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Design Optimization, Sensitivity Analysis and Optimal System Types of Hybrid Renewable Energy Systems: A Case of Health Care Clinic Building in India

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ABSTRACT: *This paper presents the design optimization, sensitivity analysis and optimal system types of the hybrid renewable energy system (HRES) for health care clinic building. Sensitivity variables are evaluated on these parameters to verify how variances in this load would change standalone wind/PV/diesel/battery hybrid system costs and optimal system configurations, and also was found to have very huge significant impact on OST configurations, although slightly less fuel was consumed on a yearly basis. The result eventually shows that benchmark system has almost 75% times higher COE where the COE came out of all sensitivity value. Important proof exists in increase of the COE by sensitivity analyses in diesel price. Final conclusion from this section is that COE has significant decrease by sensitivity analyses.*
KEYWORDS- *HOMER, Cost of Energy (COE), Net Present Cost (NPC), Saint Martin Island, Optimization, sensitivity analysis*

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I. INTRODUCTION

Around the world, many researchers have been carried out to investigate the viability, feasibility, risk factors and financing indicators in the implementation of photovoltaic electrification systems. The famous research scope is to build the Standalone Photovoltaic System (SAPVS) integrating to the power system plant in the building that not only assist in electricity generation but also help in profits income to the building owner. Several works study on development of standalone PV system are including (1), (2), The discussion in these cited papers are various including the sizing, economic operation of SAPVS and the reliability function of the developed system. Therefore, this presented article focus on the development of the sensitivity analysis method multiple optimizations are performed, each using a dissimilar set of input assumptions. A sensitivity analysis reveals how sensitive the outputs are to changes in the inputs (3). In a sensitivity analysis, a range of values for a single input variable are fed to optimization tool. A variable for which the user has entered multiple values is called a sensitivity value. Almost every numerical input variable that is not a decision variable can be a sensitivity variable. Examples include wind speed, solar irradiation, diesel price and rate of interest.

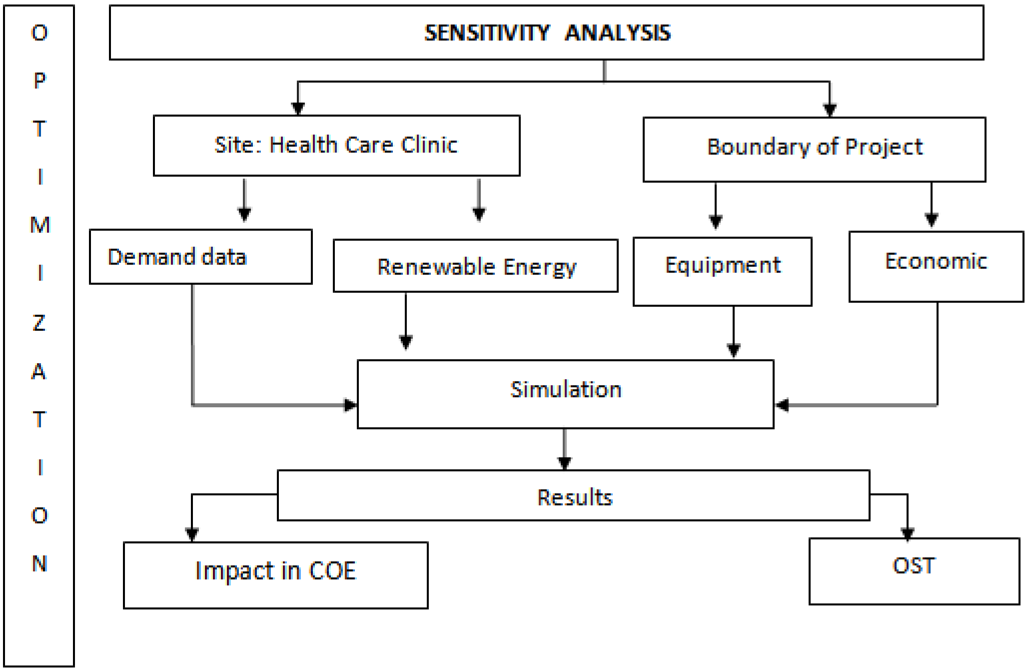


Fig 1.Flow chart of the Sensitivity Analysis

A system designer can use also sensitivity analysis to evaluate trade-offs between different options. The flow chart of the sensitivity analysis in standalone wind/PV/diesel hybrid system is shown in Figure .1.
A sensitivity value can be performed with any number of sensitivity variables. Each combination of sensitivity variable defines a distinct sensitivity case (4). A separate optimization process for each sensitivity case is performed and the results are presented in various tabular and graphic formats.
One of the primary uses of sensitivity analysis is in dealing with uncertainty (5). If a system designer is unsure of the value of a particular variable, we can enter several values covering the likely range and see how the results vary across that range. But sensitivity analysis has applications beyond coping with uncertainty.

