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Rural electrification in Sub Saharan Africa in a context of fluctuating oil-prices

Is the time ready to move from solar home systems to hybrid PV-diesel systems?

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Abstract

Solar PV is one among other low carbon technologies for rural electrification in Sub Saharan Africa (SSA). Solar PV systems have for almost 30 years been disseminated in SSA, resulting in more than half a million installations concentrated in a few countries. While PV systems have technically matured and markets have gradually developed, PV for rural electrification has often been perceived with scepticism from potential users, donors, government officials and researchers, and solar PV has in many camps been labelled as donor driven, expensive and fragile technology mainly serving the richest parts of the populations and with little or no value for productive uses.

However, feasibility for solar PV has improved in the last few years. Retail prices for solar photovoltaic modules are reduced by 20-30% since 2001, and although far from the peak in 2008, oil prices in the next two years to come are expected to settle at a level, which is about three times the world market average in the years from 1985-2003. Therefore, rather than being limited to a niche for populations living in dispersed settlements outside the reach of grid electrification, solar PV is expected to play an important role in mini grid rural electrification schemes based on hybrid solar PV-diesel generators. This may bring PV systems in line with fossil fuel based systems in terms of consumer cost and options for productive use and it changes the market for PV from mainly donor supported schemes into mainstream rural electrification schemes governed and financed by electric utilities and rural electrification agencies.

Based on a literature review and the experience with a full scale hybrid wind/PV diesel system at RISØ DTU, this paper provides cost estimates for hybrid PV-diesel systems and policy recommendations to change the application of PV technologies for development in SSA.

1 Introduction

Energy services are generally acknowledged to play a significant role in facilitating both social and economic development, and rural people desire electricity for light, telecommunication and for income generating activities (GNESD, 2007). It is therefore considered to be a serious social and economic problem that access to electricity is extremely low in most developing countries and that more than 0.5 billion people, or more than 70 % of the population in SSA, have no access to electricity (IEA, 2006).

Environmental concerns, which have increasingly been translated into concerns for climate change, is an important element influencing the debate on access to electricity. Binding targets for CO2 emissions in the North, emission trading and Clean Development Mechanism (CDM) have entered the development agenda, but while there is growing concern of the need for mitigation in the fast developing countries, such as India and China, it is increasingly acknowledged that climate change mitigation is not the first priority in SSA. Per capita emissions and poverty in SSA are today at a level that focus should be on economic and social development. This means that there is an emerging consensus among policy makers and in the donor community that least-cost options should be pursued, although still with due diligence to benefit from options for cleaner development (WB, 2007).

Electricity options for rural dwellers in SSA highly depend on whether they live in nucleated villages, outskirts of nucleated villages or in dispersed settlements. Solar Home Systems (SHS) are an interesting option for dispersed settlements, because grid electricity is not likely to be available for the next decades in most SSA countries. In this context SHS competes with charging of batteries in a nearby town, with a small gen-set or with a PV charging station. Mini-grids, in turn, are generally the most favourable option for nucleated villages, which are out of reach of the national grid. Most often, mini-grids will be established in the most densely populated part of the village, where electricity may be used for income generating purposes in shops, restaurants, workshops and in public service institutions for water, health, education and administration. Outskirts of nucleated villages may in some cases be serviced by the mini-grid, but in most cases mini-grids will for the first many years only serve the a smaller part of the population. SHS may therefore also be an interesting option in the outskirts of nucleated villages (Banks, 2007: 123)

The advantages of mini-grids compared to low voltage SHS are many. First of all, the mini-grid provides the consumer with high voltage electricity, which has advantages for productive use of electricity, whether it is for lighting, cooling or motive power, and which allows consumers to use cheaper standard AC power appliances. Secondly, investment in a mini-grid can be seen as a transitional investment for a long term strategy of being connected to the national grid, with the benefits that may give in terms of cheaper electricity from large scale hydro, natural gas or coal. Small diesel engines in the range from 10 kW up to several MW are the baseline production units for these mini-grids, and although production costs from these units are relatively high because of low efficiency and high maintenance costs, mini-grids may be a least cost option the first 5 to 10 years after establishment, when demand gradually builds up.[1]

