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Optimization of Static Wind Power Investment in the Australian National Electricity Market

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***Abstract*—This paper studies the Australian market conditions and subsidies in place to promote the growth of wind power through the use of a stochastic linear programming model. This model optimizes the profit obtained for a static investment based on a variety of wind and price scenarios. It is subject to different constraints which focus on the amount of initial capital injected by an investor, selling power through a Power Purchase Agreement (PPA) or using the Market Clearing Price (MCP). The Conditional Value-at-risk (CVaR) risk is also considered in this model to assist in differentiating between a risk-neutral and risk-averse investor. This has been evaluated for Portland on the coast of Victoria, Australia, using current data.**

***Index Terms*— Australian National Electricity Market, investment, renewable energy target, optimization methods, planning, stochastic programming, wind generation.**

NOMENCLATURE

Constants:

D	Number of days in each year
Y	Number of years of plant operation
R	Rated power of each wind turbine (MW)
M	Number of maintenance periods in one year
I_{CRF}	Capital Interest Rate of Return
I_{invest}^{MCP}	Capital Investment for MCP wind farm
I_{invest}^{PPA}	Capital Investment for PPA wind farm
C_{Cap}	Capital cost of each wind turbine
C_{Tran}	Capital transmission line cost
C_{Fix}	Fixed Annual O&M costs per wind turbine
C_{Var}	Variable O&M cost per MWh produced
C_{FTS}	Annual Salary of full-time employees per MW
C_{CNS}	Fixed cost of Construction salary
C_{Land}	Annual cost of land rent per wind turbine
k_{PPA}	PPA capacity factor of the turbine as a percentage of maximum rated power
C_{invest}^{Max}	Maximum annual investment into wind farm
P_{Max}	Maximum Rated power installed at wind farm
λ_t^{PPA}	PPA contract price per MWh generated
β	Conditional expectation of losses above Alpha
ρ	Coherent risk-averse measure

Parameters:

$\lambda_t^{MCP}(\omega)$	MCP per MWh of power generated subject to the scenario ω, at the time interval t
$k_t(\omega)$	Wind capacity factor of the turbine as a percentage of maximum rated power
$\alpha(\omega)$	Weight of scenario ω

Variables:

X_{MCP}	Number of units installed under MCP
X_{PPA}	Number of units installed under PPA
$C_{\mathrm{Re}m}^{MCP}$	Remaining Capital Investment to be repaid following initial upfront payment for MCP wind farm installation
$C_{\mathrm{Re}m}^{PPA}$	Remaining Capital Investment to be repaid following initial upfront payment for PPA wind farm installation
$P_t^{MCP}(\omega,$	Power generated under Market Clearing Price Conditions, dependent on the scenario ω, at the time interval t
$P^{PPA}(t)$	Power generated under PPA Conditions, dependent on the time interval t
ζ	Value at Risk
$\eta(\omega)$	Comparison of profit for each scenario compared with ζ value

Indices and Sets:

Ω^t	Set of indices of the time intervals in one day
Ω^ω	Set of indices of the scenarios

I. INTRODUCTION

1) *Background and motivation*

Wind power integration into the Australian National Electricity Market (NEM) has been a prominent challenge for the past decade. The NEM manages the wholesale energy exchange for multiple interconnecting markets for the eastern seaboard of Australia [1]. Following Australia's early adoption of market-based regulation and the electricity industry restructuring, the introduction of a world leading renewable Energy Target (RET) scheme was introduced in

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2001 [2], which has derived a considerable growth in renewable energy, forge a reduction in greenhouse gas emissions, and help to ensure the profitability of renewable energy sources [3-4]. The aim is to achieve 20% or 45,000GWh of Australia's energy from large-scale renewable resources by 2020 [2].

The introduction of the RET particularly triggered an increase in wind power development in South Australia and Tasmania. To reach this target around Australia, a Large-scale Generation Certificates (LGCs) subsidy was implemented, where they are sold and traded between entities to achieve the Renewable Power Percentage (RPP) [4]. It is claimed that wind is the most affordable, matured and reliable form of renewable energy technology for the Australian market, partly due to the additional revenue stream of LGCs [3].

