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Comparative Analysis of the Implementation of Solar PV Systems using the ECOS Model and HOMER Software: A Kenyan Scenario

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ABSTRACT

Several models have been suggested for the simulation of Hybrid Renewable Energy systems (HRES) among them HOMER, SAM, HOGA and INSEL. This paper compares simulation performed using HOMER and the new ECOS model for a village in Turkana district in Kenya, which has excellent direct normal irradiation (DNI) of about 1800kWh/m^2/year. The ECOS model is a new software recently developed by students of Jomo Kenyatta University of science and Technology. The metrics used for comparison are the Levelised cost of electricity, net present value represented by cash flows, externalities (environmental, social and economic factors) and the energy generated. The novel contribution of this paper is the inclusion of the social, health and environmental impacts of Solar PV which is not done by other software like HOMER. The LCOE results from ECOS model are slightly higher than those obtained from the HOMER simulation

Key words: HOMER, ECOS model, Externalities, HRES

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1. INTRODUCTION

Global attention has largely shifted focus to the generation of electricity using the hybrid renewable energy systems, attributed to the depleting fossil fuels and their GHG emissions [1]. The governments of many nations across the word have also given direct nomination to these renewable energy systems through the tradable green certificates. This has fostered tremendous efforts in the exploration of renewable energy options especially to the rural areas where grid connection is untenable because of the rugged terrain and sparse population [1-2]. In this regard, a number of software tools have been suggested for the simulation and optimization of HRES. HOMER, SAM, HOGA and RET Screen are some of the most popular Techno-Economic tools [3]. HOMER has been regarded as the global standard for optimization of HRES and one of the most widely used tool for optimization and sensitivity analysis [4-5]. According to [4], It is a computer tool that is able to simplify and design a standalone or a grid tied micro-grid. On the other hand HOMER has demerits such as the incapability to show the optimization techniques adopted in the simulation process. Further HOMER does not provide flexibility to the user to set the optimization constraints especially in cases where the prices of electricity generation fuels are already fixed by the markets. In a nut shell despite its big name and global attention, HOMER does not me*et al*l the needs HRES optimization problems thus scientist have resulted to search for other HRES optimization and sizing options based on rigorous mathematical modeling [4].

2. PREVIOUS WORK ON OPTIMIZATION AND SIZING OF HRES

A variety of studies have applied different optimization techniques for sizing of HRES. For instance Amer *et al* [6] proposed the cost reduction of HRES using the particle swarm optimization (PSO). Bansal *et al* [7] in their simulations of a hybrid wind solar and battery used a meta-heuristic particle swarm optimization for cost reduction. Ram *et al* [8] in their design of a standalone solar –wind hybrid with a diesel generator used PSO to find the optimal sizes of each to meet the existing load. In addition Trazouei *et al* [9] proposed the use of imperial competitive algorithm, PSO to establish the optimal configuration of a hybrid wind-solar and batteries. Other superior cost reduction optimization techniques such as Hybrid Genetic algorithms (GA) with PSO (HGAPSO) [10] were used for the optimization of HRES. This algorithm overcomes the low speed convergence attributed to GA and the premature convergence of PSO therefore tremendous speed of convergence and hence a global convergence. The combination of PSO and simulated annealing (SA) developed by Idoumghar [11] overcame the premature convergence of PSO.

ARENA 12 which is a commercial software was used by Ekren *et al* [12] for the simulation and optimization of various HRES at various loads. The optimal size of PV- biomass hybrid system was configured by HOMER in Egypt [13]. Ashok *et al* [14] configured the sizes of wind solar and batteries using analytical models. The speed of the wind, direct normal irradiation (DNI) and the load requirement were the main factors used to control the micro grid. The results obtained were used for calibration of the optimal power required for the load.

Important to note is all these modern tools for optimization and simulation of HRES have a clear focus on cost reduction and size configuration. The cost reduction in this case refers to the capital cost. These techniques and tools fail to address the overall reduction of LCOE which is a quotient of the life cycle costs (capital costs, operation and maintenance costs, replacement costs, salvage cost) and the life time energy generated. Also missing in all these optimization techniques and simulation tools are the levelized cost of externalities (LECOE), that is, the environmental impacts of these energy sources. This paper therefore seeks to bridge the existing knowledge gap by showing the mathematical development of the ECOS model which fills the gap as it is able to determine the configuration of solar PV and clearly demonstrates the indirect costs (externalities) incurred when generating electricity from PV. In this paper the ECOS model and HOMER software will be used to simulate PV for Turkana District in Kenya and results obtained shall be compared based on the energy generated, cash flows, environmental impacts and LCOE.

