Internalization of Externalities of Utility Scale Solar Energy Using the Ecos Model

S Kibaara[1], D.K.Murage[2], P Musau [3], and M J Saulo [4]

Abstract**—**Globally attention has always been focused on the pollution and depletion emanating from fossil fuels. The non-conventional energy/renewable energy sources have always been termed as clean and environmentally benign. Utility Scale Solar Energy (USSE) has great potential in providing energy with sustainability to the wide populations especially in African countries with good solar irradiation levels but lack grid connectivity due to the sparse population and the existence of uneven terrain. The penetration level of USSE across the world lies at 15-20%. This slow deployment is attributed to the fact that these technologies requires large tracts of land, which if deployed would in turn lead to habitat fragmentation, emissions (such at particulate matter, carbon dioxide, nitrogen oxide etc), water pollution among others. The primary contribution of this paper is the development and application of a mathematical based decision-making tool (ECOS model) which permits for quantification of environmental, social and health (externalities) impacts of USSE in order to evaluate the indirect cost while generating energy from them. The model is advantageous than the traditional techno economic modelling tools such as HOMER, HOGA, INSEl, SOMES etc , as it utilizes the probabilistic approach other than the deterministic approach. The levelised externality cost of energy (LECOE) is a discounted summation of all the indirect costs incurred during the lifespan (25 years) of USSE. The levelized cost of Electricity (LCOE) will be used as an economic measuring metric to foretell the economic worthwhile of USSE projects in Kenya. The model used for simulation of a Solar photo-voltaic system in Kakuma-kenya.

Keywords**—** Externalities, LCOE, USSE, ECOS Model, LECOE

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 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 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)

$$LCOE = \frac{C_a}{P_a} \tag{1}$$

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)

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

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, 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, SAM 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

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S. Kibaara, Department of Electrical and Electronic Engineering, TUM (phone: +2540720443813; e-mail: kariukisamuel2004@gmail.com).

D.K. Murage, Department of Electrical and Electronic Engineering, JKUAT (e-mail: dkmurage25@yahoo.com).

P. Musau, Department of Electrical and Electronic Engineering, UON (e-mail: pemosmusa@gmail.com).

M.J Saulo, Department of Electrical Engineering,TUM,(Email: michaelsaulo@tum.ac.ke)

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 and RETScreen, 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.

II. PREVIOUS WORK

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 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.

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
	Hybrid LCA	RET Screen software
	Environmental impact assessment	MARKAL
	Ecological impact assessment	EnergyPLAN
	Health impact assessment	
	Social impact assessment	

A. Simple payback period

The simple pay back methods has been widely used for determination of the economic viability of projects. It is expressed as a ratio of the additional costs to the annual savings as shown by equation (3).

$$simple\ pay\ back = \frac{extra\ \ costs\ \Delta p\ (\$)}{annual\ savings\ S\ (\$/yr)} \quad \textbf{(3)}$$

The advantage of the simple payback period method is that it is simple and easy to understand, but the disadvantage is that it hard to convince investors as it does not explore all the variables of concern for 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 [12], [65]

B. Initial (simple) rate of return

As shown by equation (4), 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.

$$initial\ rate\ of\ return = \frac{annual\ savings\ S\ (\$/yr)}{extra\ \ cost\ \Delta p\ (\$)}$$

(4)

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]

C. 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 (5) below.

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

(5)

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].

D. 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 (6).

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

(6)

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

E. 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 (7) below [9][7].

$$LCOE = \frac{Total\ life\ cycle\ costs}{Total\ life\ time\ energy\ production} \quad \textbf{(7)}$$

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 (8).

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

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

$$R_t = LCOE_t * E_t \quad \textbf{(9)}$$

Where E_t is the amount of energy generated for period t, equation (9) becomes

$$\sum_{t=1}^{T} \frac{LCOE_t * E_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \quad \textbf{(10)}$$

Which yields LCOE equation (11) below

$$LCOE = \left\{ \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \right\} \Big/ \left\{ \sum_{t=1}^{T} \frac{E_t}{(1+r)^t} \right\} \quad \textbf{(11)}$$

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].

