial parameters even though STR and IBI showed dependency. Although cash incentives had no limits to reduce LCOE, tax credit incentives reached maximum values, which meant that their impacts were limited. As cash incentives, PBI showed better results when it was compared to IBI. Maximum values of ITC maintained the same for different installed costs, while it changed for PTC. Finally, it was obtained that tax credit incentives were more meaningful at higher PPA price although PBI made more sense in lower PPA prices.

1. Introduction

The Chilean economy is based on heavily energy consumer mining activities which mostly take place in the north of the country. In order to meet the energy demand of mining industry, it is necessary to develop a sustainable energy policy by using the significant renewable energy potential. In recent years, due to the high solar potential of northern Chile with the approximate annual average of Direct Normal Irradiation (DNI) of 10 kWh/m^2 per day [1], solar energy projects have gain importance in this region. In spite of high installation cost, the lack of renewable energy incentives and regulation policies (tax incentives, rebate programs, cash-grant programs, loan programs, industry recruitment/support, bond programs, performance-based incentives) [2], high solar irradiation makes a great contribution to develop solar thermal energy projects in the area. Additionally, as reported by *Energy 2050*, Chile has the target of 70% electricity production from NCRE (Non-Conventional Renewable Energy) sources until 2050 [3,4]. It is apparent that concentrated solar power (CSP) plants with thermal storage and photovoltaic (PV) technology could have significant contribution to reach this target and have a continuous, sustainable, and clean energy planning in Chile.

When solar energy plants are compared to the conventional energy production facilities, they may require incentives and financial facilities due to high investment costs. Regulatory instruments and support mechanisms help to increase the number of installed solar power projects. Besides, tax credit and cash incentives are needed to make solar energy projects feasible and these incentives are able to diminish the gap between the levelized cost of electricity (LCOE) and the power purchasing agreements (PPA) in the projects.

According to the report of International Renewable Energy Agency (IRENA) published in 2015, Chile has renewable energy

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support mechanisms such as regulatory instruments (auctions, quota, certificate system, and net metering) and financial supports (dedicated fund, pre-investment support, and direct funding) [5]. In addition to this, in the past, investors could benefit from tax credit incentives in Arica and Parinacota region in northern Chile. According to the law of Arica in 2001, investment projects were eligible for a tax credit of 30% in Arica and 40% in Parinacota until 2008 [6]. Despite having some regulations and improvements on solar energy support policy in Chile, the mechanisms are not enough to support CSP projects and the auctions result differently each year. As mentioned before, northern Chile is an important region to develop solar energy projects due to the high solar potential. Therefore, in the latest years, CSP companies appeared in the auctions. The first offer was from Abengoa Company for Atacama-1 project in 2014 (including 110 MW solar tower power plant and 100 MW PV plant). In that year, Abengoa won the auction with a PPA price of 114.82 USD/MWh [7]. The second offer was from SolarReserve company for Copiapo Solar project (including two 130 MW solar tower power plants and 200 MW PV plant) with a PPA of 67.89 USD/MWh in 2016 [7]. However, they could not win the auction with this offer. In that year, the companies which offered less than approximately US$ 55 per MWh won this auction, and the minimum offer was given as US$ 29.2 per MWh by a PV company. Also, in South Africa, SolarReserve and ACWA Power offered 120 USD/MWh for 100 MW solar thermal project in 2015. The long-term Power Purchase Agreements (PPAs) can be considered between 100 and 120 USD/MWh for CSP technologies [8]. As a result, for CSP projects, it is hard to enter electricity market in Chile without any support mechanisms due to reducing installation costs of other technologies.

Developing and analyzing solar energy support mechanisms is important for the countries with solar potential all around the world such as Spain, USA, India, Morocco and South Africa. Spain is one of substantial example in the world in terms of having grants, soft financing and tax incentives allowing 20% reduction of income tax [9]. The USA is another important solar energy promoter with its governmental and state-based incentives. In order to support and make the solar energy prices competitive, they have income tax credit, tax exemption, production-based incentives and investment based incentives [10]. In order to understand the impact of these support mechanisms, several studies were realized. Sarzynski et al. investigated the impact of financial incentives for photovoltaic (PV) technology on market deployment in the United States of America. It was indicated that between the years 1997 and 2009, the cash incentives given by the state were more meaningful on solar market expansion than the tax incentives in USA [11]. Bolinger et al. studied the contribution of the incentives to the solar project finance for investors. It was indicated that when both 30% ITC and 5 years accelerated depreciation were considered for a project, the amount of the contribution of these incentives was near 56% of the installed cost for a non-residential PV project in USA [12]. Schmalence et al. reported that in addition to ITC, 5-year accelerated depreciation schedules, which was established by the Tax Reform Act of 1986, has a significant contribution to lowering the LCOE of solar, geothermal, and wind generation projects in the USA [13]. Sawhney et al. researched the solar incentives policy of Tennessee state of USA. It was indicated that cash-based incentives like grants affect the solar industry apparently more than the tax credit incentives [14]. El-Karmi et al. analyzed financial incentives such as grant period, discount rate, depreciation period and several accelerated depreciation methods for Jordan. As a result of the study, accelerated depreciation and discount rate variation had a notable impact on net present value (NPV), internal rate of return (IRR) and simple back pay period (SBPP) of wind and solar energy projects. The grant period and taxation rate, which were analyzed in their research, had less impact on NPV, IRR, and SBPP when they were compared with other analyzed parameters [15]. In the report of the World Bank, the impact of cash and tax incentives for concentrated solar energy projects in India, Morocco and South Africa were mentioned. As stated in the report, regarding these three countries, accelerated depreciation, soft loan term, and soft loan rates were more effective to lower the LCOE when they were compared with tax credit incentives. For example, the calculated reductions in LCOE for CSP Tower in India were respectively 0.97%, 4.17% and 16.19% for the incentives: tax reduction, accelerated depreciation, and concessional loan terms. In addition to this, when incentives having different contributions were combined, this combination contributed to reducing LCOE near 20% for India, 25% for South Africa and 30% for Morocco [16]. Servert et al. investigated the impact of the soft loan and up-front grant for the solar tower and parabolic trough projects for Chile. According to research's results, it was shown that using the grant to lower the equity share had a better effect than using it to decrease capital expenditures or to pay the loan. In other words, decreasing the equity share with the grant made CSP more competitive. When the grant was used to lower equity, the effect of the soft loan was stronger for a large amount than a small amount [8]. Finally, Blair et al. mentioned that CSP technologies would be a compelling and contributor technology in energy production with the help of expanded tax credit incentives and the cost reduction [17].

Although the studies with LCOE reduction by considering incentives and financial parameters can be found in the literature, there is no paper mentioning solar projects support mechanisms in terms of both governments cost and LCOE reduction. The purpose of this paper is to research the behaviors of incentives and essential financial parameters on costs and to find the best combinations of support mechanisms by considering maximum LCOE reduction and minimum government costs for several cases. The methodology includes both sensitivity, impact, effectiveness and limits analyses of incentives and financial conditions for two different CSP technologies. Additionally, it contributes to the literature by showing robust results to policymakers which can be state or government level to understand the costs and impacts of incentives in order to promote solar energy technologies under different conditions. Finally, the research gives an opinion about solar market and country conditions to investors who are planning to enter energy market in Chile.

