Development of Techno-Economic Modelling tool for Solar for quantifying their Environmental Impacts

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***Abstract*—**Global attention has always focused on pollution and depletion of fossil fuels associated with the conventional energy sources while the non-conventional energy/renewable energy sources have always been considered clean and environmentally friendly. Renewable energy technologies (RETs) has a great potential in providing energy with sustainability to the wide populations especially in the poor countries of the African continent where grid access is impractical because of the sparse population and the existence of the rugged terrain. Paradoxically, despite being branded economically viable and clean, RETs have not been able to realize their full potential in many parts of the world especially in the African continent. The slow deployment of RETs across the globe such as wind and solar is associated with some environmental impacts such as use of large tracts of land which would otherwise be used for other economic activities for revenue generation such as agriculture, archaeological sites, forests etc. Models previously developed for technical and economic analysis of RETs such as HOMER, HYBRID2 and HOGA are able to give valuable insights but their limitations and inconsistencies fail to achieve a complete mathematical model that fully encapsulates and quantifies the environmental impacts of RETs with their significant uncertainty. The primary contribution of this paper is the development of a decision-making tool based on probabilistic modelling approach which permits for quantification of environmental impacts of RETs in order to evaluate the indirect cost while generating energy from them.

***Keywords*—**Homer, Environmental impacts, LCOE, RETs

I. Review of existing techno-Economic Tools

The immediate and future challenge has been and will always be meeting the energy needs of the ever-growing populations at the least cost possible, without affecting the environment and human health. To assess the viability of the energy resources before the power plant is constructed, techno economic assessment tools are used to estimate the performance of the plant, the likely pollutants that the plant will emit, the overall cost of the power plant and the ultimately the unit cost of power to determine the feasibility of the plant. Many of these tools use the levelized cost of energy (LCOE) as a comparative metric for assessing different energy power plants in relation to their lifetimes, cost structures, and capacity factors from an economical perspective[1]. LCOE is used by power producers as a utility factor to estimate the cost of power produced by any power plant[2]. The calculations to arrive at this factor takes into consideration all the expected lifetime costs of the power plant that includes all taxes, cost of fuel, capital expenditure for the project, incentives in the form of grants, inflation rate, Operations and Maintenance costs and insurances, divided by the discounted energy production from the power plant[2]. The LCOE of power generation plants can be high or low. A low LCOE indicates a low unit cost of energy while a high LCOE indicates a higher unit cost of energy. In numerical form, LCOE can be expressed as Equation (1)

$$LCOE = \frac{C_a}{P_a} \quad (1)$$

Where P_a is the annual power output in kWh.
C_a is the equivalent annual lifecycle cost of the power plant given by Equation (2)

$$C_a = (C_{cap} + C_{pe})[\frac{i(1+i)^N}{(1+i)^N-1}] \quad (2)$$

Where C_{cap} is the cost of the machinery, land, construction and installation, testing and commission of the plant and C_{pe} is the cost additional to the capital cost to find out the total present value of cost over the lifetime of the power plant.

Techno-economic analysis of power generation systems gives great insights into the economic viability of the power system to be designed and constructed. Due to the great importance of these tools in modeling, simulation and techno-economic analysis, there has been a number of studies that have attempted to assess the capability of these tools. These evaluations have reviewed the features of the techno-economic tools with each of these tools having unique features tailored to meet specific objectives in techno-economic study of power generation systems[3]. Connolly *et al.*, 2010 has reviewed 68 techno-economic tools based on their capabilities to simulate, create scenarios, create equilibriums, carry out top-down analysis, carry out bottom up analysis, optimize operations and optimize the energy investments. It was concluded that the wide range of these tools in use differ significantly in terms of the regions they analyze, the technologies they consider, and the objectives they fulfil[4]. A good techno-economic assessment of the tools can be realized easily by looking at their typical applications.

