Cost Benefit Analysis: The integration of a Solar versus a combined Cycle Plant

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1.0 Introduction

According to the Africa Infrastructure Country Diagnostic, chronic power problems are impeding growth and productivity in more than 30 African countries (World Bank, 2005). Today, Africa remains one of the most poorly electrified continents in the world. Less than 20 percent of the population has direct access to electricity, and in some countries that number falls to as little as 5 percent (World Bank, 2005). Inadequate generation capacity, limited electrification, unreliable service, skyrocketing prices, and surging demand are creating enormous challenges for African countries looking to renew their energy system in the coming years. Furthermore, increased pressure from national decision makers, media and the public to invest in renewable resources as an attempt to reduce global C02 emissions, are making it increasingly expensive for developing countries such as Africa to build their energy system. In essence, countries in Africa are facing two very difficult, simultaneous challenges: i) Meeting the needs of millions of people who still lack access to basic, modern energy services; ii) Participating in a global transition to a clean, low-carbon energy system.

Unfortunately, government policies and support systems are not helping the situation. In order to maintain an efficient energy market, investors, operators and consumers should, in theory, face the full cost of their decisions. However, like much of the world's energy sector this is far from the case for

African countries. In order to cover the additional costs of producing electricity from renewable sources, African governments offer electricity producers feed in tariffs - long term contracts that ensure each kWh of power produced is sold at a higher price than that of the market. As a result, developers, financers, and private solar companies have started to build a number of renewable power projects in Africa that were once too expensive to establish (Kitasei, 2010). Although these may seem like financially attractive investments, coming from an age that is highly conscious of the environmental effects of burning fossil fuels, alternative evaluation is required as there are many other available energy sources which are capable of providing direct continuous base-load power without massive grant support.

One technology in particular is the combined cycle generator plant; a technology capable of providing continuous base-load power while operating at thermal efficiencies close to 85%. (Kaplan, 2008) These qualities alone make combined cycle plants the most efficient large energy converter available today and yet they are almost completely ignored by private investors due to their higher capital costs. Although it is clear that renewable energy sources may have the potential to increase Africa's contribution to meeting some of its electricity needs in the future, the technology has yet to reach a state capable of providing reliable, consistent, and affordable energy. Therefore, as African countries look to renew their energy sector over the next 30 years, a more complete assessment of the benefits and costs of renewable versus alternative electricity sources such as combined cycle generator must be undergone. Unfortunately, such a comprehensive comparative analysis of the economic costs and benefits of solar and combined cycle technologies, in Africa 1[1], the specific country to be focused on in this paper, has not yet occurred, at least not within the public realm.

This paper attempts to bridge this gap of knowledge by developing a clear assessment of the benefits and costs of renewable energy by evaluating a private sponsor's decision to invest in a project consisting of 20 Megawatts (MW) of concentrated solar in Africa 1. The critical issue proposed by this paper is that the private sponsor of the independent power purchaser IPP has already been approved by the government and has received enough local and foreign investments to have the solar plant in commercial production by early 2013. What this paper seeks to analyze is whether an investment in a combined cycle plant would have been a more cost-effective way for Africa 1 to expand its generation capacity. In other words the aim of this paper is to compare, on a cost benefit basis, the integration of a solar versus a combined cycle plant in response to Africa 1's growing demand to generate electricity.

2.0 Current & Historical State of Africa 1's Energy System

The Energy Information Administration (2004) found that the costs and benefits of adding additional capacity to an electricity system depend on the existing mix of generators, degree of interconnection, and load variations. Therefore, in order to recommend the least cost method, in terms of adding

[1] In order to maintain the confidentiality of the information of the country will be referred to as Africa 1 for the remainder of the paper.

additional capacity to Africa 1's generation mix, an analysis of Africa 1's current electricity system is necessary. As such, this section will briefly examine Africa 1's historical and current electricity system for the time spanning 2003-2009 using historical energy data. Following this section, the country's sources of energy supply and demand, energy production, and areas for future energy production will be examined.

2.1 Historical Energy Supply and Demand

The following table presents the evolution of energy supply and demand from 2003 to 2009 for Africa 1.

Table 1 – Africa 1's historical evolution of energy supply and demand (2003-2009)

	2003	2004	2005	2006	2007	2008	2009
Production (000's kWh)							
• Fossil Thermal	348 662	371 790	415 752	467 729	501 295	483 468	567 492
• Hydraulic	95 892	101 459	100 472	80 668	111 417	135 932	132 297
• Interconnection	69 150	96 183	125 337	139 324	123 910	135 715	144 600
Total	513 704	569 432	641 561	687 721	736 622	755 115	814 389
Demand (000's kWh)							
Delivered energy(1000Kwh)	496 927	546 646	615 562	665 404	710 277	730 378	816 071

According to Table 1, the demand for electricity in Africa 1 has increased from 496 million kWh to 816 million kWh; representing an annual increase of approximately 7.2% over the 7 year period. Supply on the other hand has increased from 513 million kWh to 814 million kWh; representing an annual increase of approximately 6.8%. If we were to forecast how this situation would unfold in the future, it becomes quite obvious that Africa 1 would experience a fairly rapid energy supply shortage given that demand is growing faster than supply. Therefore, it is reasonable to assume that Africa 1's future electricity system will, more likely than not, experience difficulties in keeping pace with demand in the coming years. This potential issue becomes even more probable when one considers that future demand in Africa 1 is projected to increase more than 7.2% a year due to highly anticipated increases in global population and economic activities. To circumvent this situation Africa 1 must evaluate where within their system it is feasible to increase supply so that the system is able to keep pace with the increased demand projections in the coming years. The next section provides a quick overview of Africa 1's current electricity sources in order to determine the most realistic options for future generation.

2.2 Historical Sources of Energy Production

Based on the data presented in Table 2, the country's main sources of energy, classified in order of total production (which was 814 million kWh), were as follows:

- Thermal hydrocarbon based sources, the predominant source, providing 64-67.5% of the total energy production;
- Electricity imports providing 17-18% of the total energy produced; and
- Hydroelectric sources accounting for approximately 15.5-18 % of the country's total energy production

Table 2 – Africa 1's Energy Sources (2008-2009)

	Installed Power	Produce energy kWh (2008) (1)	% on total (2008)	Produce energy kWh (2009) (1)	% on total (2009)
Electricity import					
Total import of electricity	NA	135 715 743	18	144 599 534	17
Fossil fuel production					
Total thermal production	124	483 468 216	64	567 492 164	67.5
Hydraulic production					
Total hydraulic production	32	135 932 318	18	132 297 083	15.5
Total	**156**	**755 116 277**	**100**	844 388 781	**100**

From the information above, it can be inferred that Africa 1's energy sources are not sufficiently diversified. The country is rather highly dependent on imported petroleum, electricity from imports and hydroelectricity for their electricity needs. Unfortunately, heavy reliance on these three sources of production is not only foreseen to be insufficient to meet future demand but the intermittent undiversified supply has already resulted in a number of past electricity shortages. For these reasons, a main focus of Africa 1's national energy strategy is to diversify their electricity generation over the next 5-10 years.

3.0 Current & Potential Sources for Future Energy Production

A brief evaluation of Africa 1's current and potential sources for future generation is presented in this section in order to assess Africa 1's current generation situation as well gain a better understanding of Africa 1's potential future generation system.