Facilitating the integration of wind into the electricity grid requires consideration of decision making within the industry; and the challenge of high levels of wind penetrations given the uncertainty of supply [2], [5]. The main challenges to be taken into account in the wind power planning projects are the unknown of future investment and operational costs; environmental gains; and the social benefits to stakeholders in the community [2].

2) *Aim*

A profitable wind generation investment strategy is a prominent challenge for current investors within Australia. This results from uncertainty in the wind industry through highly variable wind speeds, the correlation between power generated and customer demand, variations of the renewable energy subsidy policy changes, fluctuations in spot market price, and unknown future variation in equipment costs [2]. The area which provides greatest uncertainty is the amount of initial capital investment from investors at the start of the project to optimize returns. This paper investigates the above issues in a static stochastic wind investment model using accurate NEM data from Australia. A linear programming model optimizes two different wind investment options (MCP & PPA) for investors focusing on subsidy effectiveness in the NEM, and varying levels of initial capital investment. In addition, this model is formulated as a risk-constrained problem using CVaR.

3) *Literature review and contributions*

While there are many modeling approaches to profit optimization, the modeling of renewable energy source investment optimization has had limited research. Reference [6] develops a static profit maximization model for MCP, which considers network integration analysis, and local power demand which is highly variable. Authors in [7] outline the investment strategy for wind power using the assumption that generation capacity and investment resources are flexible, using mixed integer linear programming (MILP). It considers variations in wind speed, the turbine size, and the efficiency of turbines installed for a project. Turbine specific concepts are also supported in [8], which also uses discount rates or the capital recovery factor on the initial investment. Authors in [9] consider a feed-in tariff scheme for wind generation and analyses the effectiveness of this subsidy relating to profit maximization using MILP. References [6-9] outline methodologies where a static model is used to formulate a profit optimization for wind generation, where investment occurs in a target year.

Comparatively, [10] considers a dynamic model using single level MILP. Investment is targeted in multiple stages in this model, confirming the static model approaches seen in above papers. It focuses on the uncertainty in wind power investments from production variability, uncertainty of wind facilities, and fluctuations in wind equipment costs. It combines these to consider the risk associated for the investor given these uncertainties.

The main contributions of the paper are as follows:

1) Our work develops an investment plan for wind power producers, which is adapted to the Australian National Electricity Market (NEM) with unique features. To this end, a static plan is proposed and formulated in which the impacts of capital loan repayments, subsidies, land and employees as well as NEM price uncertainties are assessed on wind power investment in the Australian NEM.
2) Two types of options are modelled for selling wind energy by a wind power producer. The producer can either sell its energy into the market, which is faced by price intermittency, or set direct contracts with energy purchasers through the PPA approach. This way, the level of risk averseness is matter.

II. PROBLEM DESCIPTION

1) *Model assumptions*

The following assumptions have been used in the formulation of this model to represent the Australian market context, and to assist in simplicity of the formulation.

1) The amount of power produced under a PPA contract is equal to 28% of the nameplate power rating of the turbine.
2) The wind producer places its offer in the market at \$0/MWh, and is consequently paid at MCP.
3) Transmission line losses have been neglected.
4) Salaries of construction workers and employees have been approximated at \$60k p.a. and \$100k p.a. respectively in Australia [11].
5) The location of wind farm construction is modeled as Portland, Victoria. This location affects input data to the model regarding wind and pricing.
6) Uncertainties in this model come from wind power production and market price variation only. Cost is assumed constant.

