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Mobilising Renewable Energy Investments

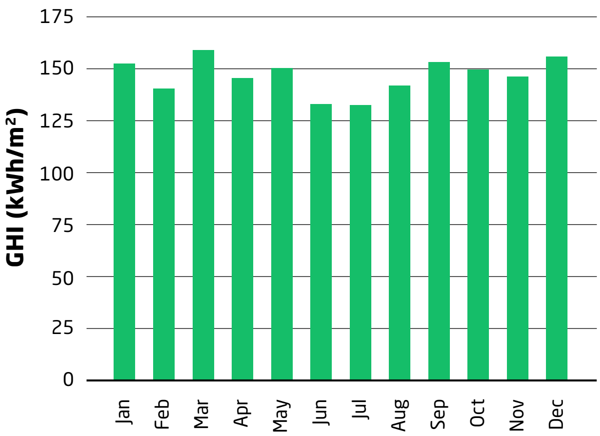
# Uganda: Captive Power

## *Case Study: 50 kWp + 20 kWp Solar PV System with Energy Storage at a Hospital*

### SITUATION DESCRIPTION

This project Case Study investigates the viability of an existing solar PV installation and the feasibility of a planned capacity expansion at a large health facility in Kampala, Uganda. Other large hospitals in the country are likely to have similar characteristics and therefore the Case Study provides indicative information on the potential for solar self-generation to reduce electricity costs.

**FIGURE 1.** Monthly fluctuation in solar irradiation




The hospital is an electricity customer of Umeme that falls under tariff code 10.2 (commercial). The annual electricity consumption of the hospital is about 400,000 kWh, with a maximum demand of up to 100 kW. There is consistent load during daytime hours and the peak usually occurs from 17:00–22:00.

Solar irradiation at the hospital site fluctuates over the course of the year. Naturally, the production of a solar PV system will follow the same course.

### PV SYSTEM CONFIGURATION

In 2016, the hospital installed a 50 kWp solar PV plant. 10 kWp of this system is tied to a battery and 40 kWp to the grid. The battery system has an energy storage capacity of 6 kWh and is intended to supply critical loads in times of grid outage. The solar PV plant only produces power for captive consumption — no electricity is exported to the grid. About 10% of the electricity production of the PV installation is used for battery charging and 90% is consumed directly as it is generated.

GET.invest is supported by

german cooperation DEUTSCHE ZUSAMMENARBEIT
Sweden Sverige
Ministry of Foreign Affairs of the Netherlands
AUSTRIAN DEVELOPMENT COOPERATION

During grid outage times, there is no solar production because the PV inverters do not have black start ability nor can they form a grid. They need a grid frequency to which they can synchronize with, which is only possible when an energized grid is available. However, when the grid is down, the 6 kWh battery is able to keep feeding critical loads, such as the blood bank, maternity station and surgery. The storage capacity is sufficient to cover 1–2 hours of electricity outages for these loads.

In the future, the system may be expanded by 20 kWp. Although the hospital has sufficient roof and ground space, an addition of more than 20 kWp is not considered due to the risk of spilling any surplus into the grid — which has technical and regulatory implications.

