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Techno-Economic Evaluation of Oil and Gas Wells as Geothermal Resource for Power Generation: A Niger-Delta Case Study

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Abstract

Nigeria despite having several depleted oil and gas wells, have been observed to have insufficient electrical power capacity, and this is attributed to zero-utilization and/or under-utilization of renewable energy sources such as geothermal energy. In this study, a techno-economic study was conducted on the power generation prospect for a Niger-Delta abandoned oil-wells using carbon (iv) oxide and steam as geofluids. From the result of the power generation study, CO_2 proved to be a better power generation alternative as it generated 58 084 884 kWh-116 009 964 kWh at 90-112ºC respectively, while steam recorded 8 931 132 kWh-11 014 920 kWh at 90-112ºC respectively. From the result of the economic analysis, CO_2 proved to be viable alternative compared to Water, with payout of 1.9yrs and profit index of 5.53, while water recorded payout time of 4years and profit index of 2.0.

Keywords: *Geothermal energy; Power generation; Renewable energy.*

1. Introduction

There is a growing demand for energy globally [1], and this is attributed to its direct positive impact on the economy of its host country. Despite its immense energy contribution, the traditional energy source derived from fossil fuel [2], is expensive, limited and not eco-friendly [3]. In order to serve the growing population, renewable and eco-friendly alternatives have proposed. Some of these energy source included solar, wind, geothermal and biogas [4]. In recent times, geothermal energy have been considered globally due to its renewable nature and the abundance of heat in-situ. These heat source however, have not been explore for generating electric power particularly in the Niger-Delta [5]. The retrofitting of millions of oil wells as heat source has been identified as the best way to lower economic waste for those infrastructure after their productive years, as it creates prospect for other utilization [6]. Geothermal power producing systems are utilized globally. However, to generate a commercial workable geothermal power producing unit, constraint such as reservoir and drilling technology, availability prospecting, resource durability and energy costs within the zone must be placed into consideration [7]. Close to 42-95% of the entire project cost for geothermal can be lowered by repurposing obsolete exploratory wellbore to the drilling process [8]. Oil & Gas wellbore can assist in the recovery of downhole geothermal energy source, with the drilled wellbore providing geological, geochemical and geophysical information about the underground reservoirs and allow direct contact to the heat energy source downhole [9-10]. Globally, several wells have been identified as suitable candidate for geothermal energy exploitation, especially mature oilfields with high water-cuts and poor oil production rate [11]. For a wellbore to be utilized, it is expected to have, high bottom-hole temperature, defined wellbore integrity [12] and high heat generation potentials. Due to this requirement in mature field there is a shift towards modifying existing wells to towards to geothermal source.

The electric power capacity of Nigeria has been discovered to be insufficient with her power generation, distribution and transmission contributing to less than a percent of its GDP, despite been tied to 54% of all activities [13]. The zero-utilization and/or under-utilization of renewable energy source such as geothermal is one of the major of insufficient electric power generation and poor electric power distribution [14]. World Energy Council report showed that Nigeria produces 120 million tons of oil annually and 4.39million tons of gas [15], majorly from the oil produced come from the Niger-Delta region. This makes the use of renewable in the Niger-Delta to be favorable and prospective considering that it utilizes similar equipment and technique [16].Nigeria's geological sequence consist of the sedimentary basins of different ages and crystalline basement complex. Studies shows that there is a prospect for geothermal energy of reservoir within the country [17]. The temperature profile derived from several drilling activities in the oil and gas industry in deep basins have been between 100°C to 175°C, and geothermal gradients of 5°C/100m around the Chad Basin, though the basin is rift-related basin with recognized faults arrangement. The warm springs located in Ruwan Zafi and Akiri within Nigeria has the temperature range of about 54°C indicating the prospect of some geothermal variation. Despite these prospect, there is little scientific expertise, information and exposure on the geothermal energy potential of the country, and this due to public acceptance and spread.