Third, the mini-grid it-self, may be supplied by electricity produced from mini and micro-hydropower schemes and from co-generation from biomass waste, where such resources are available in non-grid connected areas (EUEI, 2007). Hybrid wind-diesel systems are economically feasible options in specific areas with good and medium wind potential (Lundsager *et al.*, 2001). The recent dramatic increase in oil prices from a level

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1 The max distance for grid extension depends on a number of factors, such as the price of grid electricity, expected load in the village, prices of diesel fuel, options for clustering villages, and the price of transmission line. SWER technology has been introduced in a number of countries, among those SA, in order to reduce the investment costs in transmission lines (Banks, 2007)

of 20-30 US$ for the last two decades to the present level of above 70 US$/barrel has changed the market conditions significantly, and recent research indicates that there is also economic feasible hybrid options for inland localities with low wind potential, in terms of PV-diesel hybrids may be economically competitive compared to pure diesel solutions (Nfah *et al.*, 2008; Mahmoud and Ibrik, 2006; Shaahid and Elhadidy, 2008; Indradip, 2005; Givler and Lilienthal, 2005; Banks and Aitken, 2004).

On this background the present article explores to which extent increasing oil prices and declining costs of solar PV will allow hybrid PV systems to be competitive to dedicated diesel systems and hereby contributing to a cleaner energy production.

2 Solar PV in a context of development aid

So far solar PV has almost entirely been used for individual applications in terms of SHS in non-electrified areas. The current status of implementation of SHS points at more than 500,000 systems in Africa, concentrated in a few countries which have engaged in specific SHS programmes. Kenya has about 200,000 units, South Africa about 150,000, Zimbabwe 85,000, Morocco 37,000 and Uganda about 20,000 (REN21, 2008; Moner-Girona *et al.*, 2006). Solar PV battery charging stations have been promoted as an option for a cheaper alternative to SHS, but has only had a limited market penetration (REN21, 2008).

Besides individual use, PV systems have been used for electricity supply to radio and telecommunication amplifiers in remote areas in most of SSA. PV has been used for pumping of drinking water in West Africa, Niger, Namibia and Zimbabwe (REN21, 2008), but compared to the SHS the numbers are limited, and a high share of installations is no longer in use due to theft of modules and lack of maintenance. [2] PV is also used in stand-alone systems providing lighting of village infrastructure such as schools, health centres, police stations, street lighting etc. and for refrigeration at health centres and maternities (FEM, 1999), but although this use is widespread in all SSA countries, estimations of total numbers have not been available. PV has only in some rare cases been used as input to production, such as irrigation, mainly because of high initial costs compared to alternatives such as small diesel and petrol engines (Erickson and Chapman, 1995; Karekezi and Kithyoma, 2002: 1079).

The market for PV installations in developing countries has until today mainly been driven by direct and indirect donor funding. PV installations have been applied in a number of cases although far from being a least-cost solution, when compared to small diesel grids and not grid-extension (Drennen *et al.*, 1996). [3] A number of observers have asked the moral question, why the poorest should pay for the most expensive technology (Drennen *et al.*, 1996: 15; Villavicencio, 2004: 63), [4] and researchers have increasingly challenged the arguments in favour of PV compared to traditional sources (Wamukonya, 2007, Karekezi and Kithyoma, 2002, Jacobson, 2007). In a well researched study from Kenya, Jacobson (2007) shows: i) that the benefits of solar electrification is mainly captured by the rural middle class, ii) that solar PV plays a modest role in supporting economically productive and education –related activities, and iii) that solar PV is more closely tied to increased use of TV, and other ‘connective’ applications such as radio and cellular phones, than to income generation, poverty

2 According to Togola (2001) only 40 % of installed PV pumps for water were functioning in 2000. Newer estimates propose that more than 1000 PV pumps were in use in West Africa in 2007.

3 The price for SHS are often compared to grid extension although the least-cost option would be small-scale diesel grids, or even battery charging by means of small gasoline gen-sets, as shown by Erickson and Clapman (1995).

