Implementation of Solar and Wind Technology based on Social Impact on Investment Decision Making Tool

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***Abstract*— Since the start of the new millennium, Renewable Energy Technology has been considered harmless, clean and free. On the other hand, Non-Renewable Energy Sources are perceived as the only hostile technology to the environment without focusing on the detrimental effect of Renewable Energy Sources. It is, therefore, important to evaluate the social impacts of solar and wind technologies and decide on the net social benefit before utilization. This will ensure sustainable utilization while maintaining the quality and availability of natural resources for current and future generations. For a suitable decision from the proposed tool, there is need to interrelate resource cost and social effects of solar and wind technology to the environmental and economic impacts. This will improve the judgment on whether or not to deploy the technology depending on the net social benefit to the community. The tool is developed using Modified PowerSizing model and simulated based on the proposed Improved Strength Pareto Evolutionary Algorithm on MATLAB environment. The proposed results for this research hope to demonstrate the social impacts of solar and wind technologies and effectively make the decision on the viability of deploying the technology as per the Environmental Impact Assessment regulations provided by UNEP in the 2018 – 2021 medium term strategy. In conclusion, the proposed Social Impact on Investment Decision Making Tool (SIIDMT) will be useful in providing prior advice to the technical team on whether or not the implementation of the solar and/or wind should be carried out. A valid SIIDMT should be more than or equal to 50 percent.**

Keywords—Social Impacts, Solar-and-Wind Energy, SIIDMT, Power Sizing Model, SPEA2

I. Introduction

Conservation of natural resources necessitates a better utilization in the current world. According to oxford dictionary, utilization can be defined as an effective and practical action of using something. Environmentally friendly and economical energy implementation of Renewable Energy (RE) employment is decided properly by selection of type of energy, which suitably utilizes the air, water, land and energy resources. Before taking action, especially concerning wind and solar energies, a detailed study of the social impacts and resource costs, with fuel costs as the constraints, should be conducted.

In order to identify the effects, negative and positive impacts on environment, people and property, this paper considers a critical examination of Environmental Impact Assessment (EIA) [1] [18]. A well outlined scope and terms of reference are made before carrying out the proposed research. Gathering of baseline information is conducted and an implementation decision is reached at the final stage. This processes necessitates a decision making tool to achieve compact results.

Other than exploring the social impacts, the instructor resource, that is, the Social Impact on Investment Decision Making Tool (SIIDMT), advices the relevant authorities and experts on the decisions made about the social issues. On the other hand, aspects of materials and energy resources are explored by Modified Power Sizing Model. The proposed tool, that is, SIIDMT, makes decisions for the concerned parties and energy experts.

The proposed SPEA2 (Improved Strength Pareto Evolutionary Algorithm) is improvised and utilized for the optimization.

A. Contribution

Due to the notion that wind and solar as renewable energies, are freely available, there has been a rapid growth in the development and utilization of the two RE generation technologies, as compared to non-renewable and other renewable energy technologies. This growth has generally disregarded social impacts while rampantly implementing and utilizing these technologies. In order to aid in this decision making before RE utilization, the SIIMDT is required. Apart from availing the resources to future generations, the tool will ensure proper utilization of human and natural resources, once it is deployed.

B. Paper Organization

The remaining part of the paper is organized as follows: Section II is the Literature Review, Section III carries the Problem Formulation, Section IV is the Proposed Methodology, Section V is the Presentation of Results and Analysis, while Section VI is the Conclusion and Recommendations for further work. Finally, there is a list of references used.

II. Literature review

Moses Peter Musau, et al (2017) [2] proposed an Environmental Decision Making Tool for Renewable Energy (EDMTRE) with the resources cost as constraints. The authors used the midpoint indicators of the Modified ReCiPe version 1.3 model to indicate the negative environmental impacts while the more accurate cubic cost function was used to model the positive impacts on health and ecosystem. In addition to health and ecosystem, the proposed research also looked into reduction of emission. It was concluded that, with resource cost as a constraint, the determination of optimal environmental benefits is accurate. The findings indicate that the adverse effects of wind are four times less than those of solar. However, no research has been done on resource cost using the end-point indicator and no social aspect has been considered in the development of EDMTRE.