In this study, the techno-economic prospect Niger-Delta Oil & Gas well for power generation through geothermal energy was explored. The geofluids employed for the study was water and carbon dioxide

2. Materials and methods

2.1. Material

The materials utilized for the study includes Excel, Matlab, Tough-2 software and input datasets. The input dataset comprises of simulation input data for heat loss, other simulation data, input data for process simulation, carbon (iv) oxide, capital expenditure data and steam capital expenditure data

Table 1. Simulation input data for heat loss.

Wells	Reser temp.,°C	Reservoir depth, m	Reserv. pressure, psia	Porosity, %	Area, m ^{2}	Pay thickness, m
Well 1	104	1828.80	3992	25	576320995.59	500
Well 2	96	2438.40	3992	25	576320995.59	500
Well 3	102	2438.40	3992	25	576320995.59	500
Well 4	112	2438.80	3992	25	576320995.59	500
Well 5	91	1828.80	3992	25	576320995.59	500
Well 6	90	2438.40	3992	25	576320995.59	500
Well 7	120	2438.40	3992	25	576320995.59	500
Well 8	98	2438.40	3992	25	576320995.59	500

Table 2. Other simulation data.

Parameters	Unit	Value
The height of fluid from the producing depth	ft	8000
Thermal conductivity of the earth	Btu/hrft°F	1.4
The outside radius of the casing	ft	0.359375
Temperature at the cement formation interface	°F	325
The outside radius of the tubing	ft	0.229166667
The inside radius of the tubing	ft	0.203833333
The radius of the tubing insulation	ft	0.291666667
The inside radius of the casing	ft	0.321875
The radius of the cement/formation interface	ft	0.447916667

Parameters	Unit	Value
The thermal conductivity of the tubing wall	Btu/hrft°F	24.95664
The thermal conductivity of the tubing insulation	Btu/hrft°F	0.011554
The thermal conductivity of the casing wall	Btu/hrft°F	24.95664
The thermal conductivity of the cement	btu/hrft°F	0.595031
Convective heat transfer coefficient b/w the fluid film in tubing and the tubing wall	Btu/(hr ft2 °F)	99.9
Convective heat transfer coefficient of fluid inside annulus	Btu/(hr ft2 °F)	99.9
Radiative heat transfer coefficients of fluid inside annulus	Btu/(hr ft2 °F)	2
the production time	days	75
The thermal diffusivity of the earth	ft2/day	0.96

Table 3. Input data for process simulation.

Parameter	Value	Parameter	Value
Turbine isentropic efficiency	75%	CO_2 inlet temp (Base)	100°C
Turbine polytropic efficiency	74%	CO_2 inlet pressure (Base	20 Mpa
Pump adiabatic efficiency	75%	Working fluid inlet temperature	36.1°C
Ambient temperature	20°C	Working fluid inlet pressure	20 bars
Water mass flowrate (Base)	80 kg/s	Working fluid mass flowrate (Base)	10 kg/s
Water inlet temp (Base)	100°C	Working fluids	isopentane, n-pentane
Water inlet pressure (Base	10 bars	Geofluids	water, CO_2
CO_2 mass flowrate (Base)	80 kg/s		

Table 4. Carbon (IV) Oxide CAPEX and OPEX.

Capital expenditure for carbon dioxide		
S/N	Particulars	Amount
1	Total Cost CO_2 reinjection plant (comprising compressors, transport pipeline, injection and control)	$50,000,000
2	Cost of CO_2 for 10,000,000 tonnes	$1,850,000,000
3	Geothermal Cost	$530,000,000
	Total Capital Expenditure	$2,430,000,000
Operating expenditure for carbon dioxide		
S/N	Particulars	Amount
1	Operating Cost for 93849696Kwh	$2,815,490.88
2	Cost of CO_2 reinjection per year	$1,580,000
3	OPEX Field	10% of Yearly Revenue
4	Federal government income tax	35% of Taxable Income

Table 5. Water CAPEX and OPEX.