4 This has moral implications as long as it is a non efficient use of donor financing from the North, and severe economic consequences for the SSA governments, when the financing of large projects has been based on loans.

alleviation and sustainable development. Finally and not least – donor supported PV projects have in a number of cases only been operational for a few years due to economic, technical and organisational reasons (see e.g. Togola, 2001; Afrane-Okese and Mapako, 2003; Martinot *et al.*, 2002) . Oddly enough, while PV systems have technically matured and markets have gradually developed in a number of SSA countries, PV for rural electrification has increasingly been perceived with scepticism from potential users, donors, government officials and researchers, and PV has in many camps been labelled as a donor driven, expensive fragile technology for the richest part of the rural population, with little value for productive purposes. Changing economic conditions, however, seem to counter these claims. Consequently SHS will play an important role for electrification of dispersed settlement and outskirts of nucleated villages where it remains a least cost option, and to the extent that hybrid PV-diesel systems are economically competitive to pure diesel systems, the PV technology will provide the same grid based services as pure diesel systems. The next section will further explore this option.

3 Changing conditions

During the last few years two important economic changes favouring solar PV have occurred. Firstly, world market oil prices which were relatively stable at a level between 20 and 30 US$/barrel in the period from 1985 to 2003 have recently been strongly fluctuating, as shown in Figure 1. It peaked in June 2008 at a level higher than the 1979 level, but decreased rapidly in autumn 2008 as a consequence of the financial crises. It has in august 2009 recovered to a level of 70 US$/barrel, and it is foreseen that the world market price in the future will remain at a high level above 70 US$/barrel (EIA, 2009). This means that SSA countries face a world market price of oil products, including kerosene for oil lamps, which is about 3 times the level of what has been the reality for almost 20 years. Although existing taxation on oil products in most SSA countries, and targeted subsidies for specific products might reduce the effect of the world market prices, solar PV will become more competitive to alternative solutions for lighting, such as kerosene, small gasoline engines for individual households and for diesel engines in mini-grids.

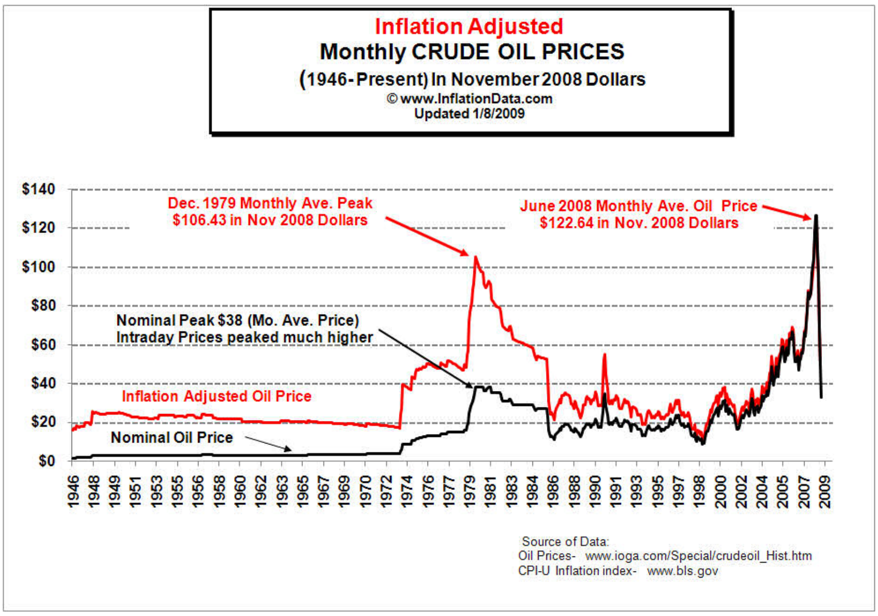

Figure 1: Crude oil prices in US$ per barrel in nominal and inflation adjusted prices

Secondly the cost of PV modules continues to decrease. The cost of PV modules has undergone significant fluctuations in recent years, but historically the cost per Watt Peak has been reduced by about 20% per doubling of installed capacity as shown in Figure 2 (EPIA, 2009a; EPIA, 2009b).