The paper is organized as follows: Section 2 includes methodology mentioning general assumptions, incentives and parameters considered for parametric analysis and calculated parameters in the research. Section 3 describes six different analyses and the results including LCOE components, sensitivity analysis of financial parameters, impact and effectiveness analysis of incentives, limit values and impact analysis for ITC, PTC and depreciation, installation cost analysis and, NPV analysis under different PPA prices. And finally, Section 4 concludes the paper.

2. Methodology

The methodology includes three main sections: general assumptions, incentives and financial parameters considered for parametric analysis and calculated parameters. In general assumption section, design-point parameters for technical simulations and equations were explained. In the following section, incentives and financial parameters considered for analysis were described. In addition to this, technical and economic analyses' results of base case scenario were given for each technology. In the last part, calculated parameters: government cost, government expense and effectiveness concepts were defined.

2.1. General assumptions

Two different types of CSP technologies: solar tower (ST) and parabolic trough (PT), with a net capacity of 100 MW were considered in the research. Several types of incentives were reviewed. Amongst, six types were selected to be analyzed including Investment Tax Credit (ITC), Production Tax Credit (PTC), Investment Based Incentives (IBI), Production Based Incentives (PBI) – also known as premium tariff-, Sales Tax Reduction (STR) and Depreciation Mode (DM). Moreover, financial parameters: debt percentage, discount rate and debt interest rate were taken into account for parametric analysis. Solar data measurement of Crucero (22.24S, 69.5W) was chosen. Crucero is one of the top worldwide sites for solar radiation and located in Northern Chile near to Maria Elena, at the Atacama Desert. According to measurement in 2012, 2584 kWh/m^2-yr for GHI and 3163 kWh/m^2-yr for DNI were obtained in Crucero [18]. The simulation of the annual technical operation was done by utilizing the System Advisor Model (SAM) developed by National Renewable Energy Laboratory (NREL). Moreover, SAM was mentioned in several articles [19–22] for CSP project simulations.

The first CSP plant considered was typical parabolic trough collector technology that uses a heat transfer fluid (HTF) to provide heat to a power cycle with an indirect thermal storage system which was similar to Andasol-1 plant configuration. The second CSP plant considered was a molten salt solar power tower plant with a thermal storage system which was similar to Crescent Dunes or Gemasolar plant configuration. The main design-point parameters of both plants were given in Table 1.

In order to determine all taxable advantages for the project owner and the government, a “single owner structure”, in which the single owner can be the sponsor or/and developer, was taken into account as a financial entity in this analysis [23]. Additionally, an economic model from SAM was improved for cash flow calculations and financial analyses by using MS Excel™ spreadsheet developed in this research. The economic model calculates the cash flow for the project, considering the income and sales tax payments, depreciation, reserves and equipment replacement, debt service, and the different incentives structures. The first improvement of the model was adding the annual earnings from the power market, which is one of the characteristics of the Chilean electricity market. The second one was the development of cash flow of tax credits for each year which enables to use the tax credits in subsequent years. If there was not enough tax liability, there was a restriction to use them which meant they can be used only for income tax payment.

In order to show the impact of the parameters financially and the feasibility of the project, the financial index “levelized cost of electricity (LCOE)” was calculated in this analysis. According to *the Future of Solar Energy* [13], the LCOE is: “*the charge* per *kilowatt-hour (kWh) that equates the discounted present value of revenues to the discounted present value of costs, including the initial capital investment and annual operating costs as well as any future replacement capital costs incurred over the life of a facility. These costs include taxes paid* “. The LCOE is defined by this formula:

$$\mathrm{LCOE} = \frac{Inv + \sum_{n=0}^{t} \frac{O\&M_n + Res_n + T_n + D_n - PE_n - PT_n}{(1+R)^n}}{\sum_{n=0}^{t} \frac{Q_n}{(1+R)^n}} \tag{1}$$

where n is the evaluated year, t is period of time of the project, Inv is the issuance of equity that is the initial investment of owner, $O\&M$ is the annual operating and maintenance cost, Res is the annual insurance and reserve cost, T is the annual income taxes paid, D is the annual debt payment that is the principal payment plus the interest debt payment, PE is the annual earnings from power market, PT is earnings from premium tariff or production base incentives, Q is the annual electricity production and R is the real discount rate. The annual income taxes paid in the equation (1) is defined as:

$$T = T_{liability} - Depr - T_{credits} \tag{2}$$

where $T_{liability}$ is the annual income taxes that have to be paid and is calculated from state taxable income, $Depr$ is the annual tax depreciation of the plant, $T_{credits}$ is the annual tax credit paid.

One of the restrictions of the model is that T must be more than 0 or equal to 0. If it is greater than 0, they will be managed to increase the tax credits disposable in further years. Furthermore, the calculations in the financial analysis were done to obtain a Net Present Value (NPV) of 0 USD and to get the LCOE for a particular Internal Rate of Return (IRR) [24], which represents the minimum feasible PPA that can allow the project with an assumed risk [10]. Chilean economic and financing characteristics were considered in the analysis. The corporate income tax rate of Chile was assumed as 22.5% according to the published information in “*Servicio de Impuesto de Interno de Chile*” [25]. Other technical values were taken from the suitable references in the literature for CSP technologies. Degradation rate for CSP were considered 0.2% [26]. The insurance rate was taken as 0.5% of the capital cost [26,27]. The analysis period of utility-scale CSP projects was considered as 25–30 years [26]. Therefore, in this analysis project lifetimes are taken into account as 25 years for both CSP technologies. Installation cost of each solar technology, LCOE and the design parameters from each plant were assumed based on previous works in the literature [28–31].

2.2. Incentives and financial parameters considered for analysis

In this research, incentives which have significant effects to support solar projects such as: investment tax credit (ITC), production tax credit (PTC), production-based incentives (PBI), investment based incentives (IBI), sales tax reduction (STR) and different depreciation modes (DM) were chosen to be evaluated at different financial parameter conditions. ITC and PTC are known as the major incentives lowering the income taxes that must be paid to the government or state [23]. IBI and PBI are cash incentives which is a common support mechanism of solar energy in Germany and Spain [32]. Sales tax reduction is another support mechanism which reduces sales tax rate and it affects investment cost directly. According to *Climate Policy Initiative* report, Sales Tax Reduction (STR) is *a number of states exempt purchases of equipment or services for renewable electricity generating facilities from sales or use taxes*

Table 1
Design-point parameters for the technical simulation.