## PLANT CHARACTERISTICS

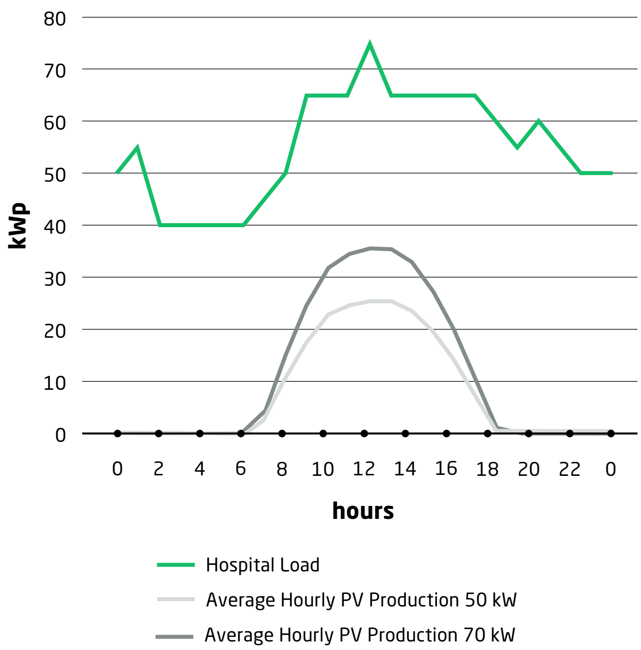
The energy yield of the existing 50 kWp PV system was estimated to be approximately 1,400 kWh/kWp per year using PVsyst software, after taking into account system losses, temperature, cloud cover and panel soiling. With the impact of grid outages on production, an annual maximum generation of approximately 68,800 kWh is estimated in year one, or 17% of the facility load.

**TABLE 1.** Solar PV system characteristics

| PARAMETER | UNIT | VALUE |
|---|---|---|
| Irradiation at 10° tilt | kWh/m²/y | 1,928 |
| System size — current system | kWp | 50 |
| System size — additional capacity | kWp | 20 |
| Approximate yield — current system | kWh/kW/y | 1,400 |
| Annual grid outage time | % | 1.6 |
| Annual generation 50 kWp year 1 | kWh | 68,880 |
| Annual generation 20 kWp year 1 | kWh | 27,552 |
| Annual degradation | % | 0.5 |
| Lifetime | year | 25 |

The average PV output (kW) over 24 hours is shown in comparison to the estimated hospital load. Maximum solar output on the sunniest day is in the range of 40 to 50 kW for the existing system and 60 to 70 kW after expansion.

**FIGURE 2.** PV production vs. building load (24 hours)




It is assumed that 41% of battery discharging occurs during peak tariff hours (18:00–24:00) and 22% during off-peak (24:00–06:00), replacing grid electricity. 37% of discharging is expected during the shoulder tariff period (06:00–18:00) replacing diesel back-up generation.

Since some energy is lost when charging and discharging the battery, an efficiency factor of 85% is applied to the battery system. This accounts for discharge overtime, converter losses and losses in other parts of the battery system.

## CAPITAL AND OPERATING COSTS

Capital expenditure (CAPEX) covers typical solar PV equipment and associated costs including for modules, inverters, mounting cabling, transport, design and commissioning. Battery storage costs are priced separately and total costs summarised.

For the annual operating costs (OPEX), a percentage of the CAPEX is applied that represents a suitable estimate. These costs include cleaning of the panels (at least twice a year), occasional visits of technicians, replacement of spare parts as well as insurance costs. Hospital management is assumed to take care of minor maintenance measures.

The estimated costs are based on project experience in Uganda and East Africa in 2016. A UGX-EUR exchange rate of 0.000235 is used.

**TABLE 2.** CAPEX and annual OPEX

| COMPONENT | UNIT COST | PROJECT COST | |
|---|---|---|---|
| | EUR/kWp | EUR | UGX |
| Current system | 1,880 | 94,000 | 400,393,000 |
| — Grid-tied | 1,600 | 64,000 | 272,608,000 |
| — Battery-tied | 3,000 | 30,000 | 127,785,000 |
| Future system | 1,400 | 28,000 | 119,266,000 |
| O&M costs 50 kWp | 1.5% | 1,410 | 6,006,000 |
| O&M costs 20 kWp | 1.5% | 420 | 1,789,000 |

Replacement of the battery after its design life of approximately 7 years is foreseen. The first replacement in 2023 is estimated to cost around EUR 10,000 and subsequent replacements in 2030 and 2037 of EUR 5,000 each time.

The case study is based on an investment in EUR. The analysis is performed before any consideration of financing[1]. The effects of currency exchange rate fluctuations or hedging costs are also not considered. Furthermore, no generation license is required for a self-consumption captive power plant of this size and an Environmental Impact Assessment and certificate of approval is unlikely to be needed.