The first part of this paper presents the detailed ECOS model development followed by the available resources and load requirements for testing. Simulations are finally carried out using the ECOS model and the HOMER software and the results tabulated for comparison**.**

3. METHODOLOGY

The core objective of this paper is the acknowledgement that nature has value in it, and therefore in the decisions to install and test the techno economic viability of solar PV the environmental impacts should be taken into consideration. Therefore, in the development of the ECOS model environmental impacts of solar PV have been identified quantified according to their believed monetary value. The ECOS model developed is based on the LCOE equation described by equation (1) below which is further broken down as shown by equation (2).

$$LCOE = \frac{Total\ life\ cycle\ \cos ts}{Total\ life\ time\ energy\ production} \tag{1}$$

$$LCOE = \left\{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}\right\} \Bigg/ \left\{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}\right\} \tag{2}$$

LCOE represents the cost of electricity that would match the cash inflows and the cash outflows normalized over the lifespan of the plant. This important metric allows the independent power producers (IPPs) to fully recover all the costs of the plant over a predetermined period of time [15-16] . The LCOE of an energy generating unit 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 (3).

$$\sum_{t=1}^{T} \frac{R_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{3}$$

Unlike the modeling done in HOMER, the LCOE equation (4) adopted by the ECOS model has included the externalities $\sum_{\mathrm{i=k}}^{\mathrm{k}} \mathrm{EC}$ (social, environmental and economic) of solar PV in the computation of LCOE and other metrics such as energy generated, cash flows among others.

$$LCOE = \frac{IC - \sum_{t=1}^{T} \frac{DEP+INT}{(1+DR)^n} TR + \sum_{t=1}^{T} \frac{LP}{(1+DR)^t} + \sum_{t=1}^{T} \frac{O\,\&\,M}{(1+DR)^t}(1-ROI) - \frac{RV}{(1+DR)^t} + \frac{\sum_{\mathrm{i=k}}^{\mathrm{k}} \mathrm{EC}}{(1+DR)^t} + RC}{\frac{\sum_{n=1}^{N} S^t * (1-SDR)^t}{(1+DR)^t}} \tag{4}$$

3.1. ECOS Model System Architecture

The ECOS model provides an interactive GUI platform developed using visual basic programming while SQL has been used for database development. The system has the user interface and the database. The GUI is window based that provides functions to manipulate the data according to the requirements. The interface calls stored procedures and views heavily for data processing and data retrieval. Finally the database stores all system data and none is held outside the database enhancing data integrity. The process flow diagram of the ECOS model is described by Fig 1 below.

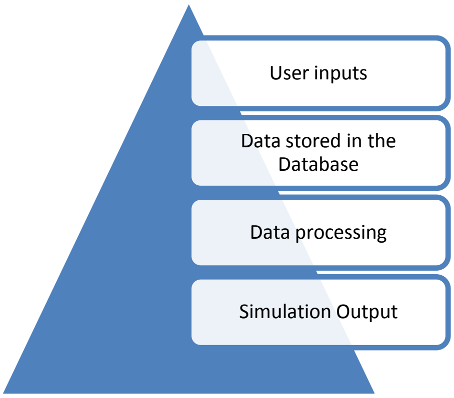

Fig. 1 ECOS Model system Architecture

The database used is a relational database management system which is a Microsoft SQL server. The database stores the tabular files of DNI, cost of equipment's used for solar photovoltaic and their types, different environmental aspects of the different regions in Kenya, batteries, inverters etc. Fig 2 shows a main features of the ECOS model derived from Equation (4) above.