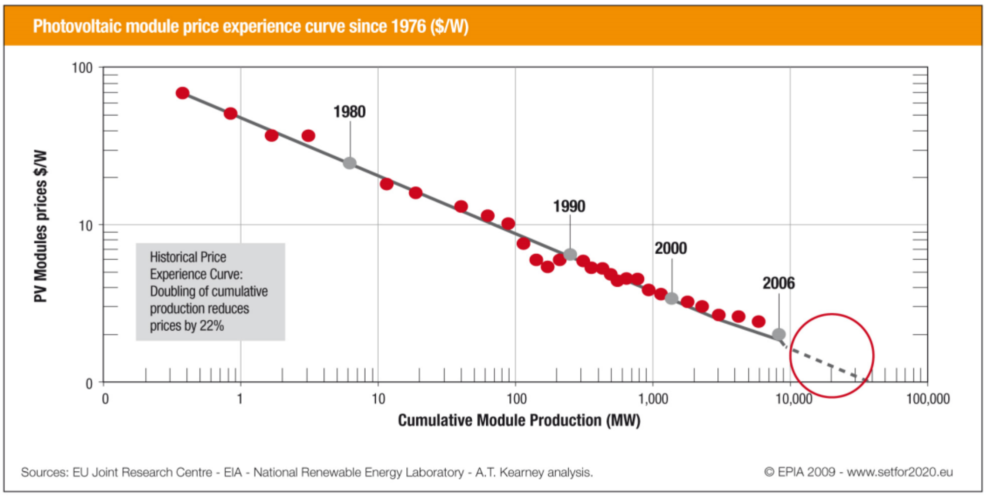

Figure 2: Photovoltaic module price experience curve since 1976 (EPIA, 2009b)

During the last 10 years, the PV market has changed from being dominated by small systems to very large scale installations, as a result of the feed-in regulations in Germany, Spain and many other industrialised countries. Grid connected solar PV has since 2004 experienced a six fold increase, with annual growth rates of more than 60 %. The growth in 2008 alone was 70%, reaching a total installed peak power of grid connected PV of 13 GWp in 2008. To this comes another 3 GWp of off grid PV (REN21, 2009). This increase in production output has reduced prices, and although the price reduction has been less than expected due to short term bottlenecks, such as shortage of silicon wafers, the European Photovoltaic Industry Association (EPIA) expects future price reduction to follow the learning curve described in Figure 2 (EPIA, 2009a).

As a logic consequence of the market for grid connected applications, producers of modules and BOS equipment have concentrated their development efforts on large mass-produced units, and their interest in specialized components for standalone or hybrid systems has been relatively limited. The cost reduction for PV plants for these applications has therefore not been so pronounced as for grid-connected systems. The web portal www.solarbuzz.com follows the international cost evolution of PV modules (those over 175 Wp) and BOS equipment, and reports the retail cost. It is therefore assumed to give a better picture of the real cost for a relatively small project such as a village electrification project in Africa. According to Solarbuzz the average retail price has been reduced from 5.5 to 4.5 € from 2001 to 2009, but there are many examples of modules as cheap as 2€/W as per August 2009. The wide span of prices reflects that not all products are of equal quality and that the market is currently rather turbulent due to the financial crisis and change of subsidy schemes.

The economy of scale for PV systems is mainly related to lower unit costs for BOS and installation costs, whereas the PV module cost is primarily a function of technology and brand. In Denmark/Europe, current system price for a 1-10 kW standard grid connected plants is about 6 Euro ex. VAT including installation, whereas large ground based systems may cost well below 4 Euro/Wp. [5]

In a sub-Saharan context there are a number of factors which may cause deviation from this figure, for example increased transportation costs, losses due to theft and vandalism,

5 Personal communication with Kenn Frederiksen, EnergiMidt, referring to Danish installations and the German 40 MW system "Waldpolenz"

less strict requirements regarding component specifications and quality assurance, and lower labor costs. According to Moner-Girona et al (2006: 42), an African consumer from Uganda may pay twice as much as an Indian consumer for an equivalent system. There are important differences among African countries, depending on tax levels, but not least on sales volume and retail market structure. However, local production, increased turnover and an increasingly globalized market supplied by relatively cheap Chinese products may gradually adapt the price level in SSA countries to the continuously decreasing world market level, and in combination with increased oil-prices it may improve the competitiveness for hybrid PV systems in mini-grids presently supplied by diesel powered electricity.

