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Economic viability of a residential building integrated photovoltaic generator in South Africa

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Abstract
A photovoltaic (PV) generator was integrated onto the north facing roof of an energy efficient house in South Africa. The building integrated photovoltaic generator (BIPV) supplies power to the household loads and the grid and is also the roof façade. This paper presents an economic evaluation of the viability of the BIPV system using methods of investment analysis. The capital cost and life cycle cost of energy were found to be ZAR 52 631-58/kW_p and ZAR 1-94/kWh respectively. The payback period was 8 years and adjusted internal rate of return 9.3%. Parametric sensitivity analysis revealed that a 50% decrease in module price results in a 29% reduction in life cycle cost of energy and more than 50% reduction in payback period.

Keywords: Building integrated photovoltaics; Discounting; Net present value; Payback period; Life cycle cost.

1. Introduction
Photovoltaics is becoming increasingly visible in the world's electricity market. Traditionally, electricity supply for residential buildings has been a preserve of utility companies. Of late, PV installations are being installed on surfaces of buildings allowing the possibility to combine electrical energy production with other functions of the building structure [1]. The creative and practical use of PV by integrating it onto a building structure is called building integrated photovoltaics.
Building integrated photovoltaic systems provide an environmentally friendly solution for displacing utility power supply in existing or new buildings at places with or without electrical grids. The attractiveness of BIPV is that electricity is generated at the point of use and therefore transmission and distribution losses are avoided leading to lower utility company's capital and maintenance costs [2]. Furthermore, no additional land and mounting structures are required. Other benefits include energy cost savings, revenue from sale of electrical power, reduction in environmental emissions, tax credits and rebates, and other qualitative benefits such as improved building aesthetics [3].
In developed countries, buildings account for up to 40% of overall energy consumption and contribute about 33% of total greenhouse gas emissions [4, 5]. Energy use by nations with emerging economies is set to grow at annual average of 3.2% and is projected to match that of developed countries whose growth rate is 1.1% by 2020 [6]. Increasing energy consumption in the building sector has compelled the PV industry to focus on grid connected BIPV products. Previous research has revealed strong correlations between peak PV power generation and peak demand, particularly in sunny climates in

which air conditioning loads dominate [7-9]. This creates opportunities for demand side management strategies such as peak load shedding. Following the merits of building integration, more countries are setting targets and legislating for the use of photovoltaics in the building sector.

Solar radiation levels in South Africa are amongst the highest in the world. Annual solar radiation averages 220W/m^2, compared with about 150W/m^2 for the USA and 100W/m^2 for Europe. Most of the interior parts of the country receive average insolation in excess of 5kWh/m^2/day with some parts of the Northern Cape Province averaging over 6kWh/m^2/day [10, 11]. Despite this, BIPV has been used more extensively in Europe than in Africa, with Japan, USA and China entering the market recently. The PV market has not grown to expected levels in South Africa other than a few rural or far off-grid solar home system applications.

In an effort to increase the penetration of renewable energy technologies into the mainstream economy, the South African Government published its White Paper on Renewable Energy which set out the objective of achieving 10,000GWh of renewable energy contribution to final energy consumption by 2013 over and above the current levels [11]. This amounts to approximately 3% of projected energy demand. Grid connected electrical power from renewable energy sources is also expected to increase following recent legislative and regulatory guidelines such as the Renewable energy Feed-In Tariff (REFIT) of 2009 and the Integrated Resource Plan (IRP) of 2010 [12]. The IRP2010 envisages a renewable energy contribution of 16.5% to the country’s electricity consumption by 2030 [13]. However, the level of implementation has been low and this has largely been ascribed to the absence of an implementation plan and high initial costs.

Given the limited or nonexistent experience of BIPV implementation in South Africa, the Fort Hare Institute of Technology designed and constructed an energy efficient building integrated photovoltaic (EEBIPV) house at the University of Fort Hare, Alice campus. The University is located latitude 32.8° south and longitude 26.8° east, at an altitude of 540m. The aim of this paper is to evaluate the economic viability of BIPV in residential housing in South Africa. Investment appraisal techniques were applied to a 3.8kW BIPV generator installed onto the north facing roof of an energy efficient solar house.