Parameters	Solar Tower	Parabolic Trough
Plant Capacity [MW]	100	100
Design Point DNI [W/m^2]	900	900
Solar Multiple	2.7	2.7
HTF	Molten Salts	Therminol VP1
Working Temperatures [C]	290–550	293–393
Storage Capacity [hr]	14	14
Heliostat/Collector Area [m^2]	138.3	817.5
Number of Heliostats/Collectors	11385	1716
Storage HTF	Molten Salts	Molten Salts

Table 2
Incentives and financial parameters considered for analysis.

	Unit	Base case	Evaluated interval	Step size
Incentives:				
ITC	% of depreciable basis	0	0–20	5
PTC	USD/MWh	0	0–10	2.5
IBI	% of installed cost	0	0–10	2.5
PBI	USD/MWh	0	0–10	2.5
Sales Tax	%	19	19–0	4.75
Depreciation (80%)	Year	20 yr-Straight Line	5-10-15yr MACRS & 15–20yr Straight Line	
Financial Parameters:				
Debt Percentage	%	70	60-90%	5
Real discount rate	%	10	6-12%	1
Debt Interest Rate	%	5	1-7%	1

[33]. Finally, depreciation can be evaluated as another incentive to lower tax burden.

In order to see their impact, the values of incentives were changed at regular intervals as shown in Table 2. The sales tax rate for Chile was taken as 19% for the base case calculation [34] and it was changed between 19% and 0%. Additionally, base case depreciation was assumed 20 years straight-line depreciation (80%) for Chile because there is no accelerated depreciation in Chile as indicated in the report of IRENA [5]. In addition to 20 years straight-line depreciation (DM-5), 5 years accelerated (DM-1), 10 years accelerated (DM-2), and 15 years accelerated (DM-3) and 15 years straight-line depreciation (DM-4) were considered in the analysis.

Each incentive was evaluated in different financial parameter conditions. In this parametric analysis, debt percentage, real discount rate, and debt interest rate were considered as financial parameters which have a significant impact on LCOE of solar projects. In this analysis, the debt percentage was assumed 70% for the base case and it was changed between 60% and 90% [35] by considering the solar projects mentioned in the literature [36]. The real discount rate was defined between 10% and 15% for CSP systems in the report of The International Energy Agency [26].

In this research, the real discount rate was assumed as 10% in the base case and changed between 6 and 12%. Debt interest rate is defined as the interest rate applied to the debt payment and generally assumed 8% for CSP projects [23]. In this study, it was supposed as 5% for the base case in Chilean conditions. Additionally, it was assumed that debt tenor was 20 years and an up-front fee of the debt was 3%. For the base case scenario, the LCOE of each technology were calculated as following: 128.93 USD/MWh for the solar tower, 138.67 USD/kWh for the parabolic trough. According to assumptions mentioned above, Table 3 shows the main technical and economic results for two different technologies. These results were obtained for base case scenario which does not include any incentives.

2.3. Calculated parameters

In this paper, important metrics were defined and calculated to make sensitivity, effectiveness and limit analyses. The first parameter considered was *the government cost* which is the sum of the earnings from income taxes paid, the sales taxes and the spending in cash incentives due to the grant and/or feed in premium. It represents the part of the LCOE that are the payments to the government and the earnings for the cash incentives. The government cost was defined as:

Table 3
Base case scenario technical and economical results for each technology.

	Solar Tower	Parabolic Trough
Produced Electricity [GWh-yr]	755.07	609.08
Capacity Factor [%]	86.3	69.6
Total installed cost [USD/W]	9.16	7.87
Fixed O&M cost [USD/kW]	50	50
Variable O&M cost [USD/MWh]	3	3
LCOE [USD/MWh]	128.93	138.67
IRR [%]	10	10

$$G_{cost} = \frac{STE - IBI + \sum_{n=0}^{t} \frac{T_n - PBI_n}{(1+R)^n}}{\sum_{n=0}^{t} \frac{Q_n}{(1+R)^n}} \tag{3}$$

where *STE* is annual sales tax earnings of the initial investment cost, *IBI* is the cash from investment base incentive, *PBI* is the cash from the annual production base incentive. Besides government cost, by considering depreciation and the increase of the expenses due to incentives applied, the parameter of *government expenses* was defined and it was calculated and as follow:

$$G_{expenses} = \frac{RSE + IBI + \sum_{n=0}^{t} \frac{Depr_n + T_{creditsn} + PBI_n}{(1+R)^n}}{\sum_{n=0}^{t} \frac{Q_n}{(1+R)^n}} \tag{4}$$

where *RSE* is the reduction in the sales taxes payments, *Depr* is the annual tax depreciation of the plant, $T_{credits}$ is the annual tax credit payment.

Moreover, the *effectiveness* of incentives was calculated by considering the changes in LCOE and government expenses for each financial parameter values. With effectiveness, it is possible to compare alternative incentives and determine which have more impact on the LCOE with each dollar spent by the government. The changes in LCOE was called ΔLCOE and was defined as the difference between the calculated LCOE based on the incentive conditions and the LCOE in each base case scenario (without incentives). Besides, ΔGovernment_cost (ΔG_{cost}) was calculated by taking the difference between a base case values and calculated values. Finally, for each value of financial parameters, data sets of ΔLCOE, ΔG_{cost} were obtained by changing incentives between intervals given in Table 2. Then the slopes of each dataset were calculated to obtain effectiveness of incentives for each financial parameter value. Also and ΔGovernment_expenses ($\Delta G_{expenses}$) was calculated for impact analysis of incentives for both technologies.

In conclusion, in the methodology section, general assumptions, incentives and financial parameters considered for parametric analysis and calculated parameters (government cost, government expense, and effectiveness) were mentioned. In the following section, the results of several analyses were given and explained.

3. Results and discussions

In this part of the study, the results for two concentrated solar technologies were discussed in five sections as follows: i) LCOE components ii) Sensitivity analysis of financial parameters iii) Impact and effectiveness analysis of incentives iv) Limit values and impact analysis for ITC, PTC, and depreciation v) Installation cost analysis and limits of ITC/PTC vi) NPV analysis under different PPA price.

3.1. *LCOE components*

Fig. 1 represents components of base case LCOE for both parabolic trough (left) and solar tower (right) technologies. The calculation of LCOE was explained in section *2.1 General assumptions*. As shown in the Fig. 1, the notable contribution to LCOE was coming from debt payment and equity, respectively. In addition to this, O&M costs and income taxes had secondly important contribution to LCOE while income for capacity (PE) reduced LCOE slightly. For the base case, no cash incentives and premium tariff were considered. Thus, the contribution of them was not seen in the figure. Due to these considerations mentioned above, base case LCOE was obtained 138.67 USD/MWh for parabolic trough and 128.94 USD/MWh for the solar tower.

3.2. *Sensitivity analysis of financial parameters*

As can be seen in Fig. 2, the sensitivities of different financial parameters on LCOE and government cost were studied. In this analysis, debt fraction, discount rate, and debt interest rate were taken into account and they were changed due to the intervals given in Table 2. In each graph, only analyzed financial parameters were variated, and other parameters were fixed as based case values. For both technologies, three financial parameters illustrate the same behaviors. By increasing debt fraction from 60 to 90%, LCOE and government cost were decreased and reached its minimum value. On the other hand, while discount rate was increased from 6 to 12%, both LCOE and government cost showed increasing trend. Furthermore, when debt interest rate was augmented from 1 to 7%, LCOE was also increased although government cost declined and reached its minimum.