Table 1 Sensitivity values

Parameters	**Actual values**	**Sensitivity Values**
Solar irradiation (kWh/m^2/d)	5.42	6.5 and 7.0
Wind speed (m/s)	5.9	6.6 and 7.0
Diesel Price (INR/lit)	62	68 and 80
Interest Rate (%)	6	0 and 10

II. LITERATURE SURVEY SENSITIVITY VARIABLES

Already the optimization technique (without sensitivity analysis) is applied in health care clinic building (6) and cost of energy for standalone wind/PV/diesel hybrid system at 18.3INR/ kWh. The optimal combination for health care clinic building is standalone wind/PV/diesel hybrid system. Table 1 gives the details about the actual value and the sensitivity value applied to the benchmark for sensitivity analysis.
A total of 81 sensitivity cases (product of wind speed (3), solar radiation (3), diesel price (3) and interest rate (3) were tested with each of the system configurations as shown in Table 1.The following section is to discuss the impact of the sensitivity value in solar irradiation, wind speed, price, and interest rate.

III. SENSITIVITY ANALYSIS BY SOLAR IRRADIATION (KWH/M^2/D)

In this Figure 2, two system set-ups (1st row and 2rd row) are of greatest interest, each supplying 79% and 84 % from renewable resources respectively. One comprises PV, wind turbine, (8) diesel generator, and converter and the other PV, wind turbine, battery, and converter. Due to adding of the battery with 2nd row of Figure 4.2 because of considering sensitivity variable in solar irradiation (6.5 kWh/m^2/d) to reduced the fuel consumption from 1380 lit/Yr to 997 lit/Yr.

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 6.5 | Wind Speed (m/s) 5.9 | Copy of Diesel Price ($/L) 1.1 | Interest Rate (%) 6

Double click on a system below for simulation results.

PV (kW)	WES5	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	opy of Diese (L)	Label (hrs)	Batt. Lf. (yr)
2	1	1		10	$ 15,800	3,319	$ 58,226	0.322	0.79	0.12	1,380	5,114	
2	1	1	10	10	$ 25,800	3,148	$ 66,039	0.338	0.84	0.02	997	3,415	12.0
10	1		10	10	$ 41,350	1,976	$ 66,609	0.336	1.00	0.00			12.0
	1	1	10	10	$ 21,800	4,357	$ 77,503	0.415	0.66	0.08	1,877	6,201	12.0
10		1	10	10	$ 40,450	3,769	$ 88,626	0.456	0.84	0.02	1,444	6,745	12.0

Fig2 Sensitivity result by solar irradiation (6.5kWh/m^2/d)

IV. SENSITIVITY ANALYSIS BY WIND SPEED (M/S)

Figure 3 represents a scenario where wind speed is high to 6.6 m/s. This is second most cost effective system, i.e. the system with the lowest COE at INR 11.7/kWh. The contribution of power from renewable energy as wind speed is 75 %. The remaining power 25% is produced by diesel generator.

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.42 | Wind Speed (m/s) 6.6 | Copy of Diesel Price ($/L) 1.1 | Interest Rate (%) 6

Double click on a system below for simulation results.

PV (kW)	WES5	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	opy of Diese (L)	Label (hrs)	Batt. Lf. (yr)
	1	1			$ 1,800	2,732	$ 36,720	0.209	0.75	0.15	1,466	5,376	
2	1		10	10	$ 25,350	1,687	$ 46,919	0.267	1.00	0.13			12.0
2	1	1		10	$ 15,800	3,127	$ 55,770	0.305	0.81	0.11	1,252	4,666	
2	1	1	10	10	$ 25,800	2,850	$ 62,231	0.317	0.87	0.01	799	2,704	12.0
	1	1	10	10	$ 21,800	3,914	$ 71,839	0.377	0.73	0.05	1,574	5,230	12.0
10		1	10	10	$ 40,450	4,178	$ 93,855	0.486	0.79	0.03	1,713	7,755	12.0

Figure 3 Sensitivity result by wind speed (6.6 m/s)

V. SENSITIVITY ANALYSIS BY INTEREST RATE

This section deals with impact of COE due to lesser value from 6% to 0 %. As shown in Figure 4, total demand is shared with PV as well wind turbine only then the renewable fraction is 100%.