3.1 Current Methods of Generation

Hydro

As was previously mentioned, between 15-18% of Africa 1's electricity generation has been generated from hydroelectric plants. Unfortunately, the potential of increasing the future capacity of hydroelectricity remains quite low. Firstly, the country's current reliance on hydroelectric power is already highly exposed to marketed episodes of drought and as a result has triggered a number of systematic blackouts throughout the country. According to the World Watch Institute (Kitasei, 2010), the drought issue is only going to worsen in future years. The World Bank predicts a reduction of more than 20 percent of Africa 1's average rainfall values by 2025 (World Bank, 2005). Given that these climate projections signify that water shortages are becoming more and more frequent it seems that hydroelectricity does not lend itself well to large scale energy production and is therefore an unrealistic option when it comes to sustaining Africa 1's higher economic growth prospects.

Imports

Currently, imports supply between 17-18% of Africa 1's generation supply and unlike hydro sources, import sources do lend themselves to large scale energy production. In fact, Africa 1's government has already decided to base one of the country's energy supply strategies on establishing interconnections with neighboring countries. An $80 million sub-regional project is set to interconnect the energy systems of Africa 1 with its neighboring countries starting in 2011 (EIA, 2004). The sub-regional interconnection project will allow Africa 1's neighbors, countries with more abundant natural resources, to generate income by selling surplus power to Africa 1 in times of need. Although this strategy is set to increase Africa1's capacity and lower the price of electricity it alone is not enough to cover the entire forecasted electricity shortage of Africa 1. Further, the sub-regional project opens Africa 1 to increased risk. For instance, the supply of imported electricity varies greatly according to the time of day and is highly contingent on the capacity and demand of the exporting country. In order to cover the supply shortages, especially during peak hours when neighboring countries need to optimize their own energy supply, importing countries must ensure that their systems are capable of dealing with situations in which the exporting countries are unable to provide or sell excess generation. Moreover, international electricity grid interconnections are complex undertakings, with varying and potentially diverse issues. Depending on how interconnection agreements are structured, grid interconnections may become political liabilities to one or more of the host countries. So although, the interconnection projects are set to increase Africa 1's electrical capacity, and are capable of providing a reliable supply of electricity to the country at a reasonable cost, additional investments in alternative sources are needed in order to meet Africa 1's future demands as well as to diversify the country's risk.

Thermal

Electricity generation in Africa 1 is currently dominated by thermal sources with close to 70% of total electricity generated by such technology. As a result, thermal generation consumes the bulk of Africa 1's energy sector investments and accounts for a significant portion of the country's import costs – approximately between 20-40% (World Bank, 2005). The high dependency on oil imports leaves Africa 1's industry highly exposed to oil price increases as global fossil fuel resources become more depleted. According to the International Energy Agency (IEA), the US Energy Information Agency, and other major sources, oil prices will only continue to rise and become more variable in the next decade; a trend that is certain to have a major impact on Africa 1's electricity cost (EIA, 2004). In order to support Africa 1's fragile system, and reduce the exposure to oil price shocks, the government has issued an annual fuel subsidy of approximately 33 million Euros to help reduce oil and fuel purchasing costs for utility companies. This subsidy has helped ensure that electricity derived from thermal sources is relatively affordable for consumers and that investment in thermal generation continues to be financially feasible for utility providers in the future. Another major reason Africa 1's government is providing a fuel subsidy is that the government realizes that thermal sources are one such technology capable of providing reliable, consistent base load power. So although Africa 1's oil imports may be highly exposed to fluctuations in oil prices, it is an energy source capable of large scale expansion.

On the other hand, it is also important to note that Africa 1 has highlighted the need to reduce their dependency on subsidies, and systems that are vulnerable to climate change and future carbon taxes. Therefore, although a primary objective of the government is to keep up with future demand, Africa 1 should also continue to focus on diversifying the current energy system into alternative sources such as renewables.

3.2 Possible Areas for Future Generation

Solar

Africa 1 has an extremely high potential for future solar generation given that the country is located in a region that has between 2,500 and 3,500 hours of annual sunshine (World Bank, 2005). Unfortunately, in spite of the country's high solar energy potential, the existing installed base in Africa 1 has been limited solely to micro solar generation units due to the high costs of installing large solar generating plants. Recently however, solar generation costs have begun to decrease as the government has increased subsidies for private companies looking to install solar plants in Africa 1. Moreover, recent shocks in oil prices and uncertainties around carbon regulation have shifted more and more investors towards investing in solar units. As the price of solar units continue to fall, and carbon regulations become more likely, investments in solar production are becoming an affordable and feasible strategy for countries looking to increase their generation capacity.

On the other hand, solar energy technologies still face a number of barriers that have continued to delay production in Africa 1. Unlike conventional energy sources, which have benefited from decades of research and development, an established industrial base, and government-subsidized support, solar production options are just becoming known in this region. Additionally, solar is highly dependent on the variability surrounding the quantity of sunlight distributed each day. Presently, a cost comparison between solar and thermal generation shows that solar power in developing countries still costs significantly more than traditional power, even after taking into consideration the available subsidies. Therefore, although investing in solar may promote sustainable development, offer reduced risk exposure to increasing oil prices, and increase the diversity of Africa 1's electricity supply sources there are a few important financial and technical obstacles that must be taken into consideration before declaring it to be an obvious choice for significant investment.

Combined Cycle

As previously mentioned, increasing global greenhouse gas (GHG) emissions have led to an increasing global emphasis on cleaner power generation systems. As a result, combined cycle generation has gained popularity among nations seeking to lower their carbon footprint while providing a reliable energy source in lieu of the technology's high efficiency capabilities. A combined-cycle generation unit generates electricity in one turbine and then captures the wasted heat energy in a second turbine in order to generate more electricity with the same amount of input. This unique characteristic increases energy efficiency, uses less fuel, and thus produces fewer greenhouse gas emissions. So much in fact that it has been suggested that natural gas combined cycle generation units can be up to 85 % energy efficient, whereas coal and thermal oil generation units are typically only 30 to 35% efficient (Kaplan, 2008). Accordingly, the World Watch Report suggests that natural gas combined cycle power plants emit nearly half as much carbon dioxide as traditional thermal coal plants (Kitasei, 2010). Due to these properties nations have started to transition their energy systems in order to incorporate more combined cycle generators in their energy supply mix. For instance, Chile, a country once depended on hydropower for 70% of its electric supply, is now boosting its gas supplies for combined cycle generation to reduce its reliance on its drought afflicted hydro dams. Similarly, China and Singapore are both currently tapping their gas reserves in order to reduce their reliance on coal (Kaplan, 2008). Furthermore, studies in the United Kingdom have predicted that by 2050, 40-50% of UK's power supply will be dominated by combined cycle power plants (Ault G, 2008). Therefore, it seems that because of the combined cycle's ability to produce consistent reliable energy, while reducing emissions, it could offer an opportunity for Africa 1 to reduce oil-related costs while at the same time increasing the reliability and supply of electricity.

However, the combined cycle power generation system is not without its disadvantages. Because the combined cycle plant is a combination of two technologies, the maintenance and capital cost of a combined cycle plant are higher than that of traditional thermal plants. Therefore, countries must compare, on a cost benefit basis, whether or not combined cycle plants result in a long term net benefit.

3.3 Summary of Africa 1's Electricity Challenge and Potential Solutions

To help alleviate Africa 1's future electricity shortage, the country needs to invest in added generation capacity immediately. The two technologies that are assessed in this paper, and seem to lend themselves well to Africa 1's shortage situation are solar and combined cycle plants. Unfortunately because each potential generating technology has a unique set of properties it is very difficult to assess which option would be the more cost-effective solution for the country. Therefore, the remainder of the paper focuses on comparing, on a cost benefit basis, the integration of a solar versus a combined cycle plant in response to Africa 1's growing demand.

4.0 Analytical Framework

The main objective of the analysis is to determine whether building a 20 MW solar plant is a more cost effective solution than building a combined cycle plant in Africa 1. A load duration curve ("LDC") base approach has been developed to assess the impacts of each option. To more thoroughly explain the cost comparison, the process is broken down step by step. The objective of each step is explained more thoroughly in section 5.0.

