# A cost-benefit analysis of implementing a 54 MW solar PV plant for a South African platinum mining company: A case study

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*Abstract*
*A reliable and secure supply of energy is a prerequisite for adequate output and economic growth – especially in a platinum mining company. With exponential tariff increases, inadequate power supply leading to power cuts, and a carbon tax introduction, this study compared the costs with benefits by implementing a 54 MW solar photovoltaic (PV) plant. Two scenarios were compared over the same 20-year period in a case study of a South African platinum mining company operating in the platinum belt of Rustenburg. The first scenario was grounded upon the decision to proceed with the conventional manner of sourcing electricity from Eskom, South Africa's power utility. The second scenario assessed the implementation of a 54 MW solar PV plant. The findings reveal that the company could generate 2 439 753 MWh of clean energy over 20 years with an investment of ZAR 910 857 920, giving a ZAR 563 205 994 (11%) carbon tax saving and a ZAR 5 614 426 335 (10%) reduction in electricity costs. Further, installing the solar PV plant could reinforce the company's dedication to protecting the environment and creating job opportunities through the employment of staff to install and maintain the plant.*

*Keywords: solar PV; platinum mining; electricity; carbon tax; cost and benefit*

*Highlights*
- *Cost and benefit analysis of implementing a solar PV plant*
- *A case study in a South African platinum mining company*
- *High electricity cost and carbon tax savings possible*

## 1. Introduction

The South African platinum mining industry relies heavily on a consistent and cost-effective supply of electricity to optimise production (Ryan, 2014; Shaw et al., 2019; Mahony et al., 2018). The primary supplier of electricity currently in South Africa is the national utility Eskom, with the state-owned enterprise supplying 95% of the country's electricity (Van der Zee, 2014; Van der Merwe et al., 2020). Electricity is primarily generated through the burning of coal that releases greenhouse gases (GHGs), contributing to global warming (Ting et al., 2020; Ndlovu et al., 2020). This type of energy source for electricity generation is non-renewable and contributes to environmental degradation, thereby constraining environmental sustainability (Nathaniel et al., 2021). Coal is also becoming scarcer and, in turn, costlier to produce, which is evident in the exponential increases in Eskom's electricity costs (Shaw et al., 2019; Votteler et al., 2016; Van der Zee, 2014). Furthermore, there is uncertainty around the reliable and consistent electricity supply provided by the utility. Eskom's power stations are increasingly unreliable as their useful lives are nearing an end, with newly erected stations reportedly being sub-standard (Maré, 2015). South Africa is therefore plagued by power cuts caused by inadequate power supply – commonly known as load-shedding (Du Venage, 2020). Platinum-mining organisations also forecast increased demand for electricity for the coming years as operations expand.

To further exacerbate the problem of using coal-generated electricity, the South African government introduced a carbon tax in 2019. The Carbon Tax Act, No 15 of 2019, became effective from 1 June 2019 – with the primary aim of reducing GHG emissions (Department of Environmental Affairs, 2019; Ntombela et al., 2019). Mining organisations must report their tier 2 emissions related to the electricity generated from burning fossil fuels (Department of Environmental Affairs, 2020). The carbon tax will be an additional cost, placing more pressure on profit margins.

It is evident that, to address the concerns of an increase in electricity costs, load-shedding, and the additional cost of carbon tax, the platinum mining sector needs to consider renewable energy sources. The notion of implementing renewable energy became more realistic on the 10th of June 2021, when President Cyril Ramaphosa announced that the threshold for electricity generation projects would increase from 1 MW to 100 MW without requiring a licence from the National Energy Regulator of South Africa.

One such renewable energy source is solar power. South Africa has ample solar resources, receiving average annual sunlight of more than 2 500 hours, or 300 days (Mhundwa et al., 2020; Department of Mineral Resources and Energy, 2019). The daily average shortwave radiation ranges between 4.5 and 6.5kWh/m², which is more than double than Germany's (Department of Mineral Resources and Energy, 2019; Van Wyk, 2014). This energy, also referred to as solar irradiation, is harnessed by photovoltaic (PV) systems to generate electricity through the photoelectric effect.

Direct normal irradiation (DNI) maps, similar to that in Figure 1, are used to calculate the kWh/m² generated when applying solar PV technology at a specific point on the map (Van Wyk, 2014). A DNI map is a valuable tool to measure the financial feasibility of solar PV plants.

Several studies have been conducted on the use of solar PV systems. Van der Merwe et al. (2020) audited the use of solar PV on various mining properties in the Northern Cape province of South Africa. Their audit revealed an annual potential to generate from 369 TWh to 679 TWh of power. This is more than South Africa's current electricity usage. Choi et al. (2017) reviewed various solar PV systems of operating and abandoned mines globally, including the Thaba mine in South Africa. They found that by utilising PV systems, the mining industry would contribute both environmentally and economically. Mhundwa et al. (2020:2), while not considering the mining sector specifically, highlighted that solar PV is 'emerging as one of the most competitive sources of new power generation capacity'. They analysed the energy saving of a 75kWp grid-tied solar PV system for an aquaculture system located in the Eastern Cape province of South Africa. For the year considered, an energy-saving of 139.82 MWh, and total avoided carbon dioxide ($CO_2$) of 141.07 t$CO_2$e were achieved.

In line with these studies, the main aim of this study was to conduct a case study comparing the cost and benefits of the conventional method of generating electricity versus solar PV electricity generation within a platinum mining operation.