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.42 | Wind Speed (m/s) 5.9 | Copy of Diesel Price ($/L) 1.1 | Interest Rate (%) 0

Double click on a system below for simulation results.

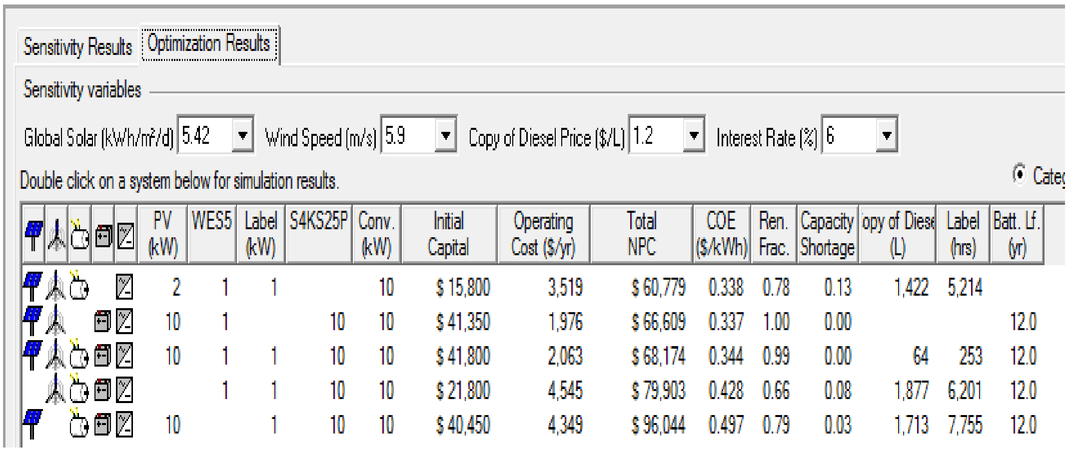
PV (kW)	WES5	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	opy of Diese (L)	Label (hrs)	Batt. Lf. (yr)
10	1		10	10	$ 41,350	1,968	$ 90,550	0.234	1.00	0.00			12.0
10	1	1	10	10	$ 41,800	2,048	$ 93,011	0.240	0.99	0.00	64	253	12.0
2	1	1		10	$ 15,800	3,365	$ 99,920	0.284	0.78	0.13	1,422	5,214	
	1	1	10	10	$ 21,800	4,347	$ 130,483	0.358	0.66	0.08	1,877	6,201	12.0
10		1	10	10	$ 40,450	4,152	$ 144,261	0.382	0.79	0.03	1,713	7,755	12.0

Fig 4 Sensitivity result by Interest rate (0%)

The following positive results can be noted from the Figure 4. For this set-up, the COE is INR 13.104 /kWh, there is no contribution from diesel generator (7). In spite of the fact that the net present cost is highest, renewable resources make fully contribution towards the energy supply.

VI. SENSITIVITY ANALYSIS BY FUEL PRICE

Figure 5 shows that the Sensitivity results for fuel price. With high fuel price, the cost of energy increased from INR 18/kWh to INR19/kWh. This happened due to the sensitivity variable.



Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.42 · Wind Speed (m/s) 5.9 · Copy of Diesel Price ($/L) 1.2 · Interest Rate (%) 6

