Assessment of the Cost of various Renewable Energy Systems to Provide Power for a Small Community: Case of Bukha, Oman

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Abstract- Renewable sources are clean, non-polluting, alternative energy sources, hence, they are considered to be environmentally friendly. This paper presents an assessment of the cost of various renewable energy systems in order to provide power solution for Bukha, small community located in Masandam, in the Sultanate of Oman. The following renewable energy sources are available in the small community; solar, wind, biomass, hydro and geothermal. The community is made up of about 1,670 inhabitants. A detailed analysis of the cost of power generation considering all the renewable energy schemes were carried out based on the total power consumption of the community. The metrics of judging the cost schemes were the net present values, the internal rate of return, the salvage values, the depreciation rate and the payback period based on the life cycle of the plants. The schemes were all assumed to have a life span of 20 years. The standard of judging the costing schemes were based on the data provided by the International Renewable Energy Agency for Asia region. Some schemes offer good advantages over the other schemes, based on the costing criteria considered. However, no scheme has all the benefits in providing power solutions to the small community.

Keywords solar energy, wind energy, biomass energy, hydropower, geothermal energy, costing.

1. Introduction

During these recent years, in which global warming is extremely evident, the demand of energy has increased prominently. Thus the depletion of fuel stocks, in which the primary sources are fossil fuels, has also become evident. These non-renewable energy resources are being used at a rate that is both phenomenal and unmaintainable. Moreover, there are very high chances that these resources will be completely gone not too long from today.

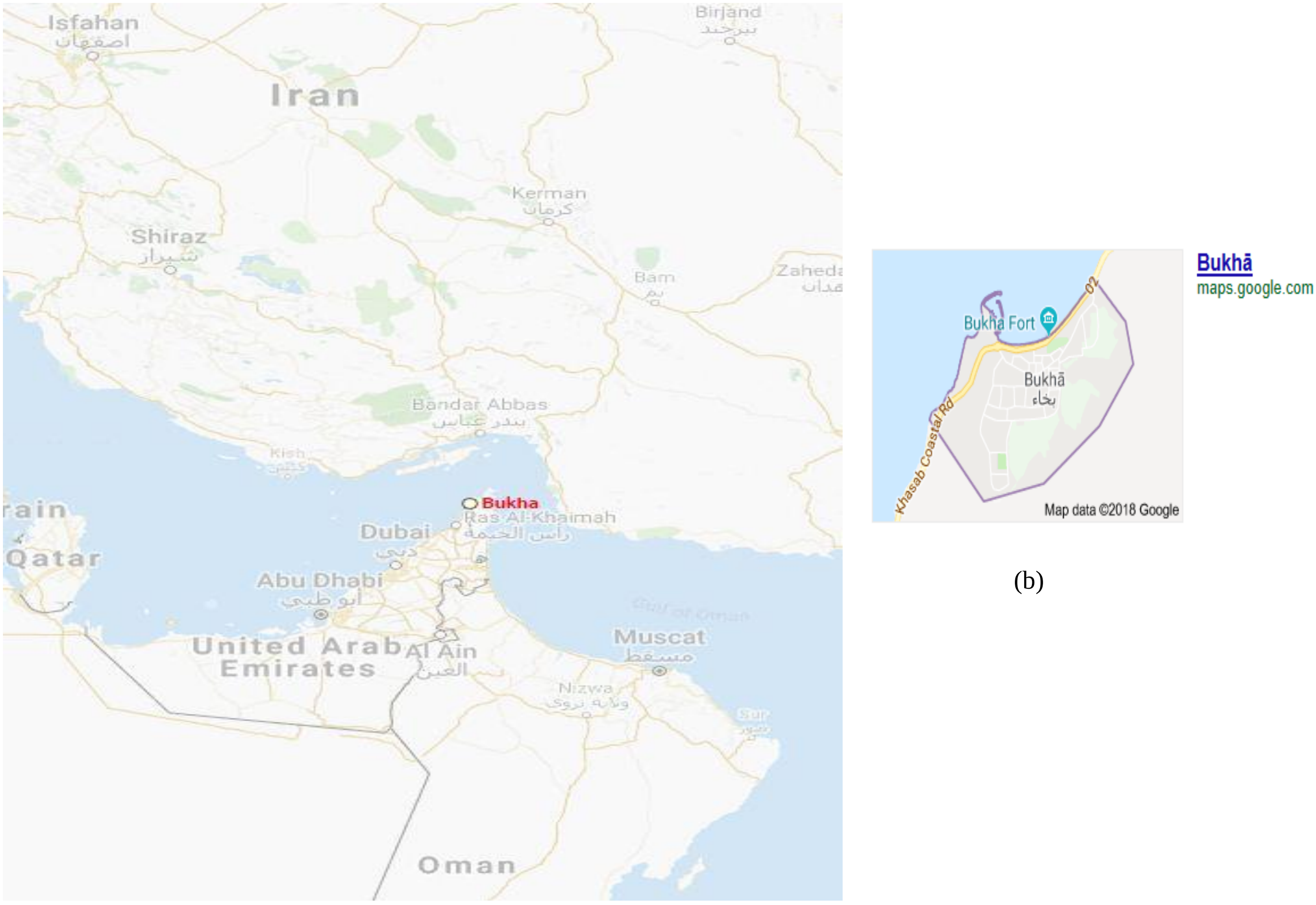
Sultanate of Oman is known to be a fast-growing country with the 5th largest market of economy in the Gulf Cooperation Council (GCC) region [1]. Sultanate of Oman, for so long, has disregarded the use of renewable energy sources for the production of energy because of the abundant reserves of both oil and natural gas that is present in the country. These types of sources provided power that causes pollution to the environment for so many years. Furthermore, Oman is known to be almost completely dependent on the oil sector for the government expenditure and the export revenues, since it is acknowledged to have the leading oil reserves among all the non-OPEC countries in the area [2].