## 2. Materials and method
### 2.1 Case study
The selected case for study is a South African platinum mining company mainly operating in the platinum belt of Rustenburg in North West province. It is so situated as to receive between 1 951 and 2 400 kWh/m² of DNI per annum. Two scenarios (hereafter referred to as scenarios 1 and 2) similar in capacity were compared over a
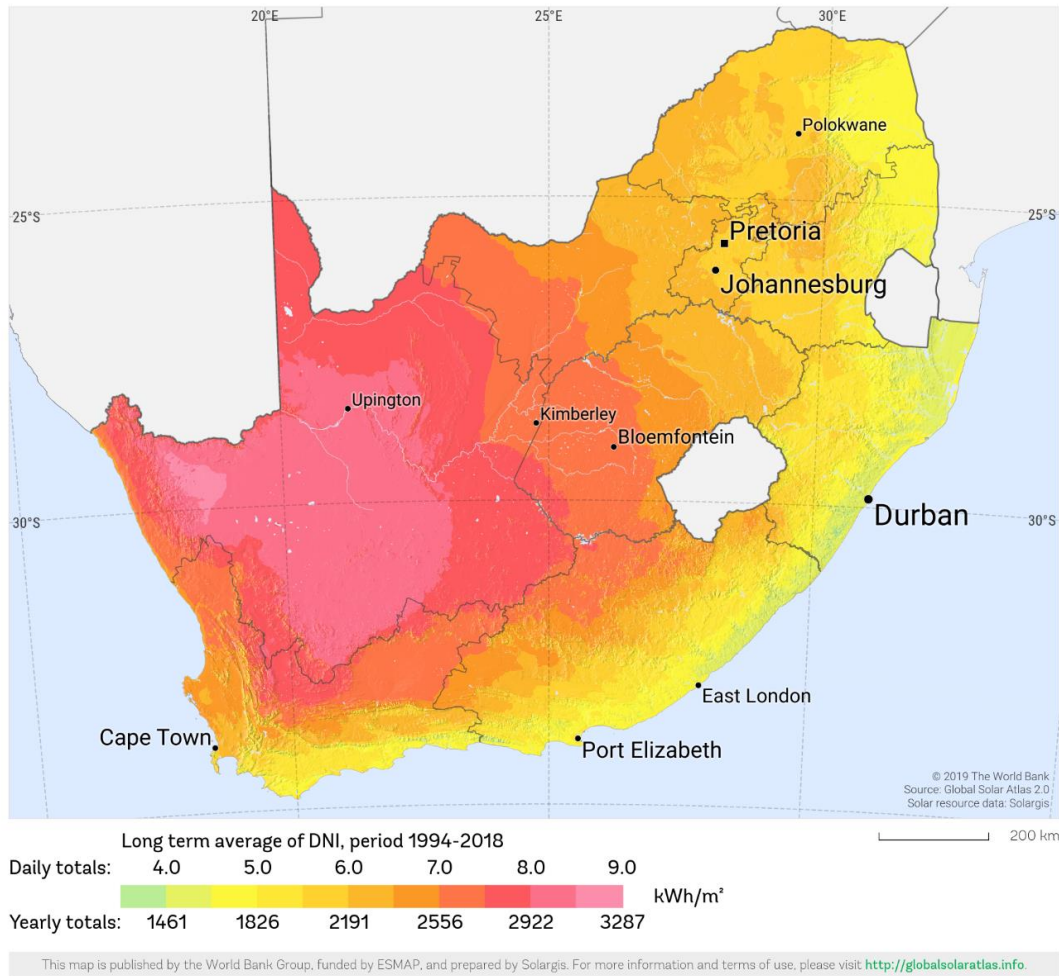
**Figure 1: Direct normal irradiation map of South Africa.**
*Source: World Bank (2019)*

20-year period – from 1 January 2018 to 31 December 2038. The first year (1 January to 31 December 2018) covers the construction and commissioning period of the PV facility, with electricity sourcing commencing on 1 January 2019 and lasting till 31 December 2038 (see Table 3). The first scenario was based on continuing with the conventional method of generating electricity, while the second was based on implementing a solar PV plant. The costs were compared against the benefits to determine which scenario was optimal for the organisation.

### 2.2 Description of the solar PV system
The solar PV facility to be constructed was a nominal 54 MW solar PV system with the characteristics displayed in Table 1. The PV facility can contribute an estimated 10.71% to the total electricity requirement of the mine and can be divided into modular 4.829 MWp inverter blocks, comprising 18 single-axis tracker array blocks and two inverter-transformer stations. Each inverter block consists of 539 strings, based on 30

strings per tracker array. However, one array has one string fewer, to create space for the inverter stations. The inverter blocks also catered for adequate internal roads enabling maintenance and cleaning of the tracker substructures, tracker actuators and PV modules. Each inverter block's dimensions, including the servitude for internal roads, are 301 m × 294 m.

**Table 1: System design characteristics of a 54 MW PV facility.**
*Source: GreenCape (2016)*

| System design characteristics | 54 MW PV facility |
|---|---|
| Nominal DC capacity (MW) | 58 |
| Inverter capacity (MW) | 54 |
| Number of PV modules | 181 104 |
| Number of inverters | 24 |
| Modules per string | 28 |
| Row pitch (m) | 5 |

The tracker array blocks comprise several horizontal (0° tilt angle) single-axis tracking tables grouped into one unit. A single tracker array consists of 30 strings driven by two actuators. The pitch between each tracker table is designed to be 5.0 m. Each string contains 28 modules, with 14 modules on either side of the drive axis, resulting in 840 modules per tracker array. A typical 268.8kWp tracker array is presented in Figure 2, 147 m long and 28.1 m wide.

Figure 3 depicts the profile of consecutive tracker tables, with each table having two modules in landscape orientation. At a pitch of 5.0 m, the designed spacing between the modules is based on a 23º shading limit angle design, decided upon through discussions with local tracker substructure suppliers. The support of each tracker table is at a height of 1.2 m, which raises the highest point of the module to 2.07 m aboveground when the table is at its maximum tilt of 55°. The available space for operations and maintenance between the tables is 3.0 m, allowing for a maintenance vehicle to move between the tracker tables.

In this case study, a single-axis tracking system was preferred over other options such as a fixed-tilt system. From a technical perspective, the energy output of a tracking system is around 20% higher than a fixed-tilt system. Although the cost is around 10% higher, it compensates by providing a higher yield of electricity.