2. Methods of investment appraisal

The BIPV generator was considered to be an investment in which financial resources are put into productive use. Economic appraisal was used to determine whether the investment is beneficial or not. Investment appraisal tools used in this study are the net present value (NPV), discounted payback period (DPBP), the benefits-to-cost ratio (B/C), adjusted internal rate of return (AIRR) and life cycle cost analysis (LCC). In order to determine the financial viability of the BIPV system, the time stream of costs and benefits was transformed to its present value by discounting. Cash flows were discounted because of the ‘time value of money’ concept. The discounting factor (*DF)* is given by [14]:

$$DF = \frac{1}{(1+r)^n} \tag{1}$$

where r is the market discount rate (%), and n is the period (years).

In an economy with inflation f and nominal interest rate i, the market discount rate r is given by:

$$r = \frac{(i-f)}{(1+f)} \tag{2}$$

The economic appraisal indices were determined after the present value of costs and benefits had been computed.

2.1 Net present value

NPV is one of the most wide-spread and commonly accepted measures of financial project performance. It is the difference of the present value of cash inflows and outflows [15]. The BIPV net present value was computed using the relation:

$$NPV = \sum_{n=0}^{N} \frac{K_{in} - K_{out}}{(1+r)^n} \tag{3}$$

where K_{in} is the cash inflow in the n^{th} year, and K_{out} is the cash outflow in the n^{th} year.

The NPV is expressed in monetary terms and is useful in expressing both absolute and relative project attractiveness. For the year the project was implemented, cash inflow was taken to be zero while cash outflow was the initial capital investment.

2.2 Payback period

Payback period is the length of time necessary for project cash flows to refinance the initial investment. DPBP accounts for the time value of money by discounting net cash flows of each period before summing them up and comparing them with initial investment. It was deduced from:

$$\frac{(K_{in} - K_{out})_1}{(1+r)} + \frac{(K_{in} - K_{out})_2}{(1+r)^2} + - - - + \frac{(K_{in} - K_{out})}{(1+r)^n} = \sum_{n} \frac{(K_{in} - K_{out})_n}{(1+r)^n} \geq K_{oo} \tag{4}$$

where K_{oo} is the initial investment.

Unlike the NPV calculations, payback period calculations begin at year one not year zero and shorter DPBP are usually favorable.

2.3 The adjusted internal rate of return

The adjusted internal rate of return is a discounted cash flow technique that measures the annual yield from a project, taking into account reinvestment of interim receipts at a specified rate. In this methodology, estimating project cost effectiveness involves comparisons of computed AIRR with the investor's minimum acceptable rate of return (MARR). In this case, the MARR is the interest cost of capital given in table 1. The internal rate of return may be computed by setting NPV = 0, then solving for *r*. The AIRR was computed from the relation [16]:

$$AIRR = \left(\frac{TV}{PVI}\right)^{\frac{1}{n}} - 1 \tag{5}$$

where *TV* is the terminal value of all cash flows (except investment costs), and *PVI* is the present value of investment costs.

2.4 Benefit-to-cost ratio

BIPV positive cash flows (benefits of project) and the negative cash flows (cost of project) were discounted and summed separately. The benefits-to-cost ratio (B/C) was computed from the equation:

$$B/C = \frac{PV_{k_{in}}}{PV_{k_{out}}} = \frac{\sum_{n} \frac{K_{in}}{(1+r)^n}}{\sum_{n} \frac{K_{out}}{(1+r)^n}} \tag{6}$$

This evaluation criterion is also known as savings-to-investment ratio (SIR).

2.5 Life cycle cost analysis

Life cycle cost takes into account only the cost items of a project over the duration of the project. The LCC of the building integrated photovoltaic solar system consists of the initial investment cost (K_{oo}), the present value of operation and maintenance costs (OM_{pv}) and the present value of balance of system replacement costs ($BOSR_{pv}$) and the salvage value (*SV*) such that:

$$LCC = K_{oo} + OM_{pv} + BOSR_{pv} - SV_{pv} \tag{7}$$

i) The initial capital investment of *BIPV* system is the sum of costs of the *BIPV* generator, balance of system components, battery bank, cabling, installation and procurement costs.
ii) The *OM* costs include annual maintenance of system and recurring costs. Kolhe and Josh [17] suggested that the OM_{pv} be calculated as:

$$OM_{pv} = OM_o \cdot \left(\frac{1+i}{r-i}\right) \cdot \left[1 - \left(\frac{1+i}{1+r}\right)^n\right] \text{for } r \neq i \tag{8}$$

and

$$OM_{pv} = OM_o \cdot n \quad \text{for } r = i \tag{9}$$

where $OM_o = m \cdot K_{oo}$ and *m* being a percentage of the initial capital cost.