P.A. Leicester, et al (2013) [3] used the Bayesian Network, to develop a socioeconomic and environmental tool for modelling solar PV to reduce the deficits in the energy needs of England. The network predicted the energy generation levels per unit area estimating levels of Carbon (IV) Oxide reduction; based on the solar PV technology used. The project involved home based solar PV installations in England. Though the project met the needs of the energy sector by installing the PV cells on the rooftops, the installations meant the environmental impact was never determined as the small-scale installations never helped determine if any birds would be killed and how many, the effect on the ecosystem, were the PV cells installed on a broad solar farm and also the scaling of the land needed to generate a given amount of solar energy. It also could not determine the number of employment opportunities that would, in the long term, be created were a solar farm been the option implemented.

A.K. Akella, et al (2009) [4] employed the Renewable Energy Technologies such as biomass; used municipal waste in India to generate electricity, solar PV, wind and small hydroelectric power generation. The authors determined socioeconomic and environmental impact of these energy sources through the determination on the levels of CO_2 emission from each of the sources for a given size of a renewable energy power plant. The study however fell short of determining the cost of land as a direct impact of setting up RE power plants and also the impact on the ecosystem by these RE power plants.

E. Ariel Bergmann, et al (2007) [5] studied the effect of the choice policy in Scotland on the use of a preferable source of energy by people against anticipated socioeconomic and environmental effects of Renewable Energy Technologies. As a consequence, an extra £53.71 is paid by the community per hour to curb effects on the ecosystem such as wildlife deaths and the loss of land's aesthetic value as a result of the use of a wind turbine. However, the issue of resource costs of renewable energy technologies in Scotland was not addressed as it was not within the scope of the study.

Positive and Negative Social Effects of Wind and Solar [6 – 12]

Positive: Wind farms are normally set up in areas outside densely populated zones such on hilltops and other raised grounds thus do not disrupt the social order or displace the population.

The wind farms provide a lot of employment opportunities during the stage of setting them up as well as when it is running and during maintenance.

Some of the wind farms become tourist attraction zones and thus open up the areas to greater investment and also integrate the local community and tourists.

The installation of solar farms results in creation of employment for many people both in solar cells industries as well as at the solar farms themselves. This improves their quality of life and spurs economic growth

Negative: Setting up the wind farms leads at times to destruction of recreational sites as they are normally on hilltops used for hiking. They are also archaeological sites thus it leads to destruction of historical artifacts and historical areas.

People living on hilly areas are displaced and migrated leading to congestion and social disputes.

There is displacement of people to pave way for solar farms thus disrupting social order.

Power Sizing Model

Renewable energy economic analysis refers to the analysis of the cost of power generation using renewable energy and the economic benefits that it gives to its users relative to other sources of energy. Depending on the size of the intended renewable energy project, provided the energy resources are sufficient, the estimates may be detailed or semi-detailed but the economic benefits, as analyzed, should be more than the cost of setting up the project in totality else the project would be rendered economically unviable.

Using the PowerSizing model, the cost of setting up a power plant can be determined by determining the cost of equipment and the scale of the size of the desired power plant non-linearly using the PowerSizing exponent, x, since the size of power plant to generate twice the amount of electrical power must not necessarily be twice the size of the other power plant. The PowerSizing model formula is [13]:

$$\frac{Cost\ of\ Equipment\ A}{Cost\ of\ EquipmentB} = \left(\frac{Size\ of\ Equipment\ A}{Size\ of\ Equipment\ B}\right)^X \quad (1)$$

Where $0 < X < 1$ is the PowerSizing exponent provided by equipment manufacturer while A is the equipment in the new power plant whose cost is being estimated and B is the equipment in the old power plant used as a point of reference. The units for the size of equipment should be the same. If the cost of an equipment known was about n years ago, the current cost can be determined as follows using the cost index:

$$\frac{equipment\ cost\ today}{equipment\ cost\ n\ years\ ago} = \frac{cost\ index\ value\ today}{cost\ index\ value\ n\ years\ ago} \quad (2)$$

