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An investigation into life-cycle costing as a comparative analysis approach of energy systems

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Abstract
Although renewable energy sources have a potentially beneficial role to play as part of South Africa's energy portfolio, the common belief is that renewable energy technology, especially solar photovoltaic (PV), is not viable for electricity production because it is too expensive compared with coal-based electricity. Statements such as these are made because the initial capital costs (procurement costs) are often used as the primary (and sometimes only) criterion for project, equipment or system selection based on a simple payback period. Due to life-cycle stages, often the real costs of the project or equipment, either to the decision maker or the cost bearer, are not reflected by the upfront capital costs. In this paper, the life-cycle costing approach is investigated as a means to improve decision making on the economic viability of energy systems. The investigation is based on a comparative analysis of decentralised residential solar power systems (RSPS) and centralised coal-fired electricity-generation systems. The case study demonstrates the ineffectiveness of the conventional (cost) analysis approaches.

Keywords: Economic viability, life-cycle costing (LCC), net present value (NPV), renewable energy

Note: The abbreviation PV is used in this paper to refer to both photovoltaic(s) and present value. However, a clear distinction regarding the intended meaning is made whenever it is used.

1. Introduction

"In order to make sensible decisions about energy policy, policy makers need to be able to compare the costs and benefits of different types of electricity-generating technologies on a like-for-like basis" (Parsons Brinckerhoff (PB) Power, 2006). Therefore, the objective of this paper is to demonstrate that a life-cycle approach rather than the more traditional once-off capital cost approach improves decision making on the economic viability of different types of electricity-generating technologies. The traditional once-off capital cost approach refers to the payback method of economic analysis. The payback method generally focuses on how quickly the initial investment can be recovered, and as such is not a measure of long-term economic performance or profitability (Fuller and Peterson, 1995). The payback method typically ignores all costs and savings occurring after the point in time in which payback is reached. It also does not differentiate between project alternatives having different lives, and it often uses an arbitrary payback threshold (Fuller and Peterson, 1995). Moreover, the simple payback method, which is commonly used, ignores the time-value of money when comparing the future stream of savings against the initial investment cost.

Due to life-cycle stages, often the real costs of the project or equipment, either to the decision maker or the cost bearer, are not reflected by the upfront once-off capital costs. The life-cycle costing approach is investigated as a means to improve decision making on the economic viability of energy systems. The investigation is based on the comparative analysis of decentralised residential solar power systems (RSPS), referred to here as Lynedoch RSPS, and centralised coal-fired electricity-generation systems, simply referred to here as Maluti coal-fired power station.

2 Life-cycle approaches: guiding principles

According to Burger and Swilling (2009), several life-cycle methodologies are used in response to the global demand for tools to determine the material and energy content of particular production and consumption processes, as well as environmental impacts. Burger and Swilling argue that a life-cycle approach is necessary because it has become imperative to take into account the full capital and operational costs of a given production or consumption process over the life-cycle of the process (Burger and Swilling, 2009). They further argue that without this kind of analysis it will not be possible at the design stage to determine which process will contribute most towards achieving a more sustainable socio-ecological regime, or alternatively, which one will do the least damage.

Burger and Swilling maintain that cost-effectiveness analysis (CEA) and/or life-cycle cost analysis (LCCA) is a technique for investment appraisal prescribed in the South African National Treasury directives (Burger and Swilling, 2009). The National Treasury expresses the following intention:

> "It is the intention of the National Treasury to progressively require more detailed analyses as funding requests are becoming larger compared to available resources. Under these circumstances it is appropriate to prioritise requests which can demonstrate the largest benefits to our country."

Since the 2007 Medium Term Expenditure Framework (MTEF), all new infrastructure projects or programmes require some form of appraisal to demonstrate advanced planning. Such appraisal may include needs analyses, options analyses, cost-benefit analyses, life-cycle cost analyses and affordability analyses (Burger and Swilling, 2009). Burger and Swilling maintain that CEA and/or LCCA was identified by the National Treasury as a tool that can help to ensure efficient use of investment resources in sectors where it is difficult to value benefits in monetary terms (Burger and Swilling, 2009). LCCA was specifically identified as useful for the selection of alternative projects with the same objective (quantified in physical terms), and it is most commonly used in the evaluation of social projects, e.g. in the health and education sectors (Burger and Swilling, 2009). It is therefore appropriate to use life-cycle cost analysis (LCCA) in this paper to evaluate the long-term cost of the socio-economic and environmental sustainability of Medupi coal-fired power station and Lynedoch RSPS.

3 Life-cycle cost analysis (LCCA) – a brief background

Life-cycle cost analysis (LCCA) is a method for assessing the total cost of system/facility or equipment ownership. It takes into account all costs of acquiring, operating, maintaining and disposing of a system (Barringer, 2003; Fuller, 2008; Hunkeler et al., 2008). Often the purchase price or initial cost does not reflect the real cost, either to the decision maker or cost bearer. This is due to the life-cycle stages, up and downstream from purchasing to production, contributing to the cost of ownership (Hunkeler et al., 2008). Many purchase and investment choices incur a stream of future costs that are sometimes difficult to identify and estimate (Hunkeler et al., 2010). People are inherently biased to pay more attention to the immediate and proximate concerns. The slow consumer acceptance of compact fluorescent lights (CFL), despite their higher energy efficiency and reduced operating costs, is but one example of this bias (Hunkeler et al., 2010). Ignoring these future costs can be expensive. It has been estimated that between 50 and 80% of the total life-cycle cost of a commercial building (depending on the assumed time cost of money) can be attributed to the operation, maintenance and retrofitting of the building over a life of 40 to 50 years (Ciroth et al., 2008).