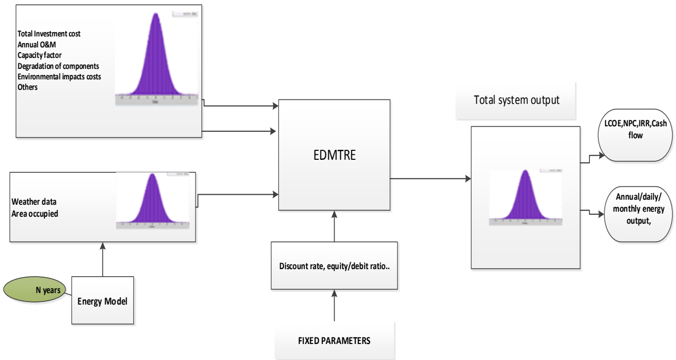

Fig. 2 ECOS Model Block Diagram

Simulation Setup for the ECOS Model

The HRES is designed considering solar PV and batteries with 2 hours of autonomy. The financial parameters used for the design are described by Table 1 below. It should be noted that some aspects like the land cost, environmental cost, social cost are treated as sunk cost in HOMER because they are not included in the user inputs nor are they displayed in the simulation results and analysis. The LCOE equation in most models includes the anticipated residual value after decommissioning the plant [15-16], which has not been included in the HOMER architecture.

Table -1 ECOS and HOMER Economic Inputs

Component	**% Amount**
Discount rate	7.5%
Expected inflation rate	7%
Project lifespan	25 years
land cost/acre (for ECOS model)	Area dependent variable
Residual value (ECOS model)	4.5% of CAPEX

4. METHODOLOGY

The economic criteria used in the sizing of the solar PV depends on the load demand. In this paper the load demand of a typical village in Turkana district was estimated which was used as an input to the ECOS model to determine the number of solar panels required and the batteries. Solar PV system includes different components that should be selected according to the system type, site location and applications. The major components for solar PV system are the PV module, inverter and the battery bank.

The sizing procedure described below mostly applies for the ECOS model. The mathematical sizing procedure used in HOMER is hardly discussed in literature and hence sizing is done by the software itself. The user chooses the location, load requirements, components, and type of fuel, and once the system is run, HOMER calculates the LCOE, NPV, and the energy produced.The procedure followed by the ECOS model for sizing the PV and batteries is described below.

4.1. Sizing of a standalone PV system

For convenience and accurate sizing of a PV system, the specific area, Direct Normal Irradiance (DNI) data and the anticipated load are defined. The size of the PV system, total number of PV panels 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, the Ah of the batteries required and the area occupied. There are several sizing techniques used previously in literature such as intuitive, numerical, analytical, commercial computer tools, artificial intelligence and the hybrid methods[17]. The numerical technique has been used in this paper for sizing the PV system because of its known accuracy and ability to easily use the linear functions unlike other tools [17].

The energy delivered by a solar PV array is given by

$$P_{ac} = P_{dc,STC} * \eta \quad (5)$$

where

P_{ac} =actual ac power delivered

$P_{dc,STC}$ =rated dc power output under standard test conditions

η =conversion efficiency which accounts for inverter efficiency, dirt, PV collectors efficiency and mismatch factor.

4.2. Steps followed in Sizing the PV Array

The insolation data (kWh/m^2) for the different sites used in the ECOS model are obtained from the NASA websites. The worst month (month with the lowest solar irradiance) of the year is used for design. As shown by Equation (6) identification of a PV module and using its rated current IR together with its columb efficiency of about 0.9 and a derating factor (DR) of 0.9 and the Direct Normal Irradiance (DNI) of the design month , the Ah/day produced by each solar PV string is determined.

$$Ah/day - string = DNI(kWh/m^2) * I_R * DR \quad (6)$$

The number of parallel strings is given by equation (7) below

$$Strings\ in\ parallel = \frac{design\ month\ load\ (Ah/day)}{Ah/day\ per\ \mathrm{mod}\,ule\ in\ design\ month} \quad (7)$$

The number of PV modules in series is determined by equation (8) below

$$\mathrm{mod}\,ules\ in\ series = \frac{system\ voltage\ (V)}{No\,\mathrm{min}\,al\ \mathrm{mod}\,ule\ voltage\ (V)} \quad (8)$$

4.2. Determination of Collector Area

The size of area occupied and the number of PV cells varies according to type, as each has different parameters.
Amount of energy delivered by a cell PV is described by Equations (9) and (10) below

$$T_{cell} = T_{ambient} + (\frac{NOCT - T_{av}}{0.8})..*DNI_{STC} \quad (9)$$

Where

DNI_{STC} =insolation under standard test conditions (kWh/m^2), $NOCT$ =Nominal Operating Cell Temperature, T_{av} =average maximum daily temperature, $P_{dc} = PV_{rating}[1-P_l](T_{cell} - T_{ov})$