III. Problem Formulation

First there is need to determine the Initial Cost of Investment (ICOI). This formulation considers variable cost (labor, direct materials) and fixed cost (capital equipment cost), which is given by equation (3), modified from equations (1) and (2).

$$\mathrm{ICOI_{new}} = \frac{\mathrm{CI_t}}{\mathrm{CI_n}}\left(\frac{\mathrm{AR_{new}}}{\mathrm{AR_{exist}}}\right)^{\mathrm{x}} \mathrm{ICOI_{exist}} \quad (3)$$

Where, $\mathrm{ICOI_{new}}$ is the optimized new initial cost of investment ($) for wind and/or solar PV, $\mathrm{CI_t}$ is cost index value today, $\mathrm{CI_n}$ is the cost index value n years ago, $\mathrm{AR_{new}}$ is the amount of new resources (kWp), $\mathrm{AR_{exist}}$ is the amount of existing resources (kWp), $\mathrm{x} = [0\ 1]$ is the PowerSizing exponent provided by resource manufacturer and $\mathrm{ICOI_{exist}}$ is the estimated existing initial cost of investment.

Using the ICOI calculated, we go ahead to develop the SIIDMT. SIIDMT is a tool that identifies the effectiveness of capital and other resources utilization of a project towards creating value for the community in terms of environmental, social and economic impacts. In measuring SIIDMT, the following elements are considered: cost of resources invested, project outputs, that is, final products including trained human resource within the community, outcomes in terms of improved standards of living or new jobs created within the community and net impact to the community resulting from the project.

The SIIDMT is formulated as:

$$SIIDMT = \frac{SIV - ICOI}{ICOI} X\ 100\% \qquad (4)$$

Where; $SIIDMT$ is the social impact on investment (%), $ICOI$ is the initial cost of investment ($) and SIV is the social impact value given by equation (5).

$$SIV = \frac{P_O X P\{P_O\} X P_I}{P_C} \qquad (5)$$

With P_O being project outcome ($), $P\{P_O\}$ is the probability of the project outcome, P_I is the philanthropic investment ($) and P_C is the project total cost ($).

This tool is subject to solar and wind fuel constraints [2, 14 - 15]

$$SCF \geq F(pv_{ji}) + F_{pv,p,i}(pv_{ji,avg} - pv_{ji}) + F_{pv,ri}(pv_{j,i} - pv_{j,i,avg}) \qquad (6)$$

In which SCF is the solar cost function, $F(pv_{j,i})$ = representation of solar irradiance cost constraint in a weighted cost function, $F_{pv,ri}(pv_{ji} - pv_{ji,avg})$ = cost requirement for penalty reserve since the scheduled solar power is more than available power and $F_{pv,p,i}(pv_{j,i,avg} - pv_{j,i})$ = penalty cost for failure of consuming the total solar PV available.

Where, $F(W_{j,i})$ is the jth wind generator scheduled output for the ith hour, $F_{W,ri}(W_{ji} - W_{ji,avg})$ is the cost requirement for penalty reserve since the scheduled wind energy is more than available energy and $F_{W,p,i}(W_{j,i,avg} - W_{j,i})$ is the penalty cost of failing to consume the total wind energy available.

$$WCF \geq F(W_{ji}) + F_{W,pi}(W_{ji,avg} - W_{ji}) + F_{W,ri}(W_{ji} - W_{ji,avg}) \qquad (7)$$

Where, WCF is the wind cost function, $F(W_{j,i})$ is the j^{th} wind generator scheduled output for the i^{th} hour, $F_{W,ri}(W_{ji} - W_{ji,avg})$ is the cost requirement for penalty reserve since the scheduled wind energy is more than available energy and $F_{W,p,i}(W_{j,i,avg} - W_{j,i})$ is the penalty cost of failing to consume the total wind energy available.

$$TCF = \{a_{0i} + \sum_{j=1}^{L=3} a_{j,i} P_{ti}^{j} + \varepsilon_i\} + |r_i \sin g_i(P_i^{min} - P_i)| \qquad (8)$$

Where TCF is the thermal cost function, P_i^{min} is minimum generation bound for i^{th} unit, r_i, a_{0i}, $a_{j,i}$, and g_i are the coefficients of the cost in the unit i^{th} and ε_i is the i^{th} equation error.