The useful life of a photovoltaic module is in the range 20-30 years, but 20 years was chosen for this analysis since it is the period the PV modules are guaranteed by the supplier.
iii) The battery bank (*BB)*, the charge controller (*CC)* and inverter (*INV)* were the *BOS* components replaced without salvage value every 5, 5 and 10 years respectively. The replacement cost is given as [18]:

$$Replacement\ \ cost = \sum \left[Item\ \ cost \cdot \left(1 + \left(\frac{1+i}{1+r}\right)^{Ry}\right)\right] \tag{10}$$

where *Item cost* refers to cost of battery, inverter or charge controller, and *Ry* is the replacement year.

The life cycle cost of energy is then given by:

$$LCC(ZAR/kWh) = \frac{K_{oo} + OM_{pv} + BOSR_{pv} - SV_{pv}}{365 \cdot n \cdot E_d} \tag{11}$$

where *n* is the life-cycle period in years, and E_d is the daily output of the system.

LCC analysis is usually used to compare energy costs of energy sources with different cost structures. In this case, it was also useful in the determination of the break even price of the BIPV generator by computing the levelized cost of energy (LCOE) as:

$$LCOE = LCC(ZAR/kWh) \cdot CRF \tag{12}$$

where *CRF* is the cost recovery factor given by:

$$CRF = \frac{r}{1-(1+r)^{-n}} \tag{13}$$

The LCOE gave us the expected break even price of electricity from the BIPV system taking into account the prevailing inflation and interest rates.

3. Materials and methods

The BIPV generator consists of 20 modules arranged in two arrays, one on the eastern and the other on the western side of the north facing roof as shown in Figure 1.

Figure 1. BIPV panels on north facing roof

Each module is rated 190W at standard test conditions (Irradiance 1000W/m^2, Air mass 1.5 and ambient temperature 25°C). The modules were connected to a 48V_{DC} x 408Ah battery bank, a charge controller and 5kW inverter. A full description of how the BIPV panels were connected is given in [19].

3.1 Parameters used in economic evaluation

Investment appraisal indices discussed in section 2 were calculated using a spreadsheet package. The discount rate was used instead of the nominal interest rate. The discount rate was adjusted to remove the effects of expected or actual inflation using equation (2). The market rates used and the base-case cost of the BIPV components are listed in Table 1. Nominal interest and inflation rates were obtained from Statistics South Africa [20].

Table 1. Economic factors and cost of components for base-case scenario

Economic factor and component	**Value**
Nominal interest rate, *i*	7.0%
Inflation, *f*	6.3%
Electricity escalation rate, *ee*	i) 24.9% (First three years starting 2009) ii) Equal to prevailing inflation thereafter
PV feed-in tariff	ZAR 3-94/kWh
Electricity cost	ZAR 0-74/kWh (For middle-to-upper income households
PV array cost	ZAR 43-00/W_p
Battery cost	ZAR 0-91/kWh
Operation and maintenance cost	1% of BIPV system capital cost
Cost of 5 kW battery charge controller	ZAR 1 100-00/kW
Cost of 5 kW grid connect Inverter	ZAR 7 000-00/kW
Avoided mounting rake cost	ZAR 1 300-00/kW
Miscellaneous costs (connectors, wires, transport, installation, etc)	ZAR 3 000-00/kW

*ZAR is South African Rand quoted at about US$ 1-00 = ZAR 8-00, December 2008.

Most of the components of the BIPV system were imported thus increasing the transport and insurance costs of the system.

