Date: December 4, 2020

To: Professor Posen, CME368

Subject: Assignment #2: Engineering Economics Case Study

This report was written entirely by the authors, is properly referenced where information came from other sources, and has not received previous academic credit at this or any other institution.		
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1.0 Introduction

This report examines the feasibility of wind power (WP) and natural gas plant (NGP) based on analyses of each option's financial performance, sensitivity, environmental, social and political implications to assist Ontario Power Generation (OPG) in project selection.

2.0 Base Case Calculations and Analysis

Annual worth (AW), present worth (PW) and internal rate of return (IRR) are developed at different minimum acceptable rate of return (MARR) to compare the cash flows of the two mutually exclusive projects at difference service lives. Since OPG is a crown corporation and a new power plant is required to meet future energy demand, one project must be chosen. Both projects belong to Capital Cost Allowance (CCA) Class 43.2 with a 50% depreciation rate for tax purposes using declining balance method, as both generate and sell electricity at the eligible power level specified under Class 43.2 [1][2].

2.1 Cash Flow General Assumptions

This is a list of general assumptions being used for all cash flow calculations:

1. Bank loans to OPG fund all its projects, so excluding loan repayment contributions from either project alternative will not affect the project recommendations [3].
2. Weighted average cost of capital derived from OPG's green bonds coupon interest and bank loans interest is 2.5% (Appendix A), so a conservative 3% MARR is used [3].
3. Corporate tax is constant at 27% and first-year rule applies in depreciation calculations.
4. Cash flows are computed in real dollars.
5. Capital cost includes permit fees and other administrative costs.
6. Property tax only applies when the infrastructure is fully constructed and subsequently gain value after operation begins [4].
7. OPG has other sources of income from other energy plants, the negative taxable income is considered as tax credit and thus positive in the cash flow analysis [3].

2.2 Wind Power Plant Base Case Analysis

Land lease agreements are assumed to span the entire project period with a constant annual rent of $2500 per MW capacity [5]. Property tax at the industrial rate of 2.24% is applied on the estimated property value, which is the sum of first cost and wind towers valued at $40,000 per MW [4][6][7]. Decommissioning cost and salvage value are determined using average values of WP plants in North America (Appendix B) [8]. An average capacity of 2 MW per wind turbine is assumed and such capacity is unchanged after installation [9].

2.3 Natural Gas Plant Base Case Analysis

The salvage value of NGP is determined using actual depreciation rate of 7.5% according to Statistics Canada (Appendix C) [10]. Decommissioning cost is calculated as the sum of salvage value and "net decommissioning cost" determined using a linear regression model developed from available NGP net decommissioning data in the US (Appendix C) [11]. Fuel cost is obtained from Deloitte's oil and gas price forecast; the reference price of natural gas in Alberta is used [12][13]. Carbon tax is calculated using the Greenhouse Gas Pollution Pricing Act (Appendix D) [14]. This report assumes the global warming potential of natural gas equal to methane's, and all combustion engines have capacity of 150 MW or less. Since efficient combustion engines are used, carbon tax does not apply.

2.4 Base Case Comparison

The breakdown of cashflow is shown in Table 1. Annual corporate tax and fuel cost contribute the most to the total costs, and the tax increases exponentially over time due to decrease in capital cost allowance. Property tax and O&M costs contribute less to the total cost.

Table 1: Cost breakdown of wind power and natural gas plant

Cost breakdown items	Units	Wind power (WP)	Natural gas plant (NGP)
First cost	$	527,600,000.00	431,600,000.00
Land lease	$/year	1,000,000.00	-
O&M cost	$/year	10,488,000.00	5,616,000.00
Decommission	$	41,186,924.00	30,051,540.48
Salvage	$	37,207,144.00	19,087,574.52
Corporate tax	%	27	27
Property tax	$/year	12,181,456.30	9,671,633.98
Natural gas price	$/mcf	-	2.65
Revenue	$/year	189,216,000.00	252,288,000.00
Construction + Service Life	years	3 + 30	3 + 40

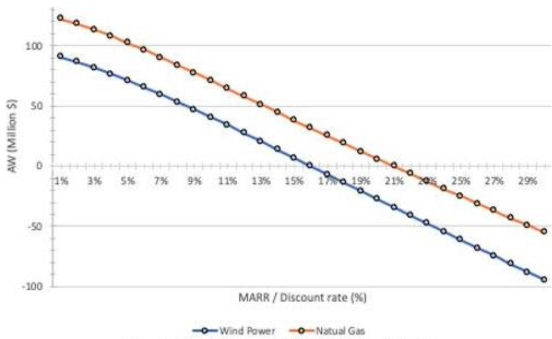

Fig. 1: Base Case AW of WP and NGP

The AW of both choices are shown on Fig 1. The IRR is at 16.0% for WP and 20.9% for NGP. With a 3% MARR, the AW of WP and NGP are $81 million and $113 million respectively, with a significant difference of 39%. The PW of NGP is $2.7 billion, 60% higher than the PW of WP of $1.7 billion (Appendix E). Since the two projects are mutually exclusive and OPG must choose either one option, NGP is recommended because it has a higher AW than WP at any MARR as the first cost and overall operation cost of NGP are lower.