Where $SIIDMT^{max}$ is the maximum Social Impacts on Investment which should be 100%. Ideally, this can only be achieved when the Initial Cost of Investment is twice the Social Impact Value.

Other constraints include:

$$0 < SIIDMT \leq SIIDMT^{max} \qquad (9)$$

Where $SIIDMT^{max}$ is the maximum Social Impacts on Investment which should be 100%. Ideally, this can only be achieved when the Initial Cost of Investment is twice the Social Impact Value.

$$\text{ICOI}_{\text{new}} \geq \text{ICOI}_{\text{exist}} \text{ if } CI_t > CI_n$$
$$\text{for AR}_{\text{new}} \geq \text{AR}_{\text{exist}} \qquad (10)$$

In order to minimize the resource cost, the new resource cost (variable and fixed) should be less than the existing resource cost for the same size of projects in line with fuel cost constraints.

IV. Proposed Method

This research proposes Improved Strength Pareto Evolutionary Algorithm (SPEA2). The Strength Pareto Evolutionary Algorithm is useful in optimizing both negative and positive social effects and improving the solution from it. The uncertainties of Wind and Solar are also considered.

SPEA2 is an extension of SPEA which is an Evolutionary and a Multiple Objective Optimization Algorithm. The SPEA has an objective of locating and maintaining a front of non-dominant set of Pareto Optimal solutions. The achievement of this is realized by using the evolutionary process (which explores the search space) and a selection process. The selection process uses a combination of the level in which candidate solution is dominated and the density of the Parent front estimation as an assigned fitness. A population of candidates and an Archive of the non-dominant set are separately maintained. This provides a form of superiority (elitism) [16].

As opposed to SPEA, SPEA2 has an improved scheme of fitness assignment. In this scheme, each individual is taken into consideration to know the number of individuals it dominates or dominate it. Besides, there is incorporation of the nearest neighbour density estimation method. This allows for the guidance of the process of searching to be more precise. Finally, SPEA2 employs a new archive truncation techniques where the boundary preservation results is guaranteed. However, this algorithm only considers the minimized distance to the optimal front [16].

Fitness Assignment: Each individual ***j*** is taken into account to know the individual numbers it dominates or dominate it. The quantity of solutions dominated by particular individual ***j*** in the population $\boldsymbol{P_n}$ and the archive ***A*** is assigned a value of strength ***S(j)*** given by [16]:

$$S(j) = |\{i | i \in P_n \cup A \wedge j \succ i\}| \qquad (11)$$

Where $|.|$ is the cardinal of a set, $\cup$ is the multiset union and $\succ$ is the Pareto dominance relation.

Based on the values of ***S(j)***, the individual ***j*** raw fitness $\boldsymbol{R_f(j)}$ is given by:

$$R_f(j) = \sum_{i \in P_n \cup A, i \succ j} S(i) \qquad (12)$$

This implies that the dominators strengths determine the raw fitness in both $\boldsymbol{P_n}$ and ***A***. Note that the minimization of $R_f(j)$ is to be done. For $R_f(j) = 0$ then the correspondence is taken to be a non-dominated individual and if $R_f(j) = high\ value$ then it implies that ***j*** is dominated by big number of individuals which in turn leads to dominance of many individuals. However, the raw fitness may fail if the domination of each other by the most individuals do not occur.

This problem can be solved by the additional density information.