### 2.3 Data collection
#### 2.3.1 Source of data
Various data were collected from the mining organisation's internal documents, including monthly energy consumption bills detailing the kilowatt/hours, rand (ZAR) value and tariff structure for 2018; forecast monthly energy consumption in kilowatt/hours and ZAR value from 2019 to 2038; costing reports relating to energy expenditure and initiatives; and quotations and invoices relevant to solar PV plants. These documents are only available in the private domain, and key individuals were consulted to acquire the information.

Public documents were also consulted, including the mining organisation's Annual Financial Statements (AFS) from 2012 until 2018, to establish a trend of rising energy expenditure compared to production figures and revenues. Eskom tariff structures and rates applicable to the mining industry; Eskom peak and off-peak schedules relating to the mining industry; and media articles about Eskom from 2008 until 2018 were assessed. To enable the comparison of scenarios 1 and 2, various data sources were also collated.
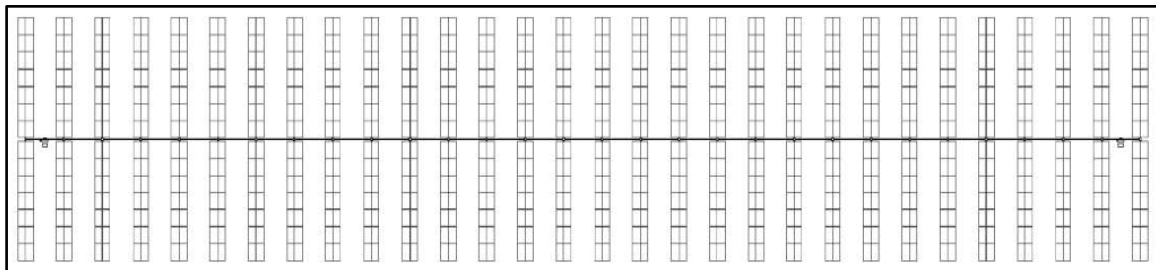


**Figure 2: Typical 268.8 kWp tracker array design.**
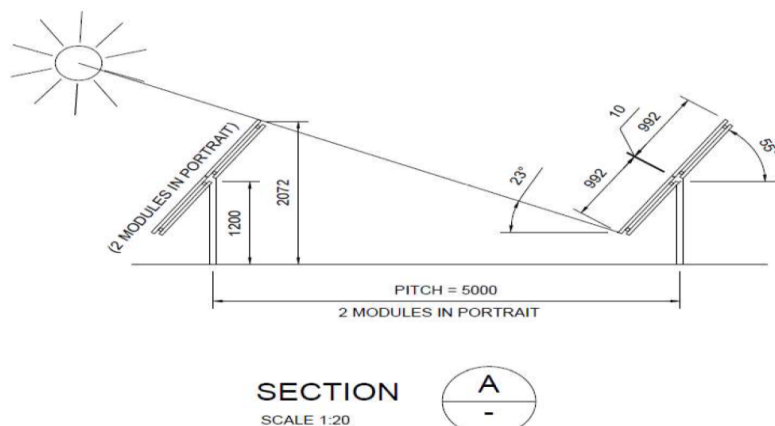*Source: Meteotest (2019)*



**Figure 3: Profile of tracker tables (dimensions in mm).**
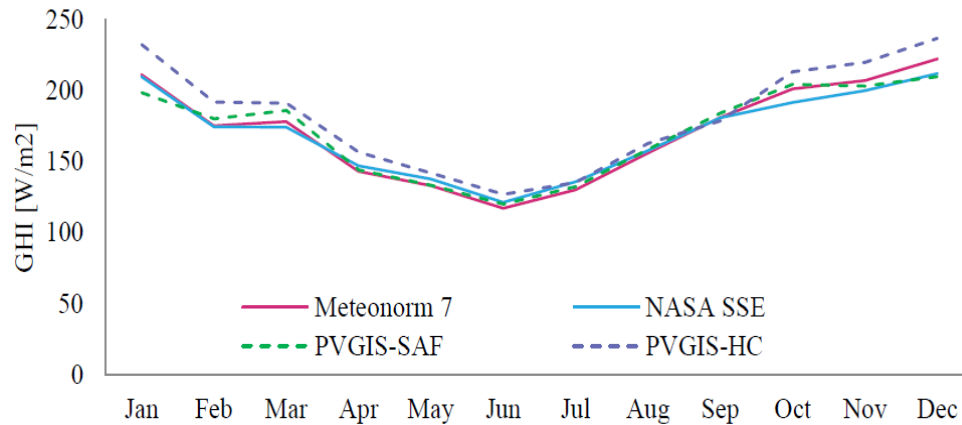*Source: Meteotest (2019)*

**Figure 4: Comparison of monthly irradiance data.**

*2.3.2 Data relating to the conventional method*
The total kWh used and corresponding costs in ZAR for the mining organisation from January 2018 to December 2018 were established from the monthly energy consumption bills. The average rate calculated over the 12 months was ZAR 0.91 /kWh.

*2.3.3 Data relating to solar PV system*
Meteonorm V7 was used to calculate the solar resource for the ground-mounted solar PV facility, compared to the solar resource values from NASA-SSE, PVGIS-Helioclim and PVGIS-SAF databases. Meteonorm data was gathered by interpolating results from records of the nearest weather stations, while satellite data were consulted where weather station records were not available. NASA-SSE, PVGIS-Helioclim and PVGIS-SAF data were sourced from satellite records (Meteotest, 2019). The periods over which solar weather data were gathered for each source is as follows: Meteonorm: 1986–2005; NASA-SSE: 1983–2005; PVGIS-Helioclim: 1985–2004; PVGIS-SAF: 1998–2005 and 2006–2010.