## LEVELISED COST OF ELECTRICITY FOR THE EXISTING SOLAR PV SYSTEM

The levelised cost of electricity (LCOE)[2] is calculated using a discount rate of 8% and determining PV system costs and electricity production for each year separately using the discount factor. The discount rate is based on an assumption that the project owner could access debt in a hard currency at an interest rate of 7%[3]. In Uganda, the Sustainable Use of Natural Resources and Energy Finance (SUNREF) initiative developed by Agence Française de Développement (AFD) could be a notable option for such projects. Alternative discount rates are also shown for comparison.

The year of the first investment (50 kWp) is 2016. The assessment period is 25.5 years (6 months development and construction, 25 years operation). The division of the present value of costs by the present value of electricity production results in an LCOE as presented for different discount rates.

**TABLE 3.** Levelised cost (50 kWp with battery, 2016 prices)

| ITEM | EUR/kWh | UGX/kWh |
|---|---|---|
| LCOE at 8% discount rate | 0.176 | 750.81 |
| LCOE at 10% discount rate | 0.198 | 842.22 |
| LCOE at 12% discount rate | 0.220 | 938.59 |
| LCOE at 14% discount rate | 0.244 | 1,038.94 |

1) It should be noted that as of the end of 2017, all of the seven existing solar PV captive systems in Uganda had been implemented without financing; the owners made the entire investment and/or grants were used. However, the accompanying Model Business Cases investigate different financing scenarios. The Model Business Cases are accessible at www.get-invest.eu

2) Levelised cost of electricity (LCOE) is the ratio of lifetime costs to lifetime electricity generation, both discounted back to a common year using an assumed discount rate

3) Loan interest rates for medium size solar PV system in Uganda may range from 5-6% (e.g. supplier credit or export finance) on hard currency to 23% on UGX from local commercial banks. The discount rate assumption used in this Case is based on the AFD-funded SUNREF facility available locally at the time of writing for captive power projects at about 6-7% interest on USD loans, as described in the financing section of the accompanying Developer Guide accessible at www.get-invest.eu

## COMPARISON TO ACTUAL ELECTRICITY COSTS

The electricity production costs of the solar PV plant are compared to grid electricity costs for the hospital without considering the monthly fixed service fee (EUR 0.79, UGX 3,360) charged by the utility, as this charge cannot be avoided.

In order to determine which time-of-use electricity tariff the PV production would offset, a simulation of the solar irradiation potential was conducted. It was found that the solar PV electricity is generated almost entirely during the shoulder tariff hours (06:00–18:00) of Umeme. Only a very small part (0.4%) of PV production falls in the peak tariff hours and none during off-peak.

The energy charges per kWh for code 10.2 (commercial) customers for the three time-of-use periods are presented for the 4th quarter of 2017.

**TABLE 4.** Umeme tariff code 10.2 (commercial)

| TIME OF USE TARIFF | UNIT | VALUE | +VAT |
|---|---|---|---|
| Peak | EUR/kWh | 0.1892 | 0.2233 |
| Shoulder | EUR/kWh | 0.1451 | 0.1712 |
| Off-peak | EUR/kWh | 0.0896 | 0.1057 |
| Peak | UGX/kWh | 806.00 | 951.08 |
| Shoulder | UGX/kWh | 618.10 | 729.36 |
| Off-peak | UGX/kWh | 381.60 | 450.29 |

To assess the cost of electricity that the PV system would offset in the future, the Umeme energy charges were adjusted for annual inflation. For 2018 and 2019 a rate of 5% was applied and a rate of 4% for the following years, based on recent trends and electricity sector forecasts[4]. The same inflation rates were also applied to the PV plant operating costs.

In order to determine annual cost savings, the projected PV captive plant electricity yield was calculated and a corresponding amount of electricity from the grid or the existing diesel generator (in kWh) was assumed to have been offset. The cost that would have been incurred if electricity had been purchased from the grid or from diesel generation was compared against the cost of production (LCOE) from the solar PV system.