As a conclusion, for considered intervals of financial parameters, debt fraction and discount rate illustrated significant sensitivities on both LCOE and government cost. In contrary, debt interest rate showed minor sensitivity on government cost while having important sensitivity on LCOE. Furthermore, the government cost increased with decreasing debt interest rate because of the decreased amount of the debt, which also meant that the amount of tax income of the government increased.

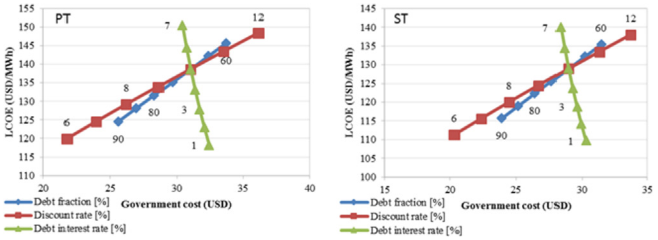

Fig. 2. The sensitivity of financial parameters for Parabolic Trough (left) and Solar Tower (right).

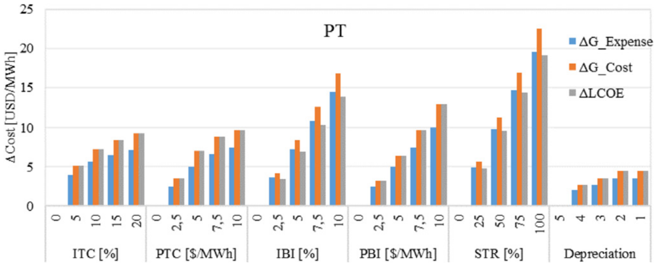

Fig. 3. Impact analysis of incentives for Parabolic Trough.

3.3. *Impact and effectiveness analysis of incentives*

After sensitivity analysis, ΔLCOE, $\Delta G_{cost,}$ and $\Delta G_{expenses}$ were calculated for different incentives values and illustrated in Figs. 3 and 4 for parabolic trough and solar tower, accordingly. Both CSP technologies showed similar results. According to the graphs, ΔLCOE, $\Delta G_{cost,}$ and $\Delta G_{expenses}$ increased with increasing amount of ITC, PTC, and DM. In addition to this, depreciation had the same results for DM mode 1 (5 years accelerated depreciation) and mode 2 (10 years accelerated depreciation). Also, ΔLCOE, $\Delta G_{cost,}$ and $\Delta G_{expenses}$ showed upward trend while IBI, PBI and STR amounts were increased. On the other hand, ΔLCOE and ΔG_{cost} had the same values for each value of ITC, PTC, PBI and DM conditions. Between these results, it was interesting to see that ΔLCOE had the same value with ΔG_{cost} for PBI. It meant that in order to reduce LCOE in an amount, the same amount of PBI was required. However, although both were cash incentives, IBI did not show the same results as PBI. It can be seen that ΔG_{cost} was superior to ΔLCOE for different IBI values which meant that in order to reduce LCOE in an amount, more IBI contribution was needed.

As mentioned above, ITC, PTC and DM as a tax credit, and PBI as cash incentive had better results when government contribution to reduce LCOE with incentives was considered. In order to understand the impact of incentives in different financial parameter conditions, effectiveness analysis was performed.

The same effectiveness results were obtained for both technologies and illustrated in Fig. 5. For different values of three financial parameters: debt percentage, discount rate, and debt interest rate, the results showed that ITC, PTC, PBI, and DM had the highest effectiveness when they were compared to IBI and STR. Also, IBI had

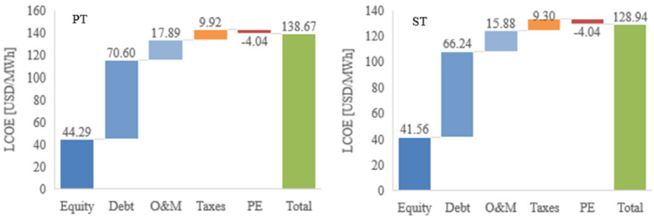

Fig. 1. LCOE components of Parabolic Trough (left) and Solar Tower (right).

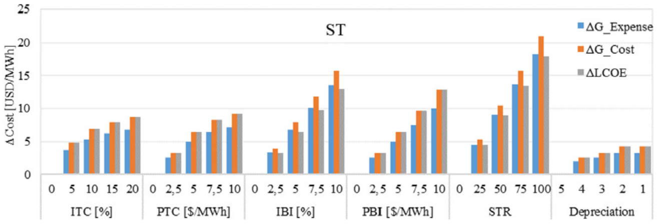

Fig. 4. Impact analysis of incentives for Solar Tower.

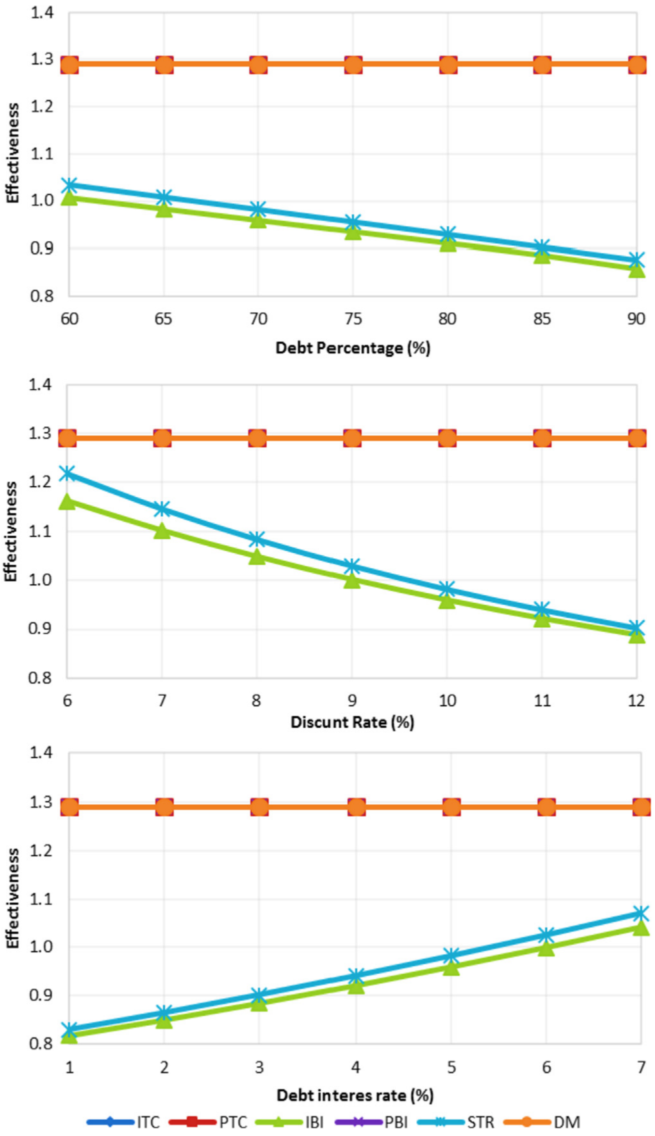

Fig. 5. The effectiveness of Parabolic Trough and Solar Power technologies.

lower effectiveness than STR. When the values of all financial parameters were increased, ITC, PTC, PBI, and DM had fix effectiveness value (1.29) in all financial conditions. On the contrary, for increased debt fraction and discount rate, STR and IBI showed decreasing trend while these two incentives went upward for the increased debt interest rate. Additionally, the minimum effectiveness was obtained as 0.82 for IBI in 1% debt interest rate.