In this paper an economic decision-making tool which fully incorporates the variability of the externalities, variability of the solar together with some key cost parameters including the uncertainty associated with their respective energy models estimates and cost data. Incorporation of externalities in USSE in cost modelling will permit for cost accounting evaluation of the indirect cost incurred while using solar PV 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.

III. 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.

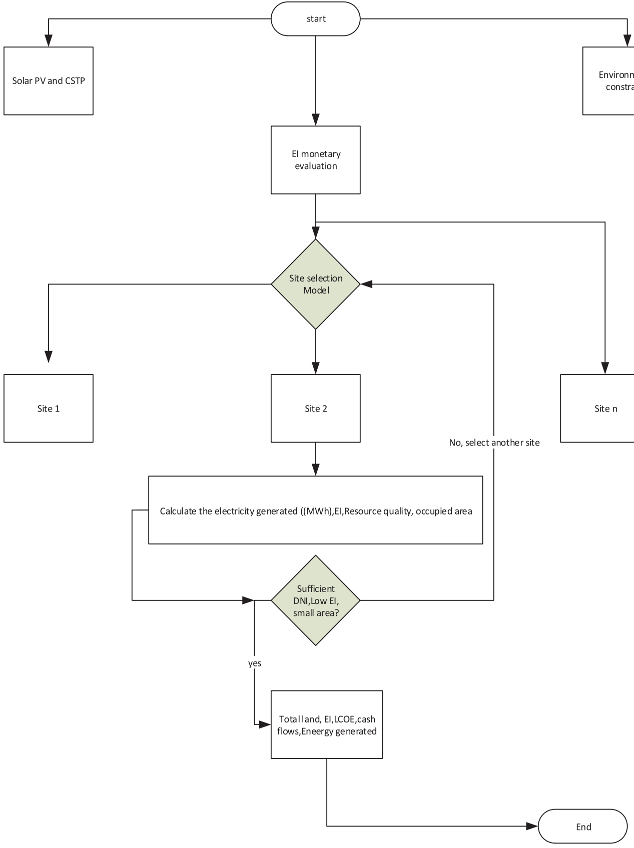

Figure 1: Flow Chart for Site selection criteria

ECOS Model

The main block diagram of the proposed economic decision making tool (ECOS model) for USSE is shown in Figure 2. The simulation program for the ECOS model was developed using Visual Basic while SQL was used for database development. The ECOS model does the computation of the total system output which includes LCOE, Net present cost, cash flow, IRR, energy output and the levelised externality cost of energy

(LECOE). This approach provides a more robust method of projection of these output parameters than can be offered by single point variables as used in deterministic approach.

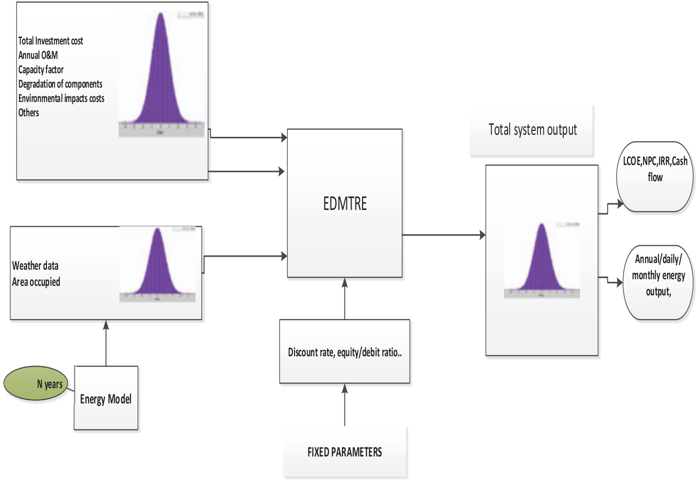

Figure 2: Economic Model

LCOE which has been applied in almost all USSE modelling is as shown in equation (12). 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 (12).

$$LCOE = \frac{Total\ life\ cycle\ \ cost}{life\ time\ \ energy\ production}$$

(12)

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 (13) and (14).

$$cash\ \inf low = \frac{\sum_{t=1}^{T} E_t * COE}{(1+r)^t} \qquad (13)$$

$$cash outflow = \frac{\sum_{t=0}^{T} C_t}{(1+r)^t} \qquad (14)$$

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 (15).

