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Designing a 10 MW peak solar power plant using a system advisor model (SAM software). Case study: Somalia, Mogadishu Region

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Abstract

Globally, there has been a sharp increase in energy needs due to industrialization and technological advancement. The wisest course of action is to switch from traditional energy sources to renewable energy sources, or ecologically friendly types of energy. Solar energy is one of the most abundant and widely accessible renewable energy sources. Photovoltaic (PV) systems using solar energy to generate electricity are weather-dependent.

With the data available in the System Advisory Model (SAM), the Mogadishu region of Somalia can produce about 10 MW peak solar PV system design, which will be helpful to reach the country's target of total installed solar energy capacity by 2025. The SAM was used in this paper to design (system technical design and financial analysis) the small, medium, and large PV systems for the different countries.

A 6% annual growth in producing capacity is the ultimate objective of the Somali National Development Plan (NDP). The nation's production capacity increased from 115 MW to 344 MW between June 2021 and June 2015. The target of the NDP is to raise generating capacity to 1043 MW between 2022 and 2027. It is intended to raise the electrification rate to 75% from its present 36% level.

41 MW of solar and 1 MW of wind power are Somalia's total installed capacity for renewable energy (RE). There are 3,000 hours of sunshine each year in the nation, and daily solar radiation levels range from 5 to 7 kWh/m^2. Somalia has 41 MW of installed solar capacity and uses it nationwide. A solar photovoltaic system in Somalia attained a performance ratio of 70.8%. By 2030, the UN wants to run all of its operations with 80 percent renewable energy.

Keywords: Renewable Energy; Photovoltaic (PV) Systems; Somali National Development Plan (NDP); Solar Radiation; Sustainable Development.

1. Introduction

Although it is well recognized that fossil fuels play a major role as energy sources for global political and economic conditions, there has been discussion about the need to switch to more environmentally friendly and sustainable energy sources in light of these issues. Research on alternative energy sources supports the main concerns about the use of fossil fuels, which are those about the environment, health, and ecology [1].

Conventional energy sources are rapidly replacing long-term, environmentally friendly energy sources. The daily increase in energy costs has forced careful consideration of the kinds of power plants. Since solar energy is the most inexpensive and exploitable of renewable energy sources, it can be used to generate power. Implementation of solar-related power projects leads to short establishment periods and non-polluting energy sources. [2].

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From the early 2000s until 2017, the capacity of solar power plants in Somalia (MW) increased; however, the installed capacity then stabilized for three years in a row [3]. Like other engineering projects with high-profit potential, solar energy projects also benefit from an understanding of the business context in which important choices are made to create a profit and strengthen the firm's overall financial position [4].

In a prompt response to international efforts to meet the goals of sustainable development, including the provision of affordable and clean energy, Somalia's Ministry of Energy aims to increase access to renewable energy sources in the production of electricity by using an energy mix approach, in addition to promoting energy conservation and efficiency [5].

1.1. Project Location

Mogadishu, one of the places with solar energy potential in Somalia, is geolocated at 2.05S latitude, 45.34E longitude, and 65m elevation above sea level (SAM-V.2022). Somalia similarly shares geolocation potential with other countries. At 91 km2 (35 square miles), the Mogadishu area is home to a population density of about 26,800 people per km², making it reasonably densely populated for the Somali mainland.

Figure 1 Location of Mogadishu Somalia in Africa.

With an average population density of 33,244 persons per square kilometer, the Mogadishu region is expected to have a total population of about 2,610,000 by 2023. Given its size, which totals 637,660 km², the region is free of land pressure.

1.2. Problem Statement

41 MW of installed solar capacity, or 11.9% of total power generation, has been installed in Somalia. There is currently about 106 MW of installed generation capacity. Somalia's energy demand is increasing exponentially, according to modeling data. In every economic sector, it was discovered that the need for energy was rising, and by the conclusion of the study period (2010–2040), the overall demand had more than tripled. The significant finding that the energy sector's demand for fossil fuels is likewise growing exponentially and has significant detrimental effects on the environment was made based on the results produced [7].

This study will establish the 10 MW peak solar energy capacity among renewables (considering its technical and economic analysis) by applying the System Advisory Model (SAM) to combat the long-term negative environmental issues worldwide.

1.3. Objectives

1.3.1. Main Objective

The main objective is to design a 10MW solar photovoltaic power plant for Somalia in Mogadishu using System Advisory Model (SAM) software.

1.3.2. Specific Objectives

- To use System Advisory Model (SAM) software for researching and evaluating the power plant's performance characteristics, including its annual electricity output, parasitic consumption, seasonal variation in plant output, etc.
- To calculate the plant's levelized cost of energy delivery and investigate how potential changes in the input parameter values might affect the outcomes.
- To assess the solar PV power plant's performance with SAM software.

2. Literature review

2.1. Solar Energy Situation in Somalia

Somalia is one of the nations with the most potential for solar energy; it receives 2,800–3,500 hours of sunshine annually and 4–7 kWh of horizontal radiation per square meter per day globally. The country's most concentrated solar energy is found in the Mogadishu Region, which serves as a hub for both grid-connected and off-grid solar solutions. With government backing and other factors, off-grid solar photovoltaics currently have an installed capacity of approximately 8 MWp of solar PV electricity in a variety of applications, including schools and health centers. The cost of electricity is still high in Somalia, despite the implementation of numerous solar projects. To compare the project's cost and profitability, a techno-economic study ought to be carried out. Grid-connected and off-grid systems can be stabilized and local loads can be continuously supplied with power via hybrid systems that integrate diesel generators, batteries, and renewable energy sources. To evaluate its larger client base and feed-in tariffs for certain renewable energy technologies, the Somali National Development Plan (NDP) is currently undertaking research [8].