Where P_{dc} =solar PV DC output power, PV_{rating} =rating of the solar PV, P_l =power loss per degree above T_{ov}

Including the dirt, mismatch and inverter efficiencies will result in an estimated ac rated power of the solar photo voltaic (P_{ac}) shown by Equation (11).

$$P_{ac} = P_{dc} * mismatch * dirt * inverter\ \eta \quad (11)$$

The collector area is governed by the yearly energy yield and the yearly energy demand as described by Equations (12)-(15) below.

$$ED/yr = P_{ac} * DNI_{site}/day * CF * 365\ days \quad (12)$$

$$P_{ac} = \frac{ED/yr}{DNI_{site}/day * CF * 365days} \quad (13)$$

$$P_{dc} = \frac{P_{ac}}{Mismatch * dirt * inverter\ efficiency} \quad (14)$$

$$Area\ occupied = \frac{P_{dc}}{DNI_{site} / year * collector\ \ efficiency} \qquad (15)$$

The different types of Solar photovoltaic panels used in the development of the ECOS model are as shown in Table 2 below.

Table -2 Types of Solar PV and their Characteristics

Module type	**Sharp NE K125U2**	**Kyocera KC158G**	**Shell SP150**	**Unisolar SSR256**
Material	Poly crystal	Multicrysta	Mono crystal	Triple junc
Rated power (P_{dc})	125W	158W	150W	256W
Voltage max	26V	23.5V	34V	66V
Max Current	4.8A	6.82A	4.4A	3.9A
O/C voltage	32.3V	28.9V	43.4V	95.2V
S/C 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
Deratiing %	90%	90%	90%	90%
Replacement $	525	663.6	630	1075
Lifespan (yrs)	25	25	25	25
O&M cost ($)	121.25	153.26	145.5	248.32

4.2. Determination of Collector Area

The different types of batteries are as shown Table 3 below

Table -3 Types of Batteries and their Characteristics

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

The battery storage capacity is determined by Equation (16) below.

$$battery\ storage\ capacity = \frac{Ah / day * days\ \ \ of\ \ \ \ autonomy}{MDOM * DR} \qquad (16)$$

Where

$MDOM$ =maximum depth of discharge

DR =% discharge rate

5. QUANTIFICATION OF LAND USE IMPACTS

Land use changes (LUC) all over the world remains to be one of the greatest contributing factor to the drastic biodiversity loss and extinction [18-19]. The ECOS model has adopted countryside Species Area Relationship (SAR) for quantification of the number of species in the areas occupied by the USSE. The SAR model has been extensively used for describing the species richness existing in different localities across the world [18]. The SAR model is described by equation (17).

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

Where

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

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

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

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

The species that remain after land is convetrted from one form to another is estimated using Equation 18 below.

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

The quotient of equation (17) and (18) yields equation (19)

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

The multiplication of equation (19) by S_{org} yields equation (20)

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

Subtracting equation (20) from the original number of species that existed before the land use change yields the prediction of the extinctions as indicated by equation (21).

Table -4 Valuation of Ecosystem Goods and Services [20]

Ecosystem Goods and services	**Valuation ($)/ha**
Regulating functions of ecosystems	
1. Regulating air	7-265
2. Climate change	88-268
3. Disturbing ecosystems goods and services	2-7240
4. Water uptake and usage	2-5445
5. Water supply	3-7600
6. Soil erosion	29-245
7. Soil 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
14 Raw materials such as wood, charcoal	6-1014
15 Genetics	6-112
16 Medicinal value	6-112

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

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 (22)

$$C \ = \sum_{i} V_i * X \tag{22}$$

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* [17] as shown in Table 4 above.

5.1. Accounting for Human Health Damages

The ECOS model developed in this paper accounts for morbidity and mortalities resulting from the installation of Solar PV. The work-related and non-work related accidents considered in this paper are for the non-organization for Economic Cooperation and Development countries where Kenya is classified into [21]. The per unit prices for treating persons suffering injuries or mortalities while working with USSE are based on the studies done by [22-23]. Morbidity and mortality 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 (23) below.

$$UV_{\mathrm{mod}}(t) = UV_{\mathrm{mod}}(1804) + \Delta UV_{\mathrm{mod}}(t) \tag{23}$$

Where $\Delta UV_{\mathrm{mod}}(t)$ is the change in morbidity value. The unit mortality values (UV_{mot},$/person) were obtained from [21] and are described by Equation (24) below

$$UV_{mot}(t) = UV_{mot}(17413) + \Delta UV_{mot}(t) \tag{24}$$

The unit mortality value and the unit morbidity value derive their costs from three phases i.e during construction, operation phase and the decommissioning phase. The parameters used for the two sub-models are described in Table 5 below.