4. Results and discussion

4.1 Economic appraisal outcomes

Economic appraisal indices were calculated using the methodology explained in section 2 and data in table 1. The BIPV system cost per unit rated capacity was found to be ZAR 52 631-58/kW$_p$ [equivalent to about US$ 6 500-00/kW$_p$ in 2009]. The Installed price compares well with reported values in the range US$ 3-00 to 24-00/W$_p$ [21-23]. The major contributor to the initial investment was the cost of solar modules at ZAR 43-00/W$_p$ followed by the bidirectional grid-tie inverter. These components were procured at market prices from outside South Africa thereby increasing the overall system cost. BIPV modules were mounted on north facing roof trusses instead of normal metal racks. This was a welcome avoided cost since neither metal racks nor north facing roofing tiles were required. The avoided cost was taken to be a benefit in year zero during economic appraisal computations.

Using equation (4) and basing on annual energy output for 2009, the discounted payback period for the system was found to be 8 years. This is the time it takes for the BIPV system to recover its initial capital cost from income and savings generated from Feed-in tariffs and energy supplied to household loads respectively. Eight years might seem like a long period for a home owner waiting for positive cash flow. However, the PV modules are typically guaranteed to last for at least 20 years at 20% maximum power derating. This assures the energy efficient solar house a minimum 12 years of free environmentally clean electricity. In addition, the computed DPBP excludes potential income from investment tax and carbon credits. Since the DPBP is not usually used as a primary but as a secondary indicator of the level of risk of an investment, other investment appraisal indices were also investigated.

The true interest yield indicated by the AIRR of the BIPV generator over its guaranteed lifetime was found to be 9.3%. The investment minimum acceptable rate of return was taken to be the maximum nominal interest rate charged by local commercial banks of 7% in 2009. The project is considered attractive and acceptable since the AIRR is greater than the MARR.

Unlike the DPBP and AIRR which do not show the magnitude of positive or negative cash flows, the projected NPV of the BIPV system in year 20 was found to be ZAR 168 265-89. During NPV analysis, the present value of cash inflows were compared to present value of cash outflows. The positive NPV value indicates that the BIPV project is feasible. In addition, the benefits-to-cost ratio of the BIPV system was found to be greater than one. A B/C ratio less than unit, calculated over the project lifespan is considered unattractive and vice-versa.

The LCC method considers the initial costs and all other future costs and discounts them to their present value. The salvage value of the system was taken to be 20% of the initial cost of the BIPV generator. Maintenance costs were set at 1% of the BIPV capital cost per annum. Using equation (11) the LCC of the BIPV generator was found to be ZAR 1-94/kWh. At a retail module price of ZAR43-00/W$_p$ [about US$5-00/W$_p$], the PV modules were the major contributor to the high LCC value (see Figure 2). As of 2010, low-cost PV cells' manufacturing cost had broken the US$1-00/W$_p$ barrier hence providing an opportunity to reduce the cost of PV modules significantly [24]. The LCC price was also significantly increased by the cost of the grid connect inverter and battery bank. This is supported by the research findings of Ren, Gao and Ruan [25] who reported that annual cost-savings ratio is maximum at PV capacity of about 1kW and starts decreasing thereafter due to increased costs of balance of system components. Figure 2 shows the life cycle cost breakdown of BIPV generator components.

The levelized cost of energy, useful in determining the break even price of the BIPV system, was found to be ZAR 0-98/kWh. The average utility supply price (covering low to high income residential tariffs) paid by consumers in the domestic sector in South Africa was ZAR 0-41/kWh in 2009. Users of electricity residing in low income households may not be willing and cannot afford to pay such high prices of BIPV electricity. Financial incentives or grants in the form of subsidies from the central government are suggested in order to promote and increase the penetration of PV in the residential sector.