2.2. System Advisory Model (SAM) Software

2.2.1. Overview

Photovoltaic systems, concentrated solar power, fuel cells, photovoltaic batteries, wind, geothermal, water heating systems, maritime energy, and biomass combustion-based power plants are just a few of the various types of renewable energy systems that may be modeled utilizing SAM. SAM is a performance and financial model developed to support decision-making amongst those working in renewable energy, including researchers, engineers, project managers, technology developers, and designers of programs for incentives. SAM can predict the performance and estimate the energy cost for grid-tied projects based on operating and installation costs, depending on the design input parameters that are introduced into the model [9].

2.2.2. Software Development History

Initially named "Solar Advisor Model," SAM was created for the first time by The National Renewable Energy Laboratory (NREL), which is a nonprofit organization dedicated to transforming energy via the creation, research, commercialization, and application of energy-efficient and renewable energy technologies.

The United States DOE (Department of Energy) Solar Energy Technologies Program used NREL in 2005 for internal usage in systems-oriented examination of prospects for solar technology improvement inside the program. The initial version was made available to the public in August 2007 and allowed solar energy specialists to examine solar thermal (solar power concentrating parabolic trough) and photovoltaic systems using standardized financial assumptions on the same modeling platform. After that, yearly updates to the software were made [10].

2.3. Regulatory Environment in Somalia

Renewable energy offers an alternative that offers opportunities to increase system capacity and reduce transmission and distribution distances, thereby accelerating electrification. The Somali National Development Plan (NDP) is responsible for the detailed design of the Power Purchase Agreement (PPA), supported by a team of experts in the fields of engineering, project finance, and law for On-grid small power projects, Isolated grid supply and Mini-grid projects [11].

The Somali government established the National Regulatory Authority to increase energy access from 15% to 45% by 2024. The National Development Plan (NDP) 9th (2020–2024) set this goal.

2.4. PV Systems Components

Solar photovoltaic systems consist of inverter (for DC to AC conversion), solar modules (for direct conversion of solar radiation to electricity), batteries, and charger controllers. For the larger application, the batteries are not used for the cost of investment reduction [12].

2.5. Solar PV Systems Financial Analysis

The financial analysis can be based on the Sensitivity analysis, which is performed to examine how the output uncertainty affects different types of inputs. Sensitivity analysis is performed to determine how input fluctuations affect the financial feasibility of installing and operating a PV system. The sensitivity analysis calculation considers changes in Net Present Value (NPV), Internal Rate of Return (IRR), and Levelized Cost of Electricity (LCOE) [13].

The Levelized Cost of Energy (LCOE) is a standard methodology used by utilities, policy-makers, and industry to calculate the cost of electricity produced by a generator over its lifetime. It is the ratio of the initial capital cost plus the present value of all future operational costs (administration, maintenance, and fuel) to the present value of all the energy produced during the anticipated lifetime of the project. For a solar project, the fuel (the sun) is free and without administration costs.

3. Methodology

The SAM software (2022.12.2) was used to design the 10 MWp solar power plant for the Mogadishu region in Somalia.

3.1. Technical Input Parameters

The useful input parameters before starting/launching the software were calculated (Appendix 3.) and the results were:

- Plant capacity (10MWp)
- Initial DC-to-AC ratio: 1.3 [14]
- Inverter capacity/specification (8MW total capacity inverter was calculated)
- Model/panel specifications (Silfab Solar Inc. SIL 500HN was selected)
- Number of strings (the number of series calculated modules was 20 and the number of parallel modules was 1,000)

3.2. System Design in SAM

Generally, the system was designed step-by-step as follows:

3.2.1. Location Data Downloading

The location data was automatically obtained in the software system in the location and resource tool by searching “Mogadishu, Somalia” based on one location, specifically 2019 data downloading.

3.2.2. Inverter Selecting

Under the inverter tool in the software, a single inverter (WSTECH GmbH: APS800-ES-1-440-5) [400V] of Paco 814,167W_{ac} was selected (appendix 2)

3.2.3. Module Selecting

In the module tool, the selected solar model/panel was Silfab Solar Inc. SIL 500HN which has non-bifacial properties in its design (appendix 1)

3.2.4. 10MWp System Design

Under the system design tool, the 20 modules in series and 1000 modules in parallel were inserted in subarray 1, 10 modules were inserted, the system was fixed mounted, the tilt angle was equal to the latitude angle of the location, ground covered ratio was 0.3 and the azimuth angle was 180 ^{o}.

3.2.5. Shading and Layout

The system was designed such that there was no self-shading among neighborhood modules for fixed-mounting modules systems.

3.2.6. System Losses

The losses considered were DC losses (module mismatch 2%, diode and connection 0.5%, D.C wiring 2%) and A.C losses 1%

3.2.7. Grid limit

No limit is applied for renewable energy projects.