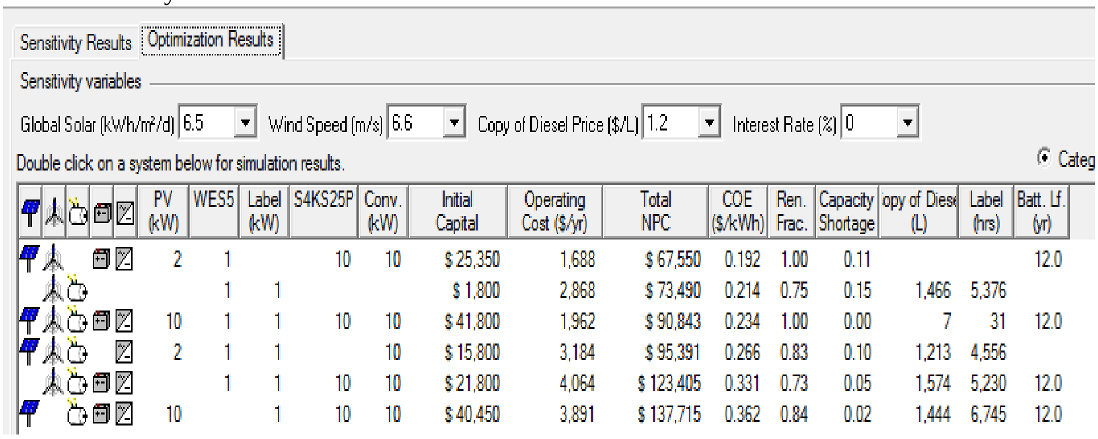
Double click on a system below for simulation results.

PV (kW)	WES5	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	opy of Diese (L)	Label (hrs)	Batt. Lf. (yr)
2	1	1		10	$ 15,800	3,519	$ 60,779	0.338	0.78	0.13	1,422	5,214	
10	1		10	10	$ 41,350	1,976	$ 66,609	0.337	1.00	0.00			12.0
10	1	1	10	10	$ 41,800	2,063	$ 68,174	0.344	0.99	0.00	64	253	12.0
	1	1	10	10	$ 21,800	4,545	$ 79,903	0.428	0.66	0.08	1,877	6,201	12.0
10		1	10	10	$ 40,450	4,349	$ 96,044	0.497	0.79	0.03	1,713	7,755	12.0

Figure 5 Sensitivity result by Fuel price (1.2 INR/lit)

VII. SENSITIVITY ANALYSIS BY ALL VALUES

The observation from the Figure 6, the cost of energy is reduced from the standard of INR 18.3/kWh to INR 10.7/kWh due to impact of overall sensitivity variables in standalone wind/PV/diesel hybrid system for demand load of 34.9 kWh/day.



Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 6.5 · Wind Speed (m/s) 6.6 · Copy of Diesel Price ($/L) 1.2 · Interest Rate (%) 0

Double click on a system below for simulation results.

PV (kW)	WES5	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	opy of Diese (L)	Label (hrs)	Batt. Lf. (yr)
2	1		10	10	$ 25,350	1,688	$ 67,550	0.192	1.00	0.11			12.0
	1	1			$ 1,800	2,868	$ 73,490	0.214	0.75	0.15	1,466	5,376	
10	1	1	10	10	$ 41,800	1,962	$ 90,843	0.234	1.00	0.00	7	31	12.0
2	1	1		10	$ 15,800	3,184	$ 95,391	0.266	0.83	0.10	1,213	4,556	
	1	1	10	10	$ 21,800	4,064	$ 123,405	0.331	0.73	0.05	1,574	5,230	12.0
10		1	10	10	$ 40,450	3,891	$ 137,715	0.362	0.84	0.02	1,444	6,745	12.0

Figure 6 Sensitivity result by all values

Proposed methodology

VIII. OPTIMAL SYSTEM TYPES (OST)

This is a graphical depiction of optimal system type provides in order that a particular system will be optimal at variable wind speed, solar irradiation, fuel cost and an interest rate. Graphical representations of the optimization are shown in Figures 4.7–4.10. Here, various optimal system types (OST) are displayed as functions of dissimilar sensitivity parameters.

8.1 Fixed Value of Diesel Price (INR 62/lit) and Interest rate (6%)

Figure 7 shows the OST for the considering fixed value of diesel price (INR 62/lit) and interest rate (6%). The figure is described that if the wind speed is nearby 6.0 m/s, only standalone wind/PV/diesel hybrid system is applicable to the energy demand of 34.9kWh/day. Similarly, if the wind speed is above 6 m/s, only standalone wind/PV/battery hybrid system is feasible for the load demand. However, the most feasible configuration of the system is categorized by hybrid system consisting wind turbine, PV array and the battery.