2) *Mathematical formulations*

Two methodologies used to generate revenue from produced power are market clearing price (MCP) and power purchase agreement (PPA) as described in [3]. The MCP is the current spot market price paid for the generated energy. Its price per MWh can vary widely. There is no certainty of revenue in this method due to the MCP potentially being paid at lower than the operational costs due to the amount of energy required varying based on consumer demand. A PPA is an energy producer contract for a fixed period, usually the length of the plant lifecycle, to produce a set amount of power and is usually determined prior to construction. If that power is not generated due to fluctuations in wind speeds, the difference must be made up in subsequent time periods. The advantage of PPA structured wind farms is that if the total contracted amount of energy is not produced in a given year, the full contracted price must still be paid by the buyer, removing risk for the investor [3].

The investment problem in wind generation can be formulated using the following model:

$Maximize\ \forall t, \omega$:

$$\begin{pmatrix} YD\begin{pmatrix} \displaystyle\sum_{\omega\in\Omega^{\omega}}\sum_{t\in\Omega^{t}}\alpha(\omega)k_t(\omega)\times\left(P_t^{MCP}(\omega,t)-\frac{P_t^{MCP}(\omega,t)}{M}\right) \\ \times\left(\lambda_t^{MCP}(\omega)-C_{var}\right) \\ \displaystyle +\sum_{t\in\Omega^{t}}k_{PPA}\times\left(P^{PPA}(t)-\frac{P^{PPA}(t)}{M}\right)\times\left(\lambda_t^{PPA}-C_{var}\right) \end{pmatrix} \\ -\begin{pmatrix} \left(X_{MCP}+X_{PPA}\right)\left(\left(C_{land}+C_{fix}\right)+RC_{fts}\right) \\ +I_{CRF}\left(C_{rem}^{MCP}+C_{rem}^{PPA}\right) \\ +0.05\times\begin{pmatrix}\left(X_{MCP}+X_{PPA}\right)\left(C_{cap}+C_{tran}\right) \\ -\left(C_{rem}^{MCP}+C_{rem}^{PPA}\right)\end{pmatrix} \end{pmatrix} \end{pmatrix}$$
$$-\left(X_{PPA}+X_{MCP}\right)RC_{cns}+\rho\left(\zeta-\frac{1}{1-\beta}\sum_{\omega\in\Omega^{\omega}}\alpha(\omega)\eta(\omega)\right) \tag{1}$$

Subject to:

$$-\begin{pmatrix}\begin{pmatrix} YD\begin{pmatrix} \displaystyle\sum_{t\in\Omega^{t}}\alpha(\omega)k_t(\omega)\times\left(P_t^{MCP}(\omega,t)-\frac{P_t^{MCP}(\omega,t)}{M}\right) \\ \times\left(\lambda_t^{MCP}(\omega)-C_{var}\right) \\ \displaystyle +\sum_{t\in\Omega^{t}}k_{PPA}\times\left(P^{PPA}(t)-\frac{P^{PPA}(t)}{M}\right)\times\left(\lambda_t^{PPA}-C_{var}\right) \end{pmatrix} \\ -\begin{pmatrix} \left(X_{MCP}+X_{PPA}\right)\left(\left(C_{land}+C_{fix}\right)+RC_{fts}\right) \\ +I_{CRF}\left(C_{rem}^{MCP}+C_{rem}^{PPA}\right) \\ +0.05\times\left(\left(X_{MCP}+X_{PPA}\right)\left(C_{cap}+C_{tran}\right)-\left(C_{rem}^{MCP}+C_{rem}^{PPA}\right)\right) \end{pmatrix}\end{pmatrix} \\ -\left(X_{PPA}+X_{MCP}\right)RC_{cns} \end{pmatrix}$$
$$+\zeta\le\eta(\omega) \tag{2}$$

$$\eta(\omega)\ge 0,\quad \forall\omega \tag{3}$$

$$0\le X_{MCP}\le\frac{P_{Max}}{R} \tag{4}$$

$$0\le X_{PPA}\le\frac{P_{Max}}{R} \tag{5}$$

$$0\le\ P_t^{MCP}(\omega,t)\le\ P_{Max},\quad \forall\omega,\forall t \tag{6}$$

$$0\le\ P^{PPA}(t)\le\ P_{Max},\quad \forall t \tag{7}$$

$$P_t^{MCP}(\omega,t)=X_{MCP}R,\quad \forall\omega,\quad \forall t \tag{8}$$

$$P^{PPA}(t)=X_{PPA}R,\quad \forall t \tag{9}$$

$$P_t^{MCP}(\omega,t)+P^{PPA}(t)\le\ P_{Max},\quad \forall\omega,\forall t \tag{10}$$