3.0 Sensitivity Calculations and Analyses

In the base case model, fluctuations in variables such as capital costs and construction time can affect the cash flow of both projects. This section systematically examines the sensitivity of current cash flow model of both projects with respect to the uncertainties in selected input parameters; an analysis of break-even price of electricity is also included.

3.1 Monetary Cost Factors and Time Period Factors

Variables for the sensitivity analysis are categorized into two groups of factors: monetary cost factors and time period factors. The former includes variations in capital cost, O&M cost, fuel costs, and the latter includes changes in construction time and operating life.

Monetary cost factors are directly associated to the cost of production and are market driven depending on the availability of human labour, material, and technology, with capital cost at the beginning of the project, annual O&M and fuel cost over the operating life. Time period factors can be influenced by external forces such as labour efficiency that are entirely market driven over the length of construction period and operating life of the plants.

3.2 Two Methods of Input Variability Range

The first method applies a constant percentage change, ranging from -30% to +30% in increments of 10%, relative to the base case value for each variable, providing an objective comparison across various factors. Results with MARR at 3% and 10% are reported to show the impacts of different levels of MARR on AW.

To capture the likelihood of variability in each variable, the second method adopts a probabilistic approach that would imply the combination of variables in the optimistic, most likely and pessimistic cases. Each variable is assumed to follow a normal distribution with the base case value as the mean. The base case value, one standard deviation above and one standard deviation below the mean are used because it captures 68.2% of all scenarios under the normal distribution model that represents most probable cases.

3.3 Sensitivity Analysis with Method 1: Fixed Percentage Variation

The results of the sensitivity analysis are shown in Table 2 with AW against percentage change in the specified variable at MARR = 3% and 10%. A steeper slope indicates the variables result in more sensitive change in AW.

Table 2: Sensitivity results using Method 1 and Method 2

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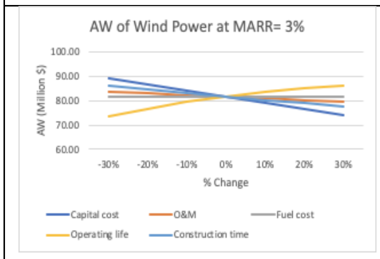

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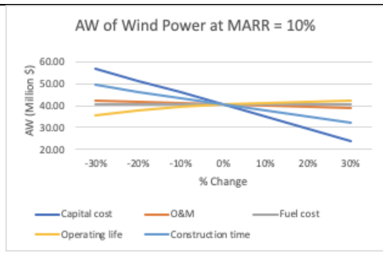

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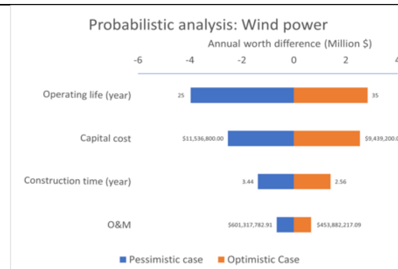

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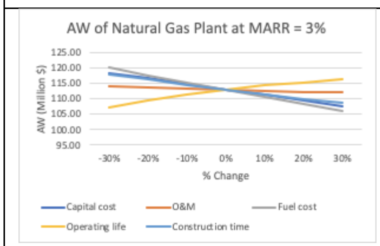

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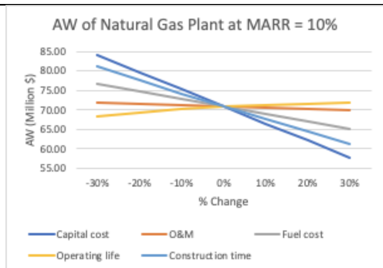

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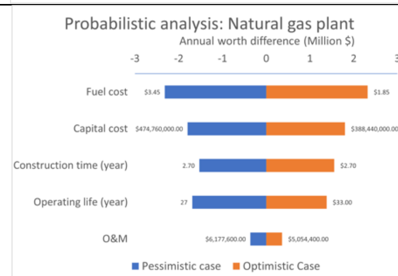

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The order of variables affecting WP starting from the most sensitive is Capital Cost, Construction Time, and Operating Life. As for NGP, the most sensitive variables are Fuel Cost, Capital Cost, and Construction Time. Capital cost is large, so a constant percentage change has a huge impact on AW; The degree of impact of changes in variables on the AW varies as MARR changes. The influences of O&M costs are marginal because O&M costs are less than 2% of first cost for both alternatives. At a constant MARR, it is worth noting that all variables except Operating Life have a constant rate of impact on AW as they change.

