# Back-up PV System Design for the Data Center in Colorado, US

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***Abstract*—The back-up generation systems of data centers are largely fossil-fuel based to safeguard the supply continuity. However, there is increasing attention for a green alternative. This report proposes a hybrid grid-tied PV system design with additional battery bank and simulates the operation for one year. The results demonstrates a reliable power supply to meet the critical load during blackouts and showcases the financial feasibility of such sustainable solution.**

***Index Terms*—PV system, Data center, Energy back-up, Battery bank**

## I. Introduction

This report aims to provide a green alternative for the back-up generation of data centers. Data centers are heavily relying on continuity of power supply since they have the obligation to provide their clients with their data at all time. When a data center fails to provide the required data it has to financially compensate its clients. To avoid such a situation, data centers are often accompanied by back-up generation systems [1]. These systems are however commonly relying upon fossil fuels, since these sources can facilitate instantaneous power and therefore provide a high 'power security'. To successfully effectuate the energy transition, it is vital to also provide these systems with a green alternative.

The solution provided in this report is a hybrid grid-tied solar PV system with additional storage capacity, which backs up a data center in Boulder, Colorado (USA). To maximise the practical feasibility of our solution, a full spectrum of parameters is taken into account during the design phase. This spectrum includes, amongst others: location/weather issues, module orientation, module temperatures, array typology, battery reliability and cost behaviour.

This report is divided into 8 chapters. Chapter 2 will provide a situational overview, which includes information on the location and load characteristics of the data center. Chapter 3 will further elaborate on the specific load behaviour of the data center. In Chapter 4, the design of the PV system is described, which also reflects on the previous chapters. Chapter 5 discusses the losses of the system. This is followed by a yield analysis, which is discussed in Chapter 6. This chapter also evaluates to what extent the system meets the reliability requirements. In Chapter 7 the profitability of the system is assessed, which is also compared to the actual reliability of the system. Chapter 8 will provide the conclusion of this report, by providing the key take-aways of our green back-up generation solution.

Answers to specific questions of this assignment are highlighted in **bold**.

## II. Location Survey

The data center is located in a warehouse park in Boulder, Colorado, which is situated in the middle of the United States of America. Table I gives a overview of the geographical data. The surrounding area can be characterized as a valley with low vegetation which only houses low-rise buildings. The horizon is therefore free of obstacles, which leads to favourable irradiation properties. The data center has a flat roof with a total available surface area of $170m^2$. The hourly weather data is obtained from the Meteonorm[1], including solar irradiance, temperature, humidity, wind speed and wind direction.

TABLE I
Location overview

| Location | Latitude | Longitude | Altitude | GMT |
|---|---|---|---|---|
| Boulder, Colorado | 40.017°N | -105.25°W | 1634m | -7 |

Due to construction work, blackouts are occurring once a week, always on Monday. A blackout has a duration of 7 consecutive hours. The exact timing of the blackout is however inferred to be randomly distributed.

The local electricity price is €100/MWh and the agreed 'no-data' compensation is €2.1/hr per client (45 in total).

## III. Load analysis

The load profile of the data center of a single day is shown in figure 1. This load profile is the same on every day of the year. The blue line represents the total power demand, and the red line represents the critical power demand, which must always be met, also in the case of a outage. The total energy consumption of the data center per year is 6236 kWh. The total peak load is 8.5 kW and the minimal total load is 6.1 kW. **The critical load always is 5.8 kW.**

[1]Meteonorm includes more than 30 different weather parameter for typical years all over the world. https://meteonorm.com/en/

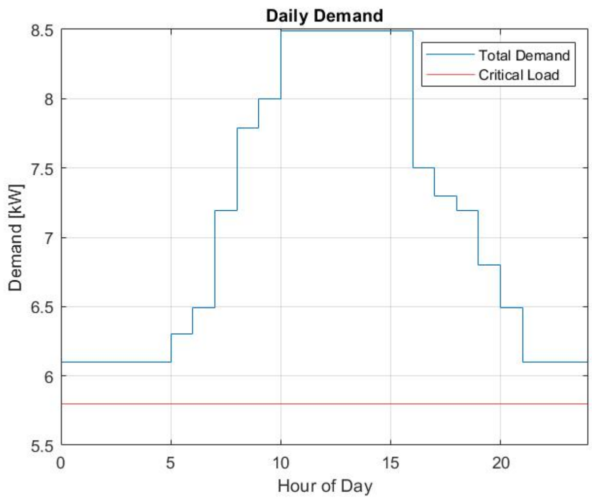


Fig. 1. Load profile of the data center

## IV. PV System Design

In this section, the determination of various parameters, as well as the selection procedure for different components for the PV system are described.

### A. PV modules

**Optimal tilt and azimuth**

Based on the location data, the best tilt and orientation for the PV module are determined in an enumerated way with one degree resolution. The annual irradiation incidents on the module are calculated and compared across 32760 combinations of tile and orientation ($tilt \in [0°, 90°]$ and $azimuth \in [0°, 359°]$). Eq.1-6. demonstrate the calculation process of the irradiance on the module.

$$cos(AOI) = cos(a_M) * cos(a_s) * cos(A_M - A_S) + sin(a_M) * sin(a_s) \tag{1}$$

$$SVF = \frac{1 + cos(\theta_M)}{2} \tag{2}$$

$$G_{Direct} = DNI * cos(AOI) \tag{3}$$

$$G_{Diffuse} = DHI * SVF \tag{4}$$

$$G_{Albedo} = GHI * \alpha * (1 - SVF) \tag{5}$$

$$G_{AOI} = G_{Direct} + G_{Diffuse} + G_{Albedo} \tag{6}$$

DNI, DHI, GHI represents Direct Normal Irradiance, Diffuse Horizontal Irradiance, Glocal Horizontal Irradiance respectively; AOI is the angle of incidence and SVF is the sky view factor; $\alpha_M$ and $A_M$ are the altitude and azimuth of the module while $\alpha_s$ and $A_s$ are altitude and azimuth of the sun; $\theta_M$ is the tilt of the module. The azimuth angle convention is set as N=0°, E=90°, S=180°, W=270°.