Annual global horizontal irradiation (GHI) data were gathered for the project location from the Meteonorm V7 data source, validated by comparing the data with NASA-SSE, PVGIS-Helioclim and PVGIS-SAF weather data sources.

The value for the annual GHI data provided by Meteonorm was within 0.10% of PVGIS-SAF, 0.54% of NASA-SSE, and 6.52% of PVGIS-Helioclim data (see Figure 4). These differences are within a reasonable range, and the Meteonorm data is thus considered appropriate for the long-term yield simulation.

These data parameters were used to generate an annual yield forecast in MWh, utilising the PVSyst software resource available within the mining organisation. The 20-year generation forecast, reflected in Table 2, was generated using Meteonorm weather data with PVSyst v6.42

software. The performance of the solar modules was adjusted for each year, and the results used to generate the probability yield for the scenario. The annual yield forecast generated by PVSyst accounts for an entire plant and grid availability of 98% and light induced degradation (LID) of 0.4%. The decline in annual yield from year 1 to year 20 displayed in Table 2 is due to the LID causing loss in the performance of the solar PV modules resulting from exposure to the sun.

**Table 2: 20-year yield forecast for the 54 MW solar PV facility.**

| Year of operation (end of year) | Annual yield (MWh/year) |
|---|---|
| Year 1 | 126 826 |
| Year 2 | 126 317 |
| Year 3 | 125 808 |
| Year 4 | 125 298 |
| Year 5 | 124 789 |
| Year 6 | 124 280 |
| Year 7 | 123 770 |
| Year 8 | 123 261 |
| Year 9 | 122 752 |
| Year 10 | 122 242 |
| Year 11 | 121 733 |
| Year 12 | 121 224 |
| Year 13 | 120 714 |
| Year 14 | 120 205 |
| Year 15 | 119 696 |
| Year 16 | 119 186 |
| Year 17 | 118 677 |
| Year 18 | 118 168 |
| Year 19 | 117 658 |
| Year 20 | 117 149 |
| **Total** | **2 439 753** |

Table 2 shows that a total of 2 439 753 MWh is on offer over 20 years for a 54 MW solar PV plant. The solar PV plant can function for more than the nameplate 20 years and will still yield positive energy generation if adequately operated and maintained. This study, however, caps the plant at 20 years for comparison reasons.

### 2.4 Analysis of data

The net present value (NPV) method was used to analyse the data of each scenario. The NPV was calculated by deducting the cash outflow of each scenario from the cash inflow, i.e. the saving achieved from the respective scenario. The difference between these cash flows is referred to as the NPV, with a positive result indicating an acceptable investment (Correia et al., 2019).

## 3.  Results and discussion

### 3.1 Scenarios

This section presents the two scenarios that were tested using the data collected from the mining organisation. As stated above, scenario 1 was built on continuing to rely on Eskom to supply electricity. Scenario 2 simulated the implementation of a 54 MW solar PV plant as a renewable energy source.

### 3.2 Simulation of scenario 1

In this first scenario, the effect of taxes paid on $CO_2$ emissions and the electricity costs for the plant over 20 years have been addressed.

### 3.2.1 Carbon tax costs

The mining organisation's current electricity consumption, which is generated by the burning of fossil fuels, substantially contributes to GHG emissions. The carbon tax rate for tier 2 emissions was ZAR 120 /$tCO_2$ as of 2018. This rate is subject to inflation plus 2% (CPI+2%) until the end of phase 1 (December 2022) and will then be increased in line with inflation, according to Writer (2019). The consumer price index (CPI) is assumed to be 6% for this simulation. It was decided to use CPI for a smoother and more conservative calculation of forward-looking amounts instead of the more volatile and unpredictable producer price index (PPI). The PPI is substantially more volatile than the CPI as the latter includes services while the PPI does not.

It is also anticipated that the MWh will remain constant throughout the project lifetime, in order to have comparable data. Table 3 consists of calculating carbon taxes payable by the mining organisation throughout the 20 years of the project. It perceived the exponential growth of the ZAR/$tCO_2$ throughout the period.

Table 3 indicates the ZAR/ton payable per annum over the 20 years. If these costs cannot be alleviated, the mining organisation faces total carbon taxes of ZAR 5 344 941 965 for the period. These taxes may be mitigated if the mining organisation obtains its electricity from a source other than utilising Eskom's conventional method of burning fossil fuels to generate electricity.

**Table 3: Estimated carbon tax payable by the mining organisation for the 20 years.**

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
|  | CF1 | CF2 | CF3 | CF4 | CF5 | CF6 | CF7 | CF8 | CF9 | CF10 |
| Year | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
| MWh ('000) | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 |
| $tCO_2$/MWh | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| $tCO_2$ ('000) | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 |
| ZAR/$tCO_2$ | 120 | 130 | 140 | 151 | 160 | 170 | 180 | 191 | 202 | 214 |
| Carbon tax (ZARm) | 138 | 149 | 161 | 174 | 184 | 195 | 207 | 219 | 232 | 246 |

| Period | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
|  | CF11 | CF12 | CF13 | CF14 | CF15 | CF16 | CF17 | CF18 | CF19 | CF20 |
| Year | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 |
| MWh ('000) | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 |
| $tCO_2$/MWh | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| $tCO_2$ ('000) | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 | 1 148 |
| ZAR/$tCO_2$ | 227 | 241 | 255 | 271 | 287 | 304 | 322 | 342 | 362 | 384 |
| Carbon tax (ZARm) | 261 | 277 | 293 | 311 | 330 | 349 | 370 | 392 | 416 | 441 |