3.2.8. Lifetime and degradation

The annual Dwasadation rate is 0.5%

3.3. Project Costs

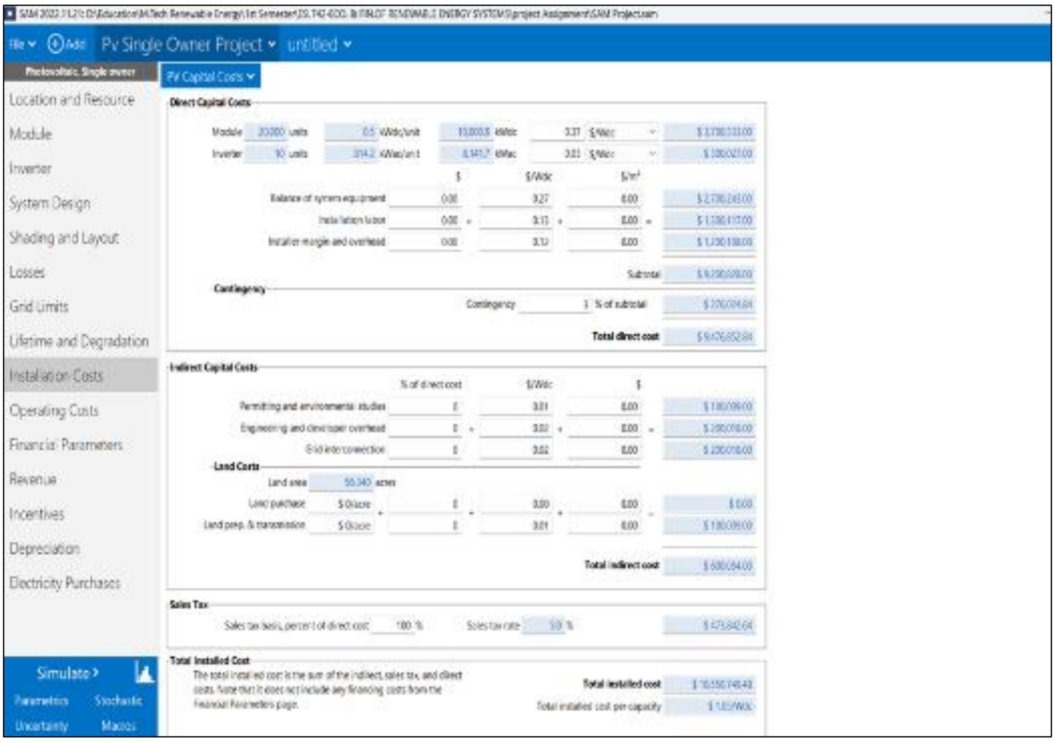

Figure 2 The project costs.

The operation and maintenance costs were taken as $15/kW/year of the total investment cost, while the installation cost (direct, indirect, and sales tax) was inserted as shown in Figure 2.

3.4. Financing Parameters

The financial parameters were inserted as shown in Figure 3.