Fig. 2 illustrates the annual irradiation under different combinations. The largest irradiation is obtained at $\theta_M = 35°$ and $A_M = 178°$ where the annual irradiation is $1.9383 MWh/m^2$ (as showned in Fig. 3)

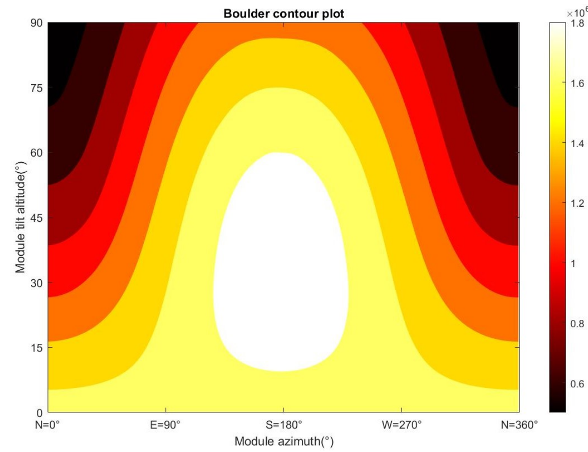


Fig. 2. Irradiation contour plot at Boulder

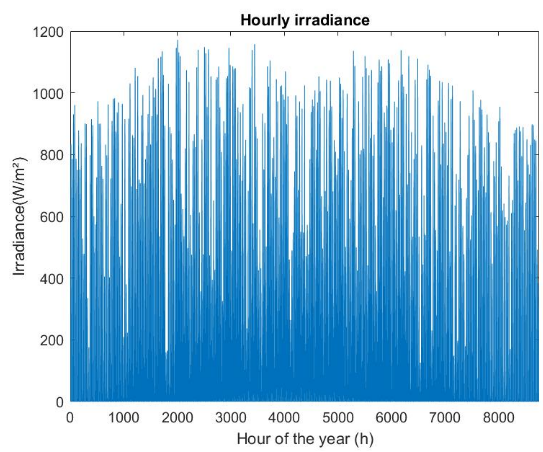


Fig. 3. Hourly irradiance ($\theta_M = 35°$, $A_M = 178°$)

**DC-side yield**

To estimate the performance and DC yield of the PV modules, firstly the module temperature under the environmental conditions at the roof of the data center has to be calculated for every hour of the year. To calculate the temperature of the module during operation accurately, the fluid-dynamic model is used [2]. This model takes into account various meteorological parameters, including for example wind speed and irradiation. To calculate the module temperature ($T_M$), Eq. 7 can be used, which includes the ambient temperature ($T_a$), the sky temperature ($T_{sky}$), the ground temperature ($T_{gr.}$), the irradiation G and $\alpha$, the absorptivity. Also, the convective heat transfer coefficients of the ground, the sky and the overall convective heat transfer coefficient, $h_{r,sky}$, $h_{r,gr.}$ and $h_c$, respectively, are included.

$$T_M = \frac{\alpha G + h_c T_a + h_{r,sky} T_{sky} + h_{r,gr.} T_{gr.}}{h_c + h_{r,sky} + h_{r,gr.}} \tag{7}$$

However, $h_{r,gr.}$ and $h_{r,sky}$ are also functions of $T_M$ and therefore Eq. 7 has to be solved iteratively. After performing these calculations, the result as depicted in Fig. 4 is obtained, which shows the module temperature for the first 200 hours of a year, as well as for every hour of the year. Also a comparison between the module temperature, wind speed, ambient temperature and the irradiation for the first 200 hours of the year is given in Appendix A, to get a feeling of the influence of these parameters on the module temperature.

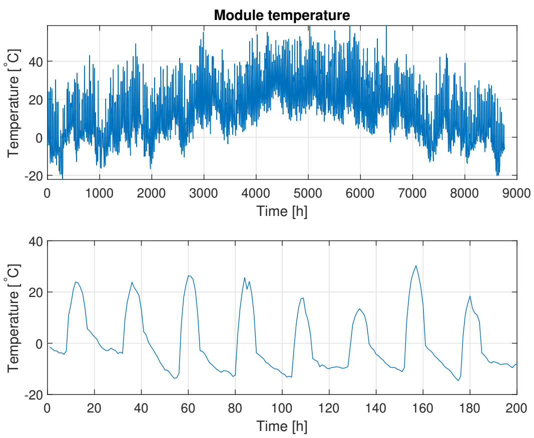


Fig. 4. Temperature of the PV module

The operative efficiency is calculated by two step according to [3], namely first considering the variable irradiance at a constant temperature of 25°C and then combining the impact of temperature (Eq.8-13). Then power generated before BoS and voltage level are obtained by Eq.14-15.

$$FF = \frac{P_{MAX}^{STC}}{V_{OC}^{STC} * I_{SC}^{STC}} \tag{8}$$

$$V_{OC}^{25^\circ C, G_{AOI}} = V_{OC}^{STC} + \frac{n * k_B * T_{stc}}{q} * ln(\frac{G_{AOI}}{G_{STC}}) * N \tag{9}$$

$$I_{SC}^{25^\circ C, G_{AOI}} = I_{SC}^{STC} + \frac{G_{AOI}}{G_{STC}} \tag{10}$$

$$P_{MAX}^{25^\circ C, G_{AOI}} = FF * V_{OC}^{25^\circ C, G_{AOI}} * I_{SC}^{25^\circ C, G_{AOI}} \tag{11}$$

$$\eta^{25^\circ C, G_{AOI}} = \frac{P_{MPP}^{25^\circ C, G_{AOI}}}{A_m * G_{AOI}} \tag{12}$$

$$\eta^{T_M, G_{AOI}} = \eta^{25^\circ C, G_{AOI}} * (1 + k_{eff} * (T_m - 25)) \tag{13}$$

$$P_{MAX}^{T_M, G_{AOI}} = \eta^{T_M, G_{AOI}} * A_m * G_{AOI} \tag{14}$$

$$V_{MAX}^{T_M, G_{AOI}} = \frac{P_{MAX}^{T_M, G_{AOI}}}{I_{MAX}^{T_M, G_{AOI}}} = \frac{P_{MAX}^{T_M, G_{AOI}}}{I_{MAX}^{25^\circ C, G_{STC}} * \frac{G_{AOI}}{G_{STC}}} \tag{15}$$