Changes in fuel costs do not affect WP as it does not consume fuel, but it is the major driving factor influencing AW of NGP because it significantly impacts the annual cost of production. Therefore, the AW of NGP is more sensitive to market fluctuations on fuel price and capital cost, while WP is mainly influenced by first cost.

3.4 Sensitivity Analysis with Method 2: Probabilistic Approach

Results of the sensitivity analysis using the probabilistic approach are shown in Table 2. The two funnel charts show the AW differences to the base case in the pessimistic and optimistic case at 3% MARR, and the values used for both cases are listed in Appendix F.

Similar observations from the first method are seen, with the sensitivity of NGP to fuel cost is further exaggerated in the probabilistic approach due to its market-driven nature is highly influential by external factors, so it is more likely to fluctuate rigorously compared to other factors. This is reflected with the high standard deviation on fuel price.

3.5 Fixed Amount of Electricity vs Fixed Initial Budget

A WP plant of equivalent capacity that produces (i) the same amount of electricity or (ii) has the same initial budget as the NGP in base case is compared to the base case NGP as all cash flow information are given per unit of capacity. From Fig 2, WP outperforms NGP when a fixed amount of base case electricity needs to be produced at MARR below 17% or when a fixed base case NPG initial budget is provided at MARR below 4% (Appendix G). Therefore, WP could be a better option if a fixed base case electricity demand needs to be met, unless OPG is constrained by initial budget or unable to acquire enough land for wind power turbines.

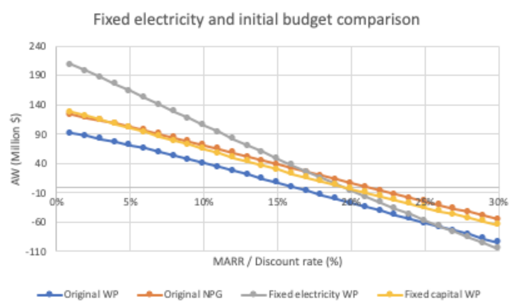

Fig. 2: Fixed Electricity & Initial Budget comparison

Fig. 3: Break-even Price Comparison

3.6 Breakeven price

Fig. 3 shows the break-even electricity price of the two projects with MARR from 1% to 30%. The break-even price of the WP project and the NGP project are $37.95 and $36.48 at 3% MARR. The break-even price varies as MARR changes. With a lower MARR between 1% to 3%, the break-even prices for both projects are similar. However, the break-even price of WP begins to increase and diverge from NGP as MARR exceeds 3%. Since WP has a wider break-even price range compared to NGP, WP's break-even price is more sensitive to MARR.

4.0 Other Considerations

Other considerations, including environmental, social and political costs associated with both NGP and WP projects, should be incorporated into OPG's decision-making process.

4.1 Environmental Impacts on Local Communities in Ontario

In general, NGP has more negative impacts on its surrounding natural environment compared to WP [15]. First, NGP has a higher amount of embedded carbon in its construction material and higher carbon emissions from natural gas combustion during operation in comparison to WP of equivalent capacities [15]. Second, NGP are more destructive towards surrounding natural environment [16]. This requires more decommissioning and environmental remediation efforts at the end of its service life compared to WP [16].

In contrast, WP generally has fewer negative environmental effects than NGP with no carbon emissions during operation and less land use impacts [17] [18]. Although WP requires large sum of land to operate, in Ontario where most turbines have been and will be built near farmland, the actual land occupied by WP is relatively small, so physical disruption to local communities will be low [18]. However, WP does negatively affect species such as birds and bats, though these impacts can be reduced by improved turbine technology [19].

4.2 Social Costs of Natural Gas Power Plants and Wind Farms in Ontario

For NGP, the most direct social cost comes from its carbon emissions. Based on a 3% MARR, the equivalent annual worth of the social cost is $65 million or $1.33 per dollar invested in NGP (Appendix H) [20]. In comparison, the social cost of WP, which will primarily be in the form of traffic congestion cost, only accounts for about $6 million annually or $0.17 per dollar invested at a 3% MARR, significantly lower than what a NGP produces (Appendix H) [21]. From the perspective of cost effectiveness, at a low MARR (<3%), WP and NGP have a similar CER, though WP performs slightly better. Beyond a 3% MARR, the CER of WP starts to grow at a faster pace than NGP, making NGP the more cost-effective option (Appendix I).