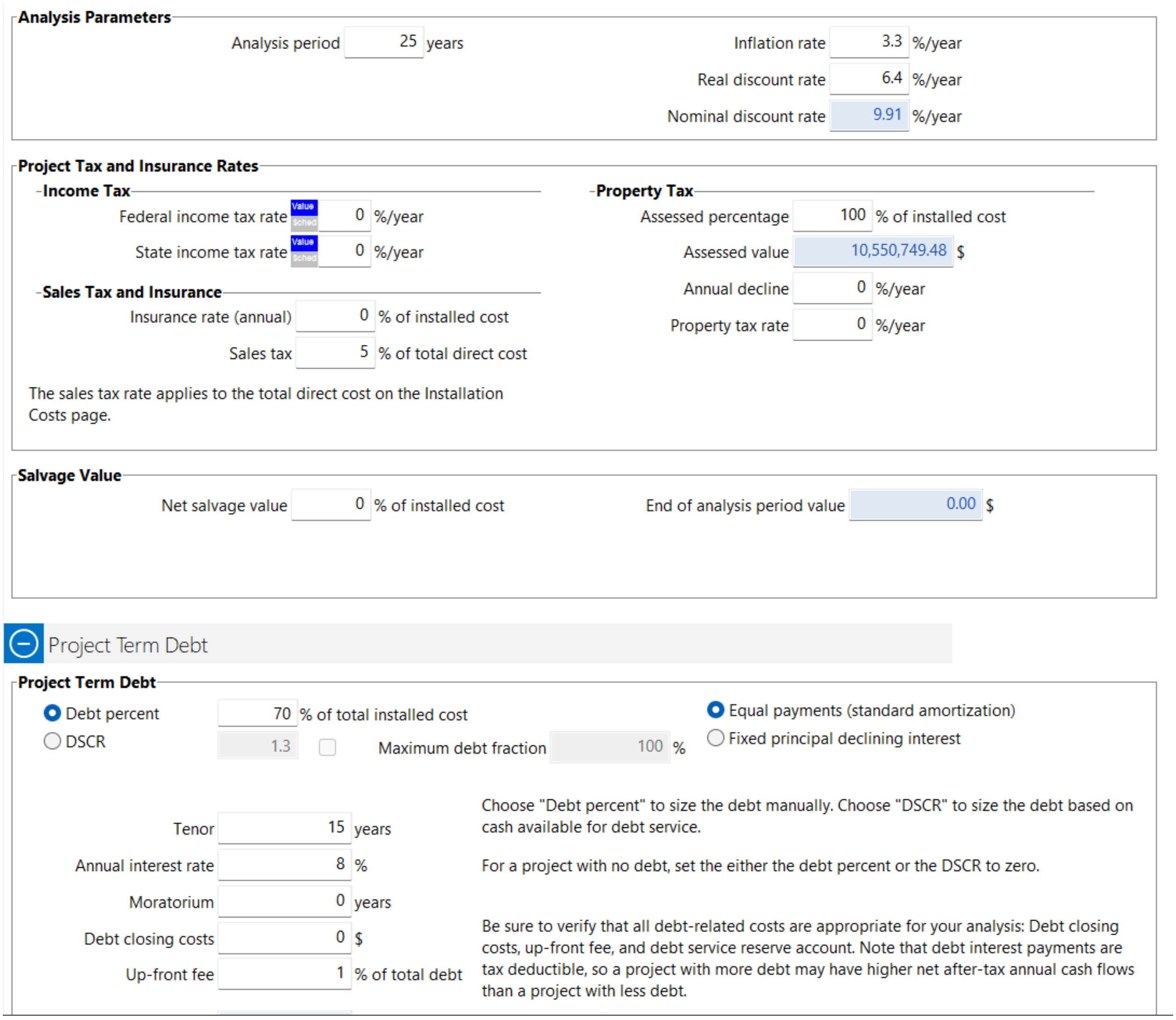

Figure 3 Financial parameters

3.5. Revenue and Incentives

Basic revenue was inserted as shown in Figure 4, while the incentive value set was 26% from the federal government.

Figure 4 Revenue Input

3.6. Depreciation

The values were set as shown in Figure 5.

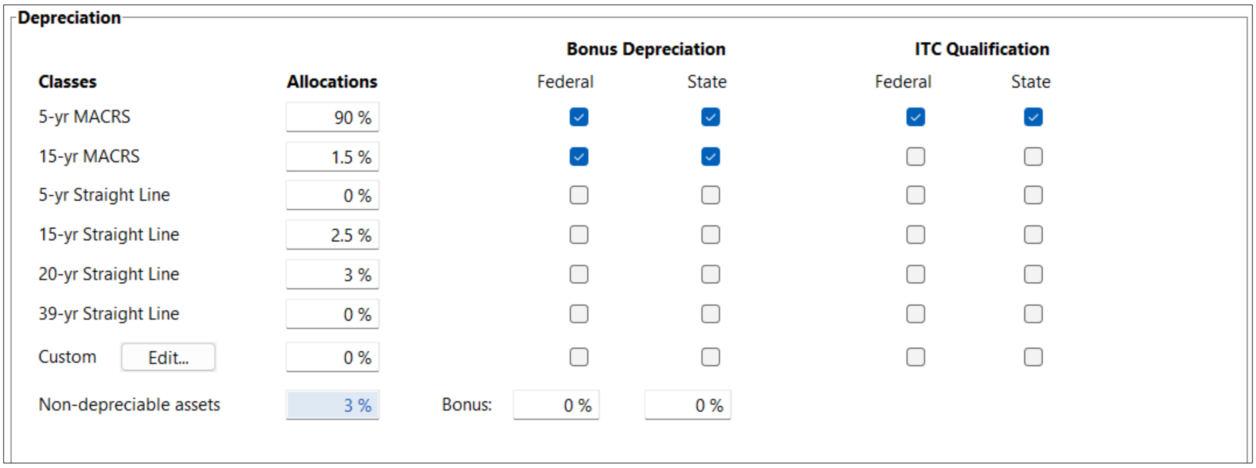

Figure 5 Depreciation

3.7. Electricity Purchase

The current installed generation capacity is approximately 106 megawatts (MW). While most power companies rely on diesel generators for electricity generation, interest, and investment are growing in hybrid systems that draw on solar and wind energy resources. Electricity costs in Somalia are the biggest obstacle to economic development in the country. It's among the highest in the world, ranging from $0.40 to $1 per kWh. The electricity purchase was set into PPA or market prices, and then a simulation was done.

In the absence of an electric grid, privately owned and operated diesel-powered mini-grids were developed, which provide nearly all of Somalia's electricity. Consumers in Somalia pay some of the world's highest prices for electricity. Private prices and service providers (ESPs) charge up to $0.65 per kilowatt-hour to deliver electricity through isolated diesel-powered grids that are unreliable and have a large carbon footprint. Even at these high prices, many ESPs fail to recover the costs of generation and delivery. Utility and commercial PPA projects are assumed to sell electricity through a power purchase agreement at a fixed price with optional annual escalation and time-of-delivery adjustment factors. For these projects, SAM calculates:

- LCOE
- PPA price (electricity sales price)
- Internal rate of return
- Net present value
- Debt fraction or debt service coverage ratio.

4. Results and discussion

There is a significant increase in the use of renewable energy systems currently. Companies and individuals have increasingly transitioned to the use of renewable energy systems (10 MW) not only to ensure a clean environment but also as a way of providing a sufficient energy supply cost-effectively.

4.1. Performance Model and Financial Model

The performance and financial models of the system under input data show that the system nameplate is 10 MW PV with a sensitive analysis output as shown in Figure 6.