However, the growth in population and the expansion of the industries in Oman, have both pressured the power infrastructure and the utilization of oil and gas. Recently one-third of the energy needs that are met by the oil reserves of Oman are expected to have a lifespan of only 40 years, which has forced the government to think of alternative sources of energy for the region [1]. The Ministry of Environment and Climate Affairs, which is the first of its kind in the region, has a vision which is proliferated under “Vision 2020” with aim of producing 10 % of the total electricity requirement only from renewable energy sources [3, 4]. Therefore, this proves that the country has stern targets to invest in its capacity of renewable energy for the future.

Different renewable energy sources have high potentials in Oman, and their utilization would be very beneficial for the region. Since Oman almost always has a ‘clear sky’, solar energy would be very beneficial and useful [5-8]. Furthermore, due to the vast spaces which are available in the region, wind energy also has very high potentials [9-12]. The fact that there are 53 boreholes in Oman that have temperatures that reach more than 100 ^{0} C, a geothermal energy power plant can be of great use [13-16]. The flood tides that enter the Gulf of Oman through the channel of Hormuz move at high speeds and tend to be continuous making the use of tidal energy in Oman also advantageous [17-18]. According to The Research Council (TRC), biomass materials are available in both the Northern and Southern parts of Oman [19-22]. These biomass materials come in the form of both agricultural waste and wastewater.

In this paper, the potential and costs of the various renewable energy sources in providing a sustainable power solution to a small remote community called Bukha, located in Musandam, Sultanate of Oman will be analyzed. This study aims to highlight the cheapest and most reliable renewable energy resource to be considered, in providing power to about 1,670 inhabitants of the community, annually. The community is availed with solar, wind, hydropower, biomass and geothermal renewable energy resources. The Levelized Cost of Energy (LCOE), which is known as the measure of a power source that endeavours the comparison of the various methods of generation of electricity on a stable basis is employed in this study. The LCOE is imperative tool for economic valuation of the total cost over a lifetime (of a power source) divided by the total output energy (which was generated over that lifetime). This factor will be taken into consideration for the calculation of the costs of the different types of renewable energy sources used in this study. Also, other key costing analysis metrics like Net Present Value (NPV), Internal Rate of Return (IRR), Salvage value would be considered in the course of the assessment and comparative analysis of the various renewable energy sources, located in the Bukha small community.

2. The Studied Community



(a)

(b)

Fig. 1 Map of Bukha community [23]

The Bukha community used in this study is located at Musandam, in the Sultanate of Oman. The community has geographical coordinates of 26° 8' 35" North, 56° 9' 10" East. The Map of the community is shown in Fig. (1a) and (1b) respectively. The community area is $5.06km^2$ and density is $252.7/km^2$, with a change of $+0.48\%$ yearly [23], the occupation is mainly fishing and farming. The estimated population of the community is about 1,670 inhabitants; with approximately 70% Omanis, while foreigners account for 30%.

3. Energy Demand in Oman

The total energy consumption in Oman has increased in the recent years in drastic measures. While the consumption accounted for the year 2000 was 6850 GWh, in the year 2018 it was computed to be 27,620 GWh [24, 25]. This energy was consumed by different sectors which includes the industrial, residential, and commercial. The main focus in this paper will be on the residential sector since our study is based on the residents of a small community. In comparison to other sectors, the residential sector has accounted for most consumption that makes up to 49 % of the total consumption of energy in the country. Figure 2 show the energy consumption in the different sectors and the growth in energy in Oman respectively.

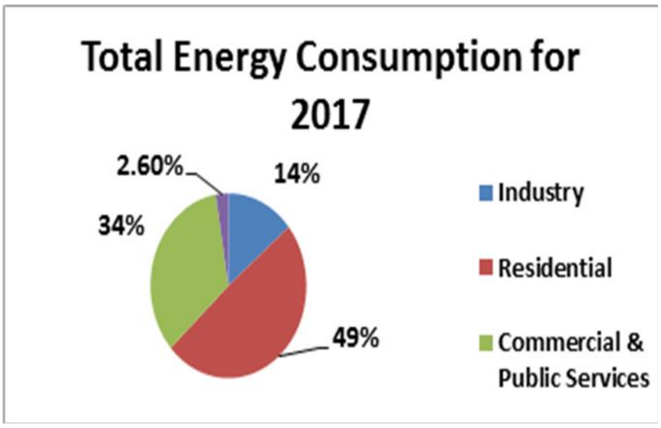


Fig. 2 Consumption of energy in different sectors in Oman [24]