**PV module selection**

The selection of PV modules is constrained by the load situation. The minimum requirement is implicated by the 7-hour critical load during the black-out. Specifically, since the black-out could start at the random hour on Monday, the power generated from Tuesday to Sunday must be sufficiency to fully charge the battery, namely bigger than the $7 * 5.8 = 40.6kWh$. The maximum limit is determined by the requirement that *the PV system must not produce any excess of energy at any time during grid-tied mode.* Table II shows the results when testing four PV modules with Maximum Power ranging from $380W_p$ to $395W_p$.

TABLE II
NUMBER OF REQUIRED PV MODULES

| Module Type | Minimum number | Maximum number |
|---|---|---|
| JKM380M-72 | 8 | 16 |
| JKM385M-72 | 8 | 16 |
| JKM390M-72 | 7 | 15 |
| JKM395M-723 | 7 | 15 |

Considering that the blackout situation is due to a temporary construction work, a minimum number of PV modules is preferable to reduce the system costs. On the other hand, to avoid the rather high compensation cost, a high supply reliability is required to guarantee that the critical load demand is met. As for the two available products, the module efficiency of JKMxxxM-72 series is higher than that of JKMxxxM-72H under the same maximum power. Therefore, **8 PV modules of JKM390M-72** are selected for the implementation. Table III shows the key parameters of selected module.

TABLE III
PARAMETERS OF THE PV MODULE JKM390M-72

| Parameter | Value |
|---|---|
| Maximum Power$P_{MAX}$ | 390W |
| Open-circuit Voltage $V_{OC}$ | 49.3V |
| Short-circuit Current$I_{SC}$ | 10.12A |
| Module Efficiency STC $\eta$ | 19.67% |
| Module Area $A_m$ | 1.983$m^2$ (1.979m*1.002m) |
| Temperature Coefficients of $k_{P_{max}}$ | -0.37%/°C |
| Temperature Coefficients of $k_{V_{oc}}$ | -0.28%/°C |
| Temperature Coefficients of $k_{I_{sc}}$ | 0.048%/°C |
| Single Module Cost | 339.3€/per |

Based on Eq. 8-15, the hourly DC yield and voltage (single module) are obtained as shown in Fig. 5. Fig. 6 illustrates the monthly power distribution for all 8 modules. **The total DC-side yield is 5825 kWh**.

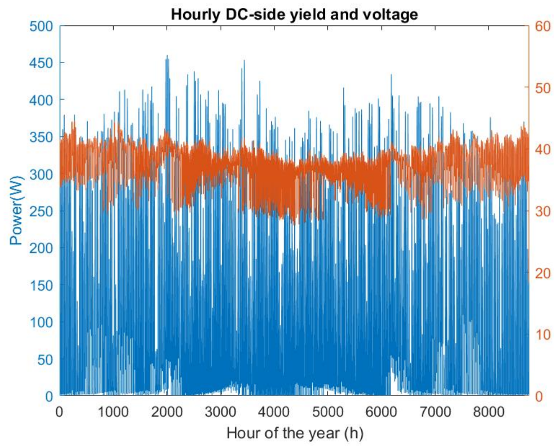


Fig. 5. Hourly DC-side yield and Voltage level-JKM390M-72

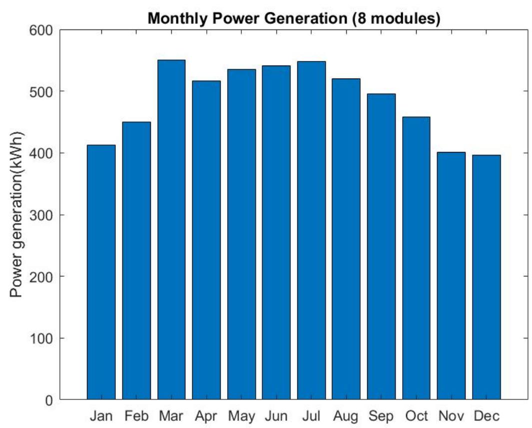


Fig. 6. Monthly DC-side yield-8*JKM390M-72

**PV array**

To guarantee no row-to-row shading, Eq. 16 is utilized to calculate the required distance, considering the worst day - Dec $21^{st}$ from 9AM to 3PM. Fig. 7 illustrates the sun path at four days and analemmas of five time points across the year.

$$d = l * (cos(\theta_M) + \frac{sin(\theta_M)}{tan(a_S)} * cos(A_M - A_S)) \qquad (16)$$

There are several topologies to deploy the 8 modules, e.g. 2 rows*4 columns, 4 rows*2 columns, etc. In reality, the typology should be adjusted according to the condition of the roof surface. Here 2*4 array is chosen to compare portrait and landscape deployment scenarios. Table IV demonstrates the row-to-row distant, required area and Ground Coverage Ratio (GCR) using Eq. 17 and Eq. 18 ($Area_{roof} = 170m^2$). Thus, **a minimum area of 71.15$m^2$ is required to avoid row-to-row shading with a corresponding GCR of 0.0764**.The low GCR implicates a poor land/roof usage and a high potential for more PV installations.