Among these tools employed for techno-economic analysis are the Hybrid Optimization for Modeling Electrical Renewables (HOMER) , RETScreen Expert, SAM, Aeolius,

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EnergyPLAN, EnergyPro, MARKAL/Times, ETEM, Modest, Sifre, LEAP, BCHP Screening Tool, HYDROGEMS, and TRNSYS16 and many more[3][5]. There are quite a number of software tools that can be used to optimize and simulate energy systems[5]. HOMER and RETScreen are the most popular Techno-Economic tools. HOMER has the capacity of simulating and optimizing renewable power systems in standalone or grid linked configurations the purposes of determining the cost effectiveness of the power plant[3]. This tool can be used to evaluate stand-alone power generation systems as well as grid connected systems in remote areas, islands and buildings to summarize their environmental, technical and economic benefits with a main objective of minimizing Net Present Costs (NPC)[3][5]. Homer optimizes the system components of the power system to provide energy cost but does not look at all the costs associated with civil and structural work, installation and operation[5]. RETScreen is a project analysis and decision support tool developed by Natural Resource Canada. Salehin *et al.*, 2016[5] used, HOMER andRETScreen, the two most favorite modeling softwares to model and simulate a hybrid energy system to assess the cost effectiveness of these HES in electrical power production. Salehin *et al.*, 2016 employed homer to optimize the HES components, LCOE and RE penetration into power systems. In this paper, necessary information was provided for identification of appropriate energy tool for various energy systems under different study objectives.

I. PREVIOUS WORK

A. *Power generation technology assessment tools and methods*

There exist several economic and financial indicators used to determine the financial worthwhile of different energy systems. These methods combine the capital costs, operation and

Table1: Power Generation Technology Assessment Tools and Methods[6]

Financial analysis	Impact analysis	Systems analysis
Life cycle cost analysis	Damage cost approach	Systems dynamics
Levelized cost of electricity	Abatement cost approach	System optimization technique
Simple payback period	Benefit transfer technique	Linear programming
Discounted payback period	Simple unit transfer	Integer programming
Internal rate of return	Meta-analysis	Dynamic programming
Modified internal rate of return	Benefit function transfer	Energy systems analysis models
Net present value	Life cycle assessment	HOMER RET Screen software
	Hybrid LCA	
	Environmental impact assessment	MARKAL EnergyPLAN
	Ecological impact assessment	
	Health impact assessment	
	Social impact assessment	

maintenance costs, fuel costs and the energy output which when computed provide the necessary metrics which are indicators of project viability [7][8][9]. As shown in Table 1 above, these methods are classified into three main categories which are financial analysis methods, impacts analysis methods and the systems analysis methods[10][6]. In the following section economic performance indicators are discussed.

I. *Simple payback period*

One of the most commonly methods to determine the economic viability of a project is by use of the payback period. It is a ratio of the extra costs to the annual savings as shown by equation (1).

$$simple\ pay\ back = \frac{extra\ \cos ts\ \Delta p\ (\$)}{annual\ savings\ S\ (\$/yr)} \quad \mathbf{(1)}$$

The advantage of the simple payback period method is that it is simple and easy to understand, but the disadvantage is that it has one of the least convincing ways of presentation of the economic viability of projects. This method is also considered as one of the most misleading ways since it does not include the lifespan of the project [8], [9]

II. *Initial (simple) rate of return*

As shown by equation (2), the initial rate of return is inverse of the simple payback period, as it is defined as the ratio of the annual savings to the extra initial costs.

$$initial\ rate\ of\ return = \frac{annual\ savings\ S\ (\$/yr)}{extra\ \cos t\ \Delta p\ (\$)} \quad \mathbf{(2)}$$

If the lifetime of the project is long enough, the initial rate of return is considered a good indicator of the true value of the investment [9][8]

III. *Net present value*

It is the difference between the present cash inflows and the present cash outflows. NPV is typically used to analyse the profitability of an investment. The present value of all the costs, that is, present and future costs are called the life cycle costs of the project under investigation. If choice is to be made between two investments, a comparison is done between their respective life cycle costs. The difference between the life cycle costs is the NPV. NPV is calculated using equation (3) below.

$$NPV = \sum_{t=1}^{T} \left\{ C_t / (1+r)^t \right\} - C_0 \quad \mathbf{(3)}$$

Where

C_t is the net cash inflow during period t, C_0 total initial investment cost, r is the percentage discount rate and t is projected lifespan of the project. Since most projects are built for profit making, a negative NPV would indicate a loss [9][8].