4.3 Political Implications of Natural Gas Power Plant and Wind Farms in Ontario

As the campaign against growing carbon emissions continues to gain traction [17], OPG will likely face growing pressure from the public to halt any NGP development plans. This can cause delays in funding approval for project planning and construction, which could increase the first cost, construction time and negatively impact the cash flow.

Meanwhile, WP also faces public opposition due to health concerns [22]. Although various studies have proven that the potential health impacts, such as noise disturbance, of wind turbines on local communities are not significant and could be mitigated through proper planning and technology improvements [22], skepticism still remains strong in the media and the general public [23]. If OPG wants to expand its wind turbine operation in Ontario, they need to develop and implement effective community consultations and public relation campaigns to improve the public perception of wind turbines and promote WP's benefits.

4.4 Future Uncertainties

Changes in policy and regulations, technologies, and market circumstances could impact the future cash flow of both NGP and WP projects in Ontario. As for NGP, if carbon pricing policies were adopted, additional operation costs can negatively impact the NGP's long-term cash flow and decrease its AW (see Table 2). Fuel price fluctuations also add uncertainties; although fuel price is predicted to only have minor fluctuations for the foreseeable future [12], the future cash flow of NGP could greatly vary as it is sensitive to even minor changes in fuel price, especially at a low MARR.

Future WP projects face two major uncertainties. First, regulatory changes could impact the cash flow of WP in different ways; on one hand, any favourable tax or policy incentives for renewable energy can boost the demand of WP and make it cheaper [24]; on the other hand, more stringent oversight and regulatory requirements can be imposed on WP and make it more expensive [24]. Second, WP technology is rapidly changing and could profoundly impact the future of the WP industry. Improvements in turbine manufacturing and maintenance technologies can prolong the operating life and lower WP's O&M cost. Since WP cannot generate electricity on demand, thus less reliable than NGP, effective energy storage techniques will be needed to store surplus WP for later usage, which could improve the supply and utility of WP [25].

5.0 Conclusions

Overall, WP is recommended over NGP for the long-term benefits and well-being of the community. Although NGP outperforms WP financially in various metrics, including higher PW, higher IRR, and higher AW in the base case analysis, WP is able to generate better AW performances when being compared to NGP at a fixed electricity production target and with a fixed initial budget within a specific range of MARR, given that OPG has sufficient financial and land resources to meet the specified electricity demand.

In addition, WP has less negative environmental and social costs to surrounding communities. NGP is also highly sensitive to fluctuating fuel prices, and would also face challenges with potential future carbon pricing policies and the growing competition from the renewable energy industry. Although WP is currently less reliable because it depends on the availability of wind along with challenges regarding potential health effects and unresolved technical difficulties, these problems could be addressed by proper community consultation, responsible planning, and increasing research and development efforts.

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7.0 Appendices

Appendix A: Weighted average interest rate on bank loans and green bond [3]

	Size	Coupon interest rate	Total size	Weighted average
Green bond (Long term debt)	$400 million (issued in March 2020)	2.89 %	$8846 million	(400 * 2.89%+ 800 * 3.22% + 400 * 1.75%) / (400+800+400) =2.77 %
	$800 million (issued in April 2020)	3.22 %		
	$400 million (issued in April 2020)	1.75 %		
Bank loans (Short term debt)	-	-	$1505 million	0.72% (fluctuates from 0.72% to 1.88% between December 31, 2019 to June 30, 2020)
Weighted average MARR	(8846 * 2.77% + 1505 * 0.72%) / (8846 + 1505) = 2.47% Since the MARR is between 2% and 3%, a conservative MARR of 3% is chosen for project evaluation in this report.			

Appendix B: Salvage value and decommissioning cost of wind turbines [8]

	USD	1 USD = 1.31 CAD
Average decommissioning cost	USD$157,202 /turbine	CAD$186,035.72 /turbine
Average salvage value	USD$142,012 /turbine	CAD$205,934.62 /turbine

Appendix C: Salvage value and decommissioning cost of natural gas plant

The net decommissioning cost data in the US is shown in Table C.1. A linear regression model is developed in the following section to determine the unit net decommissioning cost of the NGP. The total NGP decommissioning cost calculation is shown in Table C.2.