$$X_{MCP}\left(C_{cap}+C_{tran}\right)\left(1-{I_{invest}^{MCP}}/{100}\right)=\ C_{rem}^{MCP} \tag{11}$$

$$X_{PPA}\left(C_{cap}+C_{tran}\right)\left(1-{I_{invest}^{PPA}}/{100}\right)=\ C_{rem}^{PPA} \tag{12}$$

$$(X_{MCP}+X_{PPA})(C_{land}+C_{fix})+(C_{rem}^{MCP}+C_{rem}^{PPA})I_{CRF}\ \le\ C_{invest}^{max} \tag{13}$$

The objective function of model (1) represents the maximization of profit plus a coefficient times the Conditional Value at Risk (CVaR). Lines 1-3 are the formulation of MCP and PPA revenue minus the variable cost. Note that the capacity offline for annual maintenance is taken into account using the term $\frac{P_t^{MCP}(w,t)}{M}$. Additionally, the scenario weighting of the MCP model is considered through $\alpha(\omega)$. Lines 4-7 represent the costs which are subtracted from the revenue term. These occur annually or over the lifecycle and include land fees, staff salaries, operations and maintenance (O&M) costs, annual remaining capital expense (less the capital initially invested) given by a capital recovery factor, compulsory repayment of the initial capital investment from the investor, and construction costs. This gives an optimized profit function, with all monetary values given in present value without inflation. Finally the CVaR factor is added to the objective function, scaled by a factor of ρ, which materializes the tradeoff between profit and risk [10]. The larger the ρ value, the more risk-averse the wind investor is. A further explanation of CVaR can be found in [12-13].

Constraints (2) and (3) linearize the CVaR by ensuring eta for each scenario, $\eta(\omega)$, where profit is subtracted from the Value at Risk (VaR), ζ, is a positive value, else eta is zero. These variables are used in Equation 1, where the CVaR is added based on a factor of risk. Equations (4-10) place limits on the power requirements of the wind farm. Equations (4-5) show the number of units installed, X_{MCP} and X_{PPA}, must be greater than or equal to zero and less than the maximum number of units given by $\frac{P_{Max}}{R}$. Equations (6-7) ensures that the total power installed for each scenario, based on ω and t, for MCP and PPA models is between the maximum specified power limitations, P_{Max} and zero. Equations (8-9) equate the number of units installed for the MCP and PPA approaches to the total power installed given the power rating of each unit. Equation (10) relates the total power installed for each investment method (MCP and PPA), where the sum must be less than or equal to P_{Max}.

Constraints (11-13) relate to initial capital and annual investments for the wind farm. Equations (11-12) formulate the remaining amount of capital to be repaid subject to the number of units installed. Equation (13) refers to the maximum annual investment costs as for each turbine to be installed, and the percentage of remaining capital to be repaid subject to the capital recovery rate. This must be less than the maximum annual investment cost.

III. CASE STUDY

A. Data

The proposed model uses a variety of real world data from the state of Victoria in the Australian market. Data was obtained from Australian Energy Market Operator (AEMO) for the MCP data for each season, the median value taken, and is dependent on ω and t [14]. For each season, price fluctuations were included, where the price could increase 10% or 20%, remain neutral, or decrease 5% or 10%. This change was assumed to occur over 20 years. The weighting of each scenario was 0.25, 0.25, 0.2, 0.15, and 0.15 respectively.