IV. Internal rate of return (IRR)

This metric is used in capital budgeting to measure the profitability of a project. IRR is a discount rate required to make the NPV equal to zero. The formulae for IRR is shown below by equation (4).

$$0 = P_0 + \frac{P_1}{(1+IRR)_1} + \frac{P_2}{(1+IRR)_2} + \dots \frac{P_n}{(1+IRR)_n} n \quad \textbf{(4)}$$

Where P_0, P_1, P_2, P_n represents the cash flows in years 0,1,2... n

V. Levelized cost of Electricity (LCOE)

The levelized cost of a resource is defined as a constant cost per unit of generation which is computed to compare the cost of generation of one unit with other types of generating resources over a similar lifespan with similar operational profiles and system value [9]. It is an economic assessment of the cost of energy generating system that includes all the life cycle costs. The life cycle costs that are included in almost all LCOE calculations are the capital costs, fuel costs, fixed and variable operations and maintenance costs, financing costs, and the assumed capacity factor [11]. LCOE can hence be defined by equation (5) below [9][7].

$$LCOE = \frac{Total\ life\ cycle\ \cos ts}{Total\ life\ time\ energy\ production} \quad \textbf{(5)}$$

LCOE is a representation of the cost of electricity that would equalize the cash flows, that is, the inflows and the outflows which is usually normalized over a certain period of time and allows the IPPs to fully recover all the costs over a predetermined financial lifespan [9][12] . It is mainly applied in many different evaluative purposes such as utility resource selection, dispatch decisions, electricity pricing, energy conservation programs, R&D incentives, subsidy determination and environmental planning [11]. LCOE is usually determined at the point where the sum of all the discounted revenues equalizes with the sum of all the discounted cost as described by equation (6).

$$\sum_{t=1}^{T} \frac{R_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \quad \textbf{(6)}$$

Where R_t is the revenue generated for period t, C_t is the sum total of costs incurred for period t. Considering that

$$R_t = LCOE_t * E_t \quad \textbf{(7)}$$

Where E_t is the amount of energy generated for period t, equation (8) becomes

$$\sum_{t=1}^{T} \frac{LCOE_t * E_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \quad \textbf{(8)}$$

Which yields LCOE equation (2.12) below

$$LCOE = \left\{ \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \right\} \Big/ \left\{ \sum_{t=1}^{T} \frac{E_t}{(1+r)^t} \right\} \quad \textbf{(9)}$$

1) Aspects not covered by the LCOE

In the calculations of the LCOE some aspects such as externalities, system costs, technology types and the input data are not captured [13] .The externalities as mentioned earlier are cost and benefits that do not accrue to the parties involved. They include damage from air pollution, energy security, transmission and distribution costs and the environmental impacts. The environmental impacts are the impacts of energy systems on the ecosystem and human health. LCOE can only be accurate as the input data is; however, this is not the case since the input data is deterministic in nature. If the input data is converted to distributions of a stochastic nature, it will yield a more representative LCOE calculation [13].

This paper seeks to develop an economic decision-making tool which fully incorporates the variability of the environmental impacts of RETs, variability of the solar and wind resources together with some key cost parameters including the uncertainty associated with their respective energy models estimates and cost data. Incorporation of the environmental impacts of RETs in the cost modelling tool will permit for cost accounting evaluation of the indirect cost incurred while using RETs for electricity generation which will further guide investors in the approximation of their economic viability. The following section discusses the steps followed in modelling and the realization of the modelling tool 'Ecosystem'. In the following section, the methodology followed in this paper is discussed.

B. Methodology

The economic model suggested in this research work will do the site selection considering the resource availability and the conceivable environmental impacts as shown by the flowchart in Figure 1 below.