4 Economic assessment of hybrid PV-diesel mini-grids

Hybrid system comprising hydro, PV, wind and diesel have been demonstrated at various scales since the 1980's, especially for supply to isolated locations and mini-grid systems for rural electrification (Weisser and Garcia, 2005). Hybrids with hydro and wind have so far been the most widespread; as they are economically favourable compared to PV at sites with hydro potentials or good wind conditions (Ashok, 2007). For inland sites with poor wind conditions, PV hybrids, may be the least-cost option, and there have been optimistic claims of feasibility of PV compared to diesel since the beginning of the 1990s (see e.g. Singh, 1991). Until recently, however, markets seem to have been limited to development projects in a number of countries and specific demonstration projects (Phuangpornpitak and Kumar, 2007; Chokmaviroj *et al.*, 2006; Stenby and Sørensen, 2006). [6]

Recently, however, hybrid solar PV-diesel systems seem to have passed the demonstration phase, and entered into main stream rural electrification. This development is exemplified by the inauguration of a hybrid PV-diesel system as part of a rural electrification scheme in Mali in 2008. The system is built, owned and operated by a private Rural Electrification Service Company (RESCO), Yeelen Kura SSD, which is jointly owned by the French EDF, and the Dutch Noun. Main technical and economic data as presented by Yeelen Kura, is presented in Table 1.

Table 1: Key figures for PV-diesel system in Kimparana, Mali (Source: Semega, 2008; Diallo, 2008)

Technical specifications		Economic key figures	
Diesel	100 kVA	**Investment**	512.000 €
PV	72 kWp	**Subsidy**	60 %
Battery	24720 Ah	**Tax exemption**	100 %
Present max load	25 kW	**Consumer price**	0.27 €/kWh
Consumers	217 households		

The system has in line with other rural electrification projects received a subsidy of 60% in order to facilitate a consumer price of 0.27 €/kWh. In line with most project descriptions, only aggregated figures are available, and there is hence not available information neither on fuel costs nor expected production costs from the PV-diesel system.

In the academic literature, evaluations of economic performance of small hybrid systems are few and superficial (Munoz *et al.*, 2007), but recently an increasing number of publications almost unanimously claim that PV-diesel hybrids are economically

6 An inventory of hybrid (PV, wind, diesel) systems for research and demonstration is available in Hansen et al (Lundsager *et al.*, 2001: 24, 25)

competitive compared to pure diesel solutions in various contexts (Nfah *et al.*, 2008; Mahmoud and Ibrik, 2006; Shaahid and Elhadidy, 2008; Indradip, 2005; Givler and Lilienthal, 2005; Banks and Aitken, 2004). [7]

Table 2: Production prices from hybrid PV-solutions compared to pure diesel solutions in recent published literature.

Diesel fuel €/l	Hybrid €/kWh	Diesel €/kWh	Diesel gen. kW	Country	Source	Year
0.20	0.33	0.80	4.25	India	Givler	2005
0.53	0.40	1.20	4.25	Egypt	Givler	2005
0.07	0.12	-	10.00	Saudi	Shaahid	2006
1.00	0.58	-	15.00	Cameroon	Nfah	2007
0.43	0.34	0.41	17.00	Algeria	Mahmoud	2004
0.40	0.30	0.44	20.00	India	Intradip	2005

Results from the studies are compared in Table 2, which shows a remarkable variation of results. Calculated hybrid production costs are in the range of 0.12 €/kWh to 0.58 €/kWh. These are compared to diesel production costs in the range from 0.41 to 1.20 €/kWh. Unfortunately, interpretation of the results is difficult due to the high variation in diesel prices from 0.07 €/l in Saudi Arabia to 1.00 € in Cameroon. These differences are due to variation in crude oil prices over time and not least differences in level of subsidies and taxation.