System Advisor Model Report

Detailed Photovoltaic	10.0 DC MW Nameplate	2.05, 45.34
Single Owner	$1.05/W Installed Cost	UTC +3

Performance Model

Modules	
Silfab Solar Inc. SIL-500HN	
Cell material	Mono-c-Si
Module area	2.28 m²
Module capacity	500.05 DC Watts
Quantity	20,000
Total capacity	10 DC MW
Total area	45,599 m²

Inverters	
<null>	
Unit capacity	814.167 AC kW
Input voltage	648 - 1500 VDC DC V
Quantity	10
Total capacity	8.14 AC MW
DC to AC Capacity Ratio	1.23
AC losses (%)	0.00

Four subarrays:	1	2	3	4
Strings	250	250	250	250
Modules per string	20	20	20	20
String Voc (DC V)	1086.00	1086.00	1086.00	1086.00
Tilt (deg from horizontal)	2.05	2.05	2.05	2.05
Azimuth (deg E of N)	180	180	180	180
Tracking	no	no	no	no
Backtracking	-	-	-	-
Self shading	no	no	no	no
Rotation limit (deg)	-	-	-	-
Shading	no	no	no	no
Snow	no	no	no	no
Soiling	yes	yes	yes	yes
DC losses (%)	2.49	2.49	2.49	2.49

Financial Model

Project Costs	
Total installed cost	$10,550,749
Salvage value	$0

Analysis Parameters	
Project life	25 years
Inflation rate	3.3%
Real discount rate	6.4%

Financial Targets and Constraints	
Solution mode	Calculate PPA Price
Target IRR	12% in Year 20
PPA escalation rate	1%/year

Tax and Insurance Rates	
Federal income tax	0 %/year
State income tax	0 %/year
Sales tax (% of indirect cost basis)	5%
Insurance (% of installed cost)	0 %/year
Property tax (% of assessed val.)	0 %/year

Incentives	
Federal ITC	26 $
Depreciation	Depreciation allocations defined with no bounus depreciation

Results	
Nominal LCOE	10 cents/kWh
PPA price (year one)	10.3 cents/kWh
Project IRR	12% in Year 20
Project NPV	$1,495,000

Figure 6 Performance and financial model.

4.2. Performance Advancement of the project

Performance Adjustments	
Availability/Curtailment	none
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)				
GHI kWh/m²/day	4.94	4.94	4.94	4.94
POA kWh/m²/day	114.00	114.00	114.00	114.00
Net to inverter	15,118,000 DC kWh			
Net to grid	14,769,000 AC kWh			
Capacity factor	16.9			
Performance ratio	0.82			

Figure 7 Performance Advancement of the project

4.3. Electrical Generation

Monthly, the system performs better during the sunshine months compared to April to June, the period of the rainy season in Mogadishu region of Somalia, as shown in Figure 8.

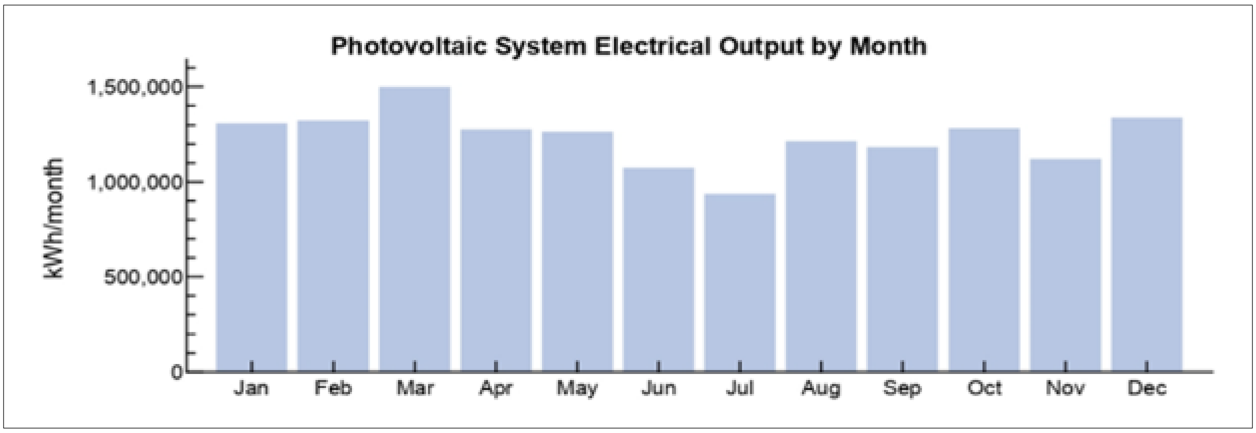

Figure 8 Photovoltaic System Electrical Output by Month.

Electricity Net Generation: as time goes by, the system performance decreases (shown in Figure 9) because it is degraded, hence reducing electricity production. In line with Somalia's National Development Plan objectives to enhance renewable energy capacity and boost the electrification rate from 36% to 75% by 2027, a 10 MW peak solar PV system in Mogadishu, Somalia, can provide 15.5 GWh of power annually.

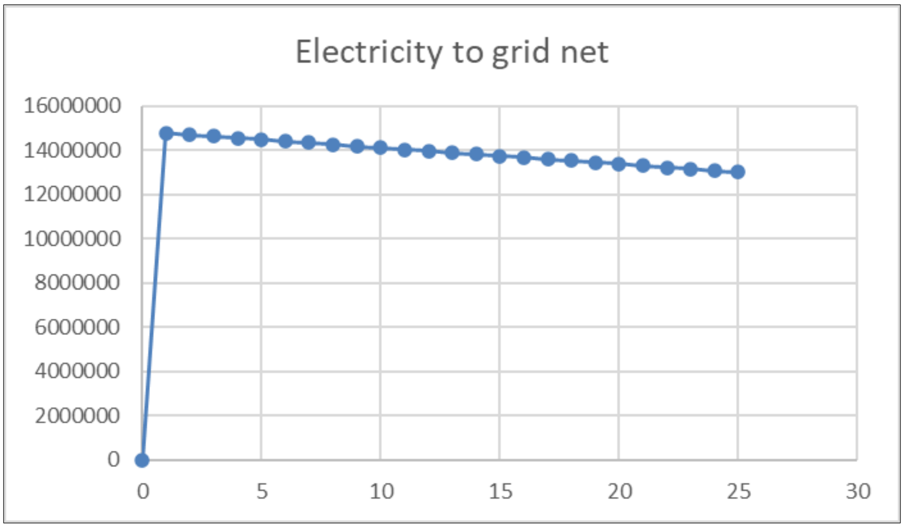

Figure 9 Electricity Net Generation

Their first-year production (Figure 10) shows that the system production is better between 09 and 15 hours of the day throughout the year; this is just because the Mogadishu region receives good solar radiation between those hours. The first-year annual production is 14,769,503 AC kWh net to the grid.