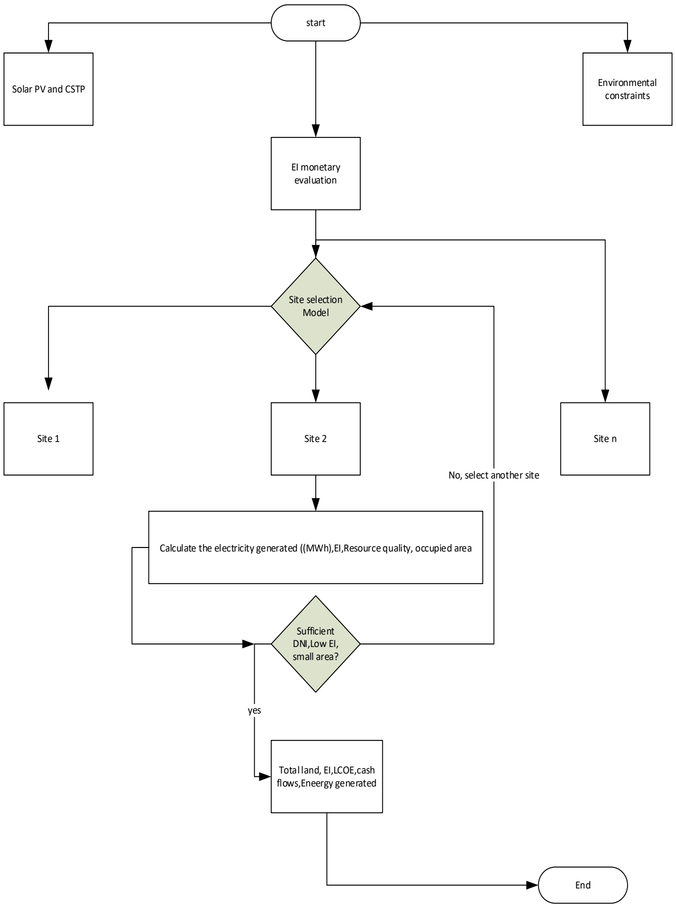

Figure 1: Flow Chart for Site selection criteria

A. ECONOMIC MODEL

The main block diagram of the proposed economic decision making tool with renewable energy Technologies (EDMTRE) is shown in Figure 2. The simulation program model which was implemented in SQL will do the computation of the total system output which includes LCOE, Net present cost, cash flow, internal rate of return, environmental impacts, energy output etc. This approach provides a more robust method of projection of these output parameters than can be offered by single point values as used in deterministic approach.

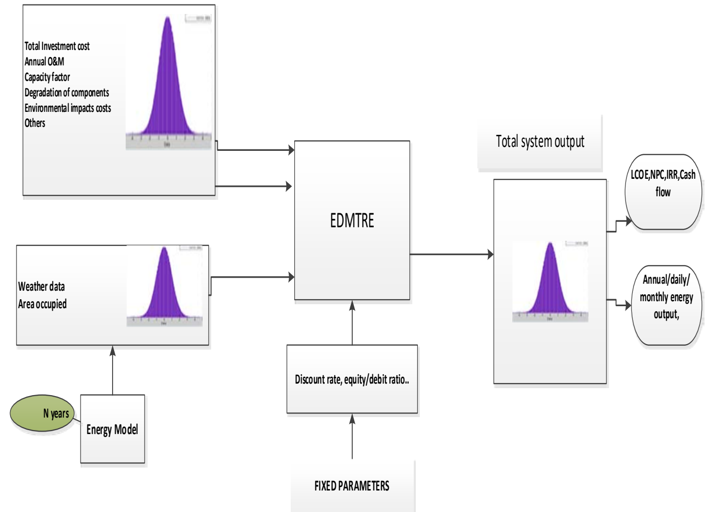

Figure 2: Economic Model

LCOE which has been applied in almost all USSE modelling is as shown in equation. This equation does not take care of the environmental impacts of renewable energy technologies and therefore does not reflect the true cost of electricity.

The LCOE is calculated for each year using the levelized lifetime cost methodology since it is considered as one of the most important indicators of financial viability of power generating systems. According to this methodology, the levelized lifetime cost per unit of electricity generated is the ratio of the life time cost and expenses versus the total expected lifetime energy output [14]. This methodology has been applied instead of the other traditional methods such as Net present value analysis, initial rate of return, internal rate of return among others, as it transforms the investment and the lifetime series of expenditures and incomes in the time span of the investment to equal annuities discounted in the present value [14]. This method hence allows for a fair comparison of electricity generation cost even for power plants that were installed in years close to the boundary of the time-period under examination whereas traditional NPV analysis fails to give reliable results as only the lifetime is considered.