There are three LGC subsidy scenarios, which have been considered in the model: where the subsidy remains, the subsidy gradually decreases over 13 years, and where the subsidy is suddenly removed after 3 years to reflect policy changes. The probability of each of these scenarios occurring is 0.45, 0.1 and 0.45 respectively. The subsidy value was the average of the LGC subsidy over the past five years at $36.89. The value of the subsidy based on the scenario type was averaged over the 20 year lifecycle, resulting in $36.89/MWh, $18.42/MWh, and $5.53/MWh for each respective scenario, and was added to the MCP price input data in the model.

Wind power was approximated using real world wind power, which is available in one hour intervals. The data was obtained from NEM Review software [15], which had accurate data for the existing Portland Wind Farm. These capacity factors were used, and 50 pseudo-random scenarios were chosen for each season, with an equal weight of 0.02 [15]. This results in a total of 1,000 scenarios for each of the three subsidy types.

The turbines simulated in this model were the Sinovel SL 3000-90 turbines, with a rated power of 3MW per unit at a cost of $6.3m [8]. The annual O&M costs were $60k, and variable maintenance costs were considered as $12/MWh [16].

The cost of renting the land which turbines were constructed on was taken as $2k; while a DC transmission line was costed at $80/m for a 66kV line [17], [18].

The capital recovery factor was approximated by:

$$CRF = \frac{j(1+j)^m}{(1+j)^m-1} \tag{14}$$

where m is the plant lifecycle (20 years), and j is the interest rate of repayment of 7% [6], [8].

B. Single Subsidy Results

A simple model to test the effectiveness of the subsidy in the current market environment was conducted. Capital is the monetary funds provided by investors upfront, which is not subject to capital recovery factor. The capital injection is increased in 10% steps from zero to 100% capital.

As can be seen from Fig. 1 below, the effectiveness of the LGC subsidy shows that wind investment is profitable if the investor is able to fund the majority of the capital costs, and the current LGC subsidy remains in effect in some form. This assumes a standard investor will not invest more than 80% of the total upfront costs. With the subsidy remaining, the project requires an initial capital investment of 16.74% of the total capital required to return a profit, compared to Australian wind farms which have approximately 50% of the required capital invested prior to construction [8]. Meanwhile, if the subsidy is reduced or removed, the negative effect on the project can be seen, with a greatly reduced profit for the gradual declining subsidy, compared to the subsidy being entirely removed, which will result in no profitability.

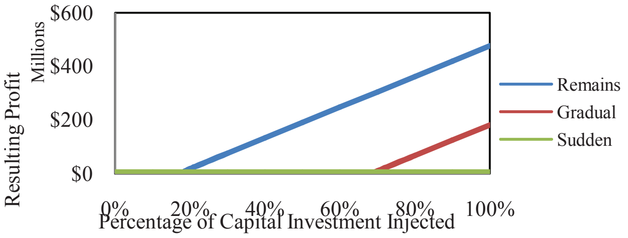

Fig. 1. Effect of LGC Subsidy on wind project profitability

C. Combined MCP and PPA Results

There are four cases considered. Cases one and two, where the subsidy remains for the duration of the wind farm lifecycle. In addition, an initial capital investment of 100% and 50% is used respectively. The final two cases are where consideration has been given to the combination of all three subsidies with weightings. These cases are subject to a 100% and 80% capital investment for MCP wind farms. The PPA model assumes 40% capital investment for the first two cases, and 30% investment for the final two. In all cases, ρ is varied, while β is kept constant at 0.95. A contract price for the PPA of $105/MWh is used. In all cases, the maximum annual investment is not limited. Note that the gradual and suddenly removed subsidies are not considered in these cases, as they would not be profitable.

<u>Case 1</u>: This case considers 100% initial capital investment for MCP, and 40% capital investment for a PPA approach. For the risk-neutral situation ($\rho = 0$), the overall profit of the MCP scheme was $476.8m. However, as risk was increased to $\rho = 1$, the profit was reduced. Consequently, the PPA method was used for construction to mitigate the risk, with a profit of $156.9m. With the subsidy remaining and maximal capital investment occurring, wind farms are highly profitable under a MCP scheme despite risk, as in Fig. 2.