**Table 4: Estimated electricity payable by the mining organisation for the 20 years.**

| Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | CF0 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
| Year | CF0 | CF1 | CF2 | CF3 | CF4 | CF5 | CF6 | CF7 | CF8 | CF9 |
| GWh | | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 |
| ZAR/kWh | | 0.91 | 0.99 | 1.08 | 1.18 | 1.28 | 1.40 | 1.53 | 1.66 | 1.81 |
| Elec. payable (ZARm) | | 1 077 | 1 174 | 1 280 | 1 395 | 1 521 | 1 658 | 1 807 | 1 969 | 2 147 |

| Period | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 |
| Year | CF10 | CF11 | CF12 | CF13 | CF14 | CF15 | CF16 | CF17 | CF18 | CF19 | CF20 |
| GWh | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 |
| ZAR/kWh | 1.98 | 2.15 | 2.35 | 2.56 | 2.79 | 3.04 | 3.31 | 3.61 | 3.94 | 4.29 | 4.68 |
| Elec. payable (ZARm) | 2 340 | 2 550 | 2 780 | 3 030 | 3 303 | 3 600 | 3 924 | 4 277 | 4 662 | 5 082 | 5 539 |

electricity. By acquiring electricity generated by a renewable energy source – such as the proposed solar PV plant – the savings can be recognised as carbon offsets. Although there are other ways of gaining offsets, such as restoring landscapes or planting trees, the scale of these alternatives would not be feasible.

### 3.2.2 Electricity costs
Electricity is one of the most substantial costs incurred by the mining organisation. It is thus imperative for it to control them in order to keep their operations sustainable. The effective electricity rate for the mining organisation was ZAR 0.91 /kWh as of 2018. This rate is subject to inflation plus any increase by Eskom (and approved by NERSA). CPI has been assumed to be 6% and the approved increase to be 3%. Thus a total rate increase of 9% per annum is set for this scenario. It is also assumed that the MWh will remain constant throughout the project lifetime, to have comparable data. Table 4 shows electricity used and payable by the mining organisation throughout the 20 years of the project.

The exponential growth of the ZAR/kWh could be observed throughout the period. If these costs cannot be reduced, payable electricity amounts to ZAR 55 116 588 687 throughout the 20 years of the project. Unfortunately, the recent above-inflation increases in the electricity tariff and the unreliability of Eskom to supply constant power to the mining industry have impeded the sustainability of the mining organisation.

The carbon tax of ZAR 5 344 941 965, combined with the electricity costs of ZAR 55 116 588 687, payable over the 20 years, amounts to ZAR 60 461 530 652. The mining organisation may be inclined to implement the solar PV plant, which provides the benefit to mitigate the additional costs of the increasing electricity tariff imposed by Eskom.

### 3.3 Simulation of scenario 2
In scenario 2, the focus was on saving the carbon tax and electricity costs over the 20 years for a 54 MW solar PV facility. After calculating these, scenario 2 considered the implementation costs of the solar PV plant. Although the cost of load shedding creates an opportunity cost it was not incorporated in the financial simulation. If, however, it were included, it could make this scenario more financially viable.

### 3.3.1 Carbon tax costs saving benefit
The annual MWh yield forecast, as illustrated in Table 2, was used to calculate the carbon tax amount that can be alleviated by implementing the solar PV plant. Table 5 shows the estimated amount of carbon tax that can be saved during the 20-year project period.

The mining organisation encountered a total carbon tax of ZAR 5 344 941 965 (as per scenario 1) for the 20 years before implementing the solar PV plant. The carbon tax-saving accumulated to ZAR 563 205 994 if the proposed solar PV plant was implemented. Figure 5 illustrates a holistic view of the total carbon tax payable, and the savings achieved, by implementing the solar PV plant. The mining organisation will generate an 11% saving throughout the 20 years if the proposed 54 MW solar PV plant is commissioned to supply the mining organisation with electricity.

**Table 5: Estimated carbon tax savings by the mining organisation for the 20 years.**

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | CF1 | CF2 | CF3 | CF4 | CF5 | CF6 | CF7 | CF8 | CF9 | CF10 |
| Year | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
| MWh ('000) saving | 127 | 126 | 126 | 125 | 125 | 124 | 124 | 123 | 123 | 122 |
| $tCO_2$/MWh | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| $tCO_2$ ('000) | 123 | 123 | 122 | 122 | 121 | 121 | 120 | 120 | 119 | 119 |
| ZAR/$tCO_2$ | 120 | 130 | 140 | 151 | 160 | 170 | 180 | 191 | 202 | 214 |
| Carbon tax saving (ZARm) | 15 | 16 | 17 | 18 | 19 | 20 | 22 | 23 | 24 | 25 |
| Period | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| | CF11 | CF12 | CF13 | CF14 | CF15 | CF16 | CF17 | CF18 | CF19 | CF20 |
| Year | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 |
| MWh ('000) saving | 122 | 121 | 121 | 120 | 120 | 119 | 119 | 118 | 118 | 117 |
| $tCO_2$/MWh | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| $tCO_2$ ('000) | 118 | 118 | 117 | 117 | 116 | 116 | 115 | 115 | 114 | 114 |
| ZAR/$tCO_2$ | 227 | 241 | 255 | 271 | 287 | 304 | 322 | 342 | 362 | 384 |
| Carbon tax saving (ZARm) | 27 | 28 | 30 | 32 | 33 | 35 | 37 | 39 | 41 | 44 |
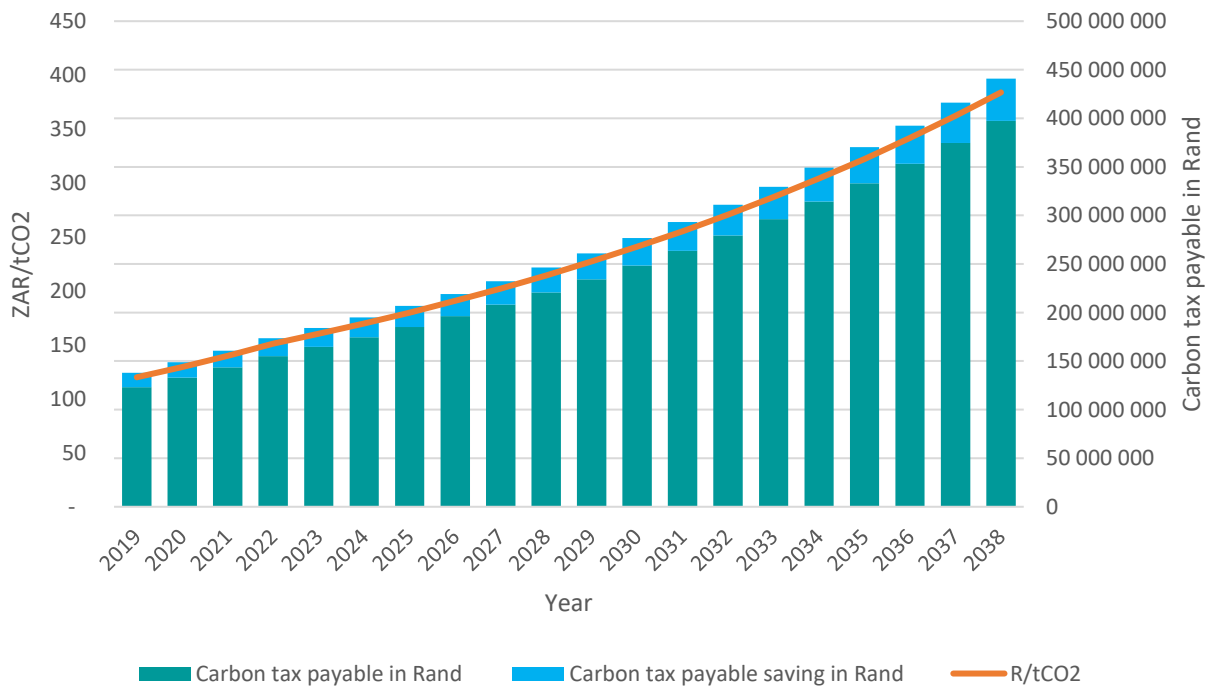