Using the first principles, LCOE is defined as shown by equation (10).

$$LCOE = \frac{Total\ \ life\ \ cycle\ \ \cos t}{life\ \ time\ \ energy\ \ production} \quad (10)$$

The summation of the net present value of the cost of electricity (LCOE) multiplied by the total amount of energy generated should be equivalent to the net present cost (NPV). The input and output cash flows are defined by equations (11) and (12).

$$cash\ \inf low = \frac{\sum_{t=1}^{T} E_t * COE}{(1+r)^t} \quad (11)$$

$$cash\, outflow = \frac{\sum_{t=0}^{T} C_t}{(1+r)^t} \quad (12)$$

Where r = % discount rate

E_t = amount of Energy generated in year t

C_t =annual cost of energy for year t

As indicated in equation (12) the summation starts from t=0 to incorporate all the costs incurred at the beginning of the project. COE is therefore a time –dependent as defined by equation (11) while $LCOE$ is usually a constant time-independent value.

LCOE is therefore determined as the lifetime energy cost. In the life cost analysis, the breakeven point is established when the sum of the discounted revenues equals the value of the discounted costs as shown in equation (13).

$$LCOE = P_{elec} = \frac{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \quad \textbf{(13)}$$

The efficiency and therefore the output of the solar photo voltaic (normally referred as output degradation) reduces with time and this applies to all energy generating technologies.

The amount of energy generated in the year t (E_t) therefore equals the initial energy generated

(E_0) multiplied by the system degradation rate $(1-d)^t$. In this case therefore the amount of energy produced reduces as the solar PV ages. Equation (13) becomes

$$LCOE = P_{elec} = \frac{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_0(1-d)^t}{(1+r)^t}} \quad \textbf{(14)}$$

Where d = systems degradation rate

The main costs in any electricity generation which are hidden inside the total life cycle costs C_t as indicated by equation (15) above include the initial capital cost IC, operations and maintenance costs $O\&M$, residue value, RV and the replacement costs RC .

$$C_t = C_0 + O\&M_t + RV + RC_t \qquad \textbf{(15)}$$

These costs once enjoined in equation 3-5 above yields equation (3.7).

$$LCOE = P_{elec} = \frac{\sum_{t=0}^{T} \frac{C_0 + O\&M_t + RC_t + RV + EC}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_0(1-d)^t}{(1+r)^t}}$$

(16)

Other sub costs and constants on the main costs and energy generated include the future discount rate $_{DR}$, system degradation value SDR , loan repayment LP , return on investment ROI and are as shown in equation (3.6) below. The financial model in this research work will include the environmental cost (EC) of USSE while computing the LCOE and other metrics such as energy generated, cash flows, energy generated etc.

$\sum_{i=k}^{k} EC$: Represents the aggregated environmental impacts cost of the USSE. The impacts of USSE are discussed and modelled in the following section.

B. Quantification of land use impacts on biodiversity

Land use changes all over the world remains to be one of the greatest contributing factor to the drastic biodiversity loss and extinction[15][16]. The countryside Species Area Relationship (SAR) will be used for quantification of the number of species in the areas occupied by the USSE. The SAR model is commonly used for describing the number of species in a given location and the respective richness[15]. The SAR model is described by equation (17) below

$$S_{org} = cA_{org}^{\ z} \qquad (17)$$

Where

S_{org} =total number of species in a given area

c =constant that depends on the taxonomic group and region being studied

A_{rg} = area occupied by the USSE (transformed land)

z = A constant that depends on the sampling regime and scale

The number of species remaining after the land is transformed to another land use type , in this case energy generation from photovoltaics, is estimated by equation (18) below.

$$S_{new} = CA_{\ new}^{\ z} \qquad (18)$$

Dividing equation (18) by equation (17) yields equation (19)

$$\frac{S_{new}}{S_{org}} = \left(\frac{A_{new}}{A_{org}}\right)^z \qquad (19)$$

Multiplying equation (19) by S_{org} yields equation (20)

$$S_{new} = S_{org}\left(\frac{A_{new}}{A_{org}}\right)^z \qquad (20)$$

Subtracting equation 19) from the original number of species that existed before the land use change yields the prediction of the extinctions as indicated by equation (21) below.

$$S_{org} - S_{new} = S_{org} - S_{org}\left(\frac{A_{new}}{A_{org}}\right)^z \qquad (22)$$

In this work the z takes the values of 0.25-0.35 while c

After the conceivable damages have been identified the, restoration cost approach will be used to damage evaluation as shown in equation 23 below.

$$C \ = \sum_i V_i * X \quad \textbf{(23)}$$

Where C is the total external cost, V is the value of each external cost and X represents the number of impacts of USSE considered in a certain region.