4.1 Analysis of impact of increasing oil prices

In order to analyse the impact of increasing oil prices on hybrid PV-diesel systems, this paper therefore uses fuel prices including import and retail costs, but excluding any tax or subsidy. The analysis has been carried out for 4 different fuel prices; 0.31€/l, 0.42€/l, 0.56€/l and 0.63€/l, which corresponds to a crude oil price in the range 25-90 US$/barrel. The analysis is conducted using a simulation case study system setup in HOMER, a hybrid systems analysis software package developed by National Renewable Laboratory (Givler and Lilienthal, 2005). The configurations that are being considered include PV, diesel, battery storage and a load. Three sizes of system are investigated: 250 kWh/d, 500 kWh/d and 1000 kWh/d.

One of the key issues when investigating feasibility of a potential system is the consumption profile. The difficulty includes estimating the initial consumption as well as the development. There can be a significant change in nature of the consumption profile from installation of a system until electric energy is just a commodity.

The chosen consumption profile shown in Figure 3 is a measured profile from a residential area in Hurghada, Egypt (Bindner *et al.*, 2001). The area has been electrified for a long period and the city is relatively well developed and includes business and hotel areas apart from the residential. The profile is characterized by a relatively large ratio between minimum and maximum load. A large ratio is often seen in systems in developing countries as the main use of electricity is for light and TV. However, as the economy develops fridges and freezers become frequent and businesses will increasingly use electricity. This entails a consumption profile with more than one daily peak and a higher minimum load as the one used here. HOMER is used to generate a full year consumption time series.

7 The research papers are mainly feasibility studies for specific cases, based on economic simulations carried out by means of the simulation software, HOMER, from NREL (Lilienthal, 2004).

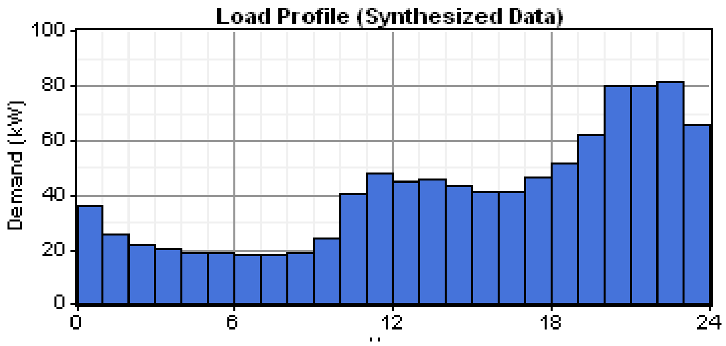

Figure 3 Daily load profile based on measurements in residential area in Egypt (Bindner et al., 2001)

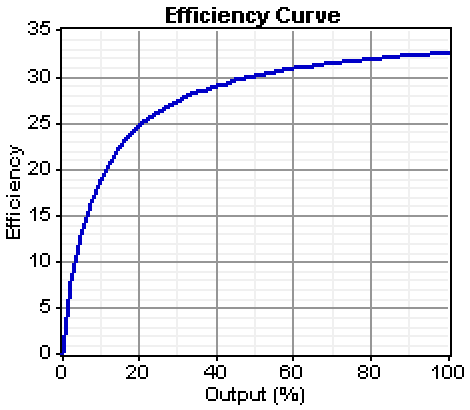

Figure 4: Efficiency curve for diesel generator (same for both sizes)