**Figure 5: Combined estimated carbon tax payable and saving by the mining organisation for the 20 years.**

*3.3.2 Electricity cost-saving benefit*
The annual MWh saving established in Table 5 has been utilised to calculate the electricity amount that can be alleviated by implementing the proposed solar PV plant. Table 6 shows the electricity saving throughout the 20-year project period.

**Table 6: Estimated electricity saving by the mining organisation for the 20 years.**

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
| Year | CF1 | CF2 | CF3 | CF4 | CF5 | CF6 | CF7 | CF8 | CF9 | CF10 |
| MWh saving ('000) | 127 | 126 | 126 | 125 | 125 | 124 | 124 | 123 | 123 | 122 |
| ZAR/kWh | 0.91 | 0.99 | 1.08 | 1.18 | 1.28 | 1.40 | 1.53 | 1.66 | 1.81 | 1.98 |
| Electricity saving (ZARm) | 115 | 125 | 136 | 148 | 160 | 174 | 189 | 205 | 223 | 242 |
| **Period** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 |
| Year | CF11 | CF12 | CF13 | CF14 | CF15 | CF16 | CF17 | CF18 | CF19 | CF20 |
| MWh saving ('000) | 122 | 121 | 121 | 120 | 120 | 119 | 119 | 118 | 118 | 117 |
| ZAR/kWh | 2.15 | 2.35 | 2.56 | 2.79 | 3.04 | 3.31 | 3.61 | 3.94 | 4.29 | 4.68 |
| Electricity saving (ZARm) | 262 | 285 | 309 | 335 | 364 | 395 | 429 | 465 | 505 | 548 |
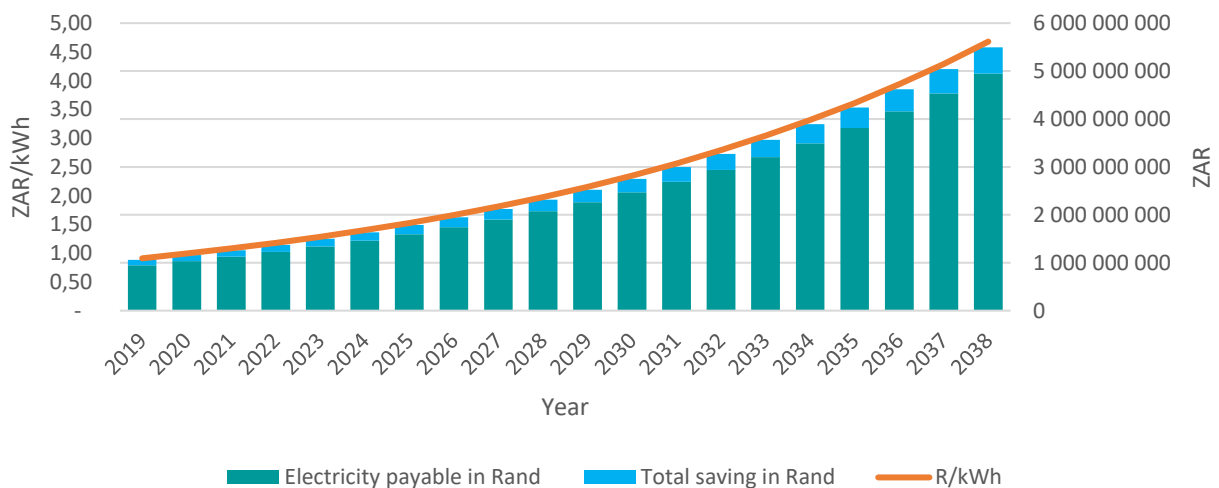


**Figure 6: Combined estimated electricity payable and saving by the mining organisation for the 20 years.**

If all the annual savings are accumulated, the electricity saving is ZAR 5 614 426 334 if the proposed solar PV plant is implemented. Figure 6 illustrates a holistic view of electricity consumption by presenting the electricity payable with the savings achieved by implementing the solar PV plant.