Table 5: Mortality and Morbidity model values

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

5.2. Water Consumption Sub-model

The ECOS model developed in this paper accounts for morbidity and mortalities resulting from the installation of Solar PV.In solar PV water consumption is used for mirror washing. Water is mainly used during construction phase and in the generation phase. The unit cost of water use (UWC,$/m^3) is determined by the change in the opportunity cost of water use ($\Delta UWC, \$ / m^3 / yr$) and is estimated using Equation (25) below.

$$UWC(t) = UWC(t) + \Delta UWC(t) \tag{25}$$

The solar PV water externality cost is estimated using two costs, that is, opportunity cost of water during construction ($UWCC$ ($/m^3) and generation ($UWCG$) shown by Equation (26) below.

$$USSECT = OCWC + OCWG \tag{26}$$

5.3. Load

The load data of Turkana district is determined by evaluating the existence of electrical appliances in a typical homestead which includes refrigerators, TV, stoves, micro waves among others. In this paper, load data used as input for the ECOS model and HOMER software was derived from Table 6 below and scaled up for 1000 households.

Table -6 Typical Load of Turkana District

Appliance	Quantity	rating (kW)	(hrs/day)	Daily consumption (kWh)
Fridge (14.cu ft)	1	0.3	24	7.2
Television (19-in)	2	0.068	8	1.088
Electric Kettle	1	1	0.5	0.5
Desktop computer	1	0.3	6	1.8
Laptop	2	0.036	6	0.432
Lights	10	0.03	5	1.5
Security Lights	2	0.045	8	0.72
Geyser	1	3	1	3
Heater	2	2	3	12
Microwave	1	1	0.33	0.33
Total				28.57*100=2857

The resulting load profile is described by Fig. 3 below with an average hourly load of 119.04kW/hr.

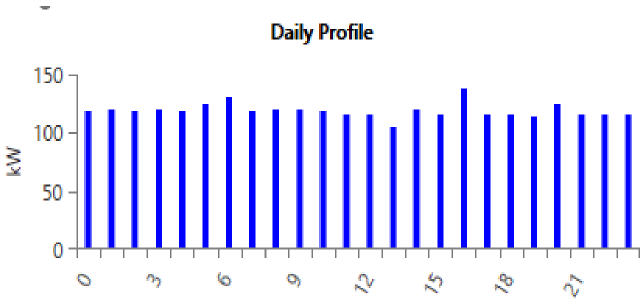

Fig. 3 Load Profile of Turkana District

5.4. Solar Resource

The site selected for the simulation is Turkana District which is $3^{0}18.7^{'}$N, $35^{0}33.9^{'}$E. HOMER and ECOS model requires the solar insolation data as an input for electricity for electricity generation from PV. The weather patterns of the different regions across the globe are inbuilt in HOMER and therefore once a site is selected, its weather data is loaded as well. The solar insolation Data is shown by Fig. 4 below.

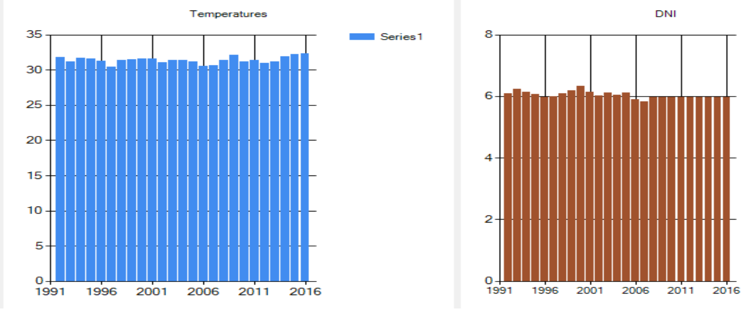

Fig. 4 Temperature and DNI of Turkana using ECOS model

5.5. Costs Considered

The basic criterion related to the selection of the power system components in this paper is the cost of components, because the main purpose of the work is searching the optimum power system configuration that would meet the demand with minimum NPC and COE. The estimation of the components cost was made based on the current cost available in the market. In this paper the all component costs and specifications were adopted from [24]. In the HOMER and ECOS model the user can change the component cost based on the market trend. The different types of component cost are:

- **Initial capital cost of components**: It is the total installed cost deployed to purchase and install the component at the commencement of the project.
- **O&M cost**: It is the cost accounted for maintenance and operation of the system. The entire scheme components considered in this paper has different operation and maintenance costs. Miscellaneous O&M costs considered by HOMER are like emission penalties, capacity shortage penalty and fixed operation and maintenance costs. The determination of the emission penalties and capacity shortage penalty used by HOMER is mathematically inbuilt in the software and hence no mathematical models available as the software does not provide them to the public. For the ECOS model the emissions are accounted for as described in sections above which includes water consumption, land usage, impacts on health and ecosystems.
- **Replacement cost:** This is the cost required to replace wear out components at the end of its life cycle. This cost is different from initial cost of the component, due to the fact that different components have different life times. There are some components that will run in the entire lifespan of the plant whereas some will be replaced midway.

6. RESULTS AND ANALYSIS

In this section the simulation results obtained from ECOS model and HOMER software for Turkana District are discussed and compared. The two softwares calculate the output based on the procedure mentioned in the methodology and the result of each software are described in the following sections.

6.1. ECOS Model Results

The ECOS model displayed results of yearly energy generated from 1992-2016 as shown in the diagram below. The energy delivered varies according to the DNI estimated at 1800kWh/m^2/yr. Fig 5 shows the yearly energy generated during the lifespan of the plant. The random variability of the solar resource leads to the uneven energy production in the different years.

The area required for installation to meet the electricity demand was estimated to be 5130 acres of land that required about 4008 solar photovoltaic panels and 394 batteries. The cascaded impacts on land as a result of this land occupation includes diseases like Cancer which results from emission of some hazardous gases such as particulate matter , lead, VOC among others. The ECOS model estimated the NPC including the externalities (environmental and health costs) to a tune of $2.07 billion for a period of 25 years The environmental cost included were the cost of land and the various function of land in this particular region as was described in Table 4. The ECOS determines the cost of a disease using two functions described above, that is, unit morbidity value and unit mortality values.

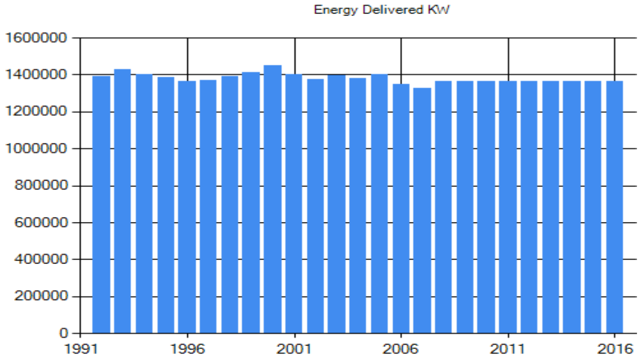

Fig. 5 Yearly Energy Generated

ECOS model further determines the LCOE to be about $3.81. As discussed earlier LCOE is a function of the Life cycle costs (LCC) and the energy generated. The ECOS model is among the first tools to accommodate the external costs of energy generation which in this case are the environmental costs and the health costs. The cash inflow and cash outflow for the whole period is shown in Fig 6 and Fig 7. The cash flow is highest at the beginning of the project and minimum near the end of the lifespan.

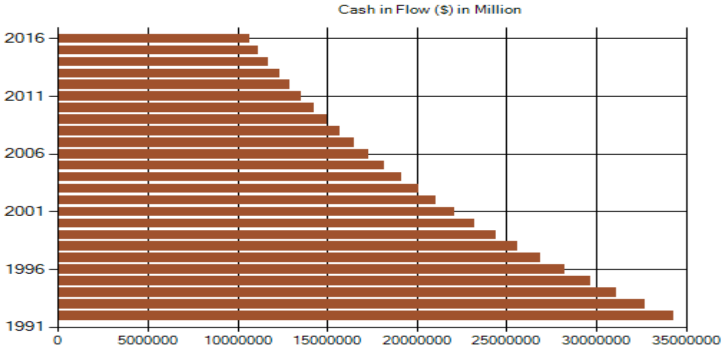

Fig. 6 ECOS Model Cash Inflow

6.2. HOMER Results

HOMER simulation estimated the total NPC to $1.7 billion while the optimal LCOE was $1.07. HOMER found the optimal LCOE by considering 138 combinations in which only 66 cases were feasible. The resultant of the input output cash-flow is as shown in Fig 8 below. In the cash-flow the plant breaks-even on the final year of production where the cash-flow is positive.