Capital expenditure for water		
S/N	Particulars	Amount
1	Total Cost water reinjection plant (comprising compressors, transport pipeline, injection and control)	$1,250,000
2	Cost of drilling water well	$800,000
3	Geothermal Cost	$530,000,000
	Total Capital Expenditure	$532,050,000
Operating expenditure for carbon dioxide		
S/N	Particulars	Amount
1	Operating Cost for 10260396Kwh	$307811.88
2	OPEX Field	10% of yearly revenue

2.2. Methods

2.2.1. Power generated from various geothermal wells

Water and super-critical CO_2 were utilized as geofluid to extract heat from the subsurface reservoir region. N-Pentane and iso-Pentane were utilized as the working fluid while designing the binary-organic-rankine (ORC) plant for power generation. The geofluids carrying the extracted heat were recovered from the well through the wellhead, and channeled to the ORC plant. Figure 1 shows the diagrammatic schematic of the simulation process utilized for the electricity binary ORC plant power generation using geofluids. The input data consists the data used for the simulation of the process. These comprise thermodynamic data, process properties and operating requirement. The thermodynamic data includes the pressure, temperature and mass flowrate of the workings and geofluids fluids.

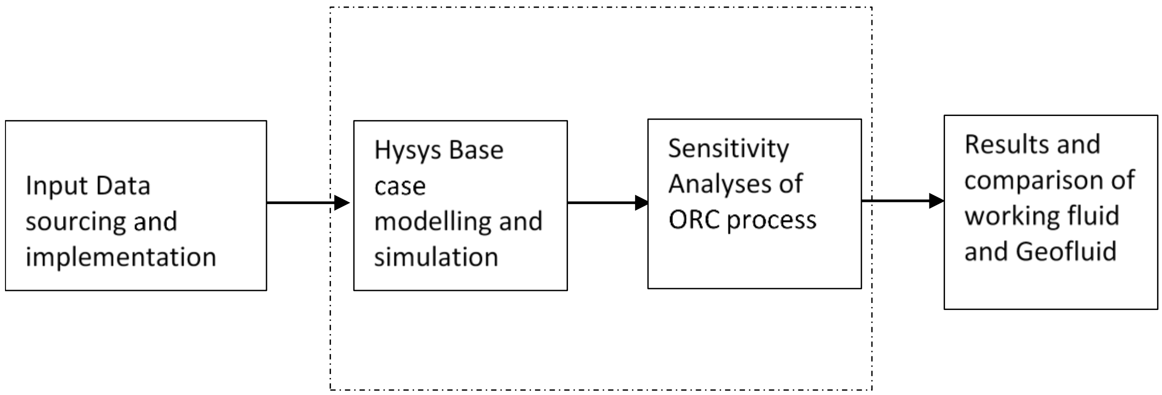

Figure 1. Simulation process block diagram in Hysis software.

2.2.2. Process simulation

Geothermal ORC was simulated using the Aspen Hysys V11 software was utilize to simulate Geothermal ORC, using the Peng Robinson property package. The critical component including expanders (representing turbine), heat exchangers (designed as evaporators), pump and air cooler (acting as condenser). Two heat exchange in series mode, HEX_1 (E-100) and HEX_2 (E-101), were utilized to optimize hear recovery from the geofluids as represented in the Process-Flow-Process (PFP) depicted in Figure 2.