The mining organisation faced an accumulated electricity cost of ZAR 55 116 588 687 payable throughout the 20 years of the project in scenario 1. Thus, it will have a 10% saving over that period if the 54 MW solar PV plant is commissioned. It faces an exponential increase in electricity tariffs, and the implementation of the proposed solar PV plant will help avoid this increase. The total savings of carbon tax and electricity totalled ZAR 6 177 632 328. These savings can be redirected where needed in the organisation.

The capital outlay of a 54 MW solar PV plant successfully is substantial – ZAR 910 857 920 as calculated in Table 7. A detailed schedule of capital costs is available on request. For the implementation of the plant in scenario 2, the NPV simulation was performed.

*3.4 Net present value simulation*
The NPV model was utilised to determine if the benefits outweigh the costs in this analysis. Table 8 presents the NPV model, accumulating the following information: electricity payable (from Table 4); electricity saving (Table 2); electricity saving (Table 6); carbon tax saving (Table 5); and investment (Table 7). A 10% discount rate was applied. The model concluded that there is a positive NPV of ZAR 1.025 billion. The model further calculated an internal rate of return (IRR) of 21% that can be realised with a payback period of 5.76

years. The organisation has a policy that requires a capital project to yield a positive NPV with a payback period of fewer than ten years when using a 10% discount rate. The policy states that a 10% cost of capital may be utilised for an investment opportunity of an environmental, social or governance nature. This suggests that implementing a 54 MW solar PV plant is a feasible project that the mining organisation may pursue, as it meets – and even exceeds – all the criteria.

**Table 7: Estimated capital cost to install and implement a 54 MW solar PV facility.**
*Source: Quotes from suppliers (their names withheld, but calculations available on request)*

| Description | Amount (ZAR) |
|---|---|
| Preliminaries and general | 13 110 000 |
| Modules | 452 487 620 |
| Mounting structure and tracking system | 156 746 352 |
| Low voltage collector network | 40 491 989 |
| Photovoltaic power station | 79 883 678 |
| Medium voltage collector network | 6 724 576 |
| Weather and performance monitoring | 755 000 |
| Site preparation, roads and laydown area | 7 676 766 |
| Stormwater drainage | 9 561 186 |
| Trenches | 655 053 |
| Transformer and inverter foundation | 2 461 050 |
| Control building | 1 256 002 |
| Fire and security system | 40 005 490 |
| Facility substation | 62 000 000 |
| Spare parts | 5 000 000 |
| Overhead line | 29 886 504 |
| Receiving end substations | 2 156 654 |
| **Total** | **910 857 920** |

Corporate tax was not included in the calculation in Table 8, and therefore wear-and-tear allowances were excluded.

Figure 7 illustrates the cash flow movement for the 20-year project period. CF0 (Cash Flow period 0) shows the ZAR 911 million investment for implementing the solar PV plant. The cash flow benefits start to accumulate once the plant is commissioned, that is, from 2019. This benefit is net of the operation and maintenance cost incurred to run and repair the plant.
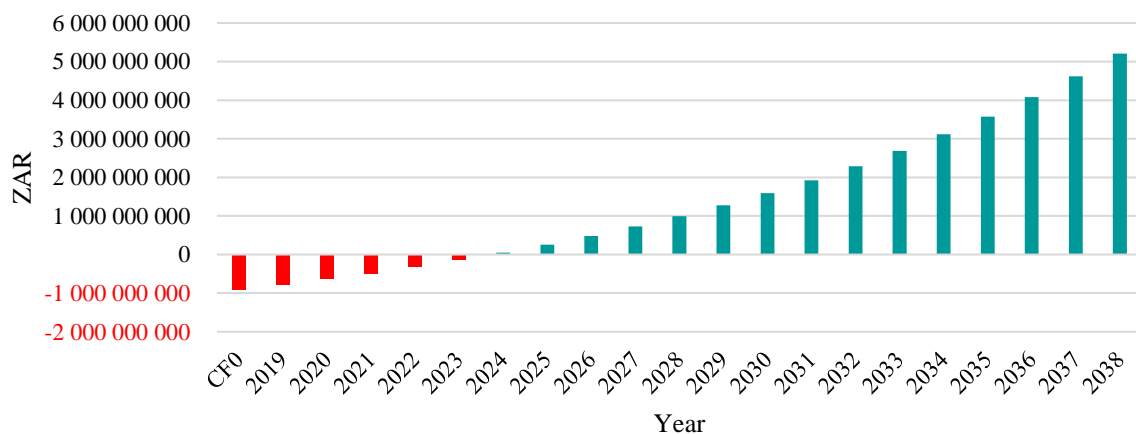