C. Component sizing

The components used during modelling of Solar photo voltaics are Solar PV module, inverters and the battery bank. In this paper the software developed 'ECOSYSTEM', allows the user to select the different components for the solar panels, inverters and the battery bank. The user also selects the environmental impacts of the solar photovoltaic in the region selected. In the following section the aforementioned components are discussed below.

I. SOLAR PV

In order to conveniently and accurately size a PV system , the specific area, Direct Normal Irradiance (DNI) data and the anticipated load must be defined [17]. The capacity of the PV system, size and number of PV modules and the number of batteries are then calculated. As such several factors considered are the amount of energy (kWh) that can be generated by the solar PV to meet the load demand, kWh/yr generated by the PV system and the Ah of the batteries required, areaoccupied bythe system and the cost of production. The different sizing techniques reported in literature includes intuitive, numerical, analytical, commercial computer tools, artificial intelligence and the hybrid methods. In this paper numerical technique will be used for sizing of the PV array, battery bank and the inverter. This research work will use the numerical technique for sizing the PV array, batteries and the inverters because it is accurate and simple coupled with its capability of utilizing linear functions unlike other methods that are based on complex algorithms [17].

The insolation data (kWh/m^2) for the different sites considered are obtained from the NASA websites. The worst month (month with the lowest solar irradiance) of the year is used for design. Identify a PV module and use its rated current IR along with an estimated coulomb efficiency of about 0.9 and a degradation factor of 0.9 and the solar insolation of the design month. This is done to determine the Ah/day produced by each solar PV string.

$$Ah/day - string = solar\ insolation\ (kWh/m^2) * I_R * derating\ \ factor$$

(24)

The number of parallel strings is given by equation (24) below

$$Strings\ in\ parallel = \frac{design\ month\ load\ (Ah/day)}{Ah/day\ per\ module\ in\ design\ month}$$

(25)

The number of PV modules in series is determined by equation (25) below

$$modules\ in\ series = \frac{system\ voltage\ (V)}{Nominal\ module\ voltage\ (V)}$$

(26)

Figure 3 Types of Solar panels and their Parameters [18]

Module type	Sharp NE K125U2	Kyocera KC158G	Shell SP150	Unisolar SSR256
Material	Poly crystal	multicrystal	Mono crystal	Triple junction
Rated power (P_{dc})	125W	158W	150W	256W
VVoltage at max power	26V	23.5V	34V	66V
Current at max power	4.8A	6.82A	4.4A	3.9A
Open circuit voltage	32.3V	28.9V	43.4V	95.2V
Short circuit voltage	5.46A	7.58A	4.8A	4.8A
Length (m)	1.19	1.29	1.619	11.124
Width (m)	0.792	0.99	0.814	0.42
Efficiency	13.3%	12.4%	11.4%	5.5%
Capital cost ($)	525	663.6	630	1075
Derating factor	90%	90%	90%	90%
Replacement cost ($)	525	663.6	630	1075
Lifespan (years)	25	25	25	25
O&M cost($)	121.25	153.26	145.5	248.32

II. Battery bank

The different types of batteries are as shown below

Table 4: Types of Batteries and their characteristics [18]

Battery	MDOD (%)	Cycle life (cycles)	Lifespan (Years)	Efficiency %	Cost ($/kwh)
Lead acid	20%	500	1-2	90	50
Golf cart Lead	80%	1000	3-5	90	60
Deep cycle lead	80%	2000	7-10	90	100
Nickel-cadmium	100%	1000-2000	10-15	70	1000
Nickel-metal Hydride	100%	1000-2000	8-10	70	1200

$$battery\ storage\ capacity = \frac{Ah/day\ * No\ of\ days\ of\ storage}{MDOM * DR}$$

Where

$MDOM$ =maximum depth of discharge

DR =% discharge rate

III. Inverters

The different types of inverters used in this pare are as shown in Table 4 below.