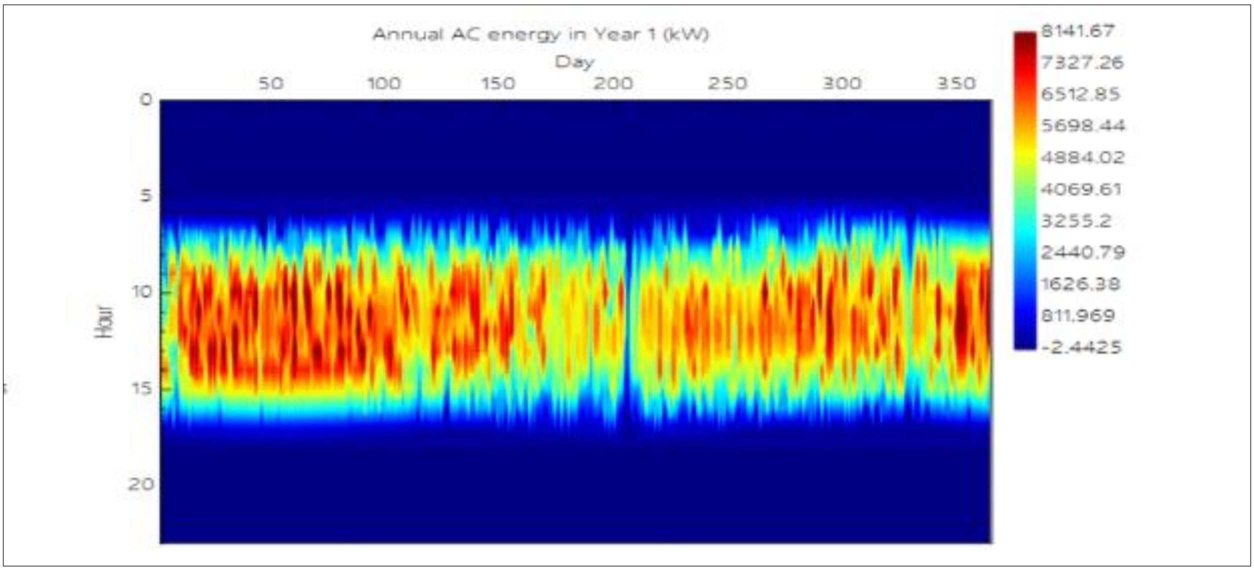

Figure 10 Annual electricity generation by the first

Based on the cash flow after tax (figure 11), cash flow decreases until the tenor period (due to the different taxes inquired in the project) and then increases after the cost reduction (for example, debt-free and learning experience).