Step 1: Forecast Africa 1's future electricity demand.

Step 2: Forecast Africa 1's future annual LDC (supply curve), in which no future solar and or combined cycle generation is added to the system

Step 3: Calculate the total production of 20MW of solar generation

Step 4: Calculate the total solar cost savings

Step 5: Calculate the amount and total production of Combined Cycle Capacity

Step 6: Calculate the total combined cycle cost savings

Although there are a variety of costs and benefits associated with adding new capacity to an electricity system, such as the idle single cycle and diesel generators that will be available as reserve in the combined cycle scenario, this cost benefit analysis will focus only on the most direct cost and benefit parameters, gathering the information from historical demand forecasts, supply projections, assumed fuel costs, feed in tariffs, capital costs, and forecasted carbon prices.

5.0 Analytical Steps

5.1. Step 1: Forecast Africa 1's Future Electricity Demand.

The key to evaluating the difference in costs between the solar and combined cycle plants is to first calculate the total future cost savings that would result from each plant as a result of the reduced cost of renewing an existing, more expensive plant. This is something that seems straightforward, but in fact there are many subtleties that arise because the value of the benefits that will be accrued from a new plant stretch many years into the future. Therefore, in order to accurately calculate the total future cost savings that would result from the addition of a new plant, an accurate depiction/database of Africa 1's current and future generation assets is necessary. Such a database is fundamental to the validity of the outcome; however, before one can build an accurate database of Africa 1's future generation supply, one must first forecast the future of electricity demand in Africa 1 over the life of the project.

Therefore, step one of the analytic process forecasts Africa 1's electricity demand over the life of the project by applying a constant annual growth forecasting technique. The annual growth rate is calculated and based on Africa 1's historical growth rate values. Although this may not be realistic, with demand in some years increasing more than other years, a constant growth rate technique has been generally accepted and used throughout the literature when calculating future electricity demand.

According to Africa 1's historical values presented in Table 1, section 2.1, the country experienced an average growth of electricity demand of approximately 7.2% between 2003-2009. Therefore, for this analysis it was assumed that the demand for electricity would continue to grow at 7.2% for the next 25 years. The following equation was used to calculate Africa 1`s forecasted demand for each year:

$$L_{j,y} = L_{j,2009} \times (1+.072)^{y-2009} \qquad \forall_j$$

Where $L_{j,y}$ is the demand load in hour j for year y, and y is any year between 2013 and 2038. For example, the load at noon in 2009 is given by $L_{12:00,2009}$.

Figure 1 illustrates the forecasted annual demand load curves for 2013, 2015, 2020, 2025 and 2030 and Table 3 converts figure 1 into numbers.

Figure 1: Africa 1 Annual Load Demand Curve Predictions under a Constant Growth Model

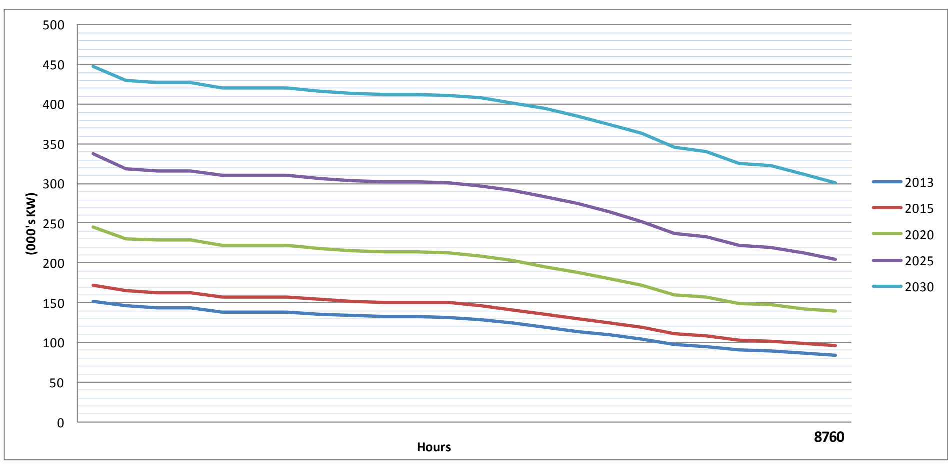


Table 3 - Africa 1`s Annual Total Predicted Demand (000`s kWh), under a constant growth model

Year	2013	2015	2020	2025	2030
Total Demand (000's kWh)	1,059,569	1,204,850	1,720,550	2,454,106	3,405,516

5.2 Step 2: Forecast Africa 1's future annual load duration curve (supply curve)

Within power markets, every power producing plant uses different levels of technology, requires different types of fuel, and consumes a different quantity of fuel in order to generate a unit of electricity. Therefore, the cost of power generation varies across each plant. In order to ensure each system is always operating at the lowest possible cost a system known as the "merit order" is often used. This system is used as a way to rank the available sources of energy in ascending order of their short-run marginal costs of production. Those with the lowest marginal costs are the first plants to be brought online to meet demand, and the plants with the highest marginal costs are the last to be brought on line.

Ranking electricity systems becomes quite complex over large time spans as demand for electricity grows, and the mix of power generators shift with the changing demand and supply. It becomes a complicated planning process in a way that it is all based on forecasted demand and supply. Further, as the system evolves and old generators, which depreciate over time, are replaced with new, more efficient generators the costs and benefits of adding new capacity to the system also adjusts. Therefore, it is fundamental to the validity of comparing the benefits and costs of adding new capacity to Africa 1’s system to have an accurate depiction of Africa 1’s generation supply over the life of the project.

The data used to construct the supply database was retrieved and extended from Africa 1’s current system operator’s statements. Three sources of electricity (thermal, hydraulic, and imports) are included in the system based on the following four assumptions:

1) Demand must equal production at all times;
2) Hydro remains constant at 132, 297 kWh over the 25 years;
3) Imports grow at the same constant rate as demand (7.2%/year); and
4) Thermal units are added to the system only when demand is forecasted to be greater than the supply

The timeline of when thermal units are added to the system are illustrated in Table 4. As indicated by the table, two new thermal units are added to Africa 1`s system over the 25 year analysis. Africa 1’s current thermal plant, capable of producing 58 MW of energy, is able to supply enough electricity to the system until 2013. At this point, in order to ensure demand equals supply (assumption 1); we assume that Africa 1 invests in a new 90 MW thermal diesel plant. This new diesel plant (New Plant 1) is assumed to be implemented in 5 phases over the course of the 25 year period. For instance, in 2013 the new plant is capable of contributing 18 MW to the system, in 2015 the new plant is capable of contributing 36 MW, in 2020 the new plant is capable of contributing 54 MW to the system, and so forth. It is only in 2025 that a second thermal diesel plant (New Plant 2) is required in order to ensure Africa 1`s supply source continues to meet the country's forecasted demand. It is assumed that the third thermal plant is capable of producing 50 MW and can cover the excess demand immediately. It is also important to note that each new diesel thermal generator added into the system is assumed to be more efficient than the previous thermal generator.