Table C.1 Net decommissioning costs of natural gas plants in the US [11]

Dependent Variable	Independent Variable			
X_i: Total Capacity (MW)	Y_i: Decommissioning Costs(USD/MW)	$X_i - X_{avg}$	$Y_i - Y_{avg}$	Y

42	$ 2,352.94	-1024.50	-16955.89	21790.95
41	$ 15,294.12	-1025.50	-4014.71	21793.37
73	$ 15,294.12	-993.50	-4014.71	21715.84
313	$ 15,300.00	-754.00	-4008.83	21135.59
21	$ 22,352.94	-1045.50	3044.11	21841.83
563	$ 15,200.00	-504.00	-4108.83	20529.90
604	$ 24,706.00	-462.50	5397.17	20429.35
896	$ 35,294.00	-170.50	15985.17	19721.91
895	$ 49,411.76	-171.50	30102.93	19724.33
958	$ 34,117.65	-108.50	14808.82	19571.70
1198	$ 43,529.41	131.50	24220.58	18990.23
1208	$ 12,941.18	141.50	-6367.65	18966.00
1250	$ 10,588.24	183.50	-8720.59	18864.25
1646	$ 7,058.82	579.50	-12250.01	17904.83
1792	$ 18,823.53	725.50	-485.30	17551.11
2010	$ 11,764.71	943.50	-7544.12	17022.95
2021	$ 2,352.94	954.50	-16955.89	16996.30
3667	$ 11,176.50	2600.50	-8132.33	13008.42
X_{avg}: 1066.50	Y_{avg}: 19308.83			

$Linear\ Regression\ Relationship: Y = a + b * X$ [28]

$$b = \frac{\{\sum_i (X_i - X_{average}) \times (Y_i - Y_{average})\}}{\sum_i (X_i - X_{average})^2}$$

$$a = \frac{\{\sum_i (Y_i - b x_i)\}}{n} = Y_{average} - bX_{average}$$

$$b \approx -2.422766$$

$$a \approx 21892.705603$$

$Linear\ Regression\ Model\ for\ the\ Net\ Decommisioning\ Costs\ of\ Natural\ Gas\ Plants:$

$$Y = 21892.705603 + (-2.422766) * X$$

$$X = 400MW$$

$$Y = 21892.705603 + (-2.422766) * 400$$

$$Y \approx \$20923.60\ USD/MW$$

$Unit\ Net\ Decommissioning\ Cost\ in\ CAD = \$20923.60 * 1.31 \approx C\$27{,}409.91/MW$

Table C.2 Total NGP decommissioning cost calculation

Capital cost ($): $431,600,000.00	Salvage value at year 43 = 431,600,000.00 * (1-7.5%)^43
Actual depreciation rate: 7.5% [10]	

Unit net decommissioning cost ($/MW): $27,409.91	= $19,087,574.52 Net decommissioning cost = $27,409.91 * 400 = $10,963,965.96 Total decommissioning cost = 19,087,574.52 + 10,963,965.96 = $30,051,540.48
Capacity (MW): 400	

Appendix D: Carbon tax calculation for NGP

The carbon tax for NGP is calculated based on the Greenhouse Gas Pollution Pricing Act, and the emission limit is determined according to the Regulations Limiting Carbon Dioxide Emissions from Natural Gas-fired Generation of Electricity. The relevant data and detailed calculations are shown in the following table.

Table D.1 Carbon tax calculation for NGP

Capacity (MW): 400	Energy generated = 400 * 0.6 * 8760 = 2102400 MWh/year Volume of natural gas consumed = 2102400 * 183 * 28.3 = 13586936.62 mcf/year Tonnes of CO_2 emission per year = 13586936.62 * 0.0549 = 745922.8206 tonnes / year Emission intensity = 745922.8206 / (2102400 / 1000) = 355 tonnes/GWh ∵ 355 < 420 ∴ No carbon tax for NGP.
Capacity Factor: 60%	
Number of hours in a year (h): 8760	
Fuel use (m^3/MWh): 183	
1 m^3 = 28.3 mcf	
CO2 emission from natural gas combustion (tonne/mcf): 0.0549 [26]	
1 GWh = 1000 MWh	
Emission Intensity Limit (tonnes/GWh): 420 [27]	

Appendix E: Base case results on PW and AW of WP and NGP

MARR	WP (PW)	NGP (PW)	WP (AW)	NGP (AW)
1%	$2,538,965,116.69	$4,261,034,235.24	$90,710,718.33	$122,408,309.36
2%	$2,071,092,779.98	$3,381,022,926.46	$86,336,673.53	$117,963,664.62
3%	$1,694,171,606.12	$2,711,525,850.13	$81,584,734.38	$113,065,503.93