Table 4: Types of Inverters and their characteristics[18]

Model Type	STXR1500	STXR2500	PV-10	SB2000	SB2500
Power (kW)	15	25	100	20	25
Efficiency [8]	92%	94%	95%	96%	94%
Capital cost ($)	1800	3000	12000	2400	3000
O&M cost ($)[19]	79.12	79.12	79.12	79.12	79.12
Replacement cost ($)	1800	3000	12000	2400	3000
Lifetime (years)	10	10	10	10	10

IV. Results and Analysis

The cash in and cash out is as shown Figure 5 and Figure 6 below. It is seen that the cash flow reduces as the plantthe end of its lifetime.

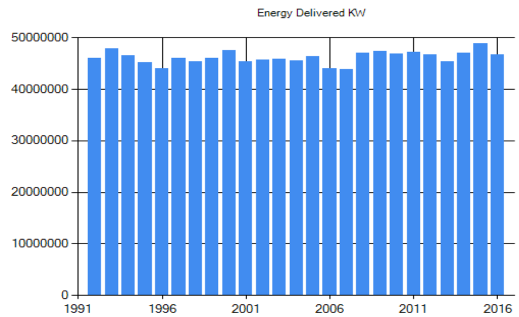

Figure 4: Energy Generated

The reason behind is that the components are aging and therefore the energy production reduces which is a function of cash flow. The LCOE was found to be 0.258 when the externalities were considered and 0.234 when the externalities were omitted.

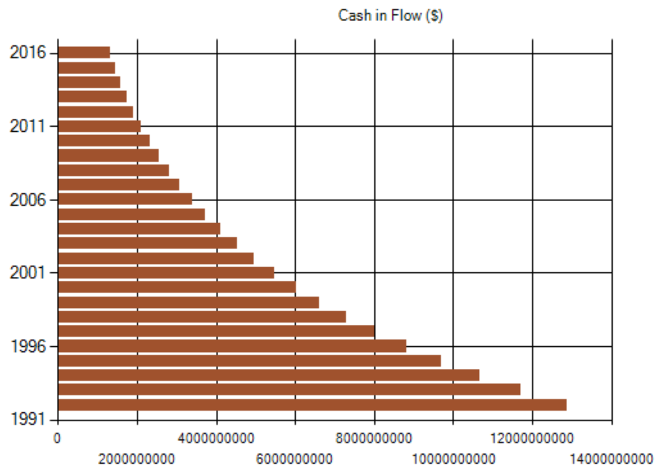

Figure 5: Cash inflow

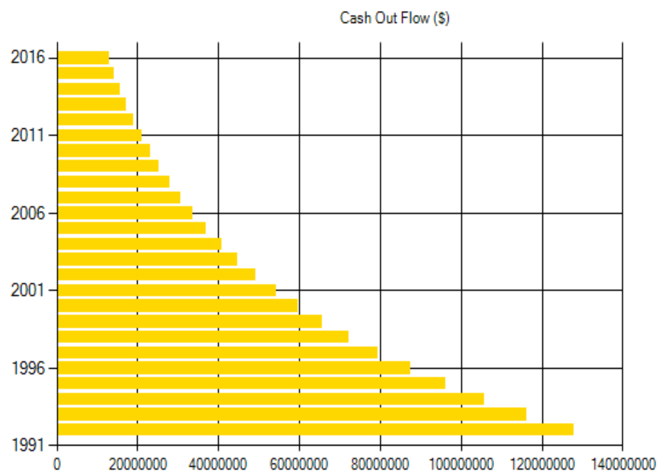

Figure 6: Cash outflow

V. Conclusions and Recommendations

The ECOSYSTEM software is able incorporate the environmental impacts in the cost modelling of solar photovoltaic. This is a very unique function of this software compared to other software's like SAM, HOMER, HOGA and others. The incorporation of the environmental, social and health impacts in the cost modelling acts as a guide to investors of solar energy. In the paper it was found that LCOE was approximately 9.3% higher when the externalities were included in the LCOE calculation. This therefore means the incorporation of externalities in the modelling may slightly increase the LCOE. Research and development should be geared towards improving the ECOSYSTEM software to accommodate more than one energy type.