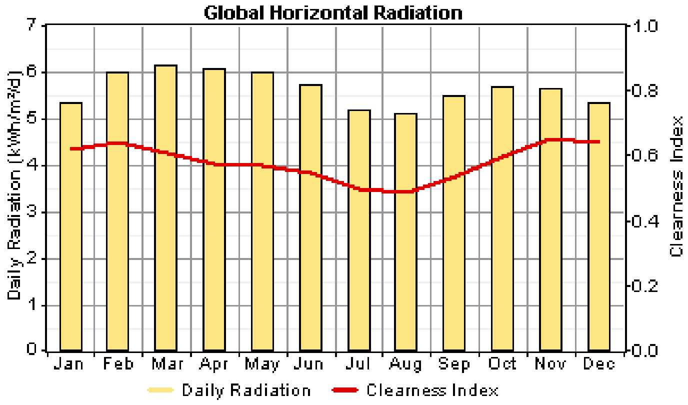

Figure 5: Solar radiation, equivalent to site in Burkina Faso

The efficiency for the diesel gensets is shown in Figure 4. The minimum load of the gensets is set to 20%, and the load margin is set to 20% i.e. the required generating capacity at each time step is the load plus 20%. The system is assumed to be placed in Burkina Faso. Monthly average solar radiation and clearness index is shown in Figure 5. The PV parameters otherwise used are the standard settings of HOMER. The battery type chosen is a lead acid battery: Hoppecke 12 OPzS 1500. The converter efficiency is set at 92% in both directions. Investment costs are shown in Table 1.

Table 1: Investment costs and lifetime used in simulations [8]

Component	Specific Investment cost, €/kW	Specific replacement cost, €/kW	O&M, €/y	Lifetime, years
PV	3000	3000	100	15
Diesel (@10kW)	1500	1000	250 €/h	15
Diesel (@48kW)	830	730	500 €/h	15
Battery	750€/unit	750€/unit	2	5136 kWh throughput
Converter	720€/kW	720	100	15

8 Cost of PV is assumed to be 25 % higher in SSA than in Europe. Real lifetime should be higher than 25 years for quality modules, so 15 years used in simulations is a conservative figure. Costs of diesel gensets based on purchase of 48 kW diesel genset at Risø DTU in December 2005.

Extra project and engineering cost for hybrid systems is set to 50,000 **€.** For each of the three systems simulated component sizes are specified. HOMER is using these component sizes simulating all the combinations.

4.2 Simulation results

The result of the economic simulations of the systems is presented in Figure 6 to 9. Figure 6 and 7 show the production costs per kWh depending on oil prices in US$ per barrel. This is shown for a small system (peak load, 37 kW) and a larger system, peak load 150 kW). The figures show that for the small system, PV-hybrid is competitive to pure diesel systems at a crude oil price above 75 US$/barrel, while for larger systems the hybrid solution is competitive already for crude oil prices above 25 US$/barrel.

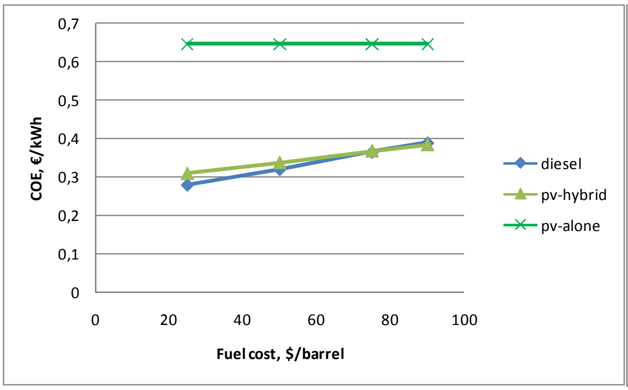

Figure 6: Production cost per KWh depending on fuel costs for small system (37 kW peak)

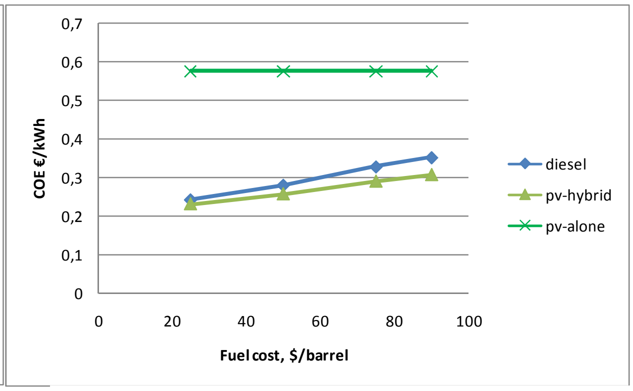

Figure 7: Production cost per KWh depending on fuel costs for large system (150 kW peak)