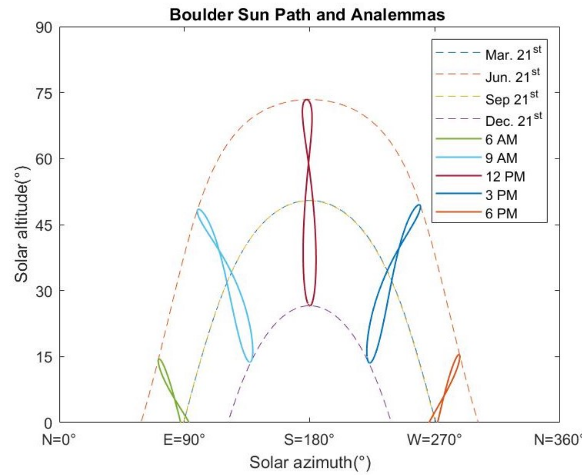


Fig. 7. Boulder Sun Path and Analemmas

$$Area = ((2-1) * d + l * (cos(\theta_M)) * 4 * w \qquad (17)$$

$$GCR = \frac{2 * 4 * l * w}{Area_{roof}} \qquad (18)$$

TABLE IV
PV ARRAY PARAMETERS-2 ROWS*4 COLUMNS

| Scenario | l | w | d | Area | GCR |
|---|---|---|---|---|---|
| Portrait | 1.98m | 1.00m | 5.11m | 71.15$m^2$ | 0.0764 |
| Landscape | 1.00m | 1.98m | 2.56m | 71.15$m^2$ | 0.0764 |

### *B. BoS Components*

**Inverter selection**

The inverter should be able to deliver the critical load when needed, which is 5.8kW. Furthermore, the inverter should work at $240V_{AC}$. This translates into a **peak current of** $5800W/240V = 24.17A$. These requirement are fulfiled by the **'Conext XW Pro Inverter for North America' inverter from Schneider.** The other inverter is not able to work under the situational requirements, such as the required $240V_{AC}$.

During a black-out the only two components active are the battery and the inverter. Looking at the output currents of these two components, we concluded that the inverter is output limiting. The maximum current the inverter could provide is 52A at 240V.

The inverter will cost $6800W_p$*€0.64 =€4,352. A summary of the inverter properties can be found in Table V.

**Battery selection**

The voltage of the batteries have to be aligned with the inverter voltage range. The chosen inverter has a nominal input voltage of $48V_{DC}$. The battery used for this system,

TABLE V
PARAMETERS OF THE INVERTER

| Parameter | Value |
|---|---|
| Power | 6800W |
| Efficiency (at critical load) | 91.7% |
| Efficiency (at normal supply to load) | 78.25%-88.4% |
| Input voltage | $48V_{DC}$ |
| Peak current | 52A |
| Total costs | €4,352 |

the 8A4DLTP-DEKA, has a nominal voltage of 12V. Therefore, 4 batteries connected in series would result in $4 * 12V = 48V_{DC}$.

From Chapter 3, it can be concluded that the critical load during blackout is 40.6kWh. This energy has to be delivered by the batteries while they maintain a minimum 40% state of charge (SoC). Subsequently, the depth of discharge (DoD) is not allowed to be lower than 60%. Furthermore, when calculating the required battery capacity to fulfil the needs of the system, an inverter efficiency of 95% should also be taken into account. This results in the following capacity:

$$C_{tot,batteries} = \frac{Total\ demand(kWh)}{\eta_{inverter} * (1 - SoC_{min.})} = 73.6kWh$$

DEKA has specified a capacity of 198Ah at a discharge rate of C/20. Using the nominal voltage of 12V, the capacity of one battery is $198Ah * 12V = 2376Wh \approx 2.4kWh$. The total battery capacity would thus be fulfilled when $73.6kWh/2.4kWh \approx 31$ batteries are used. However, given the fact that 4 batteries are connected in series, a multiple of 4 has to be used. Therefore, **32 batteries** are used to ensure the power supply. As a result $32/4 = 8$ **batteries are placed in parallel**. This leads to a total capacity of 76.8kWh. The parameters of the battery pack can be found in Table VI

TABLE VI
PARAMETERS OF THE BATTERY PACK

| Parameter | Value |
|---|---|
| Capacity | 76.8kWh |
| Efficiency | 95% |
| Voltage | 48V |
| C/20 | 198Ah |
| Total costs | €13,760 |

**Charge controller selection**

To ensure maximum use of the solar PV array power, the charge controller should match the total power of the PV array. The cheapest charge controllers, which is also the least oversized, is the **Schneider Conext MPPT 60 150** charge controller. This charge controller has a power capacity of 3.5kW. Our PV system consists of 8 panels, each having a power of 390Wp. Our charge controller will therefore not limit the PV array on a power basis.

Furthermore, the voltage and current of the PV array should also not exceed that of the charge controller. The PV panels have a $V_{oc}$ of 49.3V and a $I_{sc}$ of 11.12A. The PV array for this system has 4 parallel strings, each having 2 panels connected in series. The maximum current is therefore $4*10.12A = 40.48A$ and the maximum voltage is $2*49.3V = 98.6V$. Concluding from the charge controller information in Table VII, it can be concluded that the current and voltage levels are respected by the PV array output.

TABLE VII
PARAMETERS OF THE CHARGE CONTROLLER

| Parameter | Value |
|---|---|
| Power | 3500W |
| Efficiency | 98% |
| Max Amperage | 60A |
| Max Voltage | 140V |
| Total costs | €530 |

## V. System losses

The efficiency of the system differs amongst the grid-tied mode and black-out scenario. This is mainly caused by a difference in inverter efficiency. The inverter efficiency is namely slighly higher during the grid-tied mode, since the rated output power of the inverter is the highest in this case. During grid-tied mode a lower amount of power passes through the inverter, which subsequently leads to a lower inverter efficiency.

To estimate a more realistic inverter efficiency over time, the average inverter efficiency is calculated on a monthly basis. This is based on monthly averaged loads. An overview of the system losses can be found in Table VIII.

Furthermore, for one day per month an hourly inverter efficiency analysis is performed. This can be found in Appendix B.

TABLE VIII
SYSTEM EFFICIENCIES

| Component | Efficiency(%) |
|---|---|
| Inverter (grid-tied) | 78.25-88.4 |
| Inverter (black-out) | 91.7 |
| Charge controller | 98 |
| Batteries | 95 |
| PV modules | 19.67 |

## VI. DC and AC yield

The system has to adhere to the requirements mentioned in the previous sections. The most important requirement is the avoidance of a grid-tied production which exceeds the load. Figure 8 shows the production of the PV array and the load over time. As can be seen, the output of the PV system never exceeds the load. The exact difference between the load and the grid-tied production is shown in Figure 9. As can be seen, the difference is negative for the full year.