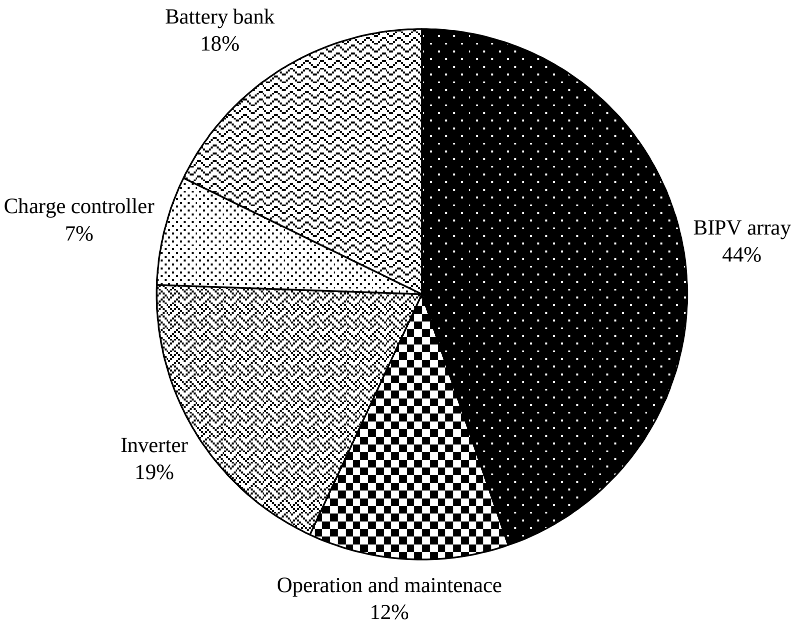

Figure 2. Life cycle cost break down of BIPV system components

4.2 Sensitivity analysis

Global or parametric sensitivity analysis can be used to characterize a renewable energy investment. In global analysis, the goal is to characterize the relationships among model inputs and outputs over a wide range of input conditions. In contrast, parametric sensitivity analysis also known as local sensitivity analysis is used to evaluate the response to a change in a single input, holding all other inputs constant [26]. Parametric sensitivity analysis, in which one input is perturbed while others are held constant, was found useful in characterizing incremental responses to changes in inputs from a reference case. Parametric analysis was used because it is easier to compute and interpret.

Balance of system component prices were individually and sequentially varied by a factor of ±20% with respect to their true price. The base case was taken to be the LCC of the BIPV system calculated using inputs listed in Table 1. By repeating LCC computations basing on the new input values, different BIPV life cycle costs of energy were predicted. Figure 3 shows a spider diagram of the new LCC prices. The base case is the point of intersection of all curves.

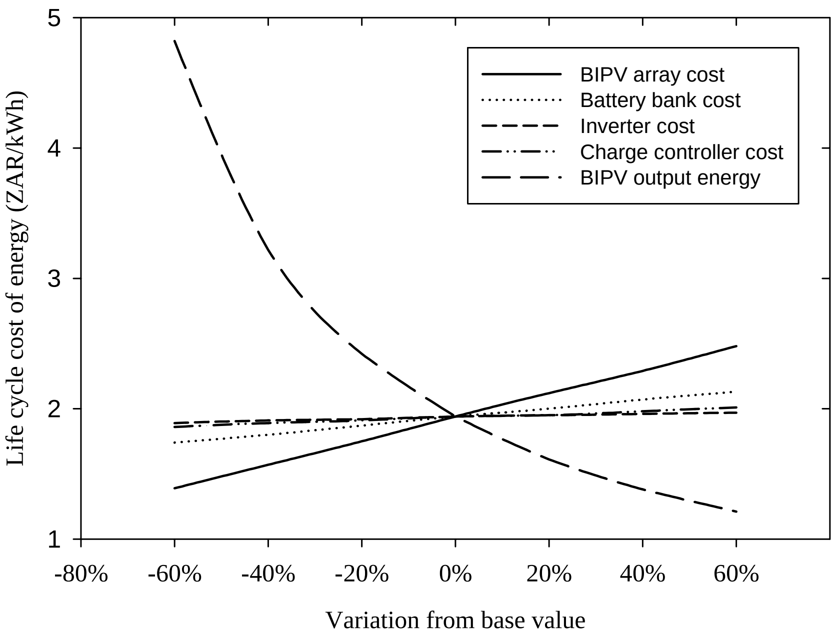

Figure 3. Spider diagram of LCC sensitivity analysis

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The calculated sensitivity LCC values give information regarding the influence of individual parameters to the system output behavior. The magnitude of the sensitivities thus indicates the degree of importance of each input. Profiles in Figure 3 suggest that the life cycle cost of energy is more sensitive to changes in BIPV generator output energy followed by changes in BIPV price. Consequently, the system has to be properly optimized for peak energy output so as to lower the life cycle cost of energy. Design and simulation of the BIPV system was done before system installation in order to minimize mismatch and shading losses that lower energy output. Obstructive materials such as leaves, dirty and other aerosol particles that tend to accumulate on the modules were periodically removed.
The impact of BIPV array price on LCC and DPBP was also investigated. For every 20% change in BIPV array price, the LCC and DPBP were calculated. Variations in BIPV array capital cost were observed to significantly affect life cycle cost of energy more than other BOS components. Figure 4 illustrates the impact of BIPV module price on the payback period. Positive percentage price changes imply an increase in price of PV modules and vice-versa.