4%	$1,387,981,462.91	$2,195,297,861.21	$76,482,728.84	$107,766,921.58
5%	$1,137,192,831.04	$1,791,924,520.41	$71,063,229.76	$102,127,750.48
6%	$930,111,144.77	$1,472,598,858.75	$65,361,639.98	$96,209,474.73
7%	$757,758,758.30	$1,216,586,892.00	$59,414,398.18	$90,071,099.77
8%	$613,200,247.39	$1,008,817,556.52	$53,257,442.47	$83,766,295.22
9%	$491,043,957.00	$838,226,635.22	$46,925,007.83	$77,341,803.27
10%	$387,071,832.41	$696,609,890.66	$40,448,776.69	$70,836,899.05
11%	$297,963,083.07	$577,822,564.73	$33,857,360.12	$64,283,605.06
12%	$221,086,816.56	$477,216,186.69	$27,176,059.94	$57,707,366.75
13%	$154,345,616.40	$391,239,155.99	$20,426,850.29	$51,127,951.41
14%	$96,056,932.31	$317,151,182.44	$13,628,516.78	$44,560,401.26
15%	$44,862,673.25	$252,817,466.21	$6,796,897.60	$38,015,936.46
16%	-$340,061.80	$196,559,139.11	-$54,818.98	$31,502,753.39
17%	-$40,452,333.69	$147,043,698.50	-$6,915,775.04	$25,026,697.99
18%	-$76,214,665.52	$103,204,082.94	-$13,777,125.86	$18,591,814.73
19%	-$108,239,183.53	$64,178,414.98	-$20,631,740.69	$12,200,783.28
20%	-$137,034,757.88	$29,264,768.93	-$27,473,930.73	$5,855,259.22
21%	-$163,026,768.57	-$2,113,055.63	-$34,299,208.19	-$443,864.00
22%	-$186,572,724.98	-$30,431,638.31	-$41,104,077.34	-$6,696,255.70
23%	-$207,974,671.29	-$56,088,003.56	-$47,885,856.31	-$12,901,997.68
24%	-$227,489,088.72	-$79,415,163.14	-$54,642,526.87	-$19,061,471.57
25%	-$245,334,838.79	-$100,694,245.66	-$61,372,609.21	-$25,175,274.75
26%	-$261,699,566.68	-$120,164,032.24	-$68,075,058.45	-$31,244,157.89
27%	-$276,744,888.07	-$138,028,506.78	-$74,749,179.52	-$37,268,978.53
28%	-$290,610,610.86	-$154,462,875.60	-$81,394,557.70	-$43,250,666.77
29%	-$303,418,187.28	-$169,618,399.26	-$88,011,002.01	-$49,190,199.80
30%	-$315,273,550.03	-$183,626,296.11	-$94,598,499.40	-$55,088,583.05

Appendix F: Method 2 - Probabilistic sensitivity analysis

The normal distribution parameters and the inputs for all the cases for WP and NGP are shown in the following tables. The average normal distribution parameters for various types of power generation investments are used for WP.

Table F.1 Normal distribution parameters for WP [29]

Category	Mean	Standard deviation	% change
Capital cost	721.67	100.83	14%
O&M	19.33	1.93	10%
Construction time	3.67	0.53	15%
Operating life	30.00	5.00	17%

Table F.2 Input cases for WP

Category	Pessimistic	Most likely	Optimistic
Capital cost	$601,317,782.91	$527,600,000.00	$453,882,217.09
O&M	$11,536,800.00	$10,488,000.00	$9,439,200.00
Construction time	3.44	3.00	2.56
Operating life	25	30	35

Table F.3 Normal distribution parameters for NGP [29]

Category	Mean	Standard deviation	% change
Capital cost	285	28.5	10%
O&M	9	0.9	10%
Fuel cost	3.3	1	30%
Construction time	2	0.2	10%
Operating life	30	3	10%

Table F.4 Input cases for NGP

Category	Pessimistic	Most likely	Optimistic
Capital cost	$474,760,000.00	$431,600,000.00	$388,440,000.00
O&M	$6,177,600.00	$5,616,000.00	$5,054,400.00
Fuel cost	$3.45	$2.65	$1.85
Construction time	3.3	3	2.7
Operating life	36	40	44

Appendix G: Fixed electricity and capital AW summary

MARR	Original WP	Original NGP	Fixed electricity WP	Fixed capital WP
1%	$90,710,718.33	$122,408,309.36	$207,963,255.26	$127,592,315.63
2%	$86,336,673.53	$117,963,664.62	$197,277,422.31	$121,036,204.70
3%	$81,584,734.38	$113,065,503.93	$186,235,335.40	$114,261,520.22
4%	$76,482,728.84	$107,766,921.58	$174,910,379.08	$107,313,286.03
5%	$71,063,229.76	$102,127,750.48	$163,374,210.28	$100,235,466.01
6%	$65,361,639.98	$96,209,474.73	$151,693,970.55	$93,069,253.73
7%	$59,414,398.18	$90,071,099.77	$139,930,249.58	$85,851,822.95
8%	$53,257,442.47	$83,766,295.22	$128,135,835.73	$78,615,561.08
9%	$46,925,007.83	$77,341,803.27	$116,355,188.76	$71,387,745.64