REFERENCES

[1] H. Lotfi and A. Khodaei, "Levelized cost of energy calculations for microgrids," *IEEE Power Energy Soc. Gen. Meet.*, vol. 2016–Novem, pp. 1–5, 2016.

[2] S. S. Chundawat and K. V. S. Rao, "Levelized electricity cost of two grid connected biomass power plants," *2016 - Bienn. Int. Conf. Power Energy Syst. Towar. Sustain. Energy, PESTSE 2016*, pp. 1–6, 2016.

[3] W. Ma, X. Xue, and G. Liu, "Techno-economic evaluation for hybrid renewable energy system : Application and merits," *Energy*, vol. 159, pp. 385–409, 2018.

[4] D. Connolly, H. Lund, B. V Mathiesen, and M. Leahy, "A review of computer tools for analysing the integration of renewable energy into various energy systems," *Appl. Energy*, vol. 87, no. 4, pp. 1059–1082, 2010.

[5] S. Salehin, M. T. Ferdaous, R. M. Chowdhury, S. Shahid, M. S. R. B. Ro, and M. Asif, "Assessment of renewable energy systems combining techno-economic optimization with energy scenario analysis," vol. 112, 2016.

[6] N. P. Nkambule, "MEASURING THE SOCIAL COSTS OF COAL-BASED ELECTRICITY GENERATION IN SOUTH AFRICA," no. February, 2015.

[7] M. D. Sklar-Chik, A. C. Brent, and I. H. De Kock, "Critical Review of the Levelised Cost of Energy Metric," *South African J. Ind. Eng.*, vol. 27, no. 4, pp. 124–133, 2016.

[8] G. M. Masters, *Renewable and Efficient Electric Power Systems*. 2004.

[9] M. El-Shimy, *Economics of Variable Renewable Sources for Electric Power Production*. 2017.

[10] T. Management, "Review of Methods and Tools Applied in Technology Assessment Literature," pp. 5–9, 2007.

[11] M. M. Aman *et al.*, "A review of Safety, Health and Environmental (SHE) issues of solar energy system," *Renew. Sustain. Energy Rev.*, vol. 41, pp. 1190–1204, 2015.

[12] C. (United S. E. I. A. Namovicz, "Assessing the economic value of new utility-scale renewable generation projects," no. July, pp. 1–15, 2013.

[13] I. F. Roth and L. L. Ambs, "Incorporating externalities into a full cost approach to electric power generation life-cycle costing," *Energy*, vol. 29, no. 12–15 SPEC. ISS., pp. 2125–2144, 2004.

[14] A. A. Rentizelas, A. I. Tolis, and I. P. Tatsiopoulos, "Investment planning in electricity production under CO2price uncertainty," *Int. J. Prod. Econ.*, vol. 140, no. 2, pp. 622–629, 2012.

[15] A. Chaudhary, F. Verones, L. De Baan, and S. Hellweg, "Quantifying Land Use Impacts on Biodiversity: Combining Species-Area Models and Vulnerability Indicators," *Environ. Sci. Technol.*, vol. 49, no. 16, pp. 9987–9995, 2015.

[16] H. M. Pereira, G. Ziv, and M. Miranda, "Countryside species-area relationship as a valid alternative to the matrix-calibrated species-area model," *Conserv. Biol.*, vol. 28, no. 3, pp. 874–876, 2014.

[17] T. Khatib, I. A. Ibrahim, and A. Mohamed, "A review on sizing methodologies of photovoltaic array and storage battery in a standalone photovoltaic system," *ENERGY Convers. Manag.*, vol. 120, pp. 430–448, 2016.

[18] E. I. Administration, "Capital Cost Estimates for Utility Scale Electricity Generating Plants," no. November, 2016.

[19] A. Islam, F. A. Shima, and A. Khanam, "Analysis of Grid Connected Solar PV System in the Southeastern Part of Bangladesh 1," vol. 49, no. 2, pp. 116–123, 2013.