Government and industry specialists have developed LCC methodologies as a stand-alone analysis to understand the cost drivers of a product system in order to identify improvement options and validate the pricing strategy (Hunkeler et al., 2010). Drivers for organisations and companies to carry out LCC include prioritising projects, projecting accruals for product recovery, evaluating customer costs and legal requirements, assessing the competitiveness of their own product, and detecting their own hidden costs and financial risks (Hunkeler et al., 2010). LCC is employed by customers and customer organisations to make product comparisons with the information provided by the producer, certifying bodies or NGOs. Although LCC is well integrated in some industry sectors, for example power plants and railway carriages, its use in practical decision making is limited (Cole and Sterner, 2000; Lindholm and Suomala, 2005). Integration of environmental and social impacts in cost studies is even less well developed, as evidenced by the recent financial crisis. Financial companies promoted subprime and reverse amortisation mortgages that yielded short-term profits and bankrupted their customers (Hunkeler et al., 2010). Vehicle manufacturers harvested short-term profits from fuel guzzling SUVs until environmental concerns for climate change and peak oil combined with the financial crisis pushed the companies into bankruptcy courts (Hunkeler et al., 2010). While LCC has been demonstrated to be a suitable tool to support business decisions, sensitivity to study assumptions, such as the discount rate, uncertainties associated with long time horizons and the modelling of complex natural systems pose barriers to broader acceptance (Hunkeler et al., 2010).

Overall, the reasons for doing LCC are no different from those for any other business process: to identify where the company can achieve a long-term competitive advantage. According to Fuller, in addition to LCC, there are other measures of economic evaluation, such as savings-to-investment ratio, internal rate of return and payback period, which can be used to determine cost-effectiveness (Fuller, 2008). But LCC is especially useful when project alternatives that fulfil the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximises net savings (Fuller, 2008). Table 1 shows examples of life-cycle costing in industry.

Table 1: Reasons for carrying out life-cycle costing

Reasons	Product category	Organisation
Procurement	Durables	Dept of Defence (USA)
Setting R&D priorities	Durables	United Technologies (USA)
Process improvement	Materials	Alcan (Canada)
Cost of ownership assessment	Durable products	Ford (Germany)
Reliability analysis	Energy	EDF (France)
Intergenerational justice	Nuclear energy	EDF (France)
Maintenance analysis	Transportation products	DB (Germany)
Tenders	Municipal services	Halton (Canada)
Sales support	Service (water)	AQUA+TECH (CH)
Environmental product declarations	Semi-durables – food	ABB (I) Fontis (New Zealand)
Equipment upgrade vs. replacement	Paper	Kemira (FI)
Tax planning	Estimating CO_2 taxes	EU
Board communication	Chemicals	BASF (Germany)
NGO purchasing recommendations	Durables	Oko-Institut (Germany)

Source: Hunkeler et al. (2010)

4 Research methodology

According to Yin (2009: 4), there is no formula for knowing which research method to use; the choice depends largely on the research questions. When to use which method depends on three conditions: (a) the type of research question posed; (b) the extent of control a researcher has over actual behavioural events; and (c) the degree of focus on contemporary as opposed to historical events (see Table 2).

Table 2: Relevant situations for different research methods

	(a)	(b)	(c)
METHOD	**Form of research question**	**Requires control of behavioural events?**	**Focuses on contemporary events?**
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival analysis	Who, what, where, how many, how much?	No	Yes/No
History	How, why?	No	No
Case study	How, why?	No	Yes

Source: Yin (2009)

Yin (2009: 9) asserts that if research questions focus mainly on ‘what’ questions, one of two possibilities arises. Firstly, some type of ‘what’ questions are exploratory, such as the following: “To what extent can the LCC method improve decision making on the economic viability of energy systems?” This question justifies conducting an exploratory study, the goal being to “develop pertinent hypotheses and propositions for further inquiry” (Yin, 2009: 9). According to Yin (2009), any of the five research methods in Table 2 can be used for an exploratory study.

As discussed in the introduction, this paper investigates the comparative analysis of decentralised residential solar power systems (RSPS), referred to here as Lynedoch RSPS, and centralised coal-fired electricity-generation systems, simply referred to here as Maluti coal-fired power station. The

Lynedoch RSPS comprises a solar water heater (SWH) and a solar PV roof tile system (5 kW) of relatively small size that would reduce electrical demand of an average South African household to an absolute minimum. The aim is to use the operational results from the 5 kW PV roof tile experiment at Lynedoch as a basis for developing a life-cycle costing model of a Lynedoch RSPS. The focus of the LCC model is on operating costs over 40 years. The results are compared with the life-cycle costs of Maluti coal-fired power plant.

Exploratory research such as this attempt to achieve the following:

- Test the feasibility of undertaking an extensive study.
- Satisfy the curiosity of the researcher and the desire for better understanding.
- Develop methods to be employed in any subsequent study.
- Determine priorities for future research.
- Develop new hypotheses about an existing phenomenon.