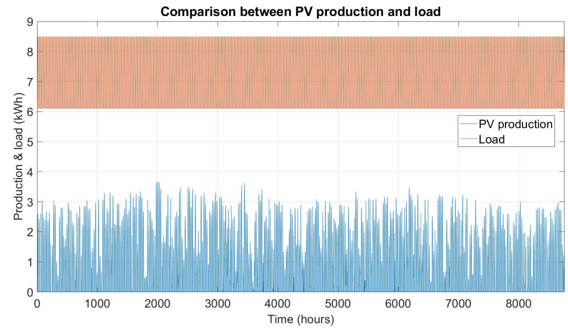


Fig. 8. Comparison between the DC production of the PV system and the electricity demand of the data center

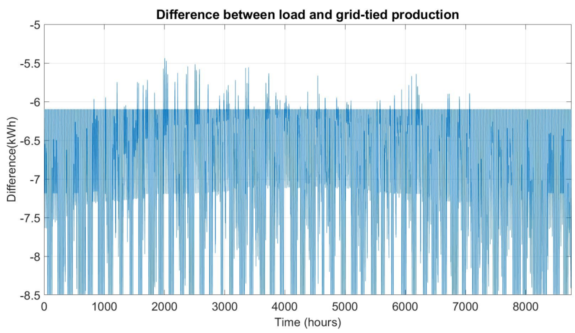


Fig. 9. The difference between the load and the grid-tied production is negative over the full time, showing that the feed-in prohibition is never violated

Furthermore, the batteries are only allowed to slightly exceed a 40% SoC for less than 10% of the time. The SoC behaviour of the battery is shown in Figure 10, which shows that the SoC is only violated for 3.7% of the time. Figure 11 provides a zoomed-in overview of the difference between the minimum SoC and the lowest SoC measured in the system.

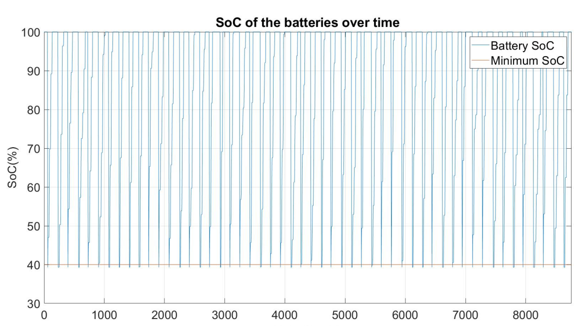


Fig. 10. Battery SoC over time, showing that the minimum Soc of 40% is only violated for 3.7% of the time

Also, the batteries have to be able to recharge in 6 days to ensure that the critical load can be supplied during a black-out. Figure 12 shows the hours the system required to fully recharge, per week. As can be seen the maximum

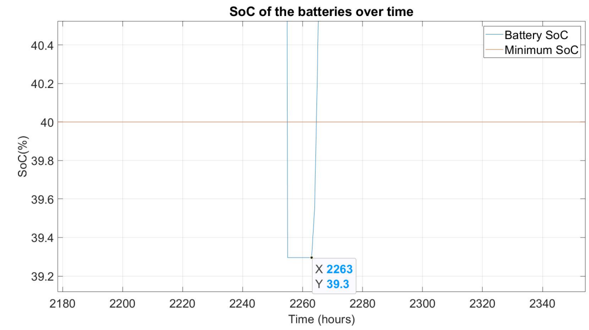


Fig. 11. Difference between lowest measured SoC and minimum required Soc, showing that a violation of the minimum SoC only yields to a difference of 1.75%

recharge interval is 139 hours, which is 5.8 days. It can thus be concluded that the system is reliable over time.

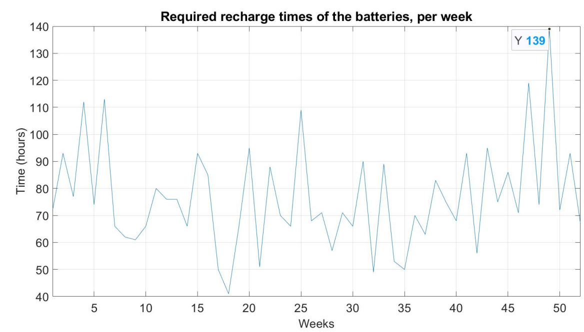


Fig. 12. Recharge times required for the batteries to be able to fully supply the critical load, measured per week.

As mentioned in the Section IV, **the total DC-side yield is 5.8MWh**. the total AC-side yield is c. 4.6MWh, specifically 2.1MWh to supply the critical load during blackouts and 2.5MWh to the main grid under the grid-tied mode. This yields an efficiency of 79%.

## VII. Cost analysis

The capital expenditures associated with our designed system are broken down in Table IX. Table X shows the price parameters which are used for the cost calculations.

TABLE IX
Capex break-down of the full installation

| Equipment | Cost (€) |
|---|---|
| PV panels | 2,714 |
| Inverter | 4,352 |
| Mounting structure | 256 |
| Charge controller | 530 |
| Batteries | 13,760 |
| DC/DC switchgear | 370 |
| AC/AC switchgear | 450 |
| Assecories | 1,716 |
| **Total capex** | **24,148** |

Provided that the electricity price is stable over the full year, one year of grid-tied operations would result in

TABLE X
PRICE ASSUMPTIONS

| Type | Price |
|---|---|
| Black-out fee | €2.10/h |
| Electricity price | €0.10/kWh |

saving about **€250** of electricity expenses. This results of a **grid-tied AC yield of c. 2.5MWh.** However, this does not weigh up against the required capex which is shown in Table IX.