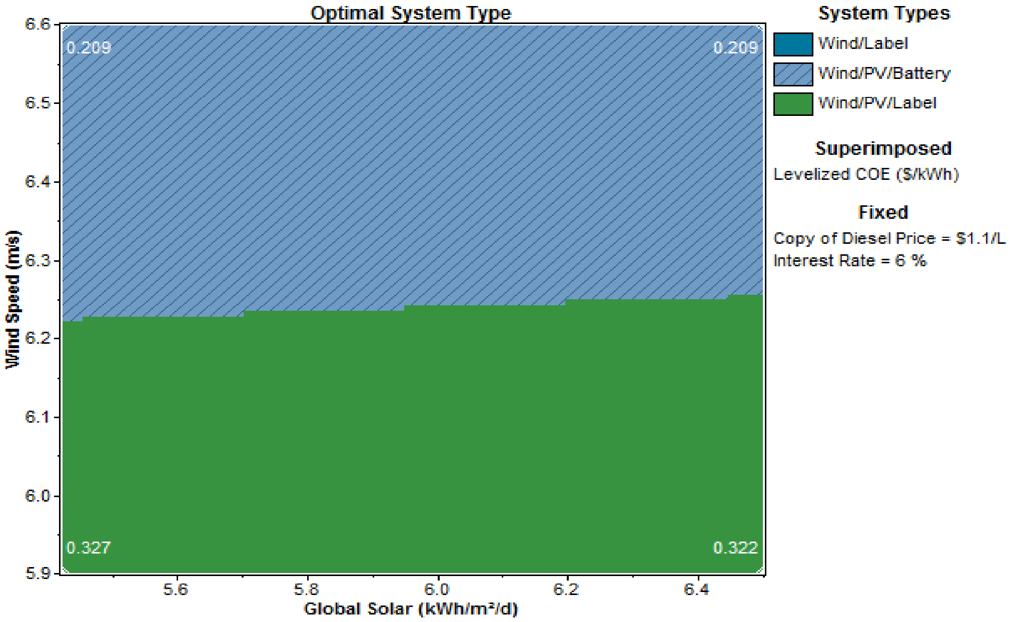


Fig 7OST by fixed value of Diesel price (INR 62/lit) and interest rate (INR 62/lit and 6%)

It is moreover, bright that the probability of only wind/PV/diesel system to meet the load is about 40% for wind speed below 6.0 m/s. Whereas the probability of only wind/PV/battery system to meet the load is about 60% for the wind speed above 6 m/s. It can also be concluded that hybrid system consisting wind/PV/battery is suitable for load demand.

For a region with very high wind speed and solar irradiation, a standalone wind/PV/battery hybrid system might be suitable. Although the capital cost and NPC are higher for such a system, the COE is much lower 11.7 INR/kWh.

8.2 Fixed Value of Diesel Price (INR 68/lit) and Interest rate (0%)

Figure 8 shows that the optimal system design depends both on fixed value of diesel price (INR 68/lit) and interest rate (0%).The conclusion from the Figure 4.8 shows that the wind/PV/battery system is feasible when the diesel price (68/lit) is increased and at the same time the interest rate is fixed at 0%

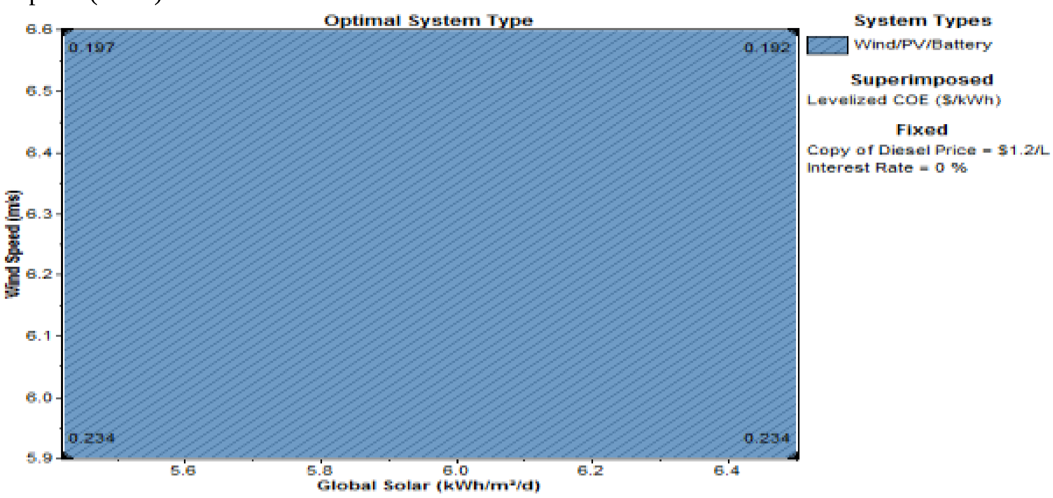


Fig 8 OST by fixed value of diesel price (INR 68/lit) and interest rate (0%)

8.3 Fixed Value of Wind speed (5.9m/s) and Solar irradiation (5.42 kWh/m^2/d)

The graph shows that the optimal system types depends fixed value of wind speed (5.9 m/s) & solar irradiation (5.42 kWh/m^2/d). Figure 9 represents a scenario due to diesel price and interest rate is elevated to 68 INR/lit and 0%. Associated costs of hybrid systems are also increased.