The unit of analysis is Lynedoch Eco-village,[1] founded by Eve Annecke (Director of the Sustainability Institute). It "is the first ecologically designed socially mixed community", and is situated in Stellenbosch near Cape Town, South Africa. At Lynedoch, where the Sustainability Institute is located, a new crèche for local children has been equipped with a solar PV roof tile system and SWH. This system was sized to provide power that would offset some of the household electrical load. The crèche is an old building that was designed to conform to the usual energy-consumption patterns, with no particular orientation towards ecological design. The solar PV roof tile system is grid interactive, producing direct current (DC) that is converted to alternating current (AC) and then fed directly into the local electricity-distribution system.

5 Sensitivities

5.1 The costs

There are numerous costs associated with acquiring, operating, maintaining and disposing of or decommissioning a facility/system and/or equipment. According to various authors (Barringer, 2003; Fuller, 2008; Hunkeler et al., 2008; Hunkeler et al., 2010), these costs fall into the following categories:

- **Initial costs – purchase, acquisition and construction costs**

Initial costs may include capital investment costs for land acquisition, construction or renovation and for the equipment needed to operate a facility (e.g. a power station). The capital costs are sensitive to site requirements, duration of construction (affecting interest on capital incurred during the construction period), price variations due to equipment supply and demand in the market, and many others. In this paper capital cost sensitivity analysis was not carried out as the actual capital costs used in this analysis are those already incurred by Maluti coal-fired power plant and Lynedoch RSPS.

- **Fuel costs – energy, water and other costs**

According to Fuller (2008), the operational expenses for energy, water and other utilities are based on consumption, current rates and price projections. Energy prices are assumed to increase or decrease at a rate similar to general price inflation. The energy price escalation needs to be considered when estimating future energy costs. Water costs should be handled much like energy costs.

In this paper volatile coal prices that are dependent on global markets have been identified as uncertain input values that may have the greatest impact on the life-cycle cost (LCC) of Maluti coal-fired power plant based on 2009 data. The fact that coal prices had increased by 30% in the 2007/2008 financial year, according to the former Chief Financial Officer of Eskom (*Engineering News*, 2009), makes the coal price a critical parameter in LCCA. The short-term contracts that Eskom has to negotiate to keep up with the country's growing electricity demand and the fact that Eskom's long-term coal suppliers are increasingly attracted to the more lucrative export markets make coal price a very uncertain input value. The export coal price for first-grade coal peaked at above US$100/ton[2] in 2008. So, the upper bound of coal price for the poor-quality coal used by Eskom in the next 40 years should be at least US$50/ton (R369.50/ton at an exchange rate of R7.39/US$ on

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[1] Refer to http://www.sustainabilityinstitute.net/lynedoch-ecovillage for more information.

[2] Refer to: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1

16 September 2009). The lower bound should be R90/ton of coal that Eskom pays its tied collieries based on their long-term agreements for coal supply.

- **Operation, maintenance and repair costs**

Operation, maintenance and repair (OM&R) costs are often more difficult to estimate than other costs. Fuller (2008) argues that operating schedules and standards of maintenance vary from one project alternative to the other. It is therefore important to use expert judgement when estimating these costs, which include the costs of long-term service agreements, routine maintenance and consumables.

- **Replacement costs**

The number and timing of capital replacements of a solar power rooftop system depend on the estimated life of the system. Both SWH and PV roof tile systems have an estimated life-span of 25 years and provision is made for a replacement after 25 years. It is recommended that the same sources that provide cost estimates for initial investments are used to obtain estimates of replacement costs and expected useful lives. Barringer and Fuller maintain that a good starting point for estimating future replacement costs is to use their (replacement) cost from the base year (Barringer, 2003; Fuller, 2008). The LCCA method will escalate base-year amounts to their future time of occurrence.

- **Residual values – resale or salvage values or disposal or decommissioning costs**

The residual value of a system (or component) is its remaining value at the end of its life/study period, or at the time of its replacement during the study period. Fuller (2008) argues that, as a rule of thumb, the residual value of a system with remaining useful life can be calculated by linearly prorating its initial costs. For example, for a solar water heater with an expected useful life of 25 years, which was installed 10 years before the end of the study period, the residual value would be approximately [(25-10)/25] = 3/5 or 60% of its initial cost.

The cost items and cost details of Maluti coal-fired power plant and Lynedoch RSPS are presented in Table 3 and Table 4 respectively, with the actual cost details. The calculations use generic assumptions for the main technical and economic parameters, such as an economic lifetime of 40 years, an average capacity factor of 90% for base-load coal-fired power plant, and a discount rate of 9%. For an RSPS, the economic lifetime is 25 years, the average capacity factor is 23% (using South African average radiation levels of 5.5 kWh/kW/day), and the discount rate is 9%.