$$LCOE = P_{elec} = \frac{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \qquad \textbf{(15)}$$

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 (15) becomes

$$LCOE = P_{elec} = \frac{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_0(1-d)^t}{(1+r)^t}} \qquad \textbf{(16)}$$

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 (17) above include the initial capital cost IC, operations and maintenance costs $O\&M$, residue value, RV and the replacement costs RC.

$$C_t = C_0 + O\&M_t + RV + RC_t \qquad \textbf{(17)}$$

These costs once enjoined in equation (17) above yields equation (18).

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

(18)

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. 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, and energy generated.

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

Quantification of land use impacts on Ecosystem

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 (19).

$$S_{org} = cA_{org}^{\ \ z} \qquad (19)$$

Where

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

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

A_{org} = 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 (20).

$$S_{new} = CA_{\ new}^{\ \ z} \qquad (20)$$

Dividing equation (20) by equation (19) yields equation (20)

$$\frac{S_{new}}{S_{org}} = \left(\frac{A_{new}}{A_{org}}\right)^z \qquad (21)$$

Multiplying equation (19) by S_{org} yields equation (22)

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

Subtracting equation (21) from the original number of species that existed before the land use change yields the prediction of the extinctions as indicated by equation (23) below.

$$S_{org} - S_{new} = S_{org} - S_{org}\left(\frac{A_{new}}{A_{org}}\right)^z \qquad (23)$$

In this paper 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 perform damage evaluation as shown in equation (24)

$$C = \sum_i V_i * X \qquad \mathbf{(24)}$$

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. The international standards of ecosystem goods and services are expressed in \$/ha/year and were estimated according to Groot et al as shown in Table 2.

Table 2:Valuation of Ecosystem Goods and Services[17]

Ecosystem Goods and services	Monetary Valuation ($/ha/year)
Regulating functions of ecosystems	
1 Regulating air	7-265
2 Climate change	88-268
3Disturbing ecosystems goods and services	2-7240
4 Water uptake and usage	2-5445
5 water supply	3-7600
6 Soil erosion	29-245
7Soil maturity and formation	1-10
8 soil nutrients recycling	87-21,100
9 plants pollination	14-25
10. Biological control	2-78
Habitat provision	
11 habitation services	3-1523
12 Nursery function	142-195
Bleeding and production services	6-2761
13 food	6-1014
14Raw materials such as wood, charcoal	6-1014
15Genetics	6-112
16medicinal value	6-112

A. Accounting for human health Damages from USSE

The human damage factor (HDF) of an emission 'i'exprerssed in Disability Adjusted Life Years (DALY) per Kg emitted as shown in Equation (25).

$$HDF_i = IF_i * EF_i = IF_i * \beta_i * D_i \qquad (25)$$

Where IF_i is the intake fraction of the mass of a chemical released by USSE to the environment and taken up by human beings through inhalation, dermal exposure or ingestion expressed in kg absorbed/kg emitted as shown in Equation (26).

$$IF = IF(inhalation) + IF(ingestion) + IF(dermal) \quad (26)$$

EF_i is the effect factor which is the product of the dose response slope factor β (risk of incidence per kg intake) and of the severity D (in DALY per incidence). The effect factor (EF_i) is estimated using Equation (27)

$$EF_i = \left[\beta ED10h^{-1} * \frac{1}{BW.LT_h.N_{365}}\right].DALY_p \qquad (27)$$

Where

EF_i is the effect factor of substance I (years lost/mass intake)

$\beta ED10h^{-1}$ is the slope factor of substance i (risk per mass/kg per day) where β =0.1, BW is the body weight (kg/person); 70 kg per person, LT_h is the life time of a human beings; 70 years, N_{365} are the number of days in one year

$DALY_p$ is the Disability adjusted life years per incidence (years/ incidence). A risk factor ranging from 10^{-4} -10^{4} has been applied in this paper.