In times where the grid is down, only energy stored in the battery can be used to replace the diesel generator. In reality, this works quite well as power cuts are relatively short and often in the range of the battery's capacity to cover critical loads.In order to confirm project attractiveness, the Net Present Value (NPV)[5] and Internal Rate of Return (IRR) as well as the simple payback period were calculated. The captive plant investment costs and the savings on the difference between the energy charges for grid electricity and diesel generation and the annual operations and maintenance (O&M) costs of the system were the basis of the calculation.

**TABLE 5.** Project indicators (50 kWp with battery)

| ITEM | UNIT | VALUE |
|---|---|---|
| Project NPV | EUR | 26,547 |
| Project NPV | UGX | 113,074,944 |
| Project IRR | % | 10.9 |
| Payback period | Years | 10 |

## FUTURE CAPACITY ADDITION

The same calculations are done for the case that the hospital invests in additional solar PV capacity of 20 kWp. The investment is expected in 2018, but the base year of the analysis remains 2016 to make the results comparable. As the battery storage capacity is not increased, and the PV price per kWp is assumed to be less in 2018 than in 2016, the LCOE is lower than that of the existing installation and, therefore, provides a better return on investment. The LCOE as well as the economic indicators for the capacity increase with a CAPEX of EUR 28,000 and an annual electricity generation of about 27,500 kWh in the first year is shown in the table:

4) See the accompanying Developer Guide accessible at www.get-invest.eu for more details

5) Net present value (NPV) is the difference between the present value of the project future cash flows and initial investment. The present value is the current worth of a future sum of money or stream of cash flows given an assumed discount rate representing the investment risk

**TABLE 6.** Project indicators (20 kWp expansion)

| ITEM | UNIT | VALUE |
|---|---|---|
| LCOE at 8% discount rate | EUR/kWh | 0.124 |
| Project NPV | EUR | 21,451 |
| Project NPV | UGX | 91,371,250 |
| Project IRR | % | 16.8 |
| Payback period | Years | 7 |

The hospital's annual Umeme electricity bill for the year 2017 was estimated to be:

— Fixed service charge: EUR 9.48 or UGX 40,320
— Time-of-use energy charge: EUR 59,383 or UGX 252,941,972

The total electricity bill was therefore EUR 59,392 or UGX 253 million. Assuming that the demand profile remains the same until 2019, when the consolidated system is in place, the solar PV plant would save around EUR 14,900 or UGX 63.5 million per year, which is about 25% of the total electricity bill.

## VALUE ADDED TAX

Value Added Tax (VAT) at 18% on equipment is not considered in this Case Study analysis as it is a throughput tax. Notice that the hospital may be exempt and usually VAT is not applicable on solar PV systems in Uganda if the equipment is imported as a complete package — e.g. in a container (otherwise VAT could apply on cabling and mounting equipment).

Nevertheless, in some circumstances (see the accompanying Developer Guide accessible at www.get-invest.eu) VAT may be charged on CAPEX.

## SENSITIVITY TESTS AND OTHER SCENARIOS – 20 KWP CAPACITY ADDITION

A sensitivity analysis was performed on key parameters for the 20 kWp capacity addition to test the economic performance of the project against the result of a change in the following variables:

— The energy yield
— The investment costs
— The discount rate

Two additional scenarios were also considered:

— Electricity bill savings including VAT

— A one-off reduction in the tariff by up to 50% in 2020 to simulate a possible outcome of lower power generation costs as new large hydro dams are commissioned in Uganda