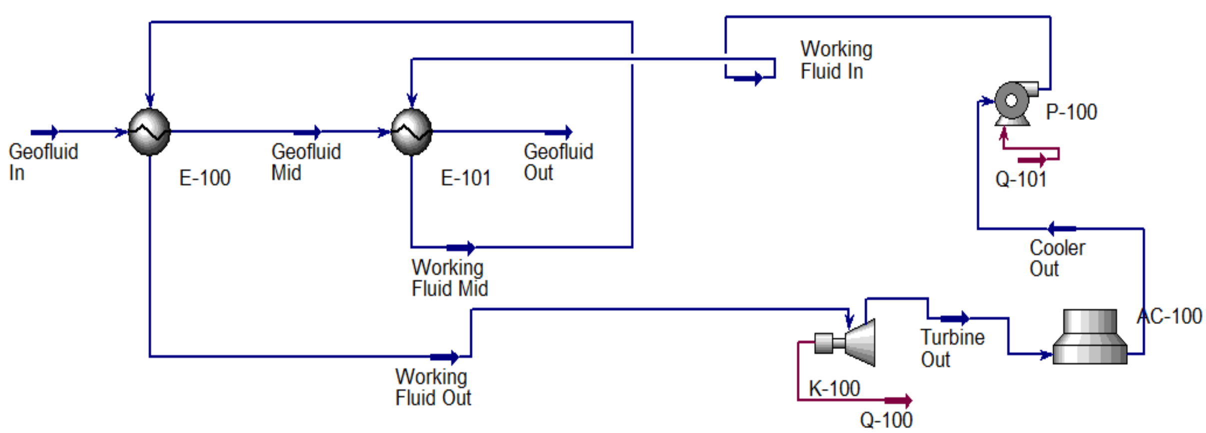

Figure 2. Process flow process (PFI) of the geothermal binary ORC system.

In the system depicted in Figure 2, the geofluid from the wellbore flows into HEX_1 before HEX_2. The working fluid introduced into these heat exchanging system, absorbed heat from both HEX_1 and HEX_2 before flowing into the turbine. The vaporized working fluids expands at the turbine to generate electricity derived at the turbine outlet (kW). After exiting the turbine at low temperature and pressure, the working fluid is cooled in the air-cooler and re-introduced into the heat-exchanger to continue the same cycle. The geo-fluid leaving HEX_2 is re-introduced into the well to sustain the cycle.

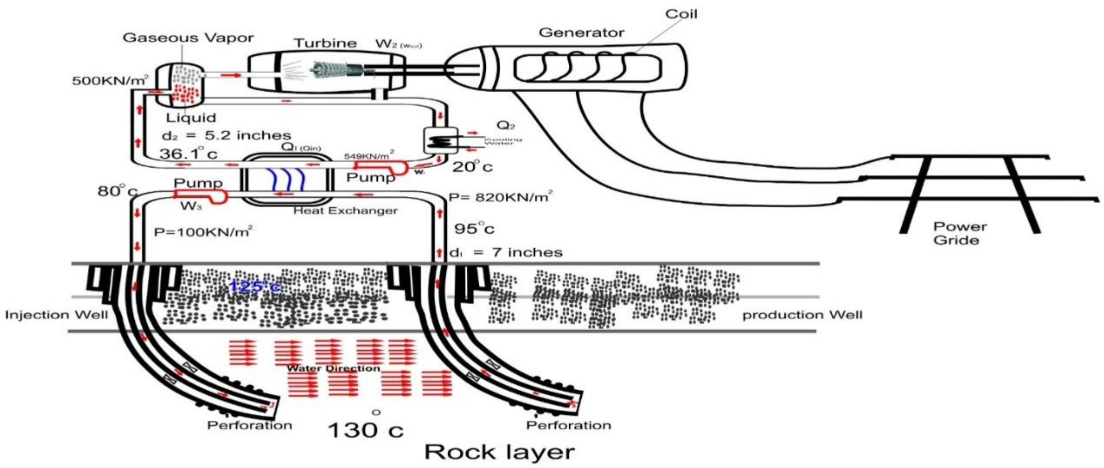

Figure 3. Geothermal thermodynamic profile for abandoned oil & gas wells.

The impact of the heat exchanger in the process is expressed in the equation 1

$$M_c C_{p.c}(T_{c2} - T_{c1}) = M_h C_{p.h}(T_{h1} - T_{h2}) \quad (1)$$

where M_c is the mass flow rate of cold fluid; C_{pc} is specific heat capacity of cold fluid; T_{c2} is the outlet temperature of cold fluid; T_{c1} is the inlet temperature of cold fluid; M_h is the mass flow rate of hot fluid; C_{ph} is specific heat capacity of hot fluid; T_{h2} is outlet temperature of hot fluid, T_{h1} is inlet temperature of hot fluid.