Morbidity and mortality sub model

In this section of morbidity and fatality sub model, the deaths and injuries occurring in the construction, operation and in the decommissioning stage of USSE is discussed. The work-related and non-work related accidents considered in this research are for the non Organisation for Economic Copeeration and Development countries where Kenya is classified into[102]. The per unit prices for treating persons suffering injuries or mortalities while working with USSE are based on the studies done by [103][47]. This sub model consists of two variables viz. unit morbidity value and the unit mortality value. The per unit morbidity value (UV_{mod} \$/person) is estimated using Equation (28) below.

$$UV_{\text{mod}}(t) = UV_{\text{mod}}(1804) + \Delta UV_{\text{mod}}(t) \qquad (28)$$

Where $\Delta UV_{\text{mod}}(t)$ is the change in morbidity value. The unit mortality values (UV_{mot},\$/person) in this research work were obtained from [102] and are described by Equation (29) below

$$UV_{mot}(t) = UV_{mot}(17413) + \Delta UV_{mot}(t) \qquad (29)$$

The unit mortality value and the unit morbidity value derive their costs from three phases, that is during the construction of the USSE , operation phase and the decommissioning phase. The parameters used for the fatalities/mortality and morbidity modelling are shown in Table 3 below.

Table 3: Values used for Morbidity and Fatalities sub-model

Parameter	Unit	Value
Unit mortality value	\$/person	17413
Unit Morbidity	\$/person	1804
Fatalities per million tons of concrete	Persons/million tons	0.159
Fatalities per million tons of steel	Persons/million tons	2.0158923
Fatalities per million tons of limestone	Persons/million tons	0.2906977
Fatalities per MWh	Persons /MWh	0.00000026
Injuries per MWh	Persons /MWh	0.0000001

Water consumption model

In USSE water consumption is used for mirror washing for PV and as a coolant for CSTP. It is used during the construction phase and the generation phase. The per unit cost of water use (UWC ,\$/m^3) is determined by change in the opportunity cost of water use ($\Delta UWC, \$/m^3/yr$) and is estimated using equation (30) below.

$$UWC(t) = UWC(t) + \Delta UWC(t) \qquad (30)$$

The USSE water externality cost (USSECT) is determined using two costs, that is, opportunity cost of water use during construction ($UWCC$ (\$/m^3)) and opportunity cost of water use in the generation phase ($UWCG$) shown by equation (31).

$$USSECT = OCWC + OCWG \qquad (31)$$

IV. 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.

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 [21]. 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, area occupied by the 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 because it is accurate and simple coupled with its capability of utilizing linear functions unlike other methods that are based on complex algorithms [21].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.

Table 4 Types of Solar panels and their Parameters [22]

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

This is done to determine the Ah/day produced by each solar PV string.

$$Ah/day - string = solar\ insolation(kWh/m^2) * I_R * derating\ factor \qquad (32)$$

The number of parallel strings is given by equation (33) below

$$Strings\ in\ parallel = \frac{design\ month\ load\ (Ah/day)}{Ah/day\ per\ \text{mod}ule\ in\ design\ month} \qquad (33)$$

The number of PV modules in series is determined by equation (34) below

$$modules\ in\ series = \frac{system\ voltage(V)}{Nominal\ module\ voltage(V)} \quad (34)$$

The different types of solar panels used in the database of the ECOS model are shown in Table 4 below.

Battery bank

The different types of batteries are as shown Table 5 below

Table 5: Types of Batteries and their characteristics [22]

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

$$battery\ storage capacity = \frac{Ah\,/\,day * no\ of\ days\ of\ storage}{MDOM * DR} \quad (35)$$

Where

$MDOM$ =maximum depth of discharge

DR =% discharge rate

Inverters

The different types of inverters used in the ECOS model are as shown in Table 6 below.

Table 6: Types of Inverters and their characteristics [22]

Model Type	STXR1500	STXR2500	PV-10	SB2000	SB2500
Power (kW)	15	25	100	20	25
Efficiency [8]	92%	94%	95%	96%	94%
Capital cost ($)	1800	3000	12000	2400	3000
O&M cost ($)[23]	79.12	79.12	79.12	79.12	79.12
Replacement cost ($)	1800	3000	12000	2400	3000
Lifetime (years)	10	10	10	10	10

Further the other financial parameters for the system were set in the ECOS model a shown in Table 7.