To conclude, ITC, PTC, and DM as tax credit incentives and PBI as cash incentive lowered LCOE with the same amount of incentive contribution. For different financial conditions, ITC, PTC, PBI, and DM had the highest and IBI had the lowest effectiveness. Additionally, the effectiveness of ITC, PTC, PBI, and DM were independent of financial parameters although STR and IBI showed dependency result under various financial values.

3.4. *Limit values and impact analysis for ITC, PTC, and depreciation*

In the previous section, impact and effectiveness analyses results showed that tax credit incentives reduce LCOE with the same amount of government cost. In order to reduce LCOE, PBI as a cash incentive has no limit. Nevertheless, a reasonable amount of PBI must be determined by considering government cost. On the other hand, ITC, PTC, and DM lower LCOE by reducing taxes. In this section, detailed limit analysis of ITC and PTC realized in order to define required tax credit incentives. Additionally, the impacts of limit values of ITC and PTC and, depreciation mode 1 and mode 2 were investigated.

Tables 4 and 5 showed the limit values of investment tax credit and production tax credit for different values of financial parameters. In addition to this, LCOE values before incentives and LCOE values with max incentives were listed in the tables for parabolic trough and solar tower, respectively. When the maximum ITC or PTC was applied, the same LCOE results were obtained. It meant that with maximum tax credit incentives, it can be reached the same LCOE values in both cases.

For parabolic trough analysis shown in Table 4, ITC and PTC have their lower limit values with increasing debt fraction. As can be seen in Table 4, LCOE can be reduced to 120.05 USD/MWh in 90% debt fraction by choosing either 17.1% ITC or 7.5 USD/MWh PTC incentives. On the other hand, when discount rate was increased, ITC or PTC reached their limits in higher values. For example, for 12% discount rate, it was needed 29.4% ITC or 12.50 USD/MWh PTC to decline LCOE from 148.34 USD/MWh to 136.62 USD/MWh. Additionally, it was interesting to obtain that by increasing debt interest rate, the limits of ITC and PTC also increased. The limit values of ITC at 26.2% or PTC at 11.4 USD/MWh reduced LCOE from 150.49 USD/MWh to 141.20 USD/MWh. For parabolic trough, the limits of ITC and PTC changed between 17.1 and 29.5% and 7.5–12.8 USD/MWh, respectively, under different financial conditions.

As can be seen in Table 5, the results of limits of tax credit incentives under different values of financial parameters were illustrated for solar tower technology. This analysis showed similar results as parabolic trough technology. For the solar tower, the limits of ITC changed as the same interval as parabolic trough which

Table 4
Limits of ITC and PTC for parabolic trough.

Conditions		LCOE before Incentives (USD/MWh)	Max ITC (USD/MWh)	Max PTC (USD/MWh)	LCOE with max incentives (USD/MWh)
Debt fraction	60%	145.66	29.5%	12.7	133.06
	70%	138.67	25.3%	11.0	128.75
	80%	131.63	21.2%	9.2	124.41
	90%	124.56	17.1%	7.5	120.05
Discount rate	6%	119.91	17.2%	7.5	113.20
	8%	129.18	21.3%	9.2	120.93
	10%	138.67	25.3%	11.0	128.75
	12%	148.34	29.4%	12.8	136.62
Debt interest rate	1%	118.23	23.7%	10.2	106.91
	3%	127.88	24.5%	10.6	117.29
	5%	138.67	25.3%	11.0	128.75
	7%	150.49	26.2%	11.4	141.20

Table 5
Limits of ITC and PTC for solar tower.

Conditions		LCOE before Incentives (USD/MWh)	Max ITC (%)	Max PTC (USD/MWh)	LCOE with max incentives (USD/MWh)
Debt fraction	60%	135.49	29.5%	12.0	123.68
	70%	128.94	25.3%	10.3	119.63
	80%	122.34	21.2%	7.8	115.56
	90%	115.70	17.1%	7.0	111.47
Discount rate	6%	111.34	17.2%	7.0	105.04
	8%	120.03	21.3%	8.7	112.30
	10%	128.94	25.3%	10.3	119.63
	12%	138.01	29.4%	12.0	127.02
Debt interest rate	1%	109.76	23.8%	12.2	99.14
	3%	118.82	24.5%	10.5	108.88
	5%	128.94	25.3%	10.3	119.63
	7%	140.03	26.2%	10.7	131.31

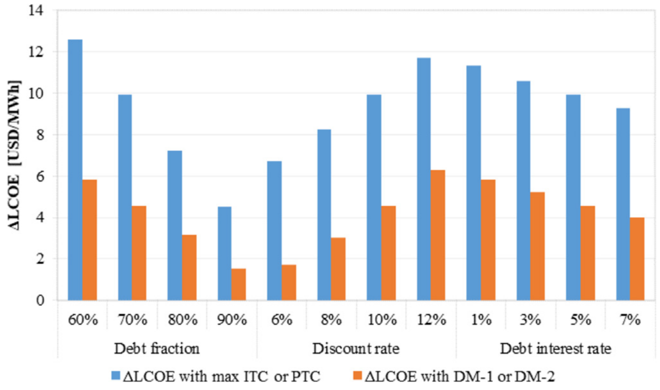

Fig. 6. Impact analysis of limit values of ITC and PTC, DM-1 and DM-2 for Parabolic Trough.

is 17.1–29.5%. However, PTC showed a change between 7.0 and 12.2 USD/MWh under different financial conditions.

After determining limits of tax credit incentives for several financial conditions, their impacts on LCOE were displayed as ΔLCOE for parabolic trough and solar tower, accordingly. In addition to ITC and PTC, depreciation mode1 or mode2 (5 and 10 years accelerated depreciation) were considered in this analysis. As shown in Fig. 6 and Fig. 7, ΔLCOE can be seen for maximum ITC or PTC values and depreciation mode 1 or mode 2 for parabolic trough and solar tower, accordingly.