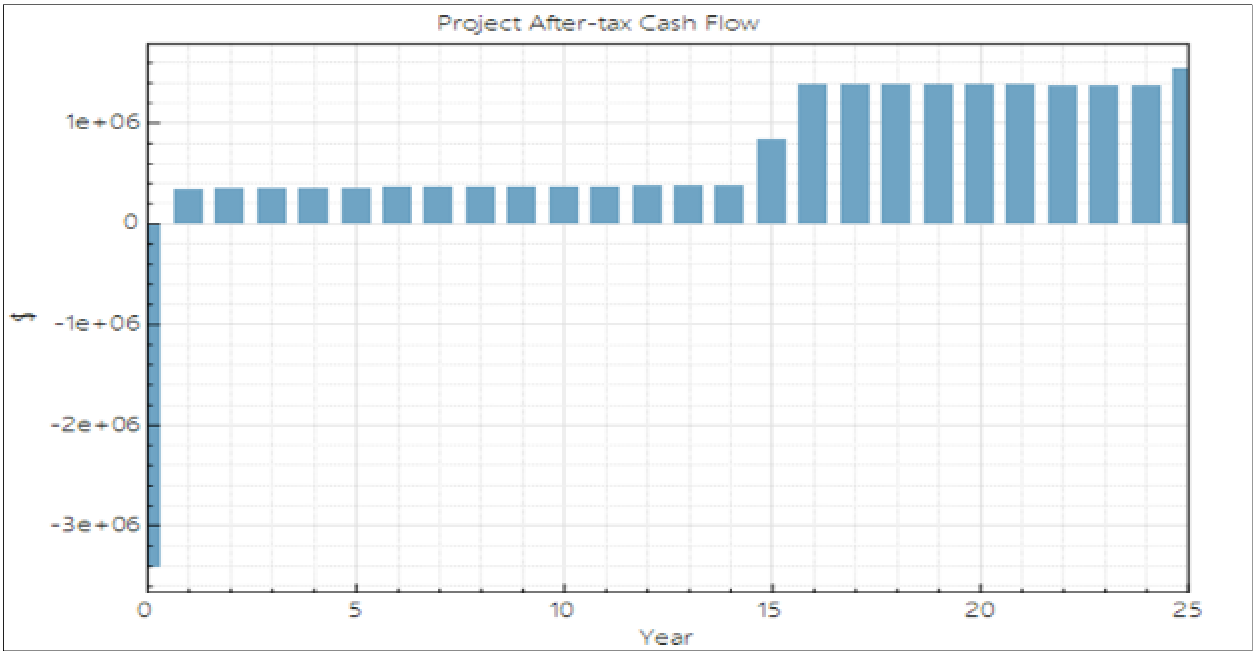

Figure 11 Project after-tax cash flow

List of Abbreviations

- **SAM**-System Advisory Model
- **D.C**-Direct Current
- **A.C**-Alternating Current
- National Development Plan (**NDP**)
- **NPV**-Net Present Value
- Internal Rate of Return (**IRR**)
- Power Purchase Agreement (**PPA**)
- **LCOE**-Levelized Cost of Electricity
- **MWp-** Mega Watts Peak

5. Conclusion

Based on the Global Sustainable Development Goals (SDGs) number 7 (Affordable and Clean Energy) and number 13 (Climate action) of the 2030 global agenda, developing a reasonable PV power plant before installation (10MWDC) is one step towards reducing poverty in Somalia as well as mitigating pollution to the environment globally. Professional decision-making among practitioners in the field can be facilitated by the use of SAM, an interactive tool for solar photovoltaic system design and performance analysis.

Therefore, the primary advantage of this renewable energy source is that solar radiation is available everywhere in the world, including rural and urban areas. When taking this into account, awareness of solar photovoltaic (PV) renewable energy sources leads to an increase in the economies of both the nation and the individual, as they currently create jobs at a faster rate than jobs requiring non-renewable energy.

Their performance as non-linear modular energy sources surely depends on climate factors. PV systems function better during the summertime when there is more intense solar energy production available and a larger project income. The fundamental aspect of investment potential for projects with an investor base is the fact that there is an independent market.

Recommendation

Due to their advantageous geographic location, REs in Somalia have great promise for supporting worldwide initiatives towards fostering sustainable development in the country. Even though Somalia still lacks an energy infrastructure, there is currently a growing trend towards alternative energy sources. The best short-term solution for the national electrification ambition is to incorporate RE because creating a national grid is just barely feasible.

Multidisciplinary stakeholders must be assembled to embrace renewable energy technologies in Somalia and beyond, and the government can play a significant role in lowering the cost of investment by providing clear incentives for solar energy products, for example. Not only that, the SAM software should be kept updated as per recent sector requirements (material used in wiring systems and easy access to the system parasitic value).

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interest to be disclosed.