From Figs. 2 and 3, the total energy consumption for the year 2018 in the residential sector is 1353 GWh. In accordance to the estimated population of Oman in the year 2018, of 4.500 million people, the total energy consumed by one individual yearly can be estimated as:

Estimated Energy consumed/person =

$$Residential\ Energy\ Consumed\ (2018) / Total\ Population\ (2018) \qquad (1)$$

$$= 1353\ x\ 10^9 Wh / 4.5\ x\ 10^6$$

= 0.3 x 10^6 Wh/ person /year

For the Bukha small community used for this study, with a population of about 1,670 people, the total energy consumption for this community will be:

Energy consumed by 1,670 people = 0.300 x 10^6 Wh/year x 1,670 = 500 x 10^6 Wh/year

4. Electricity Tariffs Billing in Oman

The electricity tariffs billing in Oman for residential areas are shown in Table 1.

Table 1. Tariffs for Electricity in Oman [25, 26]

Consumption in kWh	Tariff
Between 1 & 3000	10 Bz/kWh
Between 3001 & 5000	15 Bz/kWh
Between 5001 & 7000	20 Bz/kWh
Between 7001 & 10000	25 Bz/kWh
Over 10000	30 Bz/kWh

5. Costing Methods

The renewable energy resource costs differ from one resource to the other. The costs are categorized into two main categories: capital costs, operation and maintenance costs. Each technology has its own levelized cost which is multiplied by the energy consumed value.

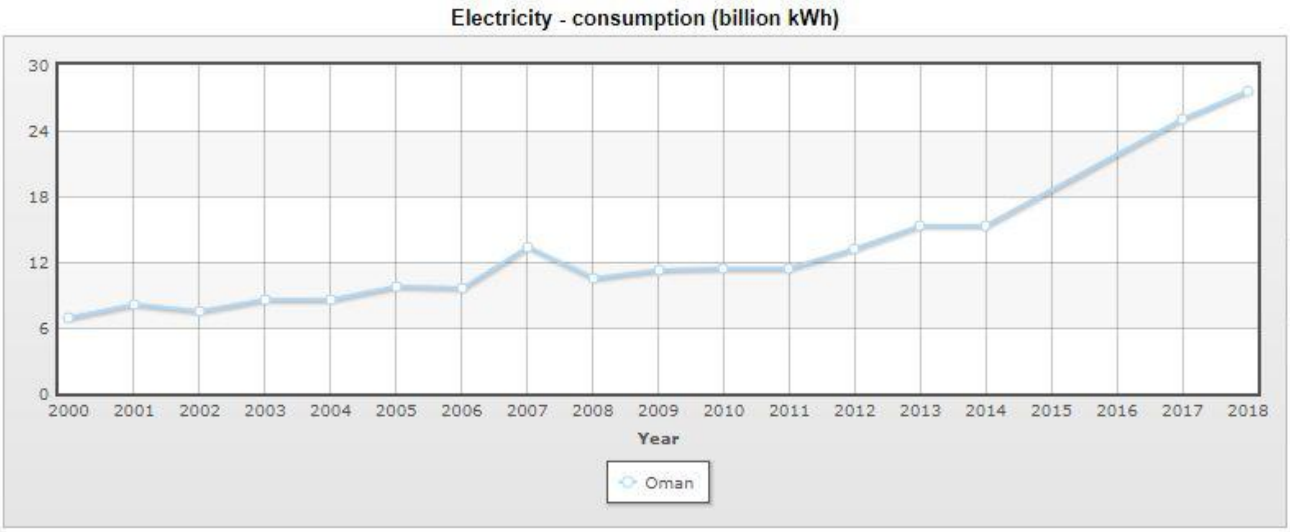
Equations used to calculate the capital cost, cash inflows, net present value, average rate of return, payback period, internal rate of return and salvage are given below based on the standard of the International Renewable Energy Agency [27]:

$$Levelized\ Cost\ \$/kWh \times Total\ Yearly\ Energy\ (kWh)\ Consumed \qquad (2)$$

$$Cash\ inflows = cost / Kwh \times energy\ consumed\ in\ Kwh \qquad (3)$$

$$Net\ Present\ Value = PV\ of\ Cash\ Inflows - PV\ of\ Cash\ Outflows \qquad (4)$$

$$Average\ Rate\ of\ Return = (Average\ Return/Capital\ Cost) \times 100 \qquad (5)$$



Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2017	2018
Oman	6.85	8.03	7.53	8.63	8.63	9.79	9.58	13.33	10.53	11.19	11.36	11.36	13.25	15.34	15.32	25	27.62

Fig. 3 Electricity consumption growth in Oman [24]

$$\text{Internal rate of return (IRR)}: NPV = \frac{\text{Capital cost} + \text{Present value of cash inflows}}{(1+R)} \quad (6)$$

When $NPV = \text{zero}$ *and if* $R < r$*, where r small is inflation rate, project is accepted*

$$\text{Salvage value} = \text{Original Price} \times (1 - \text{depreciation rate})^{n} \quad (7a)$$

$$S = P\,(1 - i)^{\,n} \quad (7b)$$

The assessment for the cost of five different technologies of the renewable energy sources available in the small Bukha community considered in this study would be analyzed in this section. The five renewable energy sources are; solar, wind, geothermal, hydropower and biomass. The metrics for assessment and comparison are the capital cost, net present value, payback period, average rate of return, internal rate of return and salvage value for each technology.