**FIGURE 3.** IRR test against variation of input assumptions

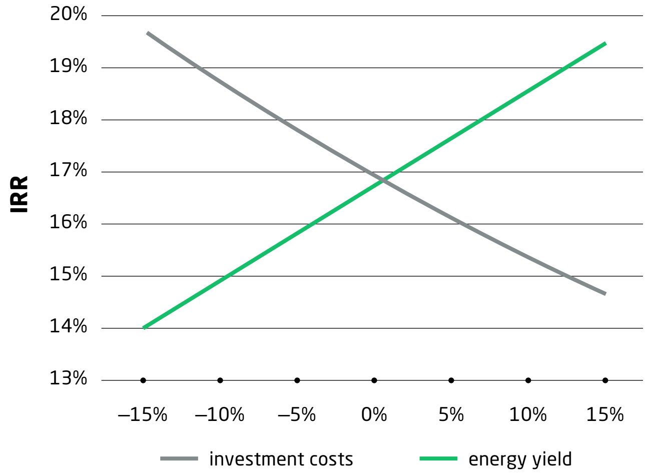
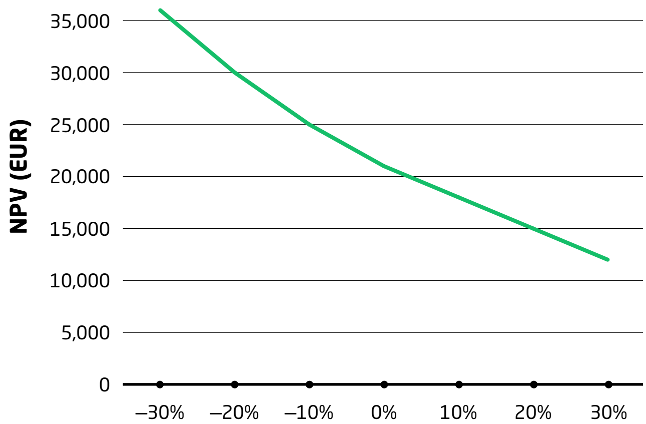



**FIGURE 4.** NPV test against variation of the discount rate



As shown in the charts, the sensitivity tests confirm that the IRR does drop beyond an acceptable range even if the capital costs increase or the energy yield decreases by 15%. In addition, the NPV remains positive even at a discount rate of 10.4% (30% increase compared to the base case)

In the base case analysis, VAT on the purchase of grid electricity is not considered as a cost that can be avoided by on-site generation. However, some facility owners may consider VAT as a cost item to factor into investment decision making. In that case, the electricity bill savings are higher and the project is more attractive.

### **TABLE 7.** Project indicators – VAT on energy charges

| ITEM | UNIT | VALUE |
|---|---|---|
| Project NPV | EUR | 30,184 |
| Project NPV | UGX | 128,567,997 |
| Project IRR | % | 20.0 |
| Payback period | Years | 6 |

The effect of electricity tariff reduction by up to 50% in 2020 (keeping the same inflation rate assumptions) is shown next:

### **TABLE 8.** Project indicators – one-off tariff reduction in 2020

| | IRR % | NPV EUR | NPV UGX |
|---|---|---|---|
| 10% reduction | 15.2 | 16,924 | 72,088,000 |
| 20% reduction | 13.5 | 12,397 | 52,805,000 |
| 30% reduction | 11.6 | 7,870 | 33,522,000 |
| 40% reduction | 9.6 | 3,343 | 14,239,000 |
| 50% reduction | 7.4 | –1,184 | –5,044,000 |

## OTHER PROJECT BENEFITS

The solar PV captive power plant at the hospital may also provide additional benefits. These include:

— **Serving critical loads in emergency situations:** The solar PV system with battery provides a constant supply for non-interruptible, critical hospital loads. The benefits of the battery cannot completely be quantified as energy storage has the potential to save lives in cases where neither the grid nor diesel fuel is available. Even though the battery costs make the system economic performance less attractive, this non-monetary benefit was key to the investment decision.

— **Hedge against inflation:** The solar PV system provides reliable electricity production at almost constant prices over many years compared to utility energy charges that are subject to inflation. Even if the OPEX is also subject to inflation, its impact on the economic performance is low.

## ACKNOWLEDGEMENTS

GET.invest deeply appreciates the time and effort spent by the facility managers to share data and information towards this case study. GET.invest expresses gratitude to all staff and individuals who reviewed the case study and provided valuable insights, guidance and feedback.

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