Table 3: Cost items and details of Maluti coal-fired power plant

MALUTI COAL-FIRED POWER PLANT		
Capacity: 4 800 MW **Capacity factor: 90%** **Annual generation: 37 843 200 000 kWh**		
Initial costs:[3]	Plant costs	R100 000 000 000
	Transmission costs	R2 000 000 000
	Fixed annual costs (R6/kW)	R28 800 000
	Other direct costs (10% of EPC)	R10 000 000 000
	Total initial costs	R112 028 800 000
Coal costs:[4]	Annual coal consumption	14 600 000 tonnes
	Coal costs	R175/tonne
	Annual coal costs	R2 555 000 000
Water costs:[5]	Water consumption	1.35 L/kWh
	Annual water consumption	51 088 320 kL
	Water costs	R7/kL

[3] Accessed from: http://www.engineeringnews.co.za/article/medupi-cost-escalates-to-r120-billion-eskom-2009-07-20

[4] Accessed from: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1

[5] Accessed from: http://www.eskom.co.za/aanreport09/ar (9/9/2009)

	Annual water costs	R357 618 240
Sorbent costs:[6]	Sorbent consumption	0.05tonne/tonne of coal
	Annual sorbent consumption	730 000 tonnes
	Sorbent costs	R125/tonne
	Annual sorbent costs	R91 250 000
O&M costs:[7]	Variable O&M costs	R1.50/MWh
	Annual variable O&M costs	R56 764 800
	Fixed O&M costs	R100/kW/year
	Annual fixed O&M costs	R480 000 000
	Total annual O&M costs	R536 764 800
Carbon costs:[8]	Carbon tax	R0.02/kWh
	Annual carbon costs	R756 864 000
	Coal carbon emission factor	1.2 kg CO_2/kWh
	Annual carbon emissions	45 411 840 tonnes CO_2

Table 4: Cost items and details of a Lynedoch RSPS (PV roof tile and SWH) including the cost of the reinforced roof

LYNEDOCH RSPS (PV roof tile and SWH)		
PV system size: 5 kW **Capacity factor:** 23% **SWH system size:** 300 litre SWH **Solar radiation (SA annual average):** 5.5 kWh/kW/day **Annual solar PV production:** 10 038 kWh (calculated) **Annual SWH energy savings:** 3 600 kWh (based on 40% monthly electricity savings)		
Initial costs:	PV system costs	R343 979.99
	PV system replacement costs (discounted at 9%)	R201 827.91
	Project management	R6 000
	Design	R2 100
	On-site visits	R4 500
	Installation	R1 800
	System commissioning	R600
	Travel	R3 500
	Additional materials	R6 485.75
	1.7 kW inverter	R20 824.60
	1.7 kW inverter replacement costs	R12 218.69
	3.3 kW inverter	R29 440.48
	3.3 kW inverter replacement costs	R17 274.00
	Web-box	R12 428.96
	Web-box replacement costs	R7 292.61
	Import and storage costs	R16 318.36
	Roof support structure	R46 396.39
	Total initial PV costs	**R732 987.74**
	SWH system costs	R13 286
	SWH replacement costs (discounted)	R7 795.47
	Generic domestic external plumbing kit	R2 500
	Pressure control valve	R495
	Geyser timer	R963
	Installation/labour costs	R2 310
	Fuel allowance costs	R125

[6] Accessed from: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1
[7] Accessed from: http://www.engineeringnews.co.za/article/eskom-to-study-how-surging-coal-price-can-be-contained-2007-11-22-1
[8] Trevor Manuel, former Minister of Finance, in his Budget Vote Speech of February 2009.

	Total initial SWH costs	**R 27 474.47**
	Combined initial PV and SWH costs	**R760 462.21**
O&M costs:	O&M costs	R1 555
Residual values:	SWH	R7 871.60
	PV roof tile	R137 592

5.2 Discount rate

According to Fuller (2008), in order to be able to add and compare cash flows that are incurred at different times during the life-cycle of a project, they have to be made time equivalent. In order to do this, the LCC method converts them to present values by discounting them to a common point in time, usually the base year. The interest rate used for discounting is a rate that reflects an investor's opportunity cost of money over time, meaning that an investor wants to achieve a return at least as high as that of his/her next-best investment. Hence, the discount rate represents the investor's minimum acceptable rate of return. Fuller (2008) argues that the discount rate for energy and water conservation projects – the real discount rate, not including the general rate of inflation – should be determined annually by the relevant stakeholders (e.g. government agencies or private entities).

According to Burger and Swilling (2009), the higher the discount rate, the smaller the weight of future costs in the net present value (NPV). These authors point out that since the majority of costs in a capital investment are incurred early in the life-cycle and the benefits are accrued over the longer term, it is advisable to use a higher discount rate in order to have a pessimistic view on future benefits. Burger and Swilling (2009) maintain that future costs should be weighted more in the NPV, meaning a lower discount rate. They argue that future costs for poor households with their lower-than-inflation increase in revenue should similarly be weighed conservatively more than present costs by means of a lower-than-social discount rate.

To avoid being accused of deliberately favouring Lynedoch RSPS with its higher capital costs and lower life-cycle operating cost over Maluti coal-fired power plant, this paper uses the 2007 National Treasury's prescribed 9% social discount rate for both alternatives. As a result no range on discount rates has been used to indicate the effect of changes in the perception of potential investors. In addition to that, the 2003 World Nuclear Association Report provides a summary of several studies carried out which compare the relative costs of generating electricity by new plants using different technologies. It is indicated that the discount rate for coal projects was 9.6% in the US in 2003 and 9.5% in 2004; 8% in the EU in 2003 and 5% in 2004; 7.5% in the UK in 2004; and 8% in Canada in 2003. The base discount rate of 9% used in this paper also reflects the balance sheet expectations of vertically integrated utilities such as Eskom.