The profitability of the system of this project depends heavily on the avoidance of the black-out fees. Provided that the black-outs occur once a week for 7 hours, the avoided black-out costs for the data centers 45 clients would yield to $45 * 52 * 7 * €2.1 = €34,398$. Compared to a capex of €24,148, the system yields a profit of €10,250.

Combining both the grid-tied mode and the avoidance of black-out costs yields to a total operational cost saving of €34,648 and a **profit of €10,500**. Including the supply of the critical load, the **total AC yield is c. 4.6MWh**. The grid-tied production only makes up for less than 1% of the operational cost savings. The pay-back time of the system is shown in Figure 13, where the total capex is plotted against both the black-out cost savings and the total cost savings.

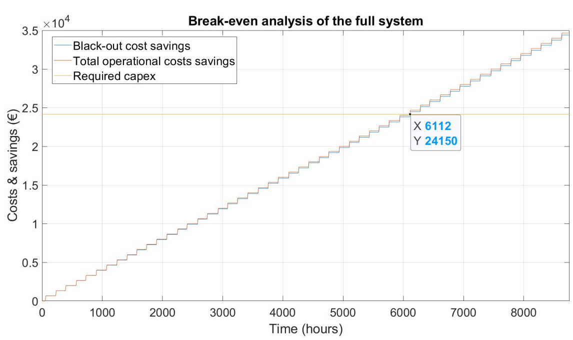


Fig. 13. Break-even analysis of the full system, based on a stable electricity price

The system would also meet the requirements when a 380Wp PV panel is used. However, its reliability would have been significantly lower. Therefore, it is assessed if the financial gains of lowering the capacity would outweigh the decrease in reliability. When running a 380Wp system, the total capex would have been €24,035. The savings in grid-tied mode are about €244 and the profit would have been €10,357. Compared to a 390Wp scenario the profit only increases by 1%.

Furthermore, this assignment is based on the assumption that the construction is paid with equity investment from the data center. However, solar PV installation can also be financed with long-term debt. The financial model which includes debt under project financing assumptions is provided in Appendix C. From the model it can be concluded that the profitability of the system can increase up to about 26% when a 15-year loan is installed against 80% leverage. Most of the debt is repaid in year one, with the avoided black-out costs. The rest of the debt is paid off by the grid-tied production savings. Furthermore, it is assumed that the risk of a black-out only occurs in the first year. During the remaining 14 years, all of the generated electricity is used to feed the load.

## VIII. Conclusions

In conclusion, with the proposed system, the goal of the project, providing a sustainable solution for the back-up generation of the data center, is achieved. The optimal parameters, topology and components for the system are determined using the requirements for the system, as well as the meteorological data at the site.
For this system, the optimal azimuth and tilt of the modules are determined, as well as the optimal topology. Further, the most suitable PV module is chosen as well as an inverter and charge controller. Also it is checked whether the output parameters of the system are within the limits of the components that are used. Finally, the financial part of the system is assessed and it can be concluded the system is not only reliable, but also profitable.

## Acknowledgment

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# Appendix A
# Module temperature