Density Estimation, k: This is useful to discriminate between individuals with similar raw fitness values. For particular individual ***j,*** the distances involving total individuals, ***i*** in ***A*** and ***P**$_n$* are computed and kept in the list. The list is then classified in ascending order for the *t-th* element to give the distance sought, σ_j^t.

t is assigned to be the square-root of the sample size,

$$t = \sqrt{M + \bar{M}} \quad (13)$$

followed by the calculation of the density ***D(j)*** for the corresponding ***j*** as:

$$D(j) = \frac{1}{\sigma_j^t + 2} \quad (14)$$

At the end, the fitness ***F(j)*** is then calculated as the sum of the density and the raw fitness, that is,

$$F(j) = R_f(j) + D(j) \quad (15)$$

Run Time: The density estimator $(O(N^2 logN))$ dominates the run time of fitness assignment procedure. $R_f(j)$ and ***D(j)*** is of complexity of $O(N^2)$ with $N = M + \bar{M}$.

Mating Selection: The search of Pareto-optimal front is guided by the mating selection where the individuals for offspring production are selected by assignment of a pool of fitness values and individuals ***i.*** This procedure for filling the mating pool is usually randomized.

Environmental Selection: This selection decides on which individuals to keep during the process of evolution. Here deterministic selection is mostly used. In this selection, there are two cases:

i. When there is constant quantity of individuals, over time, in the archive.

ii. When the boundary conditions cannot be removed due to truncation method *(Archive Truncation).*

To get the ***new generation (offspring or new archive)*** from the individuals, ***i,*** and investigate the above two cases, the following equation is used:

$$New\ Archive, A_{n+1} = \{j | j \in P_n + A_n \wedge F(j) < 1\} \quad (16)$$

When $New\ Archive, A_{n+1} = A_n = power\ output\ A$, then there is completion of the environmental selection (case i).

When $New\ Archive, A_{n+1} < A_n$ (too small archive), then there is copying of the best $A_n - |A_{n+1}|$ dominated individuals from the previous population and archive to the new archive.

When $New\ Archive, A_{n+1} > A_n$ (too large archive), then there is invocation of procedural archive truncation. This iteratively takes away individuals from A_{n+1} until $New\ Archive, A_{n+1} = A_n$. This is achieved by taking the individual with shortest distance to another individual chosen at every stage. The tie is broken by choosing the 2nd smallest distance if there are many individuals with the least distance and so forth.

Based on the existing ICOI, using the equation 3, the optimum new ICOI is plotted as shown in Figure 1. Different cost index ratios of 1, 1.04 and 1.12 have been considered. For instance, if the existing initial cost of wind project was 5 million US dollars, the proposed new project of the same size should cost averagely million USD 5.53, 5.75 and 6.19 for cost index ratios of 1.0, 1.04 and 1.12 respectively. This implies to a percentage increase of 10.6, 15.0 and 23.8 for the cost index ratios 1.0, 1.04 and 1.12 in that order.

TABLE 1: PARAMETER MAPPING THE SIIMDT PROBLEM

SPEA2 Parameter	**Mapping to the SIIMDT Problem**
Population, P_t (input)	Project total cost ($)
Individuals, i (input)	Initial cost of investment ($) Philanthropic Investment ($)
Archive, A_t (output)	Social Impact on Investment (%)
Crossover	Link between social impact value and initial cost of investment
Mutation	Link between project total cost, philanthropic investment and project total outcome
New Archive, A_{t+1}	Newly acquired Social Impact on Investment (%)
Distance sought, σ_i^k	Probability of the project outcome [0 1]

V. Simulated Results

A. Initial Cost of Investment

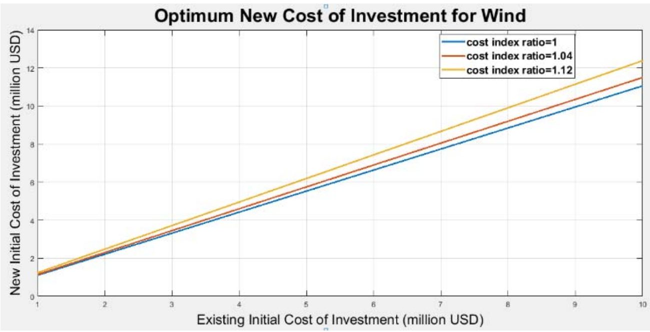

FIGURE 1: A GRAPH SHOWING OPTIMUM NEW COST OF INVESMENT FOR WIND COMPARED TO THE EXISTING COST OF INVESTMENT OF THE SAME POWER CAPACITY

Based on the existing ICOI, using the equation 3, the optimum new ICOI is plotted as shown in Figure 1. Different cost index ratios of 1, 1.04 and 1.12 have been considered. For instance, if the existing initial cost of wind project was 5 million US dollars, the proposed new project of the same size should cost averagely million USD 5.53, 5.75 and 6.19 for cost index ratios of 1.0, 1.04 and 1.12 respectively. This implies to a percentage increase of 10.6, 15.0 and 23.8 for the cost index ratios 1.0, 1.04 and 1.12 in that order.