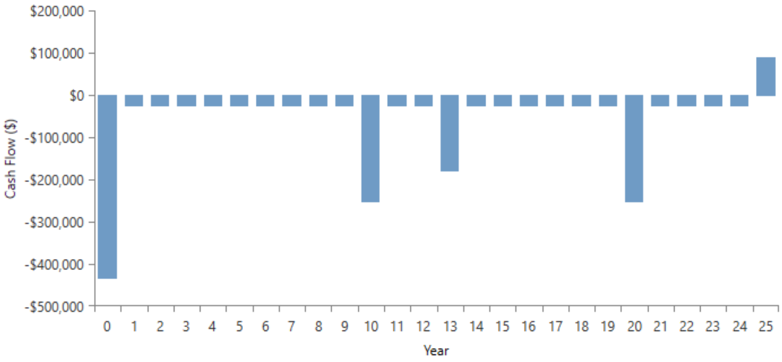

Fig. 7 HOMER Cash flow

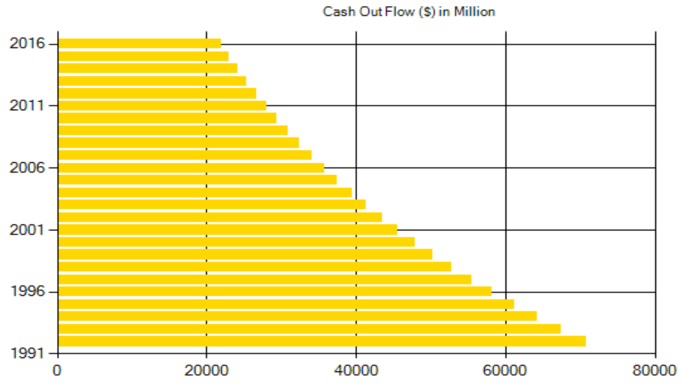

Fig. 7 ECOS Model Cash outflow

6.3. Results Comparison

The results are compared in terms of environmental impact analysis, health impact analysis and the general economics. A variety of greenhouse gases are also emitted from solar during generation as reported in literature [25]. The ECOS model considers a variety of them including PM, ammonia, CO_2, nickel, mercury, methane, and lead among others. Also in the ECOS model the land occupied is quantified according size, type vegetation, economic worth measured in terms of $/Hectare/ year. The different monetary value of land use types were obtained from the Ecosystem service value database (EVSD). The EVSD allocates monetary value to the different types of land occupation per Hectare per year. The ECOS model is equipped with SQL database that contains this data and is always recalled during calculation. On the other hand HOMER considers only the carbon Dioxide [4], which in not monetized. LCOE for the ECOS model is 70% more than that of HOMER which has been attributed to lack of monetization of the land costs, environmental cost and the social costs.

7. CONCLUSIONS

In this paper, HOMER and the ECOS modelling tool have been used to size solar photovoltaic system for Turkana District. The result analysis provides a base for comparison of the two packages. The ECOS model is a new tool and has not been explored like the HOMER software. HOMER is user friendly, flexible and good in sizing of HRES according to the resource availability. The LCOE yield in HOMER is slightly low however, during the sizing of the most optimal combination of HRES, HOMER does not consider basic things like land cost and size, environmental impacts costs and the social impacts costs. It is the opinion of the authors of this paper that if these key costs are considered in HOMER, the LCOE and NPC of the two packages would match. The other possible discrepancy with the results is that HOMER determines the NPC of a component as the present value of all the costs incurred during purchasing, installing and operating the component minus all the revenues generated by the product. On the other hand, the ECOS model does not consider the revenue from the solar PV

Research and development should be geared towards improving the ECOS model software to accommodate more than one energy resource type to enhance hybridization of renewable energy systems.

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