5.1. Levelized Cost of Energy (LCOE)

The levelized energy costs signifies the whole amount to create and function a power plant which can be alienated to equivalent yearly expenditures and repaid over predictable yearly electricity development. It imitates all the amount containing primary capital, return on investment, incessant operation, fuel, and preservation, along with the amount of time-span mandatory to create a plant in its predictable lifespan. Figure 4 shows regular levelized electricity amount in US Dollars per kilowatt-hour for each renewable of energy

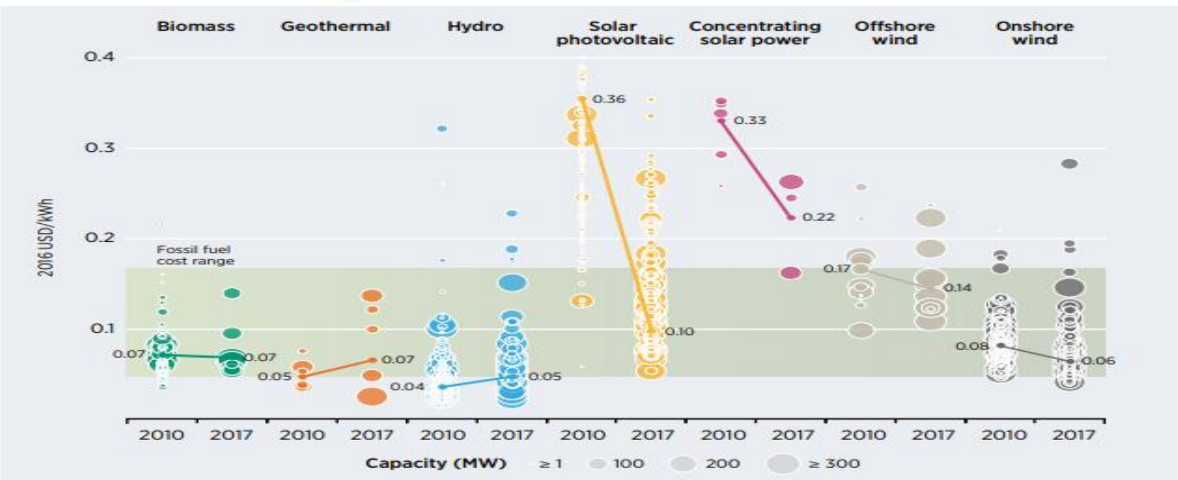


Fig.4 Global levelized cost of energy [27]

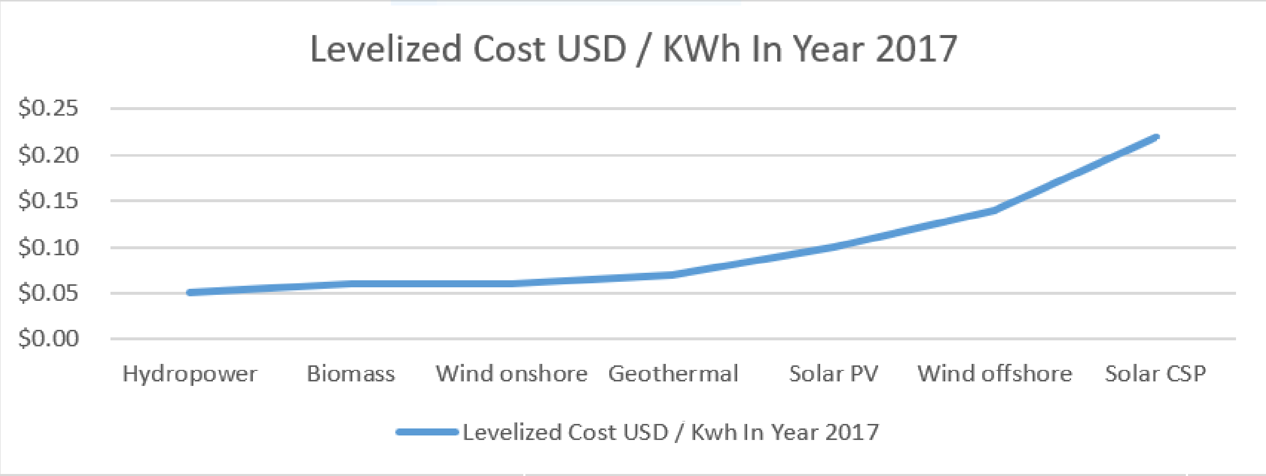


Fig. 5 Levelized cost of electricity for Asia region

technology in the globe as set by [27]. Since Oman is in Asia region, the extracts from the International Renewable Energy Agency report in Fig. 4, on the cost of the various renewable energy technologies is used to achieve Fig. 5. From Fig. 5, the hydro power take 0.05 USD per kWh, 0.06 USD per kWh for biomass, 0.06 USD per kWh for wind onshore, geothermal 0.07 USD per kWh, solar PV 0.1 USD per kWh. Wind offshore and solar CSP are 0.14 and 0.22 USD per kWh respectively.