For an investor who wants to minimize the initial cost of investment, it is advisable to invest when the inflation rate is minimum in a country, that is, when the cost index ratio is averagely 1.0 and the new cost of investment should not exceed 110.6% of the existing value of the project. Figure 1 shows the decisions that can be made on new cost based on different values of existing wind projects.

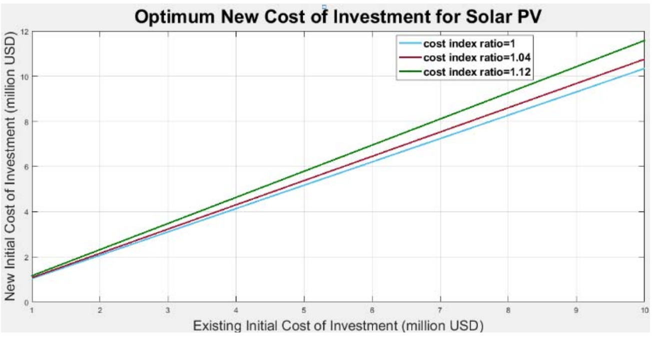

FIGURE 2: A GRAPH SHOWING OPTIMUM NEW COST OF INVESMENT FOR SOLAR PV COMPARED TO THE EXISTING COST OF INVESTMENT OF THE SAME POWER CAPACITY

Similarly, the above analysis from Figure 1 can be extended to Figure 2. For a 5 million US dollars existing project, the new initial cost of investment on solar PV project is 5.17, 5.38 and 5.79 for cost index ratios of 1.0, 1.04 and 1.12 respectively. This relates to increase of 3.4%, 7.6% and 15.8% against cost index ratios respectively. Again, here, the best option is 3.4% for cost index of 1.0.

Figure 3 shows the changes in new initial cost of investment for different cost index ratios for wind.

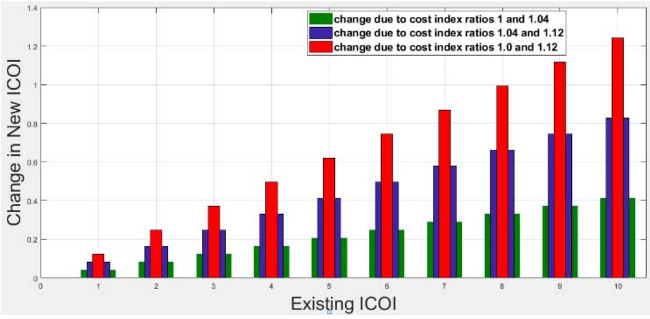

FIGURE 3: CHANGE IN NEW INITIAL COST OF INVESTMENT FOR COST INDEX RATIOS OF 1, 1.04 AND 1.12

From Figure 3, as the value of existing initial cost of investment increases, the change in value of the new initial cost of investment also increases with respect to increase in cost index ratios. Even though the trend is depicted as an increment with increase in wind costs, the percentage changes remain averagely constant as 10.50, 15.00 and 23.75% for the cost index ratios of 1.0, 1.04 and 1.12 respectively.

After making decisions on the new initial costs of investment, the cost are used to work out the Social Impact on Investment in order to make the final decision whether or not to implement the project. Here, the values of million USD 5.53, 5.75 and 6.19 for Wind project and million USD 5.17, 5.38 and 5.79 for solar PV project are used. The figures for SIIDMT are depicted in the following part *B*.