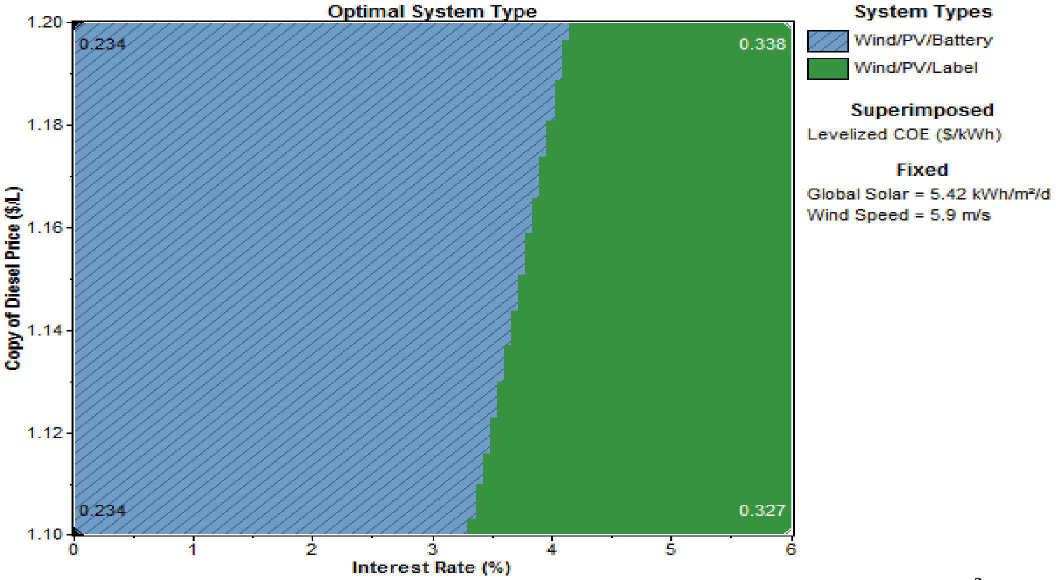


Fig 9 OST by fixed value of wind speed (5.9m/s) and solar irradiation (5.42 kWh/m^2/d)

8.4 Fixed Value of wind speed (6.6 m/s) and solar irradiation (6.5 kWh/m^2/d)

The graph shows that the optimal system types depends fixed value of wind speed (6.6 m/s) and solar irradiation (6.5 kWh/m^2/d).The outcome from the Figure 10 is that one third of the OST belongs to wind/PV/battery, and also two third of the OST belongs to wind/diesel. This is just inverse from the above section of OST.

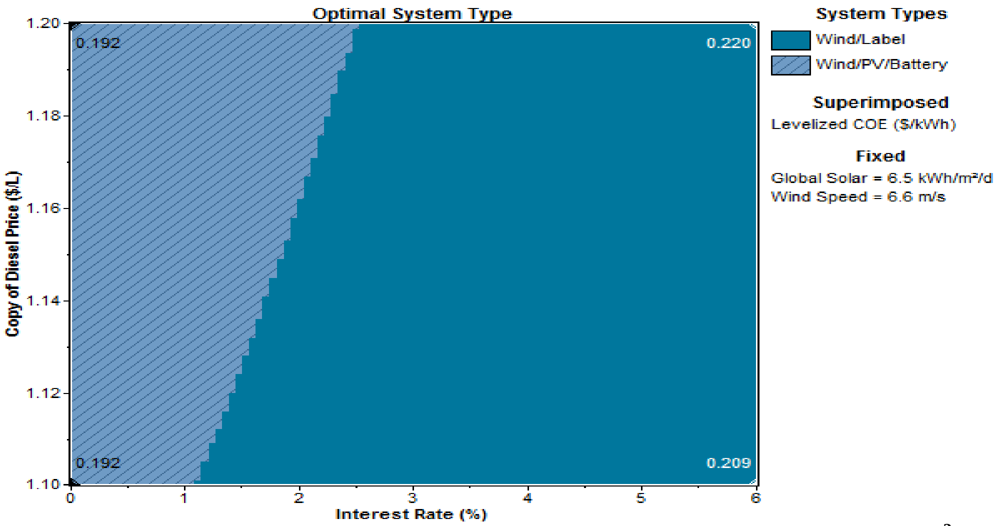


Fig10 OST by fixed value of wind speed (6.6m/s) and solar irradiation (6.5kWh/m^2/d)