5.3 Energy production

For a Lynedoch RSPS, the uncertain input value that may have the greatest impact on LCCA is the actual energy yield (output) which so far has been just less than half of the estimated energy yield of 10 038 kWh per annum. This is due to many factors but the most significant is the intermittent nature of the solar energy systems. Therefore, the sensitivity analysis was carried out using the range of the actual energy yield of 4 906 kWh per annum and an estimated value of 10 038 kWh per annum to provide an indication of the effect of changes in estimated energy output.

5.4 Carbon emissions

Carbon markets are subject to a number of major uncertainties at this stage, primarily that of the post-2012 Kyoto compliance period. Developed countries (Annex 1 countries) that have signed the Kyoto Protocol and some of the developing countries (Annex 3 countries), which are not obliged to sign the Kyoto Protocol, are preparing for a new global pact on climate change that will be negotiated in Mexico in December 2010, after the dismal failure of the Convention of Parties (COP) 15 in Denmark in December 2009. There is a high level of risk surrounding certified emissions reductions (CERs) since it is not known at this stage what is going to happen to global carbon markets after 2012. This means that no buyer is willing to pay for a future stream of CERs upfront and very few are willing to buy credits after 2012. There is also a cost implication associated with the Clean Development Mechanism registration process which needs to be assessed against project activity cash flow requirements. For these reasons carbon credits are treated as uncertain input values which may have significant impact on an LCC of the Lynedoch RSPS. This paper will therefore use €10/ton of CO_2e as used by the Kuyasa project in Khayelitsha, Cape Town, South Africa. The rand-euro exchange rate of R10.80/€ of 16 September 2009 is used in this paper. Therefore the price of R108/ton CO_2e is used only to indicate the effect of carbon credits on the total LCC of Lynedoch RSPS, i.e. does the presence of carbon credits in the calculation of LCC have a considerable impact on the total LCC of Lynedoch RSPS?

5.5 Exchange rates

The following exchange rates on 16 September 2009 have been used in deriving the capital, operation and maintenance, fuel and carbon costs:

- EUR:ZAR 1:10.80
- US$:ZAR 1:7.39

After identifying all costs by year and amount, and discounting them to present values, they are added to arrive at the total life-cycle costs for each alternative.

6 Comparison of electricity-generation costs

The objective of this research study was to choose the most cost-effective project alternative regarding its useful life with the least NPV cost per kWh. Table 5 shows the life-cycle costs of Maluti coal-fired power plant. Table 6 shows the life-cycle costs of Lynedoch RSPS; indicating the LCC of a PV roof tile without SWH, followed by an LCC of a combination of PV roof tile and the roof costs, and lastly an LCC of the entire Lynedoch RSPS (comprising PV roof tile and SWH systems, including the roof costs).

Table 5: Life-cycle cost of Maluti coal-fired power plant over 40 years in R/kWh

Maluti coal-fired power plant							
Year	**NPV Capex**	**NPV coal**	**NPV water**	**NPV sorbent**	**NPV O&M**	**NPV carbon**	**Total NPV**
0	R0.28	R0.00	R0.00	R0.00	R 0.00	R0.00	**R0.28**
0–5	R0.28	R0.36	R0.05	R0.01	R0.06	R0.10	**R0.87**
0–10	R0.28	R0.83	R0.12	R0.03	R0.13	R0.24	**R1.62**
0–15	R0.28	R1.44	R0.21	R0.05	R0.19	R0.41	**R2.57**
0–20	R0.28	R2.24	R0.32	R0.08	R0.25	R0.64	**R3.81**
0–25	R0.28	R3.29	R0.47	R0.11	R0.31	R0.94	**R5.40**
0–30	R0.28	R4.66	R0.67	R0.16	R0.38	R1.33	**R7.47**
0–35	R0.28	R6.44	R0.92	R0.22	R0.44	R1.84	**R10.15**
0–40	R0.28	R8.78	R1.25	R0.30	R0.50	R2.51	**R13.63**

Table 6: Life-cycle cost of Lynedoch RSPS over 40 years in R/kWh

PV (R/kWh)				PV (including roof) (R/kWh)				Lynedoch RSPS (PV and SWH including roof) (R/kWh)			
Year	**NPV Capex**	**NPV O&M**	**Total NPV**	**Year**	**NPV Capex**	**NPV O&M**	**Total NPV**	**Year**	**NPV Capex**	**NPV O&M**	**Total NPV**
0	R6.36	R0.00	**R6.36**	0	R6.79	R0.00	**R6.79**	0	R6.85	R0.00	**R6.85**
0–5	R6.36	R0.66	**R7.02**	0-5	R6.79	R0.66	**R7.45**	0-5	R6.85	R0.66	**R7.51**
0–10	R6.36	R1.27	**R7.63**	0-10	R6.79	R1.27	**R8.06**	0-10	R6.85	R1.27	**R8.12**
0–15	R6.36	R1.82	**R8.18**	0-15	R6.79	R1.82	**R8.61**	0-15	R6.85	R1.82	**R8.67**
0–20	R6.36	R2.32	**R8.68**	0-20	R6.79	R2.32	**R9.11**	0-20	R6.85	R2.32	**R9.17**
0–25	R6.36	R2.78	**R9.14**	0-25	R6.79	R2.78	**R9.57**	0-25	R6.85	R2.78	**R9.63**
0–30	R6.36	R3.20	**R9.56**	0-30	R6.79	R3.20	**R9.99**	0-30	R6.85	R3.20	**R10.05**