In Fig. 6, ΔLCOE results for parabolic trough were obtained with maximum values of ITC or PTC and depreciation mode 1 (DM-1) or mode 2 (DM-2) under different values of debt fraction, discount rate, and debt interest rate. DM-1 and DM-2 reached their limits at the same values as mentioned in section 3.3 (Fig. 3). Therefore, in this analysis, only depreciation mode1 or mode2 were considered. With increasing debt fraction, smaller ΔLCOE values were obtained for each case. When the discount rate was increased from 6 to 12%, bigger ΔLCOE can be obtained for maximum ITC or PTC than DM1 or DM2. Additionally, if debt interest rate was varied from 1 to 7%, the downward trend was obtained for ΔLCOE. The change in debt interest rate was less significant when it was compared to other financial parameters. The same analysis was realized for solar tower technology as shown in Fig. 7. The impact of limit values of ITC or PTC and DM1or DM2 for solar tower had very similar results to parabolic trough. ΔLCOE increased with decreasing debt fraction, increasing discount rate, and increasing debt interest rate.

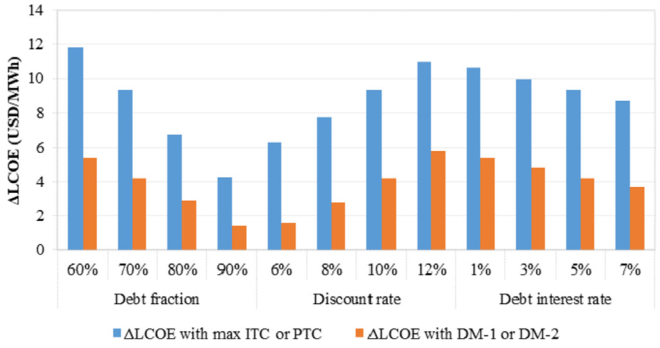

Fig. 7. Impact analysis of limit values of ITC and PTC, DM-1and DM-2 for Solar Tower.

In conclusion, as acquired from tables and graphs in this section, with the lowest debt fraction, the highest discount rate, or the lowest debt interest rate, ΔLCOE had minimum values for both parabolic trough and solar tower. Results with maximum PTC or ITC had more impact on LCOE, which meant having higher ΔLCOE than results with DM1 or DM2. The more sensitive parameter was debt fraction which showed more differentiation on LCOE. Moreover, ΔLCOE increased with lower debt interest rate because as explained in the last paragraph of section 3.2, the tax liability increased with lower debt interest rate. Thus, it was less sensitive when it was compared to other financial parameters.

3.5. *Installation cost analysis and limits of ITC and PTC*

In the previous sections, the limits of ITC or PTC, and DM-1or DM-2 were analyzed and it was obtained that although the maximum values of tax incentives were applied to reduce LCOE, it can be achieved until 106.91 USD/MWh for parabolic trough, and 99.14 USD/MWh for solar tower which were still high to enter Chilean electricity market. Therefore, it was decided to make additional analysis for each technology to see LCOE variation and the limits of tax incentives for different installation costs and financial parameters.

In the analysis, the installation cost intervals were chosen 4–9 USD/W for parabolic trough and 5–10 USD/W for the solar tower in the analysis. Besides base case, four more cases were investigated to see how the results differ.

- Base case scenario had the same conditions as mentioned in Table 2: 70% debt fraction, 10% discount rate, and 5% debt interest rate.
- Case 1: 80% debt fraction, 10% discount rate and 5% debt interest rate
- Case 2: 70% debt fraction, 8% discount rate and 5% debt interest rate.
- Case 3, 70% debt fraction, 10% discount rate and 3% debt interest rate.

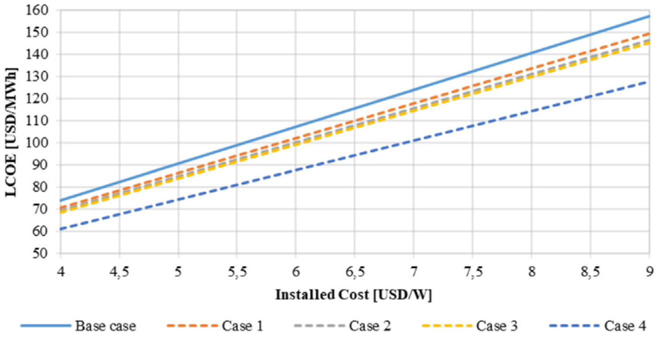

Fig. 8. LCOE variation for different installation costs for Parabolic Trough.

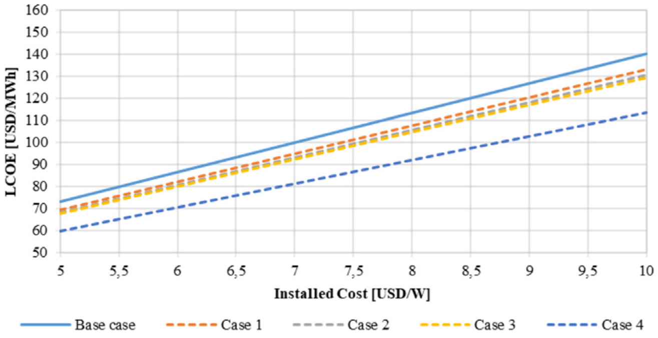

Fig. 9. LCOE variation for different installation costs for Solar Tower.

- Case 4: 80% debt fraction, 8% discount rate, and 3% debt interest rate were taken into account to see the combined impact.

In Fig. 8, LCOE versus installed costs results were illustrated for parabolic trough technology. When the installation cost varied from 4 to 9 USD/W, the dramatic drop in LCOE was obtained for all cases. For example, when the LCOE was near 160 USD/MWh for 9 USD/W installed cost for the base case, it was reduced to approximately 75 USD/MWh for 4 USD/MW installation cost. Additionally, it was obtained that LCOE changed linearly in each case and the close results were obtained for Case 1, Case 2 and Case 3. Furthermore, the minimum LCOE was obtained near 75 USD/MWh for the base case and 60 USD/MWh for Case 4. This result showed that lower installation cost changed LCOE significantly. However, a combination of changes in other parameters showed an important reduction on LCOE, too.

Fig. 9 showed LCOE variation for different installation costs for solar tower. The installation cost was differentiated from 4 to 9 USD/W due to the higher installation cost. As it was obtained for parabolic trough technology, LCOE variations also showed linear behavior for solar tower. The lowest LCOE was obtained near 60 USD/MWh for installation cost of 4 USD/W for Case4. As a conclusion for both technology, in order to reduce LCOE, both installation cost and important financial parameters combination should be considered.

After LCOE analysis for different installed costs of four cases, it was decided to define the limits of ITC and PTC for different installation costs. The same cases were considered in this analysis and the results of installation cost intervals were chosen 5–8 USD/W and 6–9 USD/W for parabolic trough and solar tower, respectively.

Table 6 showed the limits of ITC and PTC for parabolic trough for different cases. In addition to maximum reachable tax credit values, maximum LCOE decreasing values were illustrated in the table. As shown in the results, by varying installation cost from 5 to 8 USD/W, LCOE was changed from 90.72 to 140.78 USD/MWh for the base case. Furthermore, maximum ITC values remained the same for each installed cost, which meant ITC limit was independent of installed cost. On the other hand, PTC limits increased by increasing installation costs. Additionally, it was interesting to see that maximum PTC values were the same for Case 1 (80% debt fraction condition), and Case 2 (8% of discount rate condition) in each installed cost.