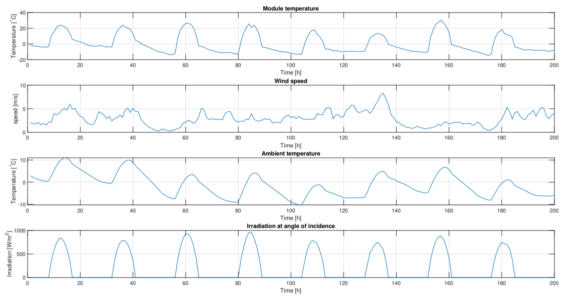


Fig. 14. Temperature of the PV module

# Appendix B
# Inverter efficiency for one day per month

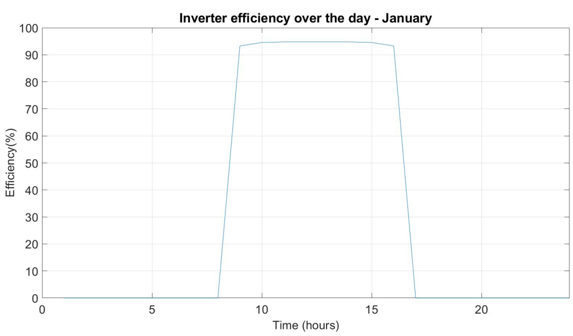


Fig. 15. Inverter efficiency for one full day - January

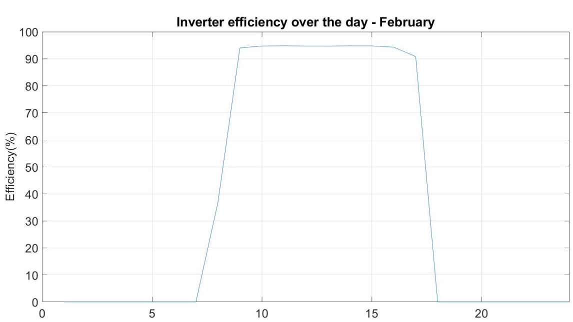


Fig. 16. Inverter efficiency for one full day - February

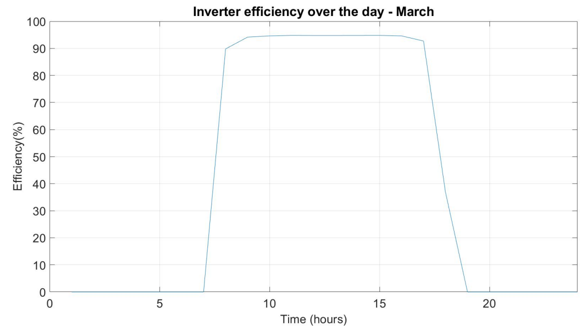


Fig. 17. Inverter efficiency for one full day - March

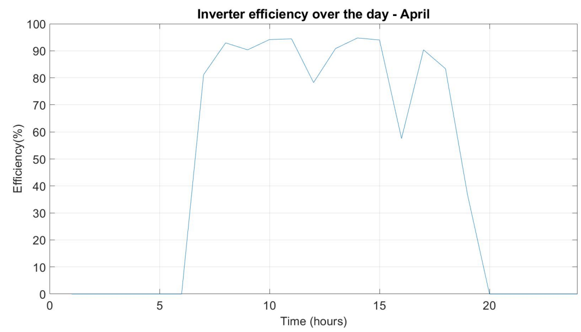


Fig. 18. Inverter efficiency for one full day - April

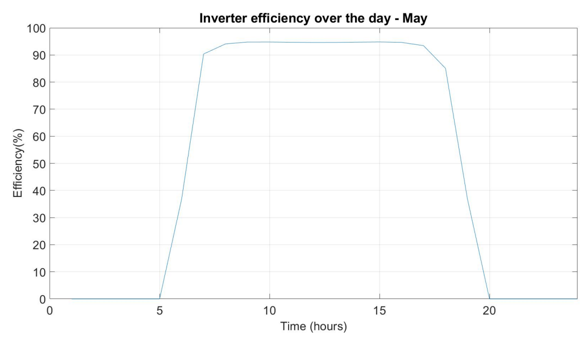


Fig. 19. Inverter efficiency for one full day - May

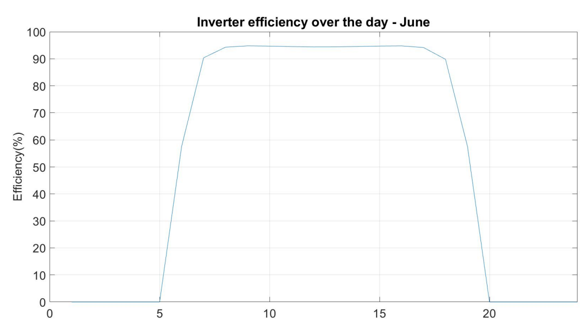


Fig. 20. Inverter efficiency for one full day - June

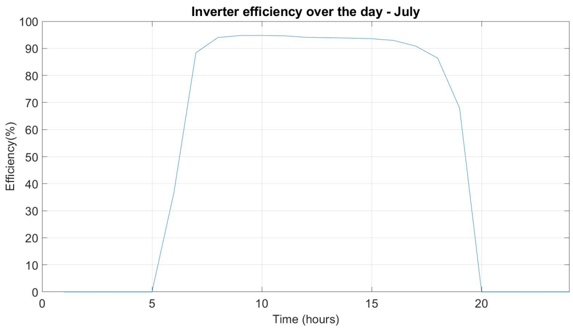


Fig. 21. Inverter efficiency for one full day - July

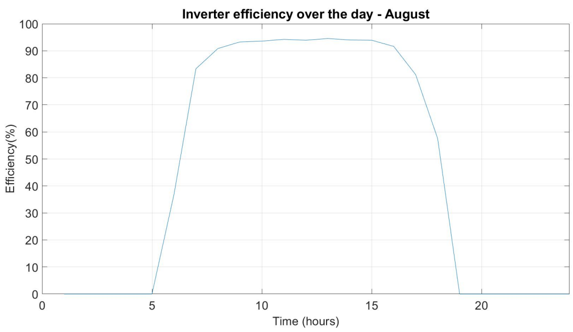


Fig. 22. Inverter efficiency for one full day - August

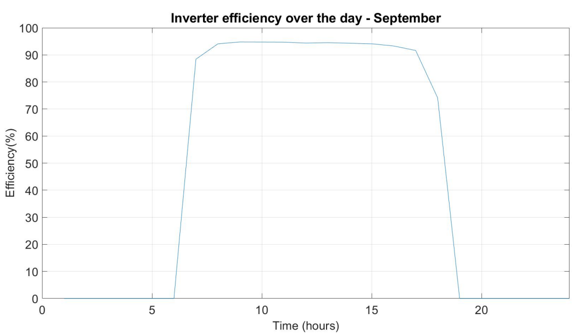


Fig. 23. Inverter efficiency for one full day - September

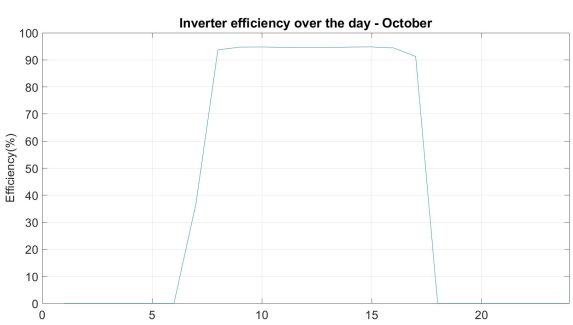


Fig. 24. Inverter efficiency for one full day - October

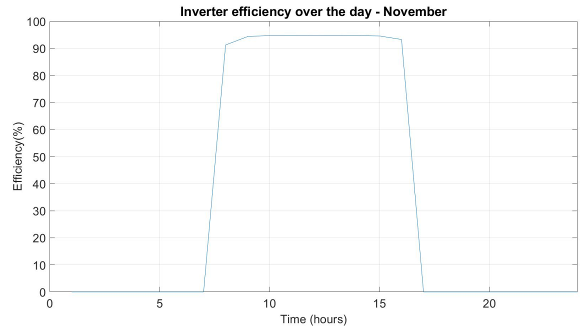


Fig. 25. Inverter efficiency for one full day - November

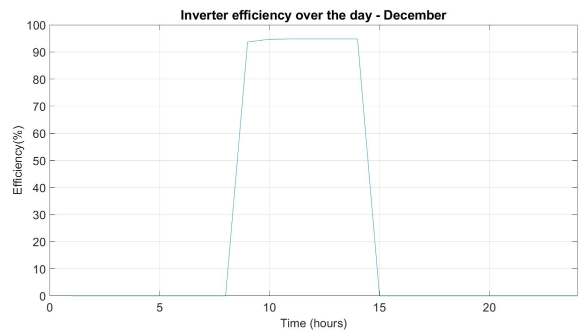


Fig. 26. Inverter efficiency for one full day - December

## Appendix C
## Financial model with debt under project financing assumptions

| Input | | |
|---|---|---|
| Production | 5520 | kWh |
| Electricity price | 0.1 | €/kWh |
| Capacity | 3.12 | kW |
| CAPEX PV/kW | 870 | €/kW |
| CAPEX PV | 2714.4 | € |
| CAPEX BOS | 21433.6 | € |
| O&M | 21.75 | €/kW/yr |
| Leverage | 80% | |
| Interest | 3.5% | |
| Loan life | 15 | yr |
| Repayment year 1 | 68% | |
| Project life | 25 | yr |
| Tax | 25% | |
| Cost of equity | 8% | |

| Output - levered | |
|---|---|
| PV | 20,980.2 |
| Investmen | 4,286.7 |
| **NPV** | **16,693.5** |
| IRR | 395% |

| Output - unlevered | |
|---|---|
| PV | 37,374.7 |
| Investmen | 24,148.0 |
| **NPV** | **13,226.7** |
| IRR | 51% |