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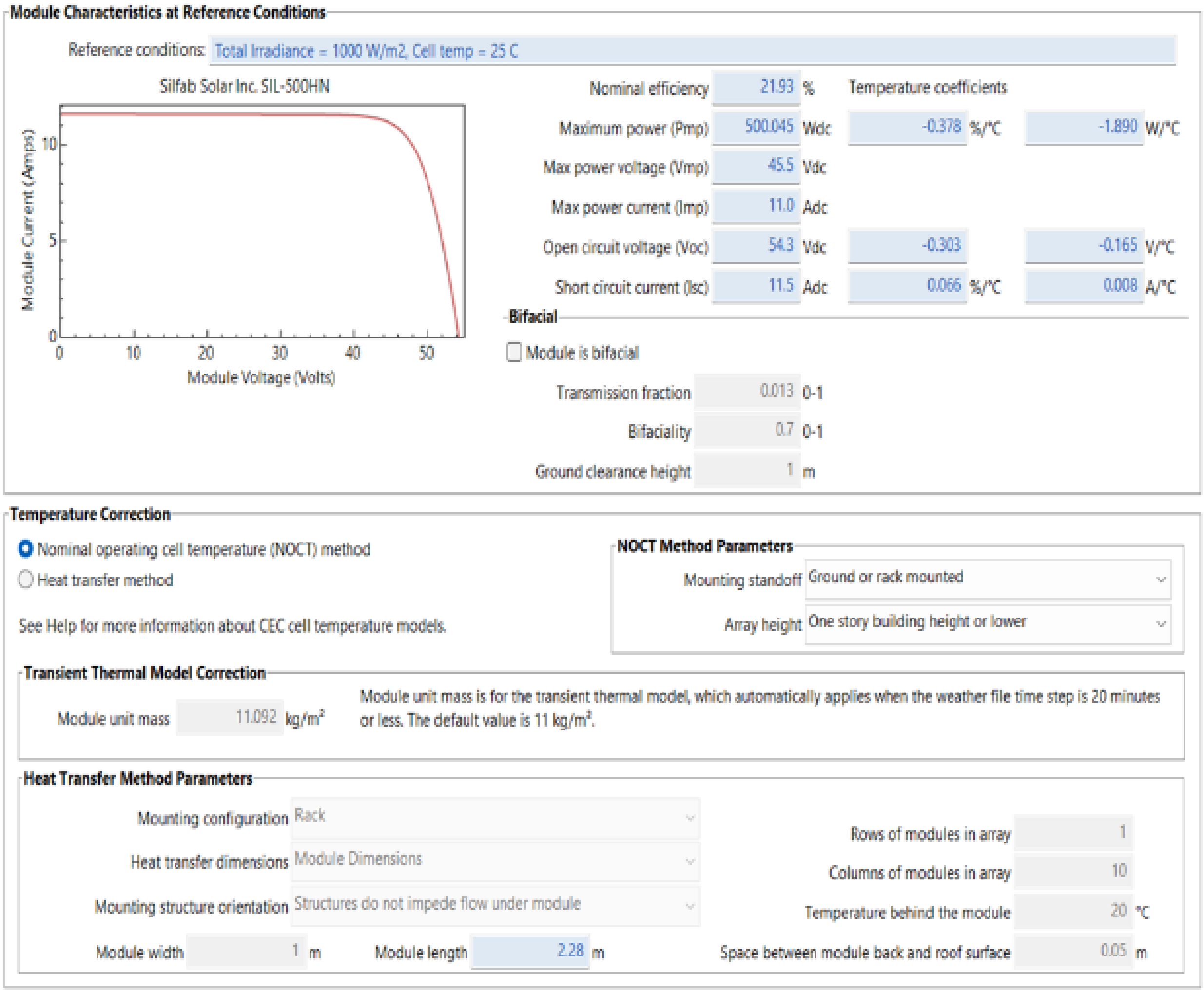
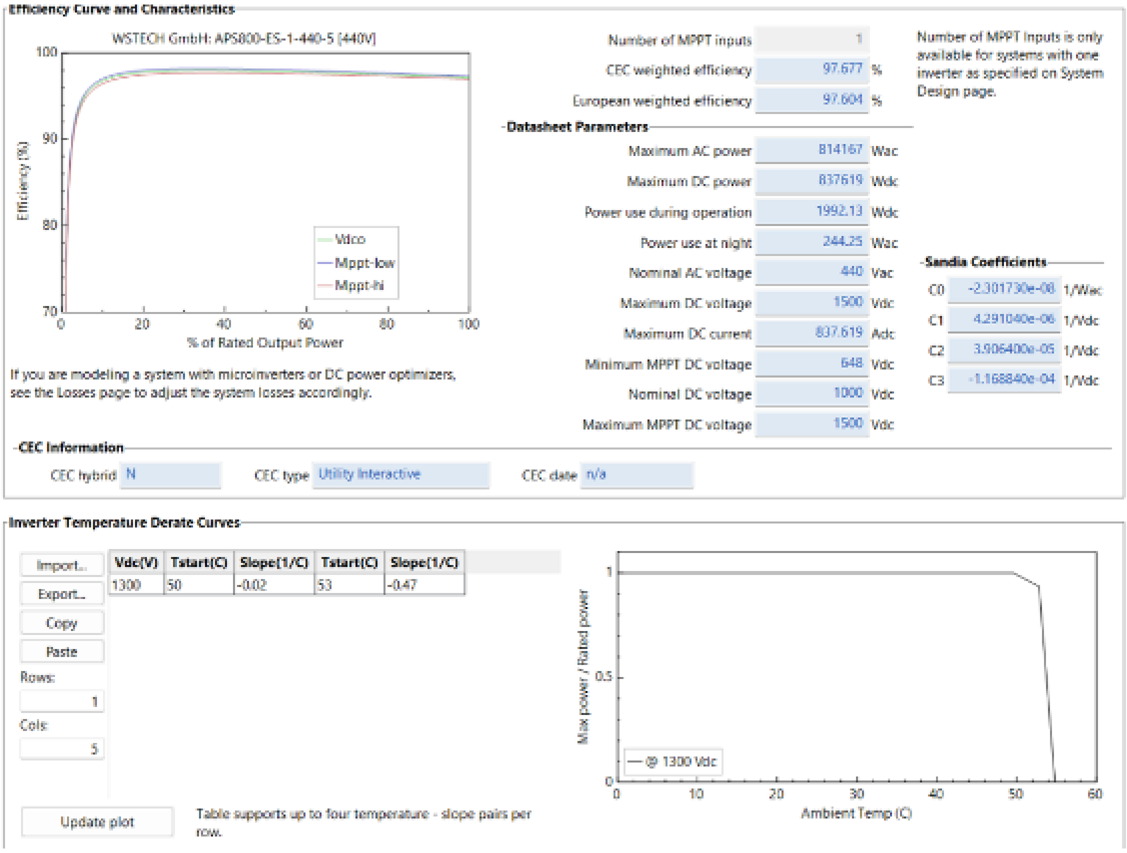
Appendices

Appendix 1. Modules Specification



Appendix 2. Inverter Specification



Appendix 3. Input Performance Parameters Calculations

Component	**Sizing Calculations**	**Useful Specification**
Inverter (W_{ac})	$\frac{DC}{AC} = 1.3$ $\frac{10\ MW}{1.3} = 7.69\ 69\ MW_{ac}$, approx. = 8MWac Selected inverter: 814167 W_{ac} Number of inverters = $\frac{8\ MW}{814167} = 10$	Maximum MPPT Voltage =1500V_{dc} Minimum MPPT Voltage =648V_{dc}
Modules	Selected module: 500.045Wdc Number of modules = $\frac{8\ MW}{500.045\ Wdc} = 20{,}000$ Panels	Capacity =500.045Wdc V_{oc} =54.3dc
String sizing	*maximum number of required series modules* $= \frac{Max.MPPT\ Inverter\ voltage}{module\ Voc} = \frac{1500}{54.3} = 27$ *Minimum number of required series modules* $= \frac{Max.MPPT\ Inverter\ voltage}{module\ Voc} = \frac{648}{54.3} = 11$ *Decided number of series modules=20* *Number of parallel modules*$=\frac{20{,}000}{20} = 100$	