Bernoulli's equation expresses conservation of energy for flowing fluids (especially incompressible fluids), such as water. Bernoulli's equation states that in an ideal incompressible fluid, when the flow is steady, and continuous, the sum of pressure energy, kinetic energy and potential energy (or datum) is constant along a stream.

2.2.3. Economic evaluation

The economic evaluation of the geothermal wells were carried out using the discount factor, profitability index and payout time, using royalty, net cash flow, contractor & govt. take statistics, and net cash flow. The net cash flow was derived using the expression (2)

$$NCF_t = GR_t - ROY_t - CAPEX_t - OPEX_t - TAX_t - DPRE_t \quad (2)$$

where NCF_t is after-tax net cash flow in year t GR_t is gross revenues in year t; ROY_t is total royal ties paid in year t; $CAPEX_t$ is total capital expenditures in year t; $OPEX_t$ is total operating expenditures in year t; TAX_t is total taxes paid in year t; and $DPRE_t$ is depreciation in year t.

The Contractor & Government Take Statistics was derived using the expressions 3 and 4.

$$CT_t = GR_t - ROY_t - OPEX_t - CAPEX_t - TAX_t - DPRE_t \quad (3)$$

$$GT_t = ROY_t + OPEX_t + CAPEX_t + TAX_t \quad (4)$$

where CT_t is total contractor take; and GT_t is total government take,

Using the contractor take, the discount factor was derived using the formula shown in equation 5.

$$Discount\ Factor = \frac{Net\ Present\ Value}{(1+i)^t} \quad (5)$$

where t and i is number of years (period number); and discounted rate.

The profitable index (PI) of the study was derived using the formula shown in equation 6.

$$PI = 1 + PVR \quad (6)$$

$$PVR = \frac{NPV}{PV\ of\ CAPEX} \quad (7)$$

The profit investment ratio was derived using the expression depicted in 8.

$$PI = \frac{\sum Cash\ Flow}{\sum Investment} \quad (8)$$

when the PI < Company threshold, the project is rejected.

In the absence of initial investment

$$PI = 1 + \frac{\sum Cash\ Flow}{\sum Investmenr} \quad (9)$$

when PI > 1, the project is accepted, while the project is at marginal threshold when PI = 1
The payout time (PO) for project was derived using the expression in equation 10.

$$\frac{(POT - IP)}{(FP - IP)} = \frac{(0 - Cum\ NCF\ at\ IP)}{(Cum\ NCF\ at\ FP - Cum\ NCF\ at\ IP)} \quad (10)$$

3. Result and discussion

3.1. Possible power generate from the various geothermal well

Table 6 depicts the possible power produced from the various wellbore using carbon (iv) oxide and water as heat fluids. As observed from Table 6, carbon dioxide recorded higher power production capacity than steam. This is attributed to carbon (iv) oxide's supercritical nature which allows it to recover more thermal energy than water and is in-line with Cabeza *et al.* [18] and Thippeswamy and Kumar [19] study. As observed from Table 6, the power generation potential of carbon (iv) oxide heat fluid increased rapidly rise in temperature, while the power generation potential of steam heat fluid increased gradually with rise in temperature.

Table 6. Possible power generated from the various wells using carbon dioxide and water.