Table 4 – Thermal Generation Capacity Added to Africa 1's System (2012- 2038)

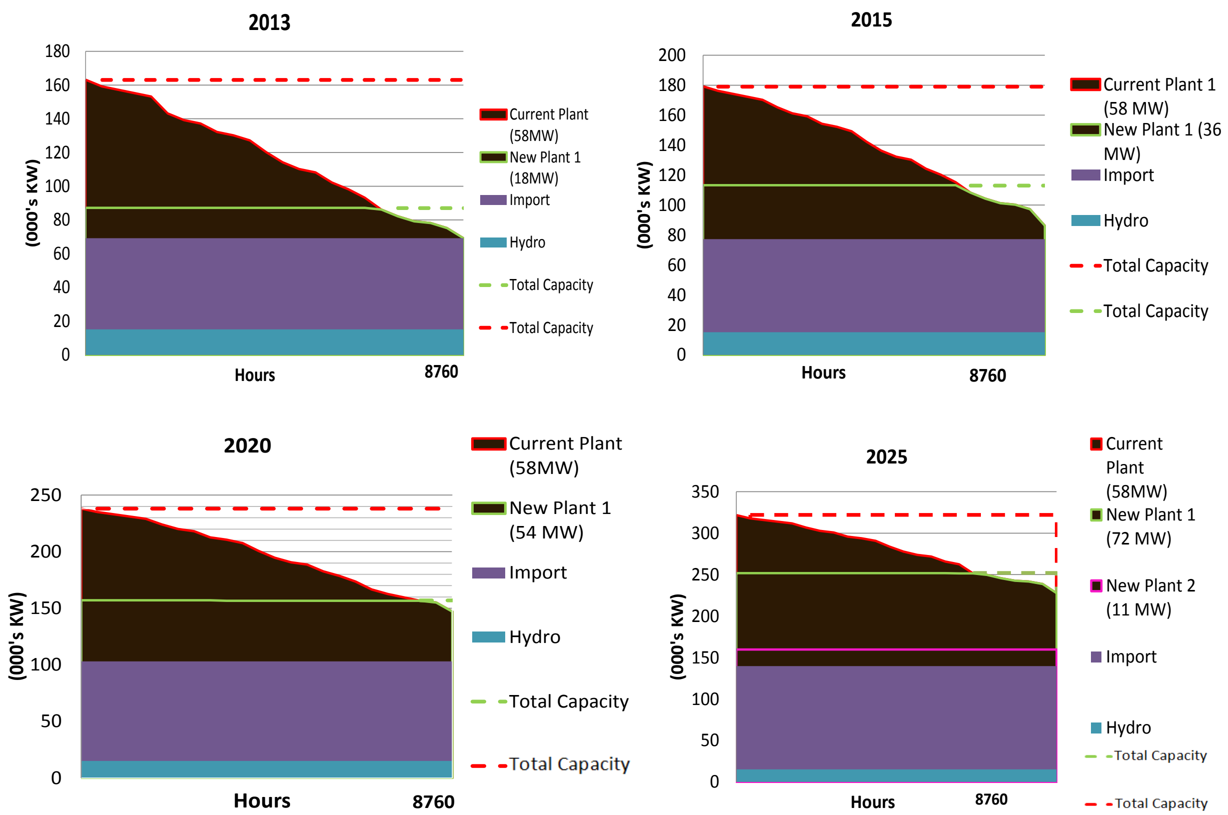
Year	2013	2015	2020	2025	2030
Plants					
Current Plant (58MW)	34	24	39	58	58
New Plant 1 (90MW)	18	36	54	72	90
New Plant 2 (50MW)	-	-	-	11	49
Total Fossil Thermal Demanded (MW)	52	60	93	141	197
Total Fossil Thermal Demanded Kwh (000's)	453,589	528,204	817,614	1,230,809	1,728,681

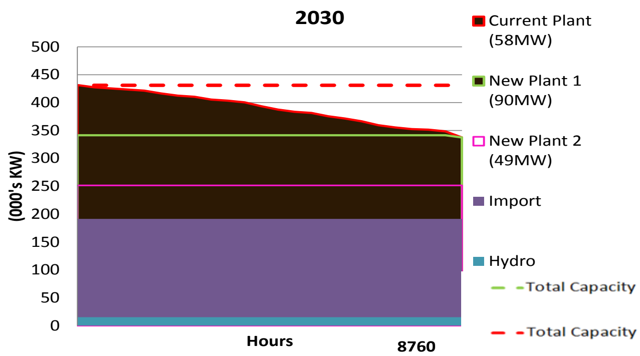
Table 5 incorporates hydroelectricity and imports into the supply mix and highlights Africa 1's total generation supply over the life of the project in 000's kWh. Figure 2 on the other hand, visually illustrates the forecasted evolution of supply in terms of an annual LDC for 2013, 2014, 2020, 2025 and 2030.

Table 5 – Africa 1's Total Energy Supply and Demand Mix

Year	2013	2015	2020	2025	2030
Production (000 Kwh)					
Thermal	453,589	528,204	817,614	1,230,809	1,728,681
Hydro	132,297	132,297	132,297	132,297	132,297
Imports	473,683	544,349	770,640	1,091,001	1,544,540
Total Supply	**1,059,569**	**1,204,850**	**1,720,551**	**2,454,107**	**3,405,518**
Total Forecasted Demand (000 Kwh)	**1,059,569**	**1,204,850**	**1,720,551**	**2,454,107**	**3,405,518**

Figure 2 – Africa 1's Total Energy Supply and Demand Mix





5.3 Step 3: Calculate the total production of 20MW of solar generation.

In order to analyze the feasibility regarding different energy source(s), one must address the questions of how much energy the source will produce and at what incremental savings to the electricity system as a whole it will add. However, before one can value the incremental cost savings the new plant will add to the electricity system, one must first calculate the total production capacity of the new plant. The main technical parameters used to calculate the total production capacity of the 20MW plant are listed and presented below in Table 6.

Table 6 - Technical Parameters and Assumptions: Production of 20MW of Solar

Location:	Africa 1
Operation and maintenance period:	25 years
Plant 's Capacity:	20 MW of nominal power
Annual degradation of the Generator:	1 % on average over 25 years
Investment Cost:	60 M €
Annual production (1st year):	35.1 Million kWh
Technology:	PV Polycrystalline
Construction time:	10 months
Average Annual solar radiation:	2 162 kWh/m2/year
Performance Ratio	76.6% Guarantee

Capacity Factor / Load Factor [2]	24.6%

Annual Solar Production

Drawing on the average annual solar radiation, performance ratio, and the installed capacity from the technical parameter able above, the expected annual solar production was calculated using the following formula:

Expected Annual Solar Production (kwh per year) = α x β x λ

Where:

α = Average Annual Solar Radiation ($kWh/m^2/year$)[3]

β = Performance Ratio for the Solar Instillation (%)[4]

λ = Power Plant Capacity after degradation (kWh)

Based on the parameters in Table 6 the total electricity production (kWh) of the 20MW solar plant is presented in Table 7. As indicated by table 7, approximately **844,042,310 kWh** of solar generation are produced over the 25 year time span.

[2] The capacity factor of a power plant is the ratio of the actual output to the potential output. To calculate the capacity factor the total amount of energy the plant was able to produce during a period is divided by the amount of energy the plant would have produced if it was operated at full capacity.
[3] The amount of solar energy that arrives at a specific area at a specific time
[4] Performance ratio measures the quality of a solar plant. It is the proportion of the energy that is available for export to the grid after the deduction of energy loss is accounted for.

Table 7 – Total Solar Production (kWh)

YEAR	2013	2014	2015	...	Total - 25 Years
Electricity Production (Solar- KWh/kWp/year)	1656	1656	1656	...	43,058
Power Plant Capacity before degradation	21,194	21,194	21,194	...	551,044
Power Plant deterioration	1	0.990	0.984	...	24
Power Plant Capacity after degradation	21,194	20,982	20,856	...	509,659
Total Electricity Production kWh	**35,099,214**	**34,748,222**	**34,539,732**	**...**	**844,042,510**

5.4 Step 4: Calculate the total solar cost savings

The next step in analytical process is to convert the total production of solar generation into the total cost savings that would result from the reduced cost of renewing the existing thermal plants when 20 MW of solar generation are added to Africa 1's system. In order to calculate the total fuel savings, a three-step calculation process is used. The steps are illustrated in Figure 3, and discussed in more detail below. Further each calculation draws directly upon the technical parameters and assumptions presented in Table 8.