10%	$40,448,776.69	$70,836,899.05	$104,624,506.66	$64,190,585.30
11%	$33,857,360.12	$64,283,605.06	$92,972,229.77	$57,041,529.14
12%	$27,176,059.94	$57,707,366.75	$81,419,826.98	$49,953,749.04
13%	$20,426,850.29	$51,127,951.41	$69,982,728.47	$42,936,711.91
14%	$13,628,516.78	$44,560,401.26	$58,671,298.83	$35,996,776.78
15%	$6,796,897.60	$38,015,936.46	$47,491,775.39	$29,137,770.46
16%	$(54,818.98)	$31,502,753.39	$36,447,124.52	$22,361,512.90
17%	$(6,915,775.04)	$25,026,697.99	$25,537,790.90	$15,668,276.94
18%	$(13,777,125.86)	$18,591,814.73	$14,762,331.81	$9,057,177.42
19%	$(20,631,740.69)	$12,200,783.28	$4,117,938.97	$2,526,491.37
20%	$(27,473,930.73)	$5,855,259.22	$(6,399,142.42)	$(3,926,084.92)
21%	$(34,299,208.19)	$(443,864.00)	$(16,793,284.80)	$(10,303,234.06)
22%	$(41,104,077.34)	$(6,696,255.70)	$(27,069,225.50)	$(16,607,862.58)
23%	$(47,885,856.31)	$(12,901,997.68)	$(37,231,876.94)	$(22,842,984.39)
24%	$(54,642,526.87)	$(19,061,471.57)	$(47,286,187.22)	$(29,011,635.34)
25%	$(61,372,609.21)	$(25,175,274.75)	$(57,237,040.82)	$(35,116,812.19)
26%	$(68,075,058.45)	$(31,244,157.89)	$(67,089,190.03)	$(41,161,430.65)
27%	$(74,749,179.52)	$(37,268,978.53)	$(76,847,210.16)	$(47,148,297.82)
28%	$(81,394,557.70)	$(43,250,666.77)	$(86,515,472.21)	$(53,080,095.44)
29%	$(88,011,002.01)	$(49,190,199.80)	$(96,098,128.69)	$(58,959,371.22)
30%	$(94,598,499.40)	$(55,088,583.05)	$(105,599,108.63)	$(64,788,535.75)

Appendix H:

Table H.1 Carbon dioxide (CO2) social cost for NGP [20]

Social cost of air pollution (per tonne of CO2): 100	CO2 social cost: 100 * 745922.8206 = $ 74,592,282.06 per year
Tonne of CO2 produced (tonne per year): 745922.8206 (See Table D.1)	

Table H.2 Traffic social cost for WP [21]

Traffic disruption: 0.25 year	Traffic social cost: 0.25 * 1 * 80000 * 14.1 * 1.31 = CAD $134,838,300.00 (Total)
Daily traffic delay: 1 hour	
Daily commuters: 80000	
Travel time cost: US$ 14.1 per person hour [21]	
Currency: 1 USD = 1.31 CAD	

Table H.3 Social cost per unit production cost (SC/PC)