*Straight line depreciation over project lifetime*

| Funding | |
|---|---|
| Debt | 19861.28 |
| Equity | 4286.72 |

| Debt schedule | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Year* | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* | *16* | *17* | *18* | *19* | *20* | *21* | *22* | *23* | *24* | *25* |
| Debt in | | 19,861.3 | 6,355.6 | 5,901.6 | 5,447.7 | 4,993.7 | 4,539.7 | 4,085.7 | 3,631.8 | 3,177.8 | 2,723.8 | 2,269.9 | 1,815.9 | 1,361.9 | 907.9 | 454.0 | | | | | | | | | | |
| Repayment | | 13,505.7 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | | | | | | | | | | |
| Debt out | | 6,355.6 | 5,901.6 | 5,447.7 | 4,993.7 | 4,539.7 | 4,085.7 | 3,631.8 | 3,177.8 | 2,723.8 | 2,269.9 | 1,815.9 | 1,361.9 | 907.9 | 454.0 | 0.0 | | | | | | | | | | |
| Interest | | 458.8 | 214.5 | 198.6 | 182.7 | 166.8 | 150.9 | 135.1 | 119.2 | 103.3 | 87.4 | 71.5 | 55.6 | 39.7 | 23.8 | 7.9 | | | | | | | | | | |

| Cash flows | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Year* | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* | *16* | *17* | *18* | *19* | *20* | *21* | *22* | *23* | *24* | *25* |
| **Revenue** | | **34,950.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** | **552.0** |
| Production | | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 | 5,520.0 |
| Price | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Penalty avoidance | | 34,398.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| OPEX | | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 | -67.9 |
| D&A | | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 | -108.6 |
| EBIT | | 35,126.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 | 728.4 |
| Interest | | -458.8 | -214.5 | -198.6 | -182.7 | -166.8 | -150.9 | -135.1 | -119.2 | -103.3 | -87.4 | -71.5 | -55.6 | -39.7 | -23.8 | -7.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **EBT** | | **34,667.6** | **513.9** | **529.8** | **545.7** | **561.6** | **577.5** | **593.4** | **609.3** | **625.2** | **641.0** | **656.9** | **672.8** | **688.7** | **704.6** | **720.5** | **728.4** | **728.4** | **728.4** | **728.4** | **728.4** | **728.4** | **728.4** | **728.4** | **728.4** | **728.4** |
| Tax | | 67.4 | 128.5 | 132.5 | 136.4 | 140.4 | 144.4 | 148.3 | 152.3 | 156.3 | 160.3 | 164.2 | 168.2 | 172.2 | 176.2 | 180.1 | 182.1 | 182.1 | 182.1 | 182.1 | 182.1 | 182.1 | 182.1 | 182.1 | 182.1 | 182.1 |
| **Profit** | | **34,600.2** | **385.5** | **397.4** | **409.3** | **421.2** | **433.1** | **445.0** | **457.0** | **468.9** | **480.8** | **492.7** | **504.6** | **516.5** | **528.5** | **540.4** | **546.3** | **546.3** | **546.3** | **546.3** | **546.3** | **546.3** | **546.3** | **546.3** | **546.3** | **546.3** |
| +D&A | | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 | 108.6 |
| CFADS | | 34,708.8 | 494.0 | 505.9 | 517.9 | 529.8 | 541.7 | 553.6 | 565.5 | 577.4 | 589.4 | 601.3 | 613.2 | 625.1 | 637.0 | 648.9 | 654.9 | 654.9 | 654.9 | 654.9 | 654.9 | 654.9 | 654.9 | 654.9 | 654.9 | 654.9 |
| Debt repayment | | 13,505.7 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 454.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **FCFE** | **-4286.72** | **21,203.1** | **40.1** | **52.0** | **63.9** | **75.8** | **87.7** | **99.6** | **111.6** | **123.5** | **135.4** | **147.3** | **159.2** | **171.1** | **183.1** | **195.0** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** |
| Depreciated FCFE | | 18,891.4 | 33.0 | 39.7 | 45.2 | 49.6 | 53.2 | 55.9 | 58.0 | 59.4 | 60.3 | 60.8 | 60.8 | 60.6 | 60.0 | 59.1 | 183.9 | 170.3 | 157.7 | 146.0 | 135.2 | 125.2 | 115.9 | 107.3 | 99.4 | 92.0 |

| | |
|---|---|
| PV | 20980.22 |
| INVESTMENT | 4286.72 |
| NPV | 16693.5 |
| IRR | 395% |

| Unlevered | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FCFE** | **-24148** | **35,052.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** | **654.9** |
| Depreciated FCFE | | 31,231.2 | 540.3 | 500.3 | 463.2 | 428.9 | 397.1 | 367.7 | 340.5 | 315.2 | 291.9 | 270.3 | 250.3 | 231.7 | 214.6 | 198.7 | 183.9 | 170.3 | 157.7 | 146.0 | 135.2 | 125.2 | 115.9 | 107.3 | 99.4 | 92.0 |

| | |
|---|---|
| PV | 37374.71 |
| INVESTMENT | 24148 |
| NPV | 13226.71 |
| IRR | 51% |