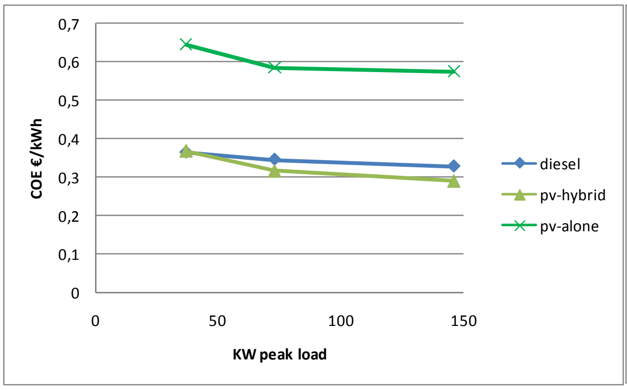

Figure 8: Production cost depending on system size at a fuel cost of 75 USD/barrel (0.56 EUR/l)

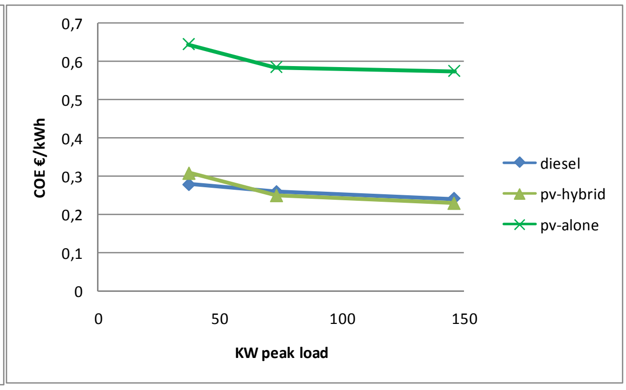

Figure 9: Production cost depending on system size at a fuel cost of 25 USD/barrel (0.31 EUR/l)

Figure 7 and 8 show the production cost depending on system size for a fuel price of 75 and 25 US$/barrel respectively. According to the simulations hybrid systems become more competitive with increasing system size. This is due to a precondition of higher fixed engineering costs for hybrid systems than for diesel systems. In the present simulations efficiency of diesel gensets are modelled to be independent of system size, while in reality, efficiency increases with engine size. Taking this into account will reduce the increasing feasibility of hybrid systems with increasing system size.

5 Policy choices to favour hybrid PV systems

A large number of people in SSA live in dispersed settlements or in the outskirts of nucleated villages, where grid electricity is not likely to reach in the near future. The increased oil prices will leave this important market to individual solutions in terms of SHSs. For these areas stand alone systems using PV have been promoted through various types of delivery models (see e.g. Nygaard, 2009). Due to different market structures for individual and collective energy solutions as outlined above, these models need be revisited for the purpose of hybrid systems.

The first step in promoting hybrid PV is to create a level playing field for PV and fossil fuels solutions, either by removing fuel subsidies or by subsidizing PV. Fuel for electricity production is often subsidized in SSA. In some cases, it is a legacy from the pre-liberalization regime, while in others; it is a reaction against increasing oil prices. Price signals at the country levels are thus not reflecting world market prices. The first condition for enhanced use of hybrid systems is therefore to levelling the playing field by harmonising import tax levels and subsidy levels for solar PV and for fossil fuel based solutions. In most cases, this will be to the benefit of solar PV.

Secondly, although economically feasible under the condition of a level playing field, it is important to create a project volume that will reduce project risk as well as planning, engineering and other overhead costs of hybrid systems to a minimum. Increasing project volume might be facilitated by state owned utilities or through concession agreements, where rural electrification in whole regions is attributed to external investors through an international tendering process. As well the state owned utilities (e.g. in Morocco) and the concessionaires (e.g. in SA, Mali and Senegal) have the advantage compared to smaller actors that they can benefit from applying solutions such as hybrid systems, which may only be least cost options if applied in packages of 10 to 100 installations. The concession model based on large external operators may further have the advantage compared to utilities that they have access to capital necessary for the extra initial investment compared to diesel solutions.

Where such measures are in place the calculations show that hybrid PV-diesel systems are economic feasible already today. If, as expected, oil prices remain above 70 UDS/barrel in the future, PV-diesel hybrid will most likely prevail in rural electrification in SSA within the next decade. This ensures that PV systems are comparable to fossil fuel based systems in terms of consumer cost and options for productive use, while at the same time contributing to cleaner energy production.

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