**Figure 7: Cash flow projection over the 20 years.**

**Table 8: Net present value simulation over the 20 years.**

| Period | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 |
| | CF0 | CF1 | CF2 | CF3 | CF4 | CF5 | CF6 | CF7 | CF8 | CF9 | CF10 | CF11 | CF12 | CF13 | CF14 | CF15 | CF16 | CF17 | CF18 | CF19 | CF20 |
| GWh | | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 | 1 184 |
| ZAR/kWh | | 0.91 | 0.99 | 1.08 | 1.18 | 1.28 | 1.40 | 1.53 | 1.66 | 1.81 | 1.98 | 2.15 | 2.35 | 2.56 | 2.79 | 3.04 | 3.31 | 3.61 | 3.94 | 4.29 | 4.68 |
| Elec. payable (ZARm) | | 1 077 | 1 174 | 1 280 | 1 395 | 1 521 | 1 658 | 1 807 | 1 969 | 2 147 | 2 340 | 2 550 | 2 780 | 3 030 | 3 303 | 3 600 | 3 924 | 4 277 | 4 662 | 5 082 | 5 539 |
| Elec. saving (GWh) | | 127 | 126 | 126 | 125 | 125 | 124 | 124 | 123 | 123 | 122 | 122 | 121 | 121 | 120 | 120 | 119 | 119 | 118 | 118 | 117 |
| Elec. saving (ZARm) | | 115 | 125 | 136 | 148 | 160 | 174 | 189 | 205 | 223 | 242 | 262 | 285 | 309 | 335 | 364 | 395 | 429 | 465 | 505 | 548 |
| Carbon tax saving (ZARm) | | 15 | 16 | 18 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 28 | 29 | 31 | 33 | 34 | 36 | 38 | 40 | 43 | 45 |
| Total saving (ZARm) | | 131 | 142 | 154 | 167 | 180 | 195 | 211 | 229 | 247 | 268 | 290 | 314 | 340 | 368 | 398 | 431 | 467 | 506 | 548 | 593 |
| Investment (ZARm) | -911 | | | | | | | | | | | | | | | | | | | | |
| O & M (ZARm) | | -1.50 | -1.59 | -1.69 | -1.79 | -1.89 | -2.01 | -2.13 | -2.26 | -2.39 | -2.53 | -2.69 | -2.85 | -3.02 | -3.20 | -3.39 | -3.59 | -3.81 | -4.04 | -4.28 | -4.54 |
| Cashflow (ZARm) | -911 | 129 | 140 | 152 | 165 | 178 | 193 | 209 | 226 | 245 | 265 | 287 | 311 | 337 | 365 | 395 | 428 | 463 | 502 | 543 | 589 |
| Cumulative cash flow (ZARm) | -911 | -782 | -642 | -490 | -325 | -146 | 47 | 256 | 482 | 727 | 992 | 1 280 | 1 591 | 1 927 | 2 292 | 2 687 | 3 115 | 3 578 | 4 080 | 4 623 | 5 212 |
| Payback period (years) | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.76 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

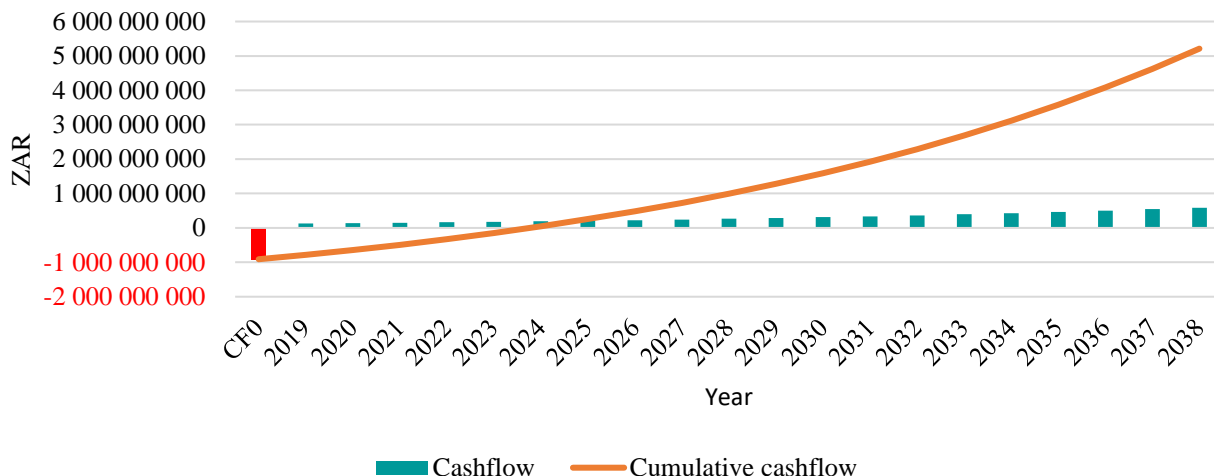| | |
|---|---|
| Discount rate | 10% |
| NPV (ZARm) | 1 025 |
| IRR | 21% |
| Payback period (years) | 5.76 |

**Figure 8: Cumulative cash flow projection over the 20 years.**

Figure 8 shows the adequate cumulative cash flow with the relevant payback period. The benefits from 2019 onwards recoup the cost of the investment in cumulative cash flow (CF0). The solar PV plant is effectively paid off in 2024 and results in a payback period of 5.76 years, which is relatively quick compared to other projects of this magnitude.

## 4. Key findings and recommendations

The practical simulation was conducted, and the two scenarios were tested. Scenario 1 had no amendments to the mining operation, and the effect of increased electricity tariffs coupled with carbon tax payable resulted in an exponential escalation in costs. The mining company currently spends ZAR 1 078 990 895 on electricity per annum. This amount will experience above-inflation increases in the following 20 years. The company also faces pending carbon taxes of ZAR 137 804 172 per annum, which is similarly affected by inflation increases for the next 20 years.

Based on the information of the empirical study in scenario 2, it is evident that the mining company can generate 2 439 753 MWh of clean energy over 20 years with an investment of ZAR 910 857 920 in solar energy. Implementing the 54 MW solar PV plant could result in a 10% saving in electricity costs coupled with an 11% saving in carbon tax payable over the 20 years. The simulation yielded positive results such as an IRR of 21%, a positive NPV, and a payback period of less than six years.

The company should consider the solar investment as an offset to imminent electricity cost increases and carbon taxes. The movement to clean renewable sources of energy will also benefit the mining organisation, as it reinforces their commitment to protect the environment by reducing GHG emissions and operating more sustainably. Moreover, its social commitment could be enhanced by employing new staff to install and maintain the plant. It will receive the additional benefit of having a reliable source of electricity, which could increase production, as the solar PV plant is based on renewable energy sources rather than the burning of fossil fuels.

## Author roles

*S.S.S. Barnard:* Conceptualised the study, conducted the case study, collected and analysed data, and drafted the manuscript.
*A.M. Smit:* Supervised the first author in undertaking the research, conceptualisation, verified results, and reviewed the text.
*S.L. Middelberg:* Drafting and development of the paper, literature review, materials and methods, and reviewed the text.
*M.J. Botha:* Drafting and development of the paper, technical correctness, provided abstract and conclusion, and reviewed the text.

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