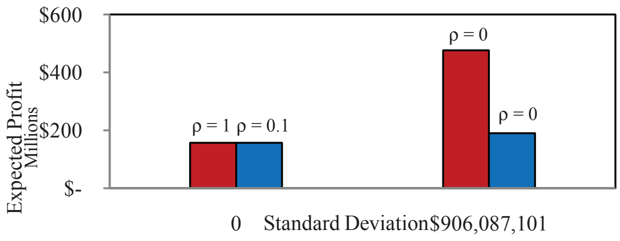

Fig. 2. Standard Deviation of PPA and MCP Models with remaining subsidy and risk

<u>Case 2</u>: This case considers the more practical example of 50% initial capital investment in the MCP model, while PPA

model is unchanged. With the lower initial capital investment, the expected profit of the MCP model is significantly lower for risk-neutral investors ($\rho = 0$). For a risk-averse investor ($\rho = 0.1$), the PPA method remains as profitable as Case 1. This is due to the PPA method having no standard deviation, ensuring no fluctuations in profit. The MCP has a large standard deviation given uncertainty in wind scenarios.

Case 3: This case considers a combined subsidy case, where three subsidy conditions are combined and weighted. A 100% investment for the MCP model occurs. The PPA contract terms remain constant, with capital investment decreases to 30%. It is confirmed again that as the risk increases the expected profit decreases as seen in Fig. 3. The standard deviation for a risk-neutral investor decreases from cases 1 and 2, due to more scenarios in the formulation of the results for the combined subsidy. Similar to Case 1, the expected profit of the MCP model is higher than that of the PPA model at $222.0m, due to the larger initial capital investment.

Case 4: This case considers the realistic example of the Australian market context. The capital investment for the MCP scheme is reduced to 80%. This investment cannot be reduced further, as for this subsidy scenario it would not be profitable. The PPA condition remains the same as discussed in Case 3 due to no standard deviation being present. The risk-averse condition for this subsidy results in a very small change in $\rho = 0.1$ seen in Figure 3. This is due to the profitability of the MCP approach resulting in $107.4m profit, compared with the PPA method profit of $99.6m. In case 4 there are no benefits being a risk-neutral investor due to the high standard deviation. Consequently the optimal investment for the Australian market context is through a PPA contract method.

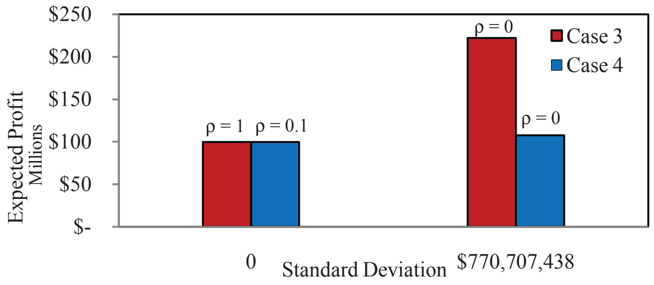

Fig. 3. Standard Deviation of PPA and MCP Models with combined subsidy and risk

IV. CONCLUSION

This paper presented a stochastic linear model aimed at optimizing wind power investment. It was found from the MCP model that in an Australian market context, constructing a wind farm and selling all power generated to the spot market at the MCP is the most economically viable option. However, this requires a large capital investment at the start of the project. Given the current market conditions and potential policy changes regarding the LGC subsidy, this strategy is correct if the LGC subsidy remains, otherwise the PPA method is more economical due to high standard deviation for the risk-neutral investor.

In the static model with risk consideration, it was observed that wind investment in Australia is a challenging task for all investors. Meanwhile, PPA provides a minimal risk solution for the risk-averse investor. There are challenges associated with securing a contract given the current volatility in the NEM. This means consumers are less likely to invest in this method, as there is a possibility of the development of a more optimal solution for their future needs, and they desire not to be locked into a fixed term contract. This thinking has resulted in an overall reluctance on the investment in wind energy in Australia, and is being reflected in actual industry decisions.

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