0–35	R6.36	R3.58	**R9.94**	0-35	R6.79	R3.58	**R10.37**	0-35	R6.85	R3.58	**R10.43**
0–40	R6.36	R3.92	**R10.28**	0-40	R6.79	R3.92	**R10.71**	0-40	R6.85	R3.92	**R10.77**

Tables 5 and 6 show that the PV roof tile (without SWH) is the most cost-effective with an LCC of R10.28/kWh, followed by the PV roof tile system, including the cost of the reinforced roof, with an LCC of R10.71/kWh, and an LCC of R10.77/kWh for the entire Lynedoch RSPS (PV roof tile and SWH, including the cost of the roof), compared with Maluti coal-fired power plant with an LCC of R13.63/kWh over a 40-year period. Overall, Lynedoch RSPS has the lowest LCC of R10.77/kWh over a period of 40 years. This means Lynedoch RSPS is the most cost-effective compared with Maluti coal-fired power plant over the same period. The LCC of Maluti coal-based electricity at R13.63/kWh is 27% higher than that of Lynedoch RSPS at R10.77/kWh. This is due to the fuel and O&M costs of operating a coal-fired power plant over 40 years. Figure 1 compares the cost-effectiveness of Maluti coal-based electricity (represented just as coal) and electricity generated by Lynedoch RSPS (represented as PV, SWH + Roof).

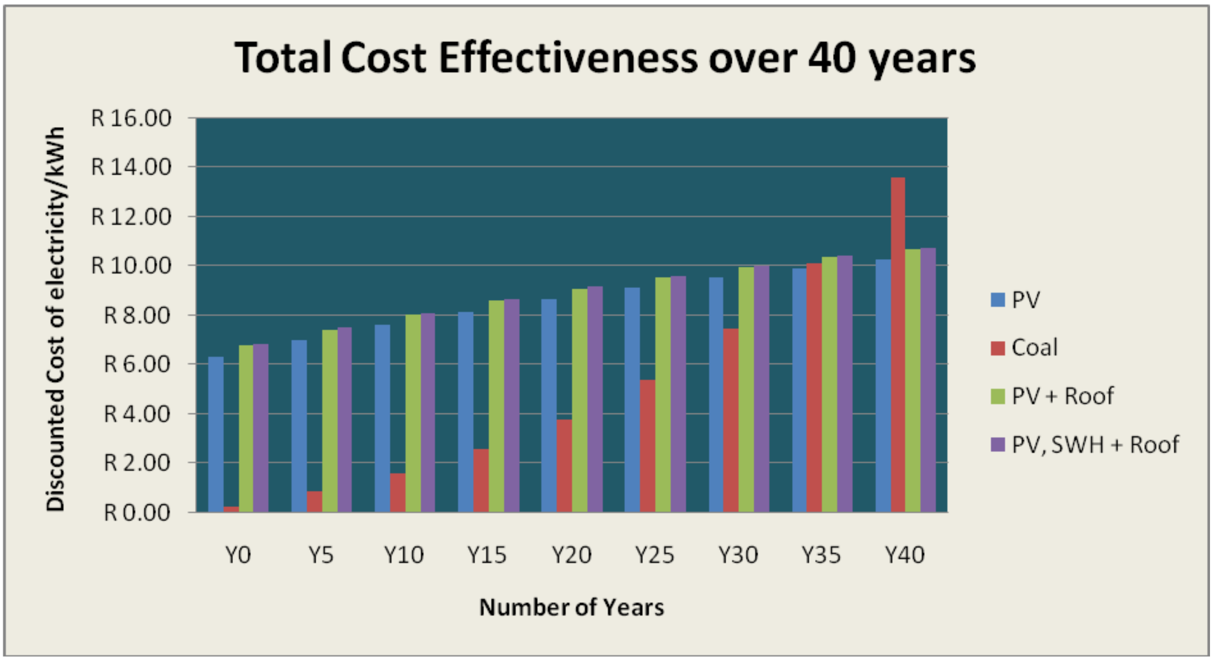

Figure 1: First total cost-effectiveness comparison of Maluti coal-based electricity and Lynedoch RSPS (PV roof tile and SWH, including roof costs) electricity over a 40-year period in R/kWh

The break-even charts are useful tools for showing the effects of fixed (capital) costs and variable (O&M) costs in the LCC process. In Figure 2, the net present values (NPVs) of the LCC are indicated on the Y-axis to combine monetary cost with time, indicated on the X-axis, and show how the effects of expenditures and cost reductions play together.