Table 8 - Technical Parameters and Assumptions: Cost Savings from 20MW of Solar Generation

Location:	Africa 1
Operation and maintenance period:	25 years
Solar Plant 's Capacity:	20 MW of nominal power
Annual increase in fuel requirement	1%
Fuel requirement of Thermal Plants[5]	.277 (litres/kWh)
PV of total subsidy savings[6]	31,822,000 (EUR)
1 bbl. of Oil	158.987 litres
Real Exchange Rate[7]	.7034 (EUR/USD)

[5] Figure is based on Africa 1's report.
[6] This is the total fraction/proportion of the subsidy that would have been provided to the thermal plant if the proposed 20MW solar plant was not added to the system.
[7] The Real exchange rate is assumed to stay constant throughout the life of the project.

FOB Oil prices, real 2012 prices [8]	80 (USD/barrel)
FOB Oil prices, real 2012 prices[9]	.354 (EUR/litre)
Additional costs (custom duty, statistical charge, handling, transportation from port to project)[10]	.261 (EUR/litre)
Total Project-site Financial Price of unsubsidized oil[11]	.616 (EUR/litre)
Required Rate of Return/Discount Rate[12]	12.7 %

Figure 3: Process for calculating the total cost savings as a result of the 20 MW of solar generation

1. **Calculate the total fuel savings in litres**

The first step to calculating the hypothetical total dollar cost savings from adding 20 MW of solar generation to Africa 1's system is to first calculate the total fuel savings in litres that are saved as a result of the renewable generation. Since solar power is considered a substitute for thermal power, the reference plant in appraising the solar plant's savings is Africa 1's most recent and efficient thermal plant. According to the technical parameters, the specific fuel requirement of the most efficient plant is 0.277 litres/kWh. It is further assumed, that like other plants, the new thermal plant will become less

[8] The price of oil is assumed to stay constant throughout the life of the project.
[9] Calculated by multiplying 80 USD by the European exchange rate 0.70374€/USD and dividing by 158.987 (litres/bbl.).
[10] Assumed to stay constant and based on Africa 1's reports.
[11] Calculated by adding the 2012 real FOB oil prices in EUR/litre with the additional costs from transportation in EUR/litre.
[12] Figure is based on Africa 1's report.

efficient over time. Therefore, a second assumption in table 8 states that the new thermal plants fuel requirement increases by 1% each year. Based on these assumptions, the total fuel savings (in litres) can be calculated by multiplying the "Total Electricity Production by Solar (kWh)" by the "Fuel Requirement of thermal plants (litres/kWh)" and factoring in the 1% increase of fuel requirement each year. Table 9 presents the calculated total fuel savings in litres.

Table 9 – Total fuel savings (litres) after adding 20MW of solar generation to Africa 1's supply mix

YEAR	2013	2014	2015	...	Total -25 Years
Total Electricity Production by Solar (kWh)	35,099,214	34,748,222	34,539,732	...	844,042,510
Fuel requirement New Thermal Plant				...	
Annual increase in fuel requirement		1.0%	1.0%	...	
Fuel requirement (liters/kWh)	0.277	0.280	0.283	...	
Total fuel Savings with Solar (liters)	**9,722,482**	**9,721,510**	**9,759,813**	**...**	**264,605,804**

2. Monetize and discount the fuel savings (litres) calculated in Step 1

The second step to calculating the hypothetical total cost savings from the new 20MW of solar generation is to monetize the total fuel savings (litres). The monetized value is calculated by multiplying the "Project-site Financial Price of Unsubsidized oil (EUR/litre)" with Step 1's "fuel savings (litre)". According to Table 8, the "Project-site Financial Price of Unsubsidized oil" is .616 EUR/litre.[13] Once the total annual fuel savings (litres) are converted to USD it must be discounted to the base year of

[13] This value was calculated by first adjusting the USD/bbl. price to EUR/litre, drawing on the real exchange rate. Secondly, the added costs of transferring a barrel of oil from port to project are added; these include the custom duty, statistical charge, handling, and transportation.

assessment (2013) using a discount rate of 12.7%. Table 10 presents the total calculated monetized and discounted fuel savings in USD.

Table 10 - Total monetized and discounted fuel savings from adding 20MW of solar generation to Africa 1's system

YEAR	2013	2014	2015	...	Total - 25 Years
Total fuel Savings with Solar (liters)	9,722,482	9,721,510	9,759,813	...	264,605,804
Project-site Financial Price of unsubsidized oil (EUR/liter)	0.616	0.616	0.616	...	
Financial Value of Total Fuel Savings (EUR)	**€ 5,985,046**	**€ 5,984,447**	**€ 6,008,026**	...	**€ 162,888,224**

	2013
PV of Total Fuel Savings (EUR)	**€ 46,064,330**

3. **Adjust the total fuel savings (USD) to account for the proportion of thermal subsidies that that will be avoided.**

In order to support Africa 1's fragile system and lower the risk of thermal investment, the government issued an annual fuel subsidy of approximately 33 million Euros to help reduce fuel purchasing costs for utility companies. Therefore, the third and final step to calculating the hypothetical total cost savings from the new 20MW of solar generation is to add the proportion of subsidy to the discounted fuel savings that would have been provided to the thermal plant had the 20MW of solar generation not been added to the system. To calculate the total amount of fuel subsidy that would have been avoided as a result of the 20MW of solar generation, the "Annual Production of Solar" is divided by the "Annual Production of Thermal" to obtain the annual proportion of thermal generation that has been avoided. This proportion is then multiplied by the annual fuel subsidy of 33 million Euros. The total proportion is then summed with the discounted total fuel savings from step 2. Table 11 presents the annual, and total discounted financial value of the subsidy savings. Table 12 adds the total monetized fuel savings to the discounted financial value of the subsidy savings and presents the total value of the cost savings from adding the 20 MW of solar capacity to the system.

Table 11 – Annual, and total; discounted financial value of subsidy savings

YEAR	2013	2014	2015	...	Total - 25 Years
Total Electricity Production by Solar (kWh)	35,099,214	34,748,222	34,539,732	...	844,042,510
Total Thermal Electricity Production (kWh)	453,589,451	453,589,451	528,204,378	...	29,348,440,696
Proportion of Solar Electricity Production (Total Electricity Production by Solar/Total Thermal Electricity Production)	7.74%	7.66%	6.54%	...	
Annual Fuel Subsidy (EUR)	€ 32,789,385	€ 32,789,385	€ 32,789,385	...	€ 852,524,020
Financial Value of Subsidy Savings as a result of 20MW of Solar generation (EUR)	**€ 2,537,276**	**€ 2,511,903**	**€ 2,144,126**	...	**€ 31,822,580**

	2013
PV of Total Subsidy Savings (EUR)	**€ 13,310,675**

Table 12 – Total discounted fuel savings

YEAR	2013
PV of Total Fuel Savings (EUR)	€ 46,064,330
PV of Total Subsidy Savings (EUR)	€ 13,310,675
PV of Total Solar Cost Savings (EUR)	**€ 59,375,005**

5.5 Step 5 – Calculate the total amount and total production of the combined cycle plant

According to Step 4, the total estimated fuel savings resulting from the installation of a 20MW solar plant into Africa 1's system was approximately **€59,375,005**. The next step therefore, in determining which alternative, among the solar or combined cycle, should be selected in order to maximize Africa 1's welfare is to calculate and compare the total cost savings of adding a combined cycle plant, equivalent to €59,375,00, to Africa 1's system. Step 5 begins the process by breaking the calculation down into two steps illustrated in figure 4 where each calculation draws directly upon the technical parameters and assumptions presented in Table 13.