6. Cost Analysis for the Various Renewable Energy

Based on the estimated load demand for the small community presented in section 3, a rough estimate of about 1,670 of the total inhabitants account for about 500MWh/year. These people consume yearly electricity amount of an average of 500 MWh by using grid connected system that is powered by conventional gas turbines. The intent is to evaluate the energy cost based on the available various renewable energy technologies.

Considering the levelized cost of renewable energy technology shown in Fig. 5 for the Asia region, the capital cost for the various renewable energy sources in this study is as follows:

$$\text{Levelized Cost \$/kWh} \times \text{Total Yearly Energy (kWh) Consumed by 1,670 persons} \quad (8)$$

The LCOEs for the different renewable energy technology for the Bukha small community, including the installation cost, operation and maintenance cost for a period of 20 years are shown in Table 2.

Table 2 Capital cost for renewable energy installation

Source	Levelized Cost $/kWh	Total Cost in USD
Hydropower	$0.05	$ 25000
Biomass	$0.06	$30000
Wind onshore	$0.06	$30000
Geothermal	$0.07	$35000
Solar PV	$0.1	$50000
Wind offshore	$0.14	$70000
Solar CSP	$0.22	$110000

Cash inflow is calculated as the total energy consumed per year for the total number of inhabitants in the community which is obtained as 500 MWh/year multiplied by 0.026 USD/kWh (10Bz/kWh) tariff cost in Oman for range of 1kWh up to 3000 kWh. This is because each person yearly consumed 0.3 MWh as obtained earlier in section 3 of this paper, which falls in tariff range of 0.026 USD/kWh in Oman by the authority for electricity regulation [26] given in Table 1. In view of the above, the conversion price to be considered for the 10 Bz/kWh or 0.026 US Dollars/kWh is given as: [1000 Bz = 1 Omani Rial (OMR) = 2.60 US Dollars].

The following equations are used for calculating the cash inflow, net present value, average rate of return, internal rate of return and salvage value:

$$Cash\ inflows = cost\ /\ Kwh \times energy\ consumed\ in\ Kwh$$

$$= 0.026 \times 500000\ Kwh = 13000\ USD/year$$

$NPV = PV\ of\ Cash\ Inflows - PV\ of\ Cash\ Outflows$

$ARR\% = (Average\ Return/Capital\ Cost) * 100$

$Discounted\ Factor = 1/(1+r)^n$

r: inflation rate

n: number of years

Note: The average inflation rate for Oman from 2005 – 2018 is 3.54% [28], this would be used as the discount factor in the cost analysis of all the considered renewable energy plants.

6.1. Cost Analysis for Hydropower Plant

The net present value, yearly cash inflows and average rate of return for the hydropower plant are shown in Table 3 respectively. The cash flow was done for a duration of 20 years (2018-2037), for the life cycle of the plant.

Table 3. Cost analysis for the hydropower plant

Source	Cash outcome	Total present value	Net present value	Average cash inflow	Average rate of return
Hydro power	-25000	184080	159080	13000	52.00%

The Internal rate of return (IRR) is:

$NPV = Capital\ cost + Present\ value\ of\ cash\ inflows/(1+R)$

$0 = -25000 + 184080/(1+R)$

$R = 6.4 > 1.83;$

where 1.83 is the inflation rate after 20 years of the project.

The salvage value for the hydropower plant is

Salvage = Original Price × $(1 - depreciation\ rate)^n$

$S = 25000\ (1 - 0.354)^{20} = 4$

6.2. Cost Analysis for Biomass Plant

The net present value, yearly cash inflows and average rate of return for the biomass plant are shown in Table 4 respectively. The cash flow was done for a duration of 20 years (2018-2037), for the life cycle of the plant.

The Internal rate of return (IRR) is:

$NPV = Capital\ cost + Present\ value\ of\ cash\ inflows/(1+R)$

$0 = -30000 + 184080/(1+R);\ R = 5.14 > 1.83;$

where 1.83 is the inflation rate after 20 years of the project

The Salvage is obtained as

$Salvage = Original\ Price \times (1 - depreciation\ rate)^n$

$S = P\ (1 - i)^n$

$S = 30000\ (1 - 0.354)^{20} = 4.8$

Table 4. Cost analysis for the biomass plant

Source	Cash outcome	Total present value	Net present value	Average cash inflow	Average rate of return
Biomass	-30000	184080	154080	13000	43.30%

6.3. Cost Analysis for Wind Onshore Plant

The net present value, yearly cash inflows and average rate of return for the wind onshore plant are shown in Table 5 respectively. The cash flow was done for a duration of 20 years (2018-2037), for the life cycle of the plant.