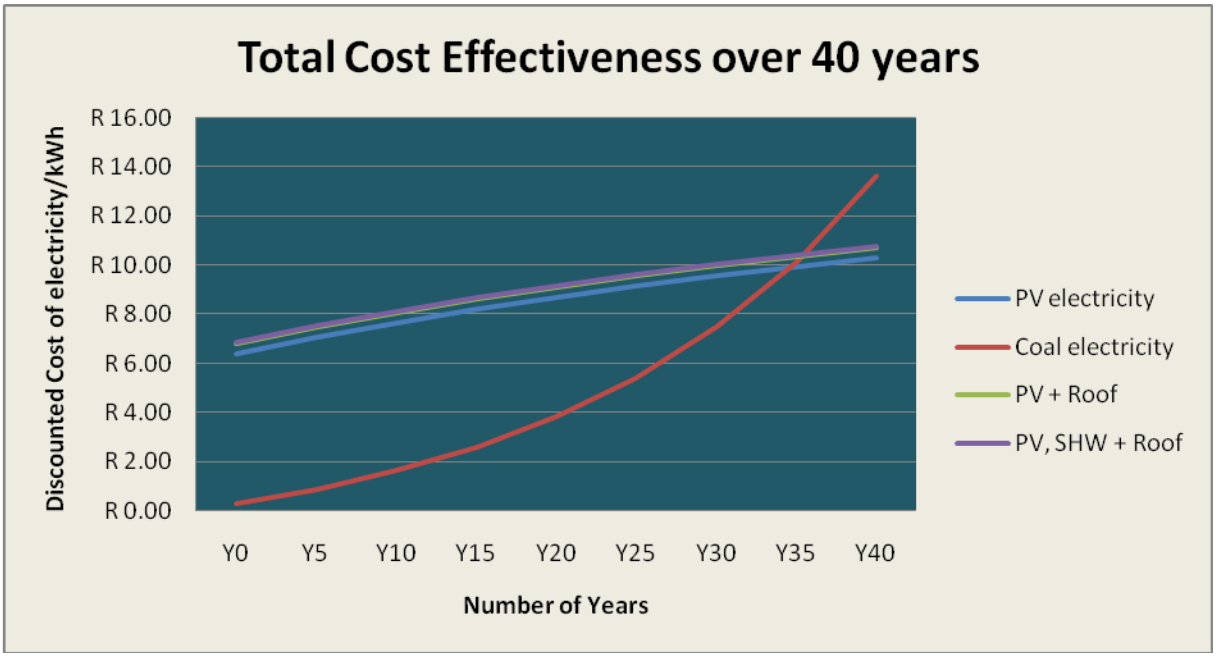

Figure 2: Second total cost-effectiveness comparison of Maluti coal-based electricity and Lynedoch RSPS (PV roof tile and SWH, including roof costs) electricity over a 40-year period in R/kWh

The Lynedoch RSPS (PV roof tile and SWH) including the cost of the reinforced roof at an LCC of R10.77/kWh is superior to that of Maluti coal-fired power plant with the LCC of R13.63/kWh at the end of the 40-year life-cycle. This is best shown by the break-even charts (see Figure 2). A Lynedoch RSPS breaks even just after year 35 at R10.77/kWh, and a PV roof tile system (without SWH and the roof) breaks even just before year 35 at R9.94/kWh.

7 Sensitivity assessment

7.1 Coal price

Figure 3 shows how the upper bound of the coal price (at R369.50/ton) affects the LCC of Maluti coal-based electricity over 40 years. This upper bound of coal price almost doubles the LCC of electricity generated by Maluti coal-fired power plant at the end of 40 years. The Lynedoch RSPS breaks even just after year 25, compared with breaking even after year 35 in the case where the price of coal is R175/ton. Overall, the Lynedoch RSPS has the lowest LCC of R10.77/kWh compared with the LCC of R22.41/kWh (based on R369.50/ton of coal) of Maluti coal-based electricity over a period of 40 years.