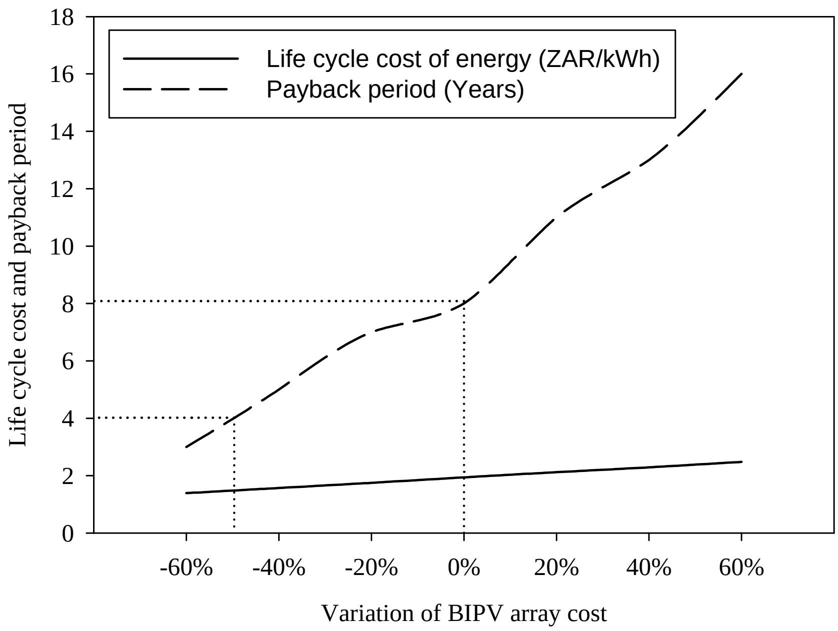

Figure 4. Decrease in payback period with BIPV price

Higher life cycle costs of energy are synonymous with higher payback periods. With reference to Figure 4, a 50% decrease in BIPV module price induces a 29% decrease in life cycle cost and more than 50% decrease in payback period. It has been reported that the price of PV modules reduces by 20% each time the PV market doubles and that the price has been decreasing by at least 50% every decade [27]. It is not known how long this PV price downward spiral will continue, but the trend is certainly making the DPBP of building integrated photovoltaics attractive and competitive.

5. Conclusion

Aiming to quantify the costs and benefits of grid-connected building integrated photovoltaics, a techno-economic assessment was carried out. The capital cost of the BIPV system was found to be ZAR 52 631-58/kW_p and the cost per square meter of roof area was ZAR10 000-00/m^2. Although these values are comparable to those reported by other authors, it is noteworthy that BIPV systems require a higher initial cost than common fossil fuel or electric systems, and most homeowners choose conventional systems for that reason. The AIRR was found to be greater than the investor minimum return rate and the benefit-to-cost ratio was greater than one, indicating that the BIPV generator is an attractive investment.
The payback period was found to be less than the BIPV module lifespan. Given that PV modules last for at least 20years, the BIPV generator is guaranteed to supply free and environmentally clean electricity for more than 12 years. The payback period only reveals the level of risk of a project but does not indicate cash flow volumes unlike the net present value. The NPV of the BIPV system over its project lifespan is positive indicating that the project is viable.

The break even, levelized cost of BIPV supply was found to be more than twice the average price paid by domestic consumers for cheap fossil fuel generated utility electricity. Without institutional or government intervention in the form of tax credits and subsidies, consumers will find BIPV electricity more expensive. Parametric sensitivity analysis revealed that the price of BIPV modules has a smaller influence on life cycle energy cost and much greater influence on DPBP compared to the price of other balance of system components. Furthermore, sensitivity analysis showed that BIPV modules need urgent cost reduction mechanisms. Current trends of decreasing module retail prices on the international market coupled with local production of modules that commenced in 2009 is expected to further reduce life cycle energy cost and payback periods.

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