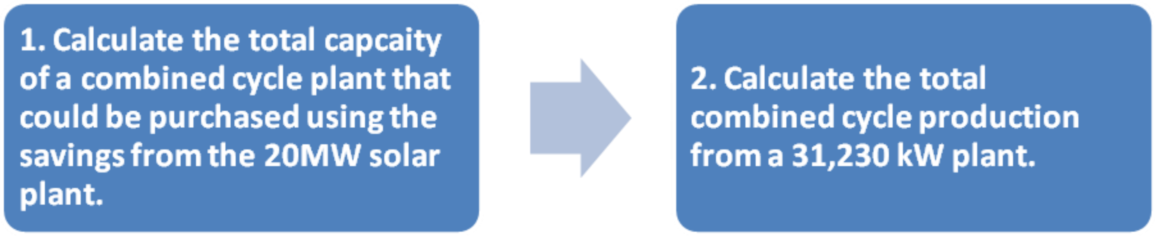
Technical Parameters

Table 13 - Technical Parameters and Assumptions: Potential Capacity and Production of a Small Combined Cycle Plant

Location:	Africa 1
Capital Cost Assumptions	
US Based Capital Cost per KW (USD)	$ 1,003
LDC Base (Assumption)	2.7
EUR Capital Cost per KW (EUR)	€1901.22
Capacity of Alternative Plant KW	31,230
Exchange Rate (US/EUR)	.7034
Electricity Production Assumptions	
Operation and maintenance period	25 years
Annual degradation	1 % on average over 25 years
Technology	New Technology CC Power Plant
Annual potential production hours	8760
Capacity Factor[14]	85%[15]

[14] Capacity factor is a standard measure of how intensively a power plant is utilized. It is the ratio of how much electricity a power plant produces over a period of time compared to how much electricity the plant could have produced if it was operated continuously at full capacity.
[15] According to the report *Displacing Coal with Generation from Existing Natural Gas-Fired Power Plants* combined cycle plants operate at a capacity factor of 85%.

Figure 4: Process for calculating the total capacity and production of a combined cycle plant



1. **Calculate the total capacity of a combined cycle plant that could be purchased using the savings generated from the 20 MW solar plant**

To estimate the potential capacity of combined cycle plant that could be purchased using the total fuel cost savings of **€59,375,005**, data from the U.S Department of Energy is drawn upon (EIA, 2004). According to Table 13, the "US Based Capital Cost of a Combined Cycle" plant is approximately $1003/kW (€1901.22/kW). Therefore, to calculate the total capacity of a combined cycle plant that could be purchased using the total fuel cost savings, €59,375,005 is divided by €1901.22. The result is **31,230 kW (31.23MW)** of combined cycle capacity.

2. **Calculate the total combined cycle production from a 31,230 kW Plant**

The total combined cycle production from a 31.23 MW combined cycle plant is calculated using the formula below. Table 14 then presents the total expected electricity production (kWh/year) of the 31.23 MW combined cycle plant.

Expected Annual Combined Cycle Production (kWh per year) = 8760 hours x $\varkappa$ x λ x Depreciation

Where:

8760 represents the total hours in a year (365 days* 24 hours)

ϰ = assumed average capacity of a combined cycle plant

λ = installed capacity (kWh/year)

Depreciation = the downward trend of benefits of the combined cycle plant (1 %/yr.).

Table 14 – Total expected combined cycle production of a 31.23 MW Plant (kWh/year)

YEAR	2013	2014	2015	...	Total - 25 Years
Electricity Production (CC- KWh/kWp/year based on 85% capacity)	7446	7446	7446	...	193,596.00
Power Plant Capacity before degradation	31,230	31,230	31,230	...	
Power Plant deterioration	1	1	0.984	...	
Installed CC Capacity after degredation	31,230	30,918	30,732	...	
Total Expected CC Production kWh	**232,538,580**	**230,213,194**	**228,831,915**	**...**	**5,591,932,843.00**

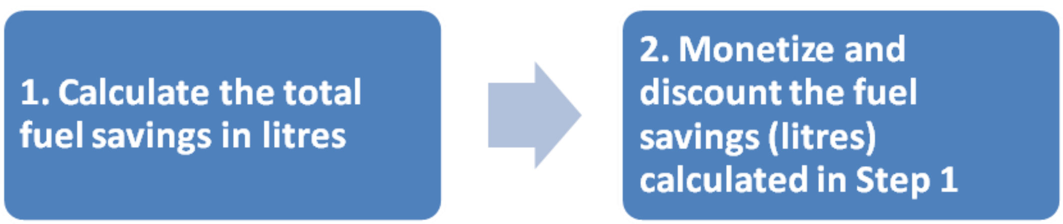
5.6 Step 6: Calculate the total combined cycle plants cost savings

In order to calculate the total cost savings that result from the reduced cost of renewing the existing thermal plants when 31.23 MW of combined cycle are added to Africa 1's System, a two-step calculation process is used. The steps are illustrated in Figure 5, and discussed in more detail below. Further each calculation draws directly upon the technical parameters and assumptions presented below in Table 15.

TABLE 15 - Technical Parameters and Assumptions: Cost Savings from 31.23 MW of Combined Cycle Generation

Location:	Africa 1
Operation and maintenance period:	25 years
Combined Cycle Plant 's Capacity:	31.23 MW of nominal power
Annual increase in fuel requirement	1%
Fuel requirement of Thermal Plants[16]	.277 (litres/kWh)
Fuel Requirement of a CC Plant [17]	.128(litres/kWh)
Difference in Fuel Requirement of Thermal vs. CC Plant	.149 (litres/kWh)
1 bbl. of Oil	158.987 litres
Real Exchange Rate[18]	.7034 (EUR/USD)
FOB Oil prices, real 2012 prices [19]	80 (USD/barrel)
FOB Oil prices, real 2012 prices[20]	.354 (EUR/litre)
Additional costs (custom duty, statistical charge, handling, transportation from port to project)[21]	.261 (EUR/litre)
Total Project-site Financial Price of unsubsidized oil[22]	.616 (EUR/litre)
Required Rate of Return/Discount Rate[23]	12.7 %

Figure 5: Process for calculating the total cost savings as a result of the 31.23 MW of combined cycle generation



[16] Figure is based on Africa 1's report.
[17] Figure is based on Africa 1's report.
[18] The Real exchange rate is assumed to stay constant throughout the life of the project.
[19] The price of oil is assumed to stay constant throughout the life of the project.
[20] Calculated by multiplying 80 USD by the European exchange rate 0.70374 and dividing by 158.987 (the amount of litres in a bbl.
[21] Assumed to stay constant and retrieved from Africa 1's Reports.
[22] Calculated by adding the 2012 real FOB oil prices in EUR/litre with the additional costs from transportation in EUR/litre.
[23] Figure is based on Africa 1's report and utility sector's needs.

1. **Calculate the total fuel savings in litres**

The first step to calculating the hypothetical total dollar cost savings from adding 31.23 MW of combined cycle generation to Africa 1's system is to calculate the total fuel savings in litres. Since the combined cycle plant is considered a substitute to thermal power, the reference plant in appraising the combined plant is the most recent and efficient thermal plant. According to the technical parameters presented in Table 15, the specific fuel requirement of the most efficient plant is 0.277 litres/kWh whereas the fuel requirement of the combined cycle plant is 0.128 litres/kWh. It is further assumed, that like other plants, the new thermal plant, and new combined plant will become less efficient over time as the fuel requirement of each plant increases by 1%/year. Based upon these assumptions, the total fuel savings (in litres) can be calculated by multiplying the "Total Electricity Production by Combined Cycle (kWh)" by the "Difference of the thermal and combined plants Fuel Requirement (litres/kWh)" and factoring in the annual increase of fuel requirement of 1% each year. Table 16 presents the total calculated fuel savings in litres after adding the combined cycle plant to the system.