Table 5. Cost analysis for the wind onshore plant

Source	Cash outcome	Total present value	Net present value	Average cash inflow	Average rate of return
Wind onshore	-30000	184080	154080	13000	43.30%

The Internal rate of return (IRR) is:

$NPV = Capital\ cost + Present\ value\ of\ cash\ inflows/(1+R)$

$0 = -30000 + 184080/(1+R);\ R = 5.14 > 1.83$

where 1.83 is the inflation rate after 20 years of the project.

The salvage value is

$Salvage = Original\ Price \times (1 - depreciation\ rate)^n$

$S = 30000\ (1 - 0.354)^n = 4.8$

6.4. Cost Analysis for Geothermal Plant

The net present value, yearly cash inflows and average rate of return for the geothermal plant are shown in Table 6 respectively. The cash flow was done for a duration of 20 years (2018-2037), for the life cycle of the plant.

Table 6. Cost analysis for geothermal plant

Source	Cash outcome	Total present value	Net present value	Average cash inflow	Average rate of return
Geothermal	-35000	184080	149080	13000	37.14%

The Internal rate of return (IRR) is:

$NPV = Capital\ cost + Present\ value\ of\ cash\ inflows / (1 + R)$

$0 = -35000 + 184080/(1 + R)\ ;\ R = 4.3 > 1.83$

$where\ 1.83\ is\ the\ inflation\ rate\ after\ 20\ years\ of\ the\ project.$

The salvage value is

$Salvage = Original\ Price \times (1 - depreciation\ rate)^n$

$S = 35000\ (1 - 0.354)^{20} = 5.6$

6.5. Costing analysis for solar PV plant

The net present value, yearly cash inflows and average rate of return for the solar PV plant are shown in Table 7 respectively. The cash flow was done for a duration of 20 years (2018-2037), for the life cycle of the plant.

Table 7. Cost analysis for solar PV plant

Source	Cash outcome	Total present value	Net present value	Average cash inflow	Average rate of return
Solar PV	-50000	184080	134080	13000	26.00%

The Internal rate of return (IRR) is:

$NPV = Capital\ cost + Present\ value\ of\ cash\ inflows / (1 + R)$

$0 = -50000 + 184080/(1 + R); R = 2.7 > 1.83$

$where\ 1.83\ is\ the\ inflation\ rate\ after\ 20\ years\ of\ the\ project.$

The Salvage is

$Salvage = Original\ Price \times (1 - depreciation\ rate)^n$

$S = 50000\ (1 - 0.354)^{20} = 8$

6.6. Cost Analysis for Wind Offshore Plant

The net present value, yearly cash inflows and average rate of return for the wind offshore plant are shown in Table 8 respectively. The cash flow was done for a duration of 20 years (2018-2037), for the life cycle of the plant.

Table 8. Cost analysis for wind offshore plant

Source	Cash outcome	Total present value	Net present value	Average cash inflow	Average rate of return
Wind offshore	-70000	184080	114080	13000	37.14%

The Internal rate of return (IRR) is:

$NPV = Capital\ cost + Present\ value\ of\ cash\ inflows / (1 + R)$

$0 = -70000 + 184080/(1 + R)\ ;\ R = 1.63 < 1.83$

$where\ 1.83\ is\ the\ inflation\ rate\ after\ 20\ years\ of\ the\ project.$

The project is rejected for this case because R < r.

The Salvage is:

$Salvage = Original\ Price \times (1 - depreciation\ rate)^n$

$S = 70000\ (1 - 0.354)^n = 11.2$

6.7. Cost analysis for solar CSP plant

The net present value, yearly cash inflows and average rate of return for the solar Concentrating Solar Panel (CSP) plant are shown in Table 9 respectively. The cash flow was done for a duration of 20 years (2018-2037), for the life cycle of the plant.

Table 9. Cost analysis for solar CSP plant

Source	Cash outcome	Total present value	Net present value	Average cash inflow	Average rate of return
Solar CSP	-110000	184080	74080	13000	11.8%

The Internal rate of return (IRR) is:

$NPV = Capital\ cost + Present\ value\ of\ 0 = -110000 + 184080/(1 + R$

$); R = 0.67 < 1.83$; where 1.83 is the inflation rate after 20 years of the project. The project will be rejected for this case because $R < r$.

To evaluate the Salvage value;

$$Salvage = Original\ Price \times (1 - depreciation\ rate)^n$$

$$S = 110000\,(1 - 0.354)^{20} = 17.6$$

7. Analysis of Results

A summary of the cost analysis [29] for all the considered renewable energy sources are presented in Figs. 6 to 12. Figure 6 shows the linear trajectory relationships for the yearly cash flow, discount factor and present values for the renewable plants from the year 2018-2037. The relationships of the parameters are similar for the considered renewable energy plants, except for the present value cost for the year 2018, which ranges from -25,000 for the hydropower plant to -110,000 for the solar CSP system.