Wells	Reservoir temp. °C	Carbon dioxide (kW)	Water (kW)	Carbon dioxide, kWh	Steam, kWh
Well 1	104	3910404.0	427 516.5	93 849 696	10 260 396
Well 2	96	3022360.5	398 746.5	72 536 652	9 569 916
Well 3	102	3611185.5	419 571.0	86 668 452	10 069 704
Well 4	112	4833748.5	458 955.0	116 009 964	11 014 920
Well 5	91	2452659.0	376 095.0	58 863 816	9 026 280
Well 6	90	2420203.5	372 130.5	58 084 884	8 931 132

3.2. Economic analysis

Table 7 shows the economic analysis of power generation using carbon dioxide and water. As observed from Table 7, power generation with carbon (iv) oxide proved to be more profitable than power generation with water as it recorded higher profitability index and less payout time. As observed also from the table, the profitability index of wells increased with increased in their temperature values. Figures 4-9 shows the discounted net cashflow of CO_2 and water for Well-1, Well-2, Well-3, Well-4, Well-5 and Well-6. As shown in Figure 4, CO_2 recorded maximum disc investor of \$434.46MM at 0.6768 discount rate before a declining to \$299.09MM at discount rate of 0.7107. Further discount increase to 0.8227, yield net cashflow increase to \$431.76MM before a continuous decline to \$0 at discount rate of 1. For water system, the maximum net cashflow was attained at 0.6139 discount rate, before continuous reduction in net cash-flow was up-to \$2.25MM was recorded at 0.7835 discount rate. Further increase in discount rate yield \$0 discount. For Well-2, the maximum investor take for CO_2 was \$334.57MM at 0.6768, while for water the maximum investor stake was \$38.17MM at 0.587. For Well-3, the maximum investor stake for CO_2 was \$465.12MM at 0.8638 while for water, the optimum investor stake is \$42.22MM. For Well-4, CO_2's maximum investor stake is \$567.48MM at 0.8638 discount rate, while for water, the maximum investor stake is \$46.26MM at 0.6139 discount rate. For Well-5, the optimum investor take of \$258.25MM for

0.6446 for CO_2, while for water, investor take of $36.11MM was achieved at 0.5847 discount rate. For Well-6, the optimum investor take of $254.68MM of 0.6446 discount rate for CO_2, while an investor taker of $35.82MM at discount rate of 0.5847 for Water. As observed from Figures 4-9, CO_2 proved to be more economically viable than water-powdered system, with higher discounted investor and government. As observed also, the discounted investor take proved to be higher than discounted government take for the CO_2 system, while in the water system, the discounted investor take was slightly higher than the discounted investor take.

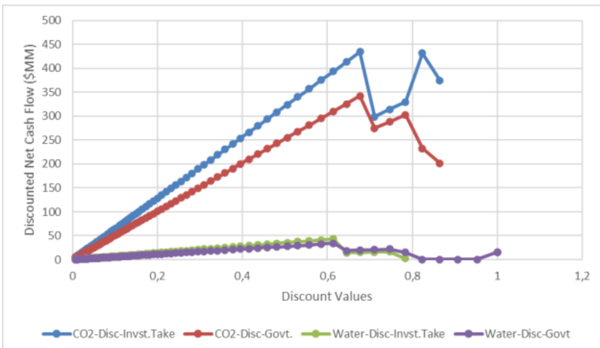

Figure 4. Discounted net cash flow versus discounted value for well-1, using CO_2 and water.

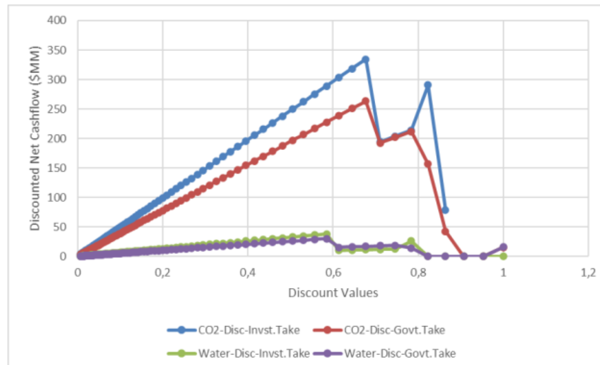

Figure 5. Discounted net cash flow versus discounted value for Well-2, using CO_2 and water