TABLE 16 – Total fuel savings (litres) after adding 31.23MW of combined cycle generation to Africa 1's system

YEAR	2013	2014	2015	...	Total - 25 Years
Total Electricity Production by CC Plant at 85% Capacity (kWh)	232,538,580.00	230,213,194.20	228,831,915.03	...	5,591,932,843
Fuel requirement				...	
Annual increase in fuel requirement	1.00	1.00	1.00	...	
Difference in Fuel requirement (liters/kWh)	0.149	0.150	0.152	...	
Total fuel Savings with Combined (litres)	**34,648,248.42**	**34,644,783.60**	**34,781,284.04**	**...**	**942,982,194**

2. Monetize and discount the fuel savings (litres) calculated in Step 1

The second step to calculating the hypothetical total cost savings derived from adding 31.23 MW of combined cycle generation to Africa 1's system is to monetize the total fuel savings. The monetized savings are calculated by multiplying the "Project-site Financial Price of Unsubsidized oil (EUR/litre)" with Step 1's "fuel savings in litres". According to the parameters in Table 15, the "Project-site Financial Price of Unsubsidized oil" is .616 EUR/litre. Once the total fuel savings are monetized for each year they are discounted to the base year of assessment (2013), using a discount rate of 12.7%. Table 17 presents the total monetized and discounted fuel savings derived from adding a combined cycle generator to Africa 1's system.

Table 17 - Total monetized and discounted fuel savings from adding 31.23MW of CC generation to Africa 1's system

YEAR	2013	2014	2015	...	Total - 25 Years
Total fuel Savings with CC (liters)	34,648,248	34,644,784	34,781,284	...	942,982,194
Project-site Financial Price of unsubsidized oil (EUR/liter)	0.616	0.616	0.616	...	
Financial Value of Total Fuel Savings (EUR)	**€ 21,329,055**	**€ 21,326,922**	**€ 21,410,950**	...	**€ 580,488,760**

	2013
PV of Total Fuel Savings (EUR)	**€ 164,160,583**

6.0 Identify, analyze, interpret, and compare the outcomes

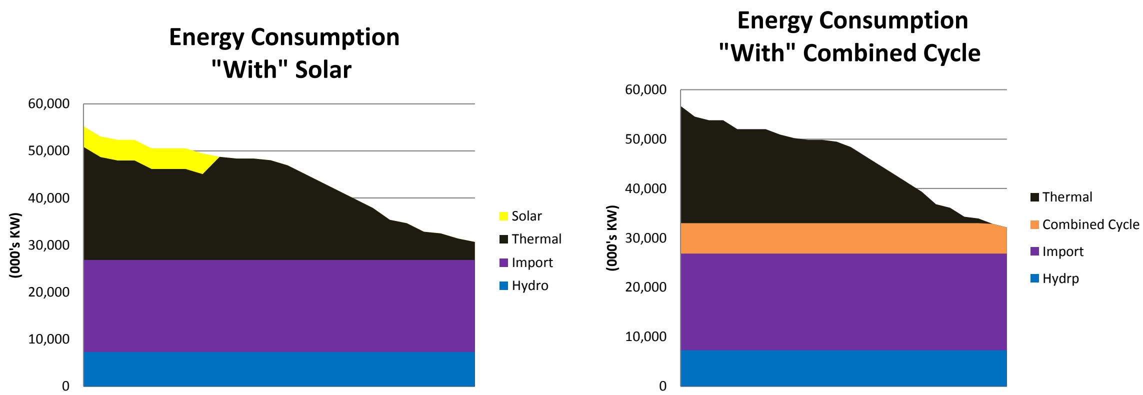
The integration of a solar plant as well as a combined cycle plant into Africa 1's system have been calculated, on a cost benefit basis, throughout the analysis section (5.0) of this paper. This section of the paper focuses on comparing and interpreting the results of each project. The following parameters are compared and interpreted:

- Total Expected Electricity Production (kWh)
- Total Expected Fuel Savings (litres)
- Total Present Value of Fuel Savings ($)

6.1 Total Expected Electricity Production (kWh)

The demand for electricity, faced by an electric power system varies moment to moment with changes in business, residential activity, and the weather. The generating units available to the meet the system load are dispatched in order of lowest variable cost. Solar and combined cycle plants both have very different characteristics and variable costs and are therefore dispatched in a different manner. Figure 6 directly compares Africa 1`s load curve with the integration of 20 MW of solar, to Africa 1's load curve with the integration of a 31.23 MW combined plant.

Figure 6 –Africa 1's Load Duration Curve: Solar vs. Combined



As is apparent in Figure 6, the energy production of the solar plant is far less than energy production of the combined cycle plant. This is because the combined cycle plant is used as a base load unit, and is able to run continuously, whereas the solar plant simply provides a substitute form of generation, and is run only when the sun is shining. Consequently, the amount of expected electricity produced each year differs greatly between the two plants. Table 18 sheds further light on the difference of production between these two plants by comparing the total electricity production of the solar and combined cycle plants over 25 years. It turns out that combined cycle generation is 6.5 times larger than the total expected solar production over this time horizon.

Table 18 - Total Expected Electricity Production: Solar vs. CC

Total Expected Electricity Production (Solar vs. CC)	
Total Expected Solar Production (kWh)	**844,042,510**
Total Expected CC Production (kWh)	**5,591,932,843**

6.2 Total Expected Fuel Saved (litres)

Although the combined cycle plant generates approximately 6.5 times more electricity (kWh) than the solar plant, the combined cycle plant still remains dependent on fossil fuels; whereas the solar plant does not and has an initially higher potential of saving more fuel as a result. Table 19 highlights and compares the specific fuel required (litres/kWh) for each plant. Table 20 then compares and contrasts the total expected fuel savings of each plant. After interpreting the results, it is clear that although the combined cycle plant runs on fossil fuels, the ability of the plant to produce more electricity than the solar plant allows it to save approximately 3.5 times as much fuel savings than the solar plant regardless of its dependency on fossil fuels. Although this is still quite a large margin, the solar plant seems to make up some of the production difference as a result of its renewable nature.

Table 19 - Fuel Requirement (Thermal vs. Solar vs. CC Plants)

Fuel Requirement (Thermal vs. Solar vs. CC)	
Fuel Requirement of a Thermal Plant (litres/kWh)	**0.277**
Fuel Requirement of a Solar Plant (litres/kWh)	**0**
Fuel Requirement of a CC Plant (litres/kWh)	**0.128**

Table 20- Total Expected Fuel Savings Solar vs. CC

Total Expected Fuel Saved (Solar vs. CC)	
Total Expected Solar Fuel Savings (litres)	**264,605,804**
Total Expected CC Fuel Savings (litres)	**942,982,194**

6.3 Total Present Value of Fuel Savings (USD)

As is expected, the total PV of the CC Fuel savings (USD) outweighs the total PV of Solar fuel savings given the greater capacity to save more fuel year after year. However, the proportion of fuel subsidy that would have been provided to the thermal companies in place of the solar plant must also be factored in as savings. The results of adding the fuel subsidy savings to the total PV of solar fuel savings and comparing it to the total savings of the combined cycle plant is presented below in Table 21. According to these values the combined cycle plant provided 2.67 times more savings than the Solar Plant. Therefore, based on the analytical framework chosen for this paper, the combined cycle plant continues to remain at a higher value in terms of total dollars saved in Africa 1.