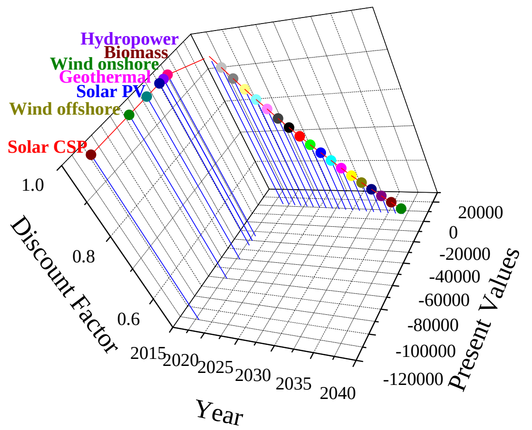


Fig. 6 Yearly cash flow, discount factor, and net present values of the renewable plants

Based on Table 2, the capital cost of the solar CSP seems to be the highest with a value of 110,000 USD to provide power solutions to the small community as shown in Fig. 7.

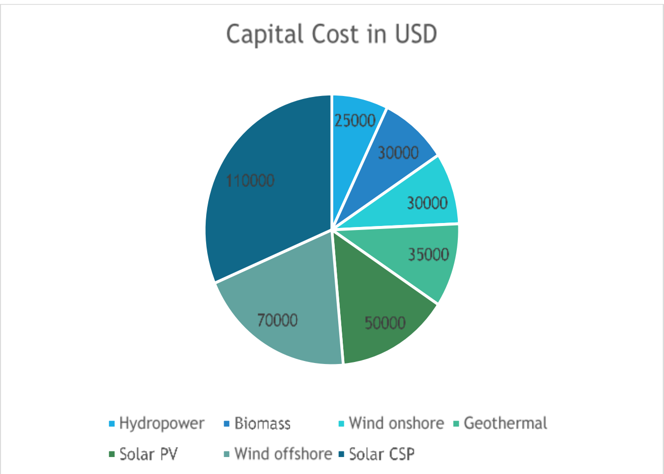


Fig.7 Capital cost of the considered renewable plants

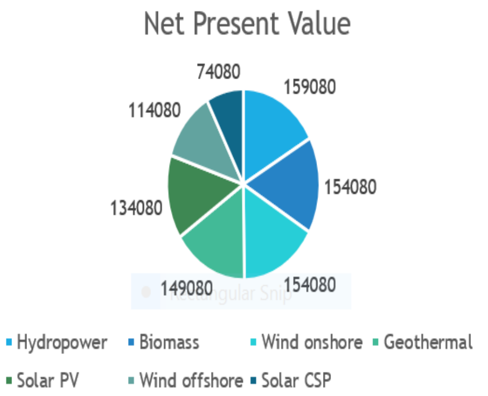


Fig.8 Net present value of the considered renewable plants

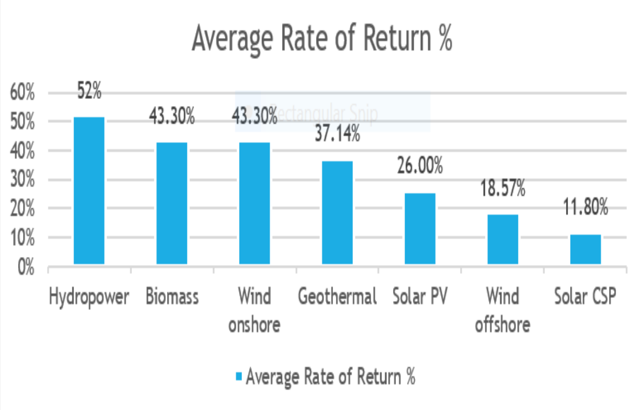


Fig.9 Average rate of return of the considered renewable plants

Table 9. Payback periods of the considered renewable

Payback Period	Year & Month
Hydropower	1 & 11
Biomass	2 & 3.7
Wind onshore	2 & 3.7
Geothermal	2 & 8.3
Solar PV	3 & 10
Wind offshore	5 & 4.6
Solar CSP	8 & 5.5