The same analysis was performed for solar tower and the results were demonstrated in Table 7. As can be seen from the table, minimum LCOE was obtained in Case4 for each installed cost. Additionally, the same ITC limits were obtained for each installed cost. It meant that ITC limit was independent of installed cost although the maximum PTC values were depended on installation costs.

In conclusion, the same limits of ITC were obtained for different installation cost for each solar technology. Also, it was achieved similar results of ITC limits for parabolic trough and solar power

Table 6
Limits of ITC and PTC and Max LCOE decreasing for Parabolic Trough.

Installed cost	Conditions	LCOE (USD/MWh)	ITC (%)	PTC (USD/MWh)	LCOE with max incentives (USD/MWh)	Max LCOE decreasing (USD/MWh)
5 USD/W	Base	90.72	25.3	7	84.42	6.3
	Case 1	86.26	21.2	5.9	81.67	4.59
	Case 2	84.7	21.3	5.9	79.46	5.24
	Case 3	83.87	24.5	7.1	77.15	6.78
	Case 4	74.11	17.3	4.9	69.78	4.33
6 USD/W	Base	107.41	25.3	8.4	99.85	7.56
	Case 1	102.05	21.2	7	96.54	5.5
	Case 2	100.18	21.3	7	93.9	6.28
	Case 3	99.19	24.5	8.5	91.12	8.07
	Case 4	87.48	17.3	5.8	82.27	5.21
7 USD/W	Base	124.09	25.3	9.8	115.28	8.82
	Case 1	117.84	21.2	8.2	111.42	6.42
	Case 2	115.66	21.3	8.2	108.33	7.33
	Case 3	114.51	24.5	9.9	105.09	9.42
	Case 4	100.84	17.3	6.8	94.77	6.07
8 USD/W	Base	140.78	25.3	11.2	130.7	10.08
	Case 1	133.63	21.2	9.4	126.29	7.34
	Case 2	131.13	21.3	9.4	122.76	8.37
	Case 3	129.82	24.5	11.4	119.06	10.77
	Case 4	114.2	17.3	7.8	107.26	6.94

Table 7
Limits of ITC and PTC and Max LCOE decreasing for Solar Tower.

Installed cost	Conditions	LCOE (USD/MWh)	ITC (%)	PTC (USD/MWh)	LCOE with max incentives (USD/MWh)	Max LCOE decreasing (USD/MWh)
6 USD/W	Base	86.44	25.3	6.8	80.34	6.1
	Case 1	82.12	21.2	5.7	77.68	4.44
	Case 2	80.6	21.3	5.7	75.54	5.06
	Case 3	79.81	24.5	6.9	73.3	6.51
	Case 4	70.36	17.3	4.7	66.16	4.2
7 USD/W	Base	99.9	25.3	7.9	92.79	7.11
	Case 1	94.85	21.2	6.6	89.68	5.18
	Case 2	93.09	21.3	6.6	87.18	5.91
	Case 3	92.17	24.5	8	84.57	7.6
	Case 4	81.14	17.4	5.5	76.24	4.9
8 USD/W	Base	113.36	25.3	9	105.23	8.13
	Case 1	107.59	21.2	7.6	101.67	5.92
	Case 2	105.58	21.3	7.6	98.82	6.76
	Case 3	104.52	24.5	9.2	95.84	8.68
	Case 4	91.92	17.4	6.3	86.32	5.6
9 USD/W	Base	126.82	25.3	10.1	117.67	9.14
	Case 1	120.33	21.2	8.5	113.67	6.66
	Case 2	118.06	21.3	8.5	110.46	7.6
	Case 3	116.87	24.5	10.3	107.11	9.77
	Case 4	102.7	17.4	7	96.4	6.3

tower technologies. It meant that ITC limits were independent of installation cost and technology, and it only changed with different financial structure.

3.6. Net present value (NPV) analysis under different power purchasing agreement (PPA) price

In the previous sections, sensitivity analysis of financial parameters, impact and effectiveness analysis of incentives, limit values analysis, and installation cost analysis were realized. Besides these analyses, NPV under different PPA prices was also analyzed to see the impact of incentives on NPV. In this analysis, installation costs were taken as 6USD/W and 7USD/W for parabolic trough and solar tower technologies, respectively. In addition to the base case, four different cases were also considered:

- Base case (without incentives)
- Maximum ITC or PTC (*ITC/PTC*)
- PBI of 10 USD/MWh (*PBI*)
- Maximum ITC or PTC with PBI of 10 USD/MWh (*ITC/PTC + PBI*)
- Maximum ITC or PTC with 3% of debt interest rate (*3% + ITC/PTC*)

In Fig. 10, the results for parabolic trough were illustrated. In the graph, NPV values less than 0 were colored to compare the cases clearly. It can be seen that the NPV was positive when the PPA price differed between 90 and 100 USD/MWh for all cases. In base case which has no incentives, the project could be feasible near PPA price of 90 USD/MWh although other cases included incentives, NPV was obtained 0 with less PPA price such as 85 USD/MW with maximum ITC or PTC, and 75 USD/MWh with maximum ITC or PTC and PBI of 10 USD/MWh. In higher PPA prices, maximum ITC or PTC had more impact on NPV than lower PPA prices. The feasible points for *PBI* and *3% + ITC/PTC* cases were obtained similar which was near 78 USD/MWh PPA price.

For solar tower analysis, similar behaviors were obtained for each case. In Fig. 11, NPV values less than 0 were colored to see the feasible areas. It can be seen that the NPV was positive when the PPA price was more than 86 USD/MWh for all cases. For the base case, the feasible price was obtained near 86 USD/MWh although it was obtained near 80 USD/MWh with maximum ITC or PTC contribution. Additionally, in higher PPA prices, maximum ITC or PTC had more impact on NPV than lower PPA prices. The feasible points for PBI and 3% + ITC/PTC cases were obtained similar which was near 73 USD/MWh PPA price. Also, it was interesting to see that although maximum ITC or PTC (ITC/PTC) and PBI of 10 USD/MWh (PBI) did not show similar results in lower PPA prices, they had close NPV for 100 USD/MWh PPA price.

In conclusion, for solar tower technology, it can be seen that NPV for each case decreased more sharply than parabolic trough technology. It meant that NPV was more sensitive to the PPA in solar tower technology due to the surplus production compared to parabolic trough. In this analyses, for both technologies, it was

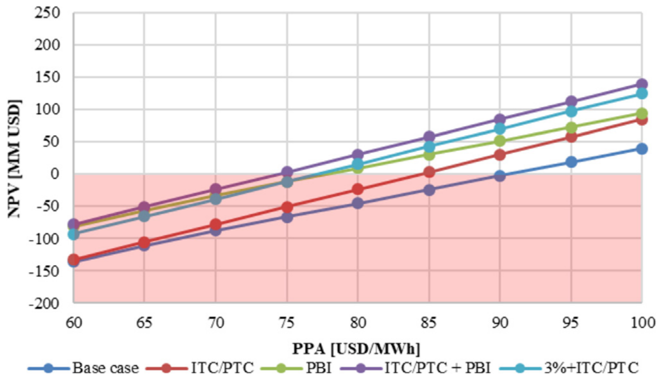

Fig. 10. NPV analysis under different PPA prices for Parabolic Trough.