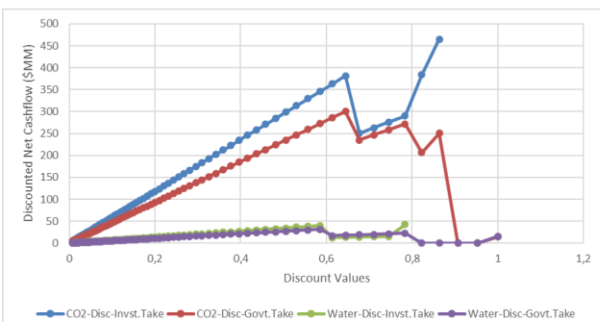

Figure 6. Discounted net cash flow versus discounted value for Well-3, using CO_2 and water

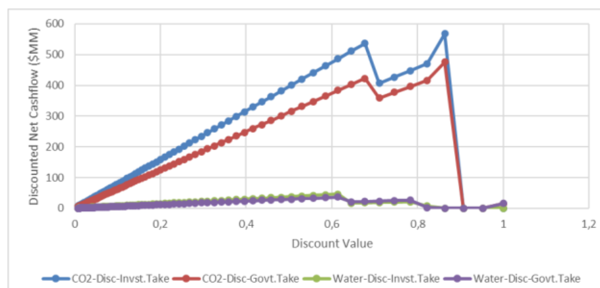

Figure 7. Discounted net cash flow versus discounted value for Well-4, using CO2 and water.

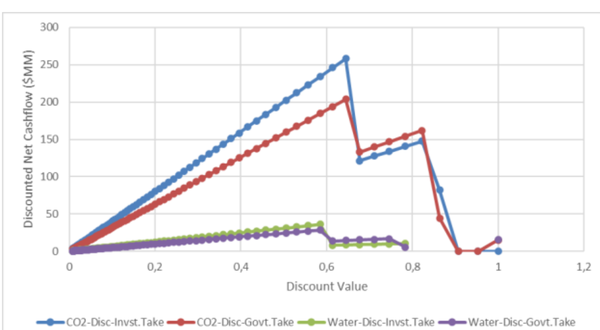

Figure 8. Discounted net cash flow versus discounted value for Well-5, using CO_2 and water.

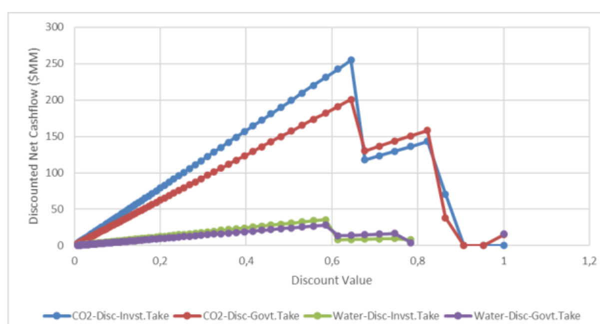

Figure 9. Discounted net cash flow versus discounted value for Well-6, using CO_2 and water.

Table 7. Economic analysis of power generation using carbon dioxide and water.

		Carbon dioxide			Water		
Wells	Reservoir temp. °C	Payout time y-m-d	Profit index	Summary	Payout time	Profit index	Summary
Well 1	104	2.31yr	4.43	Profitable	5 years	1.7	Profitable
Well 2	96	2.74yr	3.26	Profitable	5year	1.58	Profitable
Well 3	102	2.24yr	4.04	Profitable	4years	1.78	Profitable
Well 4	112	1.9yr	5.53	Profitable	4years	2.0	Profitable
Well 5	91	2.83yr	2.51	Profitable	5year	1.51	Profitable
Well 6	90	2.83yr	2.47	Profitable	5years	1.49	Profitable

4. Conclusion

From the power generation study, CO_2 proved to be a better power generation heat fluid compared to water, as it generated 58 084 884kWh-116 009 964kWh at 90-112°C respectively, while water recorded 8 931 132kWh-11 014 920kWh respectively. Temperature has influence on the power generation potential of CO_2 and water heat fluids. From the economic study, CO_2 proved to be viable alternative compared to water, with payout of 1.9yrs and profit index of 5.53. From the discounted cashflow rate of return, CO_2 recorded a wide rate than water proving its superior viability.