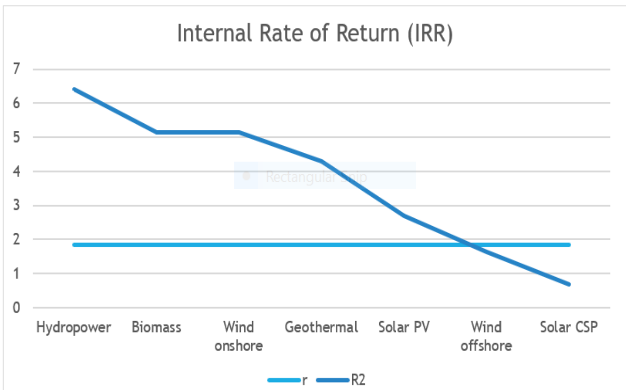


Fig.10 Internal rate of return of the considered renewable plants

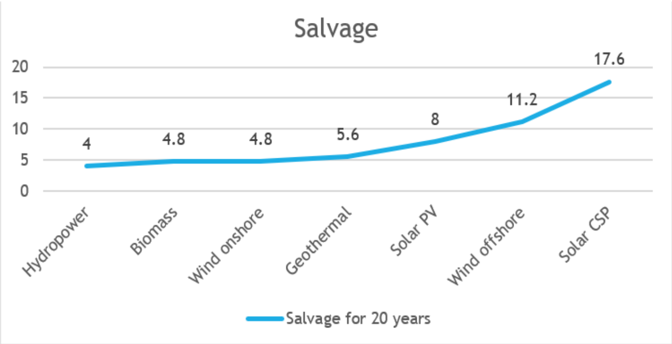


Fig.11 Salvage values of the considered renewable plants

The hydropower has the least capital cost of 25,000 USD. Figure 8 shows the net present values of the considered renewable energy systems. Conversely, the hydropower has the highest average rate of return with a value of 52% compared to the solar CSP with the least average rate of return value of 11.80% as shown in Fig. 9. A summary of the payback periods for the various renewable technologies are given in Table 9. The solar CSP has the highest payback period of over eight years, while the hydropower has the least payback period of less than two years. In Fig. 10, r is the inflation rate and R is the internal rate of return. The hydropower has the highest internal rate of return of 6.4%, while that of the solar CSP is 0.67%. However, the solar CSP has the highest salvage value of 17.6 compared to the hydropower with salvage value of 4, as shwon in Fig. 11. The inflation rate r is fixed at 1.83% after 20 years in Oman as earlier discussed in section 6. The relationship of the average rate of return, the present capital cost and the levelized cost of energy for the considered renewable energy plants in this work are shown in Fig. 12. The hydropower seems to be more cost effective while the solar CSP system been the least cost effective system.

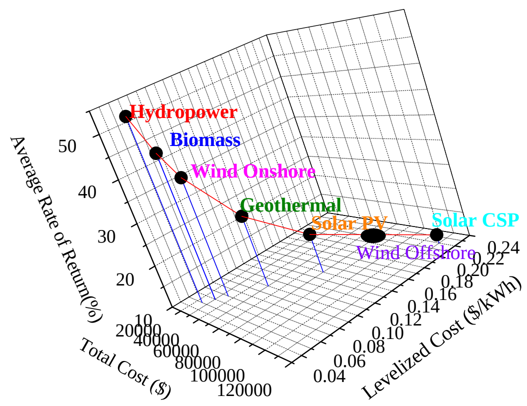


Fig.12 The average rate of return, capital and levelized cost of the renewable plants

In light of the above, the key findings of this work are as follows, based on a 20 year duration and life cycle of the various renewable energy technologies, with energy charges in Oman according to the electricity and regulation permitted tariff set at 0.026USD/kWh up to 2018. The cost parameters like capital cost, cash inflows, net present value, average rate of return, payback period, internal rate of return and salvage are calculated for the different renewable technology considered in this study. The highest levelized cost of electricity was found in solar CSP, then wind offshore, solar PV, geothermal, wind onshore, biomass and hydropower respectively. For producing 500MWh per year for the Bukha small community, it is more expensive to use solar CSP and the wind offshore technologies in the current state. This is because of the very high capital cost and very low internal rate of return involved for the 20 years period. Where the capital cost shows 110,000 USD and the calculated internal rate of return is less than the stipulated inflation rate after 20 years. In this scenario, there is need to increase the current energy charges per kWh from the stipulated 0.026 USD/kWh in the Sultanate of Oman. The current energy charges in Oman according to the authority of electricity and regulation permitted tariff determined as 0.026 USD / kWh up to 2018. Similar situation holds for the wind offshore technology. Other technologies are feasible and accepted based on the evaluated internal rate of return for the duration of operation of the considered renewable energy plants. Therefore, since the same electricity price is used for selling the energy produced by the generating power from the conventional power sources, it will be better to increase the charges of electricity produced in the current state by renewable energy resources because of the initial high costs of the renewable energy systems.

8. Conclusion

The use of renewable energy in power generation is on the rise in many countries. This study presented an assessment of the cost of using the various renewable energy technologies in providing power solution to Bukha, small community located in Musandam, Sultanate of Oman. The various renewable energy resources considered were the hydropower, biomass, wind, geothermal and solar energy systems. The energy consumption of the small community was used in the cost analysis of the various energy resources based on the levelized cost of electricity set by the International Renewable Energy Agency (IRENA) and the stipulated energy sales charges set by the electricity authority in Oman. The presented results show that the solar concentrated solar panel (CSP) and the wind offshore technologies have very high capital cost and very low internal rate of return compared to the hydropower and biomass technologies, which have the lowest capital cost and highest internal rate of return respectively. The payback period of both wind offshore and solar CSP technologies are also very high. Although the salvage value for both solar CSP and wind offshore technologies are the highest respectively, as compared to the hydropower and biomass technologies. Thus, no renewable energy source has all the benefits to provide power solutions, considering the same capacity of the plants, as it depends on the metrics used in carrying out the cost analysis. However, the more feasible renewable resources for this case study are the hydropower, biomass, wind onshore, geothermal and solar PV in order of increasing capital cost. In the extreme, the most reliable renewable energy resource to the Bukha community is the solar CSP, based on its availability, if the cost of the system could be contained. On the other hand, the cheapest and more feasible renewable energy resource to provide power solution to the Bukha community is the hydropower, considering the financial strength of the small community. Since the same electricity price is used for selling the energy produced by generating power plants from the conventional power sources in the case of Oman, it will be better to increase the charges of electricity produced by renewable energy resources, in order to mitigate the high initial costs involved in setting up the renewable energy plants.

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