Table 21- Total Present Value of Fuel Savings (Solar vs. CC)

Total Present Value of Fuel Savings (Solar vs. CC)		
Total PV of Solar Fuel Savings ($)	**€**	**59,375,005**
Total PV of CC Fuel Savings ($)	**€**	**164,160,583**

7.0 Sensitivity Analysis

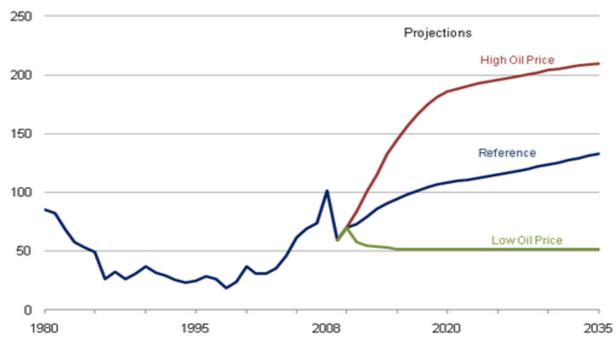
The analytical framework presented in Section 4 is a starting point for comparing how two different scenarios, building a 20MW solar plant versus building a 31.23 MW combined cycle plant, would compare with regards to costs savings. The objective of this section is to provide insight into how key variables used in the analytical framework above, influence the outcome of the result. Three key variables are explored:

- Higher fuel price
- Influence of federal and state incentives
- Carbon control and costs

7.1 Fuel Costs

The economics of thermal plants pivot on fuel prices. Therefore, fuel price uncertainty is especially important in determining the outcome of the comparative cost effectiveness analysis between a 20MW solar plant and a 31.23 MW CC plant. For the base assumption used in this study, the price of oil is assumed to stay constant throughout the life of each project at 80 USD/barrel. As discussed earlier in this report, oil prices have been exceptionally difficult to forecast. If future oil prices are higher than assumed, the economics of combined cycle generation could change substantially. According to EIA (figure 5), three scenario forecasts predict oil prices to be anywhere between $50 a barrel and $210 barrel.

Figure 5 – EIA's average annual world prices in three cases, 2005-2035.



With such variability, it is possible that the base assumption of 80 USD/barrel is not an accurate representation for an effective comparative cost effectiveness analysis. Therefore, for this case's sensitivity analysis an alternative set of fuel prices is applied. The results are re-analyzed when fuel is $50, $100, $150, and $200/ barrel. Table 22 presents the impact on total fuel savings of combined versus solar based on the varying oil prices.

Table 22 - Impact on Total Fuel savings (Combined versus Solar) based on varying oil prices

Present Value of Total Fuel Savings (EUR)	Baseline Assumption ($80USD/barrel)	$50 USD barrel	$100 USD barrel	$150 USD barrel	$200 USD barrel
Solar Plant (20MW)	€59,375,005	€42,100,880	€70,891,087	€99,681,293	€128,471,500
Combined Cycle Plant (31.23 MW)	€164,160,583	€102,600,364	€205,200,729	€307,801,093.79	€410,401,458

As the fuel price increases from $50 USD barrel to $200 USD barrel, so does fuel savings for both solar and combined generation. This is as expected because the value of the fuel savings is directly related to the price of oil. In this particular analysis the increase in saving is occurring at a faster rate for the combined cycle plant than it is for the solar plant. This result is driven directly by the fact that the combined cycle plant has a higher capacity to save more litres of fuel.

7.2 Influence of federal and state incentives

Government financial incentives can make high-cost technologies into low-cost options. In order to support Africa 1`s fragile generation system and lower the risk of thermal investment the government issued an annual fuel subsidy of approximately 33 million Euros to help reduce fuel purchasing costs for utility companies. This helped ensure that electricity derived from thermal sources was relatively affordable for consumers and to ensure that investment in thermal generation continued to be a financially feasible option for utility providers. If a similar annual subsidy was provided to reduce the price of the solar plant perhaps it would also ensure that electricity derived from renewable generation was a feasible option for utility providers. The question is how much would the government need to provide annually to help reduce the cost of solar and to ensure it was comparable to a combined cycle plant? Table 22 presents the amount of solar subsidy that would be required to make the savings similar for the solar and combined investments.

Table 22 - Total Solar Subsidy Required (EUR)

Total Solar Subsidy Required (EUR)		
Total PV of Solar Fuel Savings (EUR)	**€**	**59,375,005**
Total PV of CC Fuel Savings (EUR)	**€**	**164,160,583**
Solar Subsidy Required	**€**	**104,785,579**

According to Table 22 **€104,785,570** would be required as a solar subsidy over the 25 year investment to make it competitive with the combined cycle plant. This amounts to **€4,191,423** annually which is much less than the current annual fuel subsidy of 33 million Euros. Therefore, with a solar subsidy the savings from derived from a solar plant flips from a low-savings option (€59,375,005) to a competitive savings option (€164,160,583).

7.3 Carbon Costs and Carbon Offsets

Although estimates of carbon-related costs and carbon offsets are subject to an exceptional degree of uncertainty, it is important and interesting to assess the impact these variables would have on the comparative cost effective analysis of a solar and combined cycle plant. Therefore, a carbon price ranging from €10/tonne to €50/tonne is used in this analysis to assess the impact it would have on each plant's fuels savings respectively. Table 23 presents the impact a carbon price would have on a combined cycle plant whereas Table 24 present the impact a carbon offset would have on a solar plant.

Table 23- Impact of carbon price on CC fuel savings

Carbon Cost for CC Plant	€ 0	€ 10	€ 20	€ 30	€ 40	€ 50
PV of Total Offset cost	€ -	€ 6,216,147	€ 12,432,294	€ 18,648,441	€ 24,864,588	€ 31,080,735
PV of Total CC Fuel Savings	**€ 164,160,583**	**€ 157,944,436**	**€ 151,728,289**	**€ 145,512,143**	**€ 139,295,996**	**€ 133,079,849**

Table 24- Impact of carbon price on solar fuel savings

Carbon Benefit for Solar Plant	€ 0	€ 10	€ 20	€ 30	€ 40	€ 50
PV of Total Offset benefit	0	$ 1,744,284	$ 3,488,568	$ 5,232,851	$ 6,977,135	$ 8,721,419
PV of Total Solar Fuel Savings	**$59,375,005**	**$61,119,289**	**$62,863,572**	**$64,607,856**	**$66,352,140**	**$68,096,424**

In the combined cycle case, carbon offsets would need to be purchased in order to offset the carbon that is released from the plant. Therefore, as the cost of a carbon offset increases, the PV of total combined cycle plants fuel savings decreases. On the other hand, the impact on the solar case is the opposite. As the solar plant generates renewable energy, the plant would be able to sell offsets for all the carbon it is offsetting. Therefore, as the cost of a carbon offset increases the PV of the total solar fuel savings also increase.

As table 23 and table 24 indicate, the combined cycle plant still remains the most competitive option under the highest carbon price scenario (Carbon Price of 50 EUR and Carbon Offset price of 50 EUR).

8.0 Conclusion

The cost benefit analysis of this paper, which attempts to determine whether building a 20 MW solar plant is a more cost effective solution than building a combined cycle plant in Africa 1, suggests that Africa 1 should invest in a combined cycle generation plant. Even under high oil prices, and/or with the possibility of a non-zero carbon price, the combined cycle plant still remains the most competitive option for Africa 1. It is only when a solar subsidy of approximately 4.2 million EUR is provided annually that the two technologies become competitive with one another. According to the analysis, most of the benefits stem from the fact that combined cycle plants can be run continuously whereas solar plants are subject to the variability of the sun. Therefore, the amount of reliable electricity that can be produced is much greater with a combined cycle generator than it is with a solar plant and this leads it to be a more cost effective option for Africa 1.

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