B. Social Impact on Investment Decision Making Tool (SIIDMT)

From the values of new ICOI of wind project stated above, the social impact on investment is simulated. It is observed that these investment costs have no effect on social impacts therefore we have just picked million USD 5.53 for illustration and analysis of SIIDMT. The graph of SIIDMT against probability of project outcome is shown in figure 4.

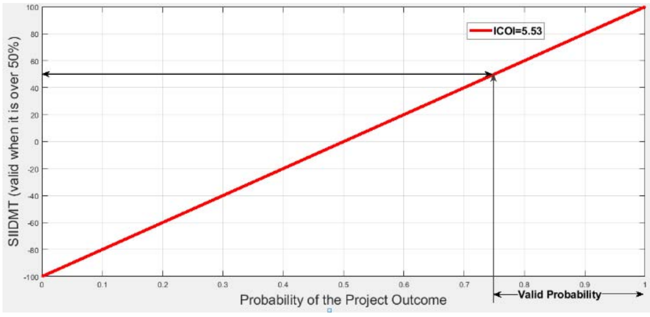

FIGURE 4: A GRAPH OF SOCIAL IMPACT ON INVESTMENT DECISION MAKING TOOL VERSUS THE PROBABILITY OF PROJECT OUTCOME

For a project to be valid as a project that is having positive impact to the community, at least the positive social impact on investment should be 50 percent. This implies that, from Figure 4, the probability of the project outcome should not be less than 0.75. This shows that at least the community should benefit directly from the project 75 percent more than other people who may be directly involved in the project.

Once the decision has been made on the portion of project outcome that should be felt directly by the community, then there is need to know the value of philanthropic investment before assigning this value to various investments like school support, hospital support, setting up of recreational facilities among others. This, here, we call it indirect community support from the project. The decision on indirect community support is illustrated in Figure 5.

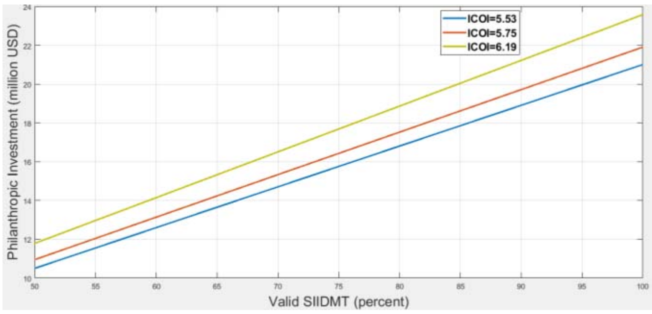

FIGURE 5: A GRAPH SHOWING PHILANTHROPIC INVESTMENT BASED ON VALID SIIDMT

From Figure 5, the value of philanthropic investment is evidently affected by the initial cost of investment. Large investments will require an investor to hugely invest philanthropically. The minimum cumulative amount to be philanthropically invested is million USD 10.50, 10.95 and 11.79 and the maximum amount is twice the minimum amount (21.00, 21.90 and 23.58) for optimum new initial cost of investment of million USD 5.53, 5.75 and 6.19 respectively. The valid minimum cumulative value of philanthropic investment is therefore at least 90 percent more than the initial cost of investment and should not exceed 380 percent of the initial cost of the project.

VI. CONCLUSION

Before putting a wind or solar project, the investor need to consider the following:

i. Optimum initial cost of investment based on the existing cost of investment. This cost is optimized based on the best choice of power sizing exponential. For wind is it 0.45 and solar PV it is 0.15.

ii. The optimum initial cost of investment is used to calculate the social impact on investment but it has no effect on the direct impact of the project to the community, that is, the probability of project outcome. The valid SIIDMT is above 50 percent which is given by probability of project outcome of 0.75.

iii. Once the SIIDMT passed the valid test, an indirect project impact (philanthropic investment) is investigated. This cost should be cumulatively more than 90 percent of the ICOI but not exceeding 380 percent of ICOI.

Further works need to investigate emission levels of these two technologies (solar PV and wind) and consider the impacts these sources of energy have on health and ecosystem. From emission level, social impacts, health and ecosystem effects, a net economic value of the project need to be investigated and an overall tool should be modelled.

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