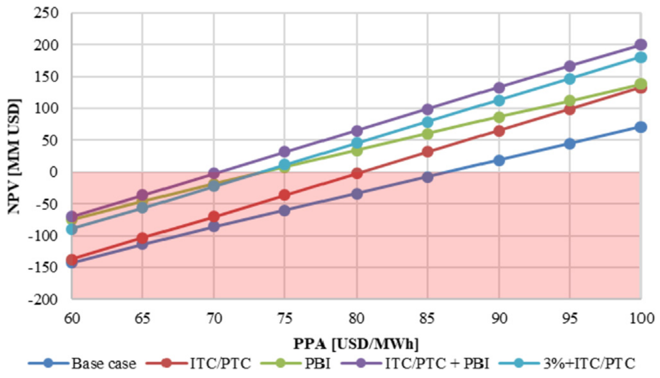

Fig. 11. NPV analysis under different PPA prices for Solar Tower.

observed that the maximum tax credit incentives had a different impact on NPV depending the PPA because, in lower PPA prices, the income taxes would be lower than higher PPA prices. Also, it was found that the impact of the tax credit incentives was negligible less than 85 USD/MWh for parabolic trough and 80 USD/MWh for the solar tower. Thus, tax credit incentives were more meaningful at higher PPA price although PBI made more sense in lower PPA prices. In lower PPA prices, projects with the soft loan (loans with interest rate lower than 3%) or the combination of soft loans and maximum ITC or PTC incentives can be an alternative to be considered by policymakers.

4. Conclusions

This paper presented several analyses for concentrated solar power projects in Chile to understand the behaviors of incentives and essential financial parameters on costs and to find the best combinations of incentives by considering maximum LCOE reduction and minimum government costs. The main contribution of the research is evaluating CSP projects from the perspective of policymakers or government. The methodology includes both sensitivity, impact, effectiveness and limits analyses of incentives and financial conditions for two different CSP technologies. Additionally, it contributes to the literature by showing robust results to legislators to make a decision on a tax credit or cash incentives while promoting concentrated solar energy technologies under different conditions. As a final point, the results give opinions for investors planning to enter Chilean solar market by considering country conditions and installation costs.

In general, it was found that the expansion of CSP technologies has a high dependency on financial costs of the projects, support mechanisms, and the installation costs of other developed technologies. The government can support the solar business by giving some tax or cash incentives. However, this decision must be done precisely by taking into account of government cost. The best way of supporting solar energy projects is a combination of lowering government cost and maximizing LCOE reduction. In this paper, for evaluated intervals of financial parameters: debt fraction and discount rate illustrated meaningful sensitivities on both LCOE and government cost. In contrary, debt interest rate showed less sensitivity on government cost while having significant sensitivity on LCOE for both CSP technologies.

Additionally, ITC, PTC, and DM as a tax credit and PBI as cash incentives had the best effectiveness, and reduce LCOE better than IBI and STR. The effectiveness of ITC, PTC, PBI, and DM was independent of financial parameters even though STR and IBI showed dependency results for various financial values. Although cash incentives had no limits to reduce LCOE, tax credit incentives reached maximum values, which meant that their impacts were limited. Moreover, it was obtained that depreciation mode 1 and mode 2 showed the same impact on the LCOE. As cash incentives, PBI showed better results when it was compared to IBI. It meant that in order to reduce LCOE in an amount, the same amount of PBI was required while more IBI was required.

In the limit analyses, it was obtained that when the maximum ITC or PTC was applied, the same LCOE reduction was achieved in their limits. From the installed cost analysis, it was acquired that with the uncertainty of installed cost in the further years, an ITC incentive scheme can be more appropriate than a PTC because the values for maximum impact are similar for the different installed cost. Nevertheless, a PTC incentive scheme can encourage the plant performance because of the productivity.

Finally, in NPV analysis, for both technologies, it was obtained that the maximum tax credit incentives had a different impact on NPV depending the PPA since the income taxes in lower PPA prices would be minor than higher PPA prices. Also, it was found that tax credit incentives were more meaningful at higher PPA price although PBI made more sense in lower PPA prices. In lower PPA prices, projects with the soft loan (loans with interest rate lower than 3%) or the combination of soft loans and maximum ITC or PTC incentives can be an alternative as support mechanisms. PPA prices around the world are on the decreasing trend. Thus, tax credit incentives will be continued to be considered as support mechanisms in the future.

As a conclusion, solar power plants especially concentrated solar energy technologies have big potential to contribute to sustainable future. In order to make them more feasible, they may require incentives and financial facilities due to high investment costs. Regulatory instruments and support mechanisms help to diminish the gap between the levelized cost of electricity (LCOE) and the power purchasing agreements (PPA) in the projects. The studies as mentioned in this paper has an importance for policymakers. Thus, governments as policymakers can have an idea about support mechanisms to promote solar energy technologies by considering maximum LCOE reduction and minimum government costs. Further studies are planned to evaluate the impacts of possible combinations of several incentives under different financial structures to reduce LCOE with minimum government cost for the condition of other countries in the solar belt.

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Nomenclature

CSP	Concentrated solar power
D	Annual debt payment
Depr	Annual tax depreciation of the plant
DM	Depreciation Mode
DNI	Direct Normal Irradiation
G_{cost}	Government cost
$G_{expenses}$	Government expenses
HTF	Heat transfer fluid
IBI	Investment Based Incentives
Inv	The issuance of equity that is the initial investment of the owner
IRENA	International Renewable Energy Agency
IRR	Internal rate of return
ITC	Investment tax credit
LCOE	Levelized cost of electricity
MIT	Massachusetts Institute of Technology
n	Evaluated year
NCRE	Non-conventional renewable energy
NPV	Net present value
NREL	National Renewable Energy Laboratory
O&M	Annual operating and maintenance cost
PBI	Production Based Incentives
PE	Annual earnings from power market
PPA	Power purchasing agreement
PT	Parabolic Trough
PTC	Production tax credit
PT_n	Earnings from premium tariff or production base incentives
PV	Photovoltaic
Q	Annual electricity production
R	Real discount rate
Res	Annual insurance and reserve cost
RSE	Reduction in the sales taxes payments

SAM	System Advisor Model
SBPP	Simple back pay period
ST	Solar tower
STE	Annual sales tax earnings of the initial investment cost
STR	Sales Tax Reduction
T	Annual income taxes paid
T	Period of time of the project
$T_{credits}$	Annual tax credit payment
$T_{liability}$	Annual income taxes
USA	United States of America

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