Reference

[1] Roksland M, Basmoen TA, and Sui D. Geothermal energy extraction from abandoned wells. 8th International Conference on Applied Energy (ICAE2016), 2017.

[2] Kerunwa A, Izuwa NC, Dike CF, Okereke NU, Udeagbara SG, Obibuike JU, Emenke BUK. Review on the Utilization of Local ASP in the Niger-Delta for Enhanced Oil Recovery. Pet. Coal, 2024; 66(1): 256-275.

[3] Ahmad M, Akram W, Ahmad, N, Tasneem MA, Rafiq M, Latif, Z. Assessment of reservoir temperatures of thermal springs of the northern areas of Pakistan by chemical and isotope geothermometry. Geothermics. 2002; 31(5):613–31.

[4] Mehmood A, Yao J, Fan D, Bongole K, Liu J, and Zhang X. Potential for heat production by retrofitting abandoned gas wells into geothermal wells. PLoS ONE. 2019; 14(8): e0220128. https://doi.org/10.1371/journal.pone.0220128

[5] Okoroafor RA. Geothermal Energy- Journal of Petroleum Technology, 2024; 76(3).

[6] Betkowski B. Geothermal energy could give old oil and gas wells a new lease on life, University of Alberta, 2022.

[7] Caulk RA, and Tomac I. Reuse of abandoned oil and gas wells for geothermal energy production. Renewable Energy. 2017; 112: 388–97.

[8] Tester J, Herzog H, Chen Z, Potter R, and Frank M. Prospects for universal geothermal energy from heat mining. Science & Global Security. 1994; 5(1): 99–121.

[9] Wang K, Yuan B, Ji G, and Wu X. A comprehensive review of geothermal energy extraction and utilization in oilfields. Journal of Petroleum Science and Engineering. 2018; 168:465–477.

[10] Mehmood A, and Yao J. Fun DY. Future Electricity Production from Geothermal Resources Using Oil and Gas Wells. Open Journal of Yangtze Oil and Gas. 2017; 2(04): 191–200.

[11] Wang K, Liu J, and Wu X. Downhole geothermal power generation in oil and gas wells. Geothermics. 2018; 76: 141–8.

[12] Moustafa AM, Ahmed SS, Shehata AS, and Hanafy AA. Reuse of Abandoned oil and gas wells for power generation in Western Dessert and Gulf of Suez Fields of Egypt. TMREES22-FR, EURACA, Metz-Grand Est., France, 2022.

[13] Adeola AF. Electric Infrastructure Failures in Nigeria: A survey-based analysis of the costs and adjustment responses. Elsevier, Energy Policy, 2003; 31: 1519-1530.

[14] Bamisile OO. A Review of Solar Chimney Technology: Its Application to Desert Prone Villages/Regions in Northern Nigeria. International Journal of Scientific and Engineering Research. 2004, Vol. 5(12): 1210-1216

[15] World Energy Council, 2014. http://www.worldenergy.org/data/trilemmaindex/country/Nigeria/

[16] Cole CA. Review of Geothermal Heating and Cooling of Buildings. 2nd Climate Change Technology Conference, 2014.

[17] Okeifufe FN, Izuwa NC, and Nwogu N. Estimating the Quantity of Recoverable Heat in a Geothermal Reservoir in Nigeria. SPE NAICE Paper, 2020; SPE-203643, 1-14.
[18] Cabeza FL, Gracia A, Fernández AI, and Farid M.M. Supercritical CO_2 as heat transfer fluid: A review. Applied Thermal Engineering. 2017; 125: 799-810, https://doi.org/10.1016/j.applthermaleng.2017.07.049.
[19] Thippeswamy LR, and Kumar YA. Heat transfer enhancement using CO_2 in a natural circulation loop. Sci Rep, 2020; 10, 1507. https://doi.org/10.1038/s41598-020-58432-6

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