Table 7: Economic parameters

Item	Cost
Discount rate (%)	10
Expected inflation (%)	7
Project lifetime (yrs)	25
Residue value	20,000
Implementation cost	60,000
Land capital cost($/acre)	10,000

V. RESULTS AND ANALYSIS

The amount of energy delivered for the period 1992-2016 is as shown in figure 3 below. As depicted the energy is highest in the years with the highest DNI. The graph of the cash in and cash out is as shown Figure 4 and Figure 5 below. It is seen that the cash flow reduces as the plant the end of its lifetime.

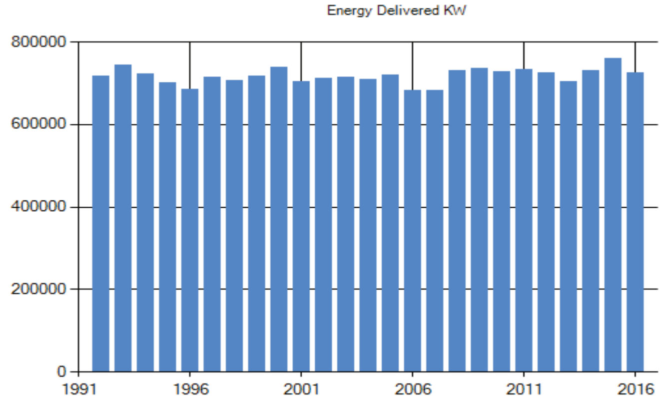

Figure 3: Energy Generated

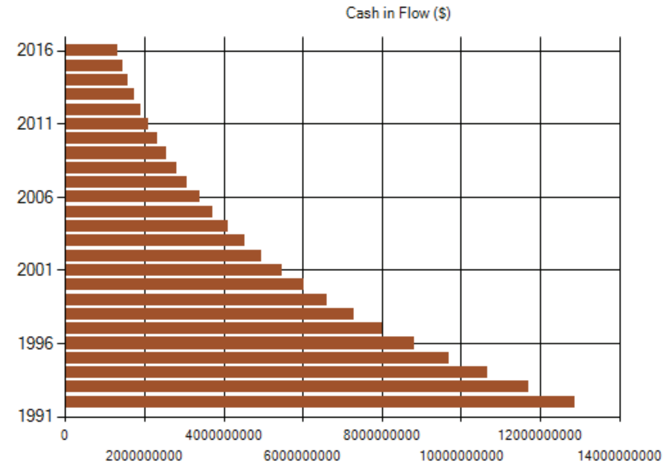

Figure 4: Cash inflow

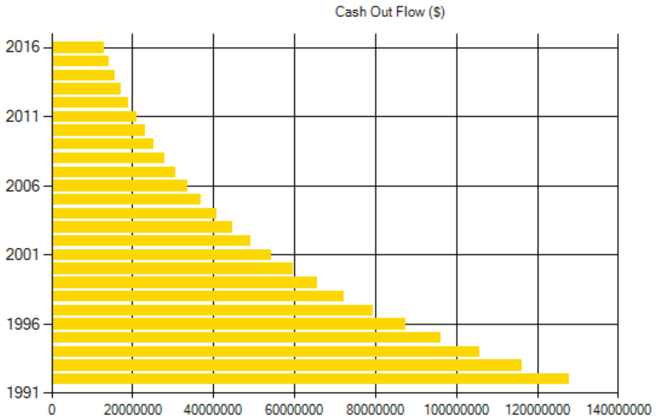

Figure 5: Cash outflow

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. The overall impact of externalities on LCOE is about 10.25%. The total number of PVs were 20,246 occupying a total area of 26,724.4296m^2.

VI. CONCLUSIONS AND RECOMMENDATIONS

The ECOS model is able to incorporate LECOE of USSE in the LCOE metric. This is a very unique function of this software compared to other software's like SAM, HOMER, HOGA and others. The incorporation of externalities in the cost modelling acts as a guide to investors of solar energy. In the paper it was found that LCOE was approximately 10.25% higher when the LECOE 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 ECOS model software to accommodate more than one energy type to enhance hybridization of convectional and non-convectional energy technologies.

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