IX. RESULT AND DISCUSSION

This section to discuses about the individual impacts of the sensitivity variable in term of % of COE with respect to actual value of COE that is INR18.31/kWh shown in Figure 11. Except the diesel price all other sensitivity variable like wind speed, solar irradiation and interest rate is made huge positive impact in COE. Amongst the three sensitivity variable, the highest positive impact is made by interest rate.

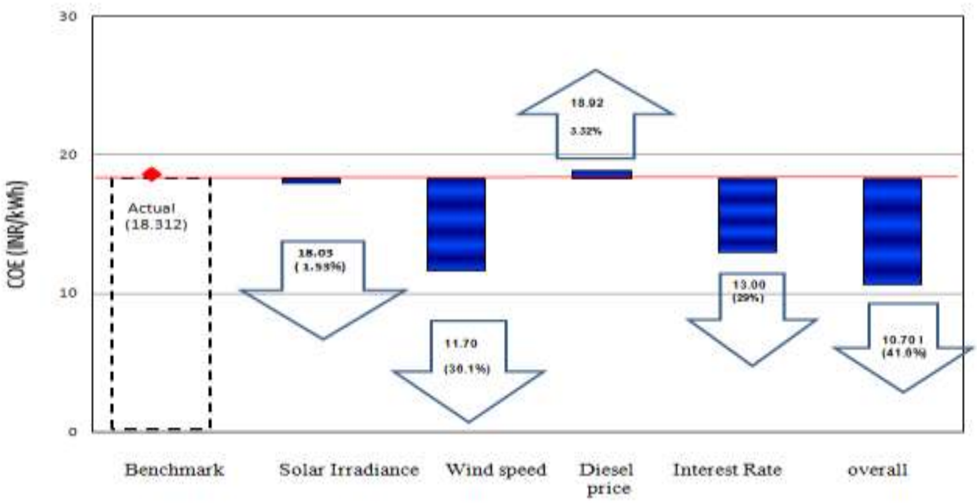


Fig 11 Overall impacts

The impact of the sensitivity analysis in COE is shown in Table 2.The COE is INR 18.30/kWh before the sensitivity analysis after that huge change in COE is made by application of sensitivity analysis is shown in table.

Table 2 Comparison of COE due to sensitivity variable

Type of hybrid system : PV/wind/diesel/battery				
Types of renewable energy	**Actual value**	**Sensitivity variable**	**COE(INR/kWh)**	
			From	**To**
Solar irradiation (kWh/m^2/d)	5.42	6.5 and 7.0	18.30	18.03
Wind speed (m/s)	5.9	6.6 and 7.0	18.30	11.70
Diesel price (INR/Lit)	62	68 and 80	18.30	18.92
Interest rate (INR)	6	0 and 10	18.30	13.00
Overall			18.30	10.70

The actual COE (without sensitivity analysis) is compared to COE (with sensitivity analysis) shown in Table 2. Observations from Table 2 the huge reduction in COE is INR 10.70/kWh from 18.30 /kWh due to overall sensitivity analysis. The next highest reduction in COE is INR 11.70/kWh to INR 18.30/kWh. The final result from the application of sensitivity analysis in diesel price is leads to increase the COE. The final outcome from this section except the diesel price, all other variables like solar irradiation, wind speed, interest rate is given in reduction of COE.

X. CONCLUSION

Sensitivity variables are evaluated on these parameters to verify how variances in this load would change standalone wind/PV/diesel/battery hybrid system costs and optimal system configurations, and also was found to have very huge significant impact on OST configurations, although slightly less fuel was consumed on a yearly basis.

The result eventually shows that benchmark system has almost 75% times higher COE where the COE came out of all sensitivity value. Important proof exists in increase of the COE by sensitivity analyses in diesel price. Final conclusion from this section is that COE has significant decrease by sensitivity analyses.

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