	Traffic cost AW	CO2 AW	WP cost AW	NGP cost AW	WP*	NGP*

1%	$4,769,729.68	$68,290,220.95	-$32,903,352.32	-$46,201,981.61	-$0.14	-$1.48
2%	$5,510,726.45	$67,086,918.88	-$35,185,422.52	-$47,675,642.97	-$0.16	-$1.41
3%	$6,304,164.67	$65,794,290.36	-$37,727,890.16	-$49,382,270.97	-$0.17	-$1.33
4%	$7,144,299.26	$64,430,657.36	-$40,522,823.64	-$51,314,008.80	-$0.18	-$1.26
5%	$8,024,810.73	$63,015,039.14	-$43,558,449.58	-$53,457,982.56	-$0.18	-$1.18
6%	$8,939,134.99	$61,565,769.03	-$46,820,082.06	-$55,797,973.56	-$0.19	-$1.10
7%	$9,880,757.22	$60,099,479.95	-$50,291,088.40	-$58,316,043.51	-$0.20	-$1.03
8%	$10,843,450.43	$58,630,501.58	-$53,953,798.47	-$60,993,903.14	-$0.20	-$0.96
9%	$11,821,450.10	$57,170,626.02	-$57,790,292.76	-$63,813,925.25	-$0.20	-$0.90
10%	$12,809,565.73	$55,729,152.95	-$61,783,033.72	-$66,759,795.81	-$0.21	-$0.83
11%	$13,803,236.31	$54,313,114.45	-$65,915,331.54	-$69,816,854.77	-$0.21	-$0.78
12%	$14,798,540.70	$52,927,592.02	-$70,171,654.25	-$72,972,203.00	-$0.21	-$0.73
13%	$15,792,174.40	$51,576,060.56	-$74,537,804.13	-$76,214,652.81	-$0.21	-$0.68
14%	$16,781,404.19	$50,260,717.35	-$79,000,987.43	-$79,534,587.15	-$0.21	-$0.63
15%	$17,764,009.91	$48,982,773.41	-$83,549,804.98	-$82,923,775.88	-$0.21	-$0.59
16%	$18,738,220.83	$47,742,698.21	-$88,174,188.35	-$86,375,181.77	-$0.21	-$0.55
17%	$19,702,651.86	$46,540,417.42	-$92,865,302.29	-$89,882,775.33	-$0.21	-$0.52
18%	$20,656,243.23	$45,375,468.01	-$97,615,429.35	-$93,441,368.90	-$0.21	-$0.49
19%	$21,598,205.56	$44,247,117.17	-$102,417,848.42	-$97,046,473.46	-$0.21	-$0.46
20%	$22,527,971.32	$43,154,451.65	-$107,266,715.11	-$100,694,178.59	-$0.21	-$0.43
21%	$23,445,153.05	$42,096,443.79	-$112,156,949.03	-$104,381,053.49	-$0.21	-$0.40
22%	$24,349,507.82	$41,071,999.59	-$117,084,130.81	-$108,104,066.45	-$0.21	-$0.38
23%	$25,240,907.68	$40,079,993.29	-$122,044,410.07	-$111,860,519.65	-$0.21	-$0.36
24%	$26,119,315.22	$39,119,291.64	-$127,034,424.65	-$115,647,996.76	-$0.21	-$0.34
25%	$26,984,763.63	$38,188,770.92	-$132,051,230.45	-$119,464,320.64	-$0.20	-$0.32
26%	$27,837,340.56	$37,287,328.35	-$137,092,241.23	-$123,307,519.16	-$0.20	-$0.30
27%	$28,677,175.22	$36,413,889.68	-$142,155,177.22	-$127,175,797.52	-$0.20	-$0.29
28%	$29,504,427.97	$35,567,413.92	-$147,238,021.45	-$131,067,515.60	-$0.20	-$0.27
29%	$30,319,282.13	$34,746,896.10	-$152,338,982.90	-$134,981,169.29	-$0.20	-$0.26
30%	$31,121,937.52	$33,951,368.62	-$157,456,465.29	-$138,915,374.98	-$0.20	-$0.24

* Social cost per unit cost of investment made

<u>Appendix I:</u> Cost Effectiveness Ratio (CER) - Cost $ per MW electricity

MARR	WP ($ per MW electricity)	NGP ($ per MW electricity)	Wind/Gas
1%	$182,796.40	$192,508.26	0.95
2%	$195,474.57	$198,648.51	0.98
3%	$209,599.39	$205,759.46	1.02
4%	$225,126.80	$213,808.37	1.05
5%	$241,991.39	$222,741.59	1.09
6%	$260,111.57	$232,491.56	1.12
7%	$279,394.94	$242,983.51	1.15
8%	$299,743.32	$254,141.26	1.18
9%	$321,057.18	$265,891.36	1.21
10%	$343,239.08	$278,165.82	1.23

11%	$366,196.29	$290,903.56	1.26
12%	$389,842.52	$304,050.85	1.28
13%	$414,098.91	$317,561.05	1.30
14%	$438,894.37	$331,394.11	1.32
15%	$464,165.58	$345,515.73	1.34
16%	$489,856.60	$359,896.59	1.36
17%	$515,918.35	$374,511.56	1.38
18%	$542,307.94	$389,339.04	1.39
19%	$568,988.05	$404,360.31	1.41
20%	$595,926.20	$419,559.08	1.42
21%	$623,094.16	$434,921.06	1.43
22%	$650,467.39	$450,433.61	1.44
23%	$678,024.50	$466,085.50	1.45
24%	$705,746.80	$481,866.65	1.46
25%	$733,617.95	$497,768.00	1.47
26%	$761,623.56	$513,781.33	1.48
27%	$789,750.98	$529,899.16	1.49
28%	$817,989.01	$546,114.65	1.50
29%	$846,327.68	$562,421.54	1.50
30%	$874,758.14	$578,814.06	1.51