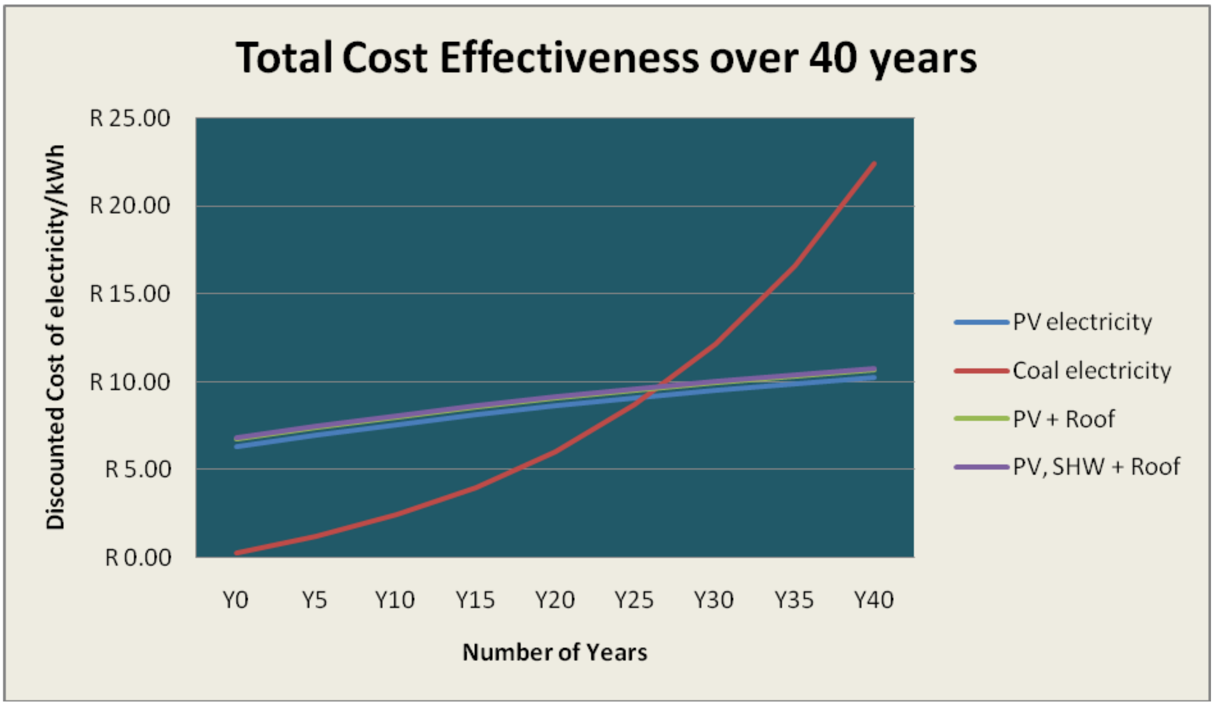

Figure 3: Effect of R369.50/ton of coal on a 40-year LCC of Maluti coal-based electricity compared with Lynedoch RSPS electricity, in R/kWh

Figure 4 shows the lower bound of the coal price at R90/ton and what impact it has on the LCC of Maluti coal-based electricity over 40 years. The coal option is cost-effective for the entire life-cycle of the two project alternatives. Overall, the Lynedoch RSPS has an LCC of R10.77/kWh compared with the LCC of R8.61/kWh for Maluti coal-based electricity over a period of 40 years. Here it is shown how the variability in the coal price affects the range of LCC of Maluti coal-based electricity when all other items are kept constant.

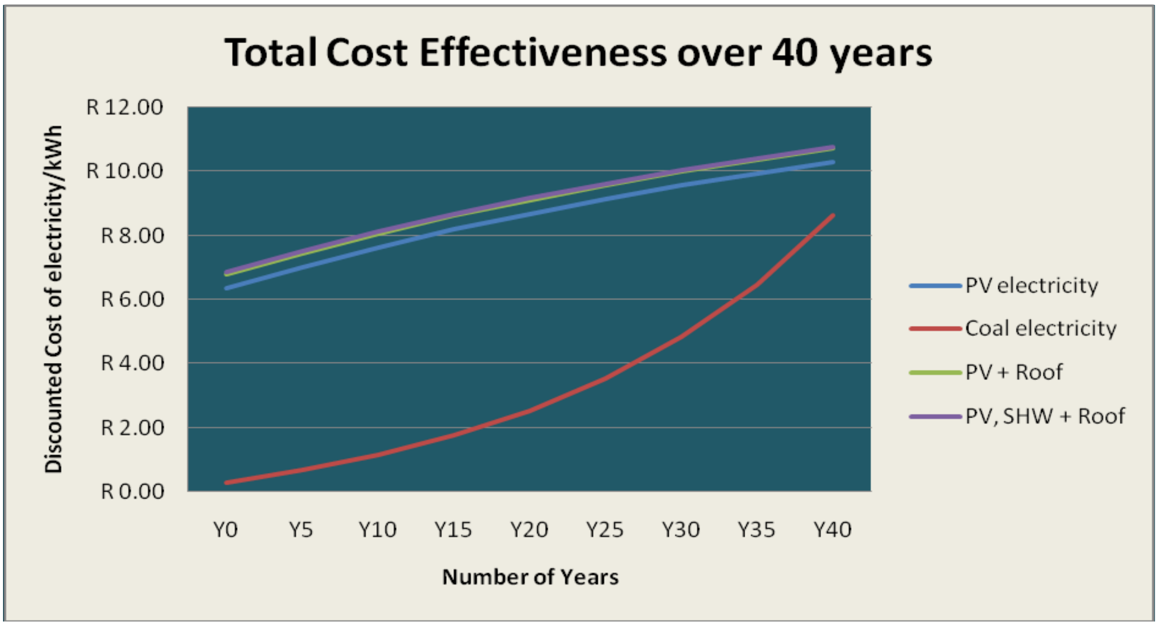

Figure 4: Effect of R90/ton of coal on a 40-year LCC of Maluti coal-based electricity compared with Lynedoch RSPS electricity in R/kWh

7.2 Energy production

The uncertainty in input values means that actual outcomes may differ from estimated outcomes, as is the case with estimated energy yield and actual energy yield from the 5 kW PV roof tile system of the Lynedoch RSPS. The estimated annual energy yield of 10 038 kWh was used in the calculations of LCC. The actual annual average energy yield of 4 906 kWh forms part of this uncertainty assessment.

All other items were kept constant while changing the energy yield from 10 038 kWh (calculated) to 4 906 kWh (actual energy yield) to see the effect on the LCC of the Lynedoch RSPS. The Lynedoch RSPS has an LCC of R17.93/kWh compared with the LCC of R13.63/kWh of Maluti coal-based electricity. The PV roof tile system (forming part of the Lynedoch RSPS) has an LCC of R16.93/kWh. Maluti coal-based electricity is again the most cost effective of the two alternatives over the 40-year life-cycle. A Lynedoch RSPS breaks even just after year 35 at R10.77/kWh when using estimated 10 038 kWh, whereas the coal option is superior one for the entire life-cycle of the two project alternatives when using the actual annual energy yield of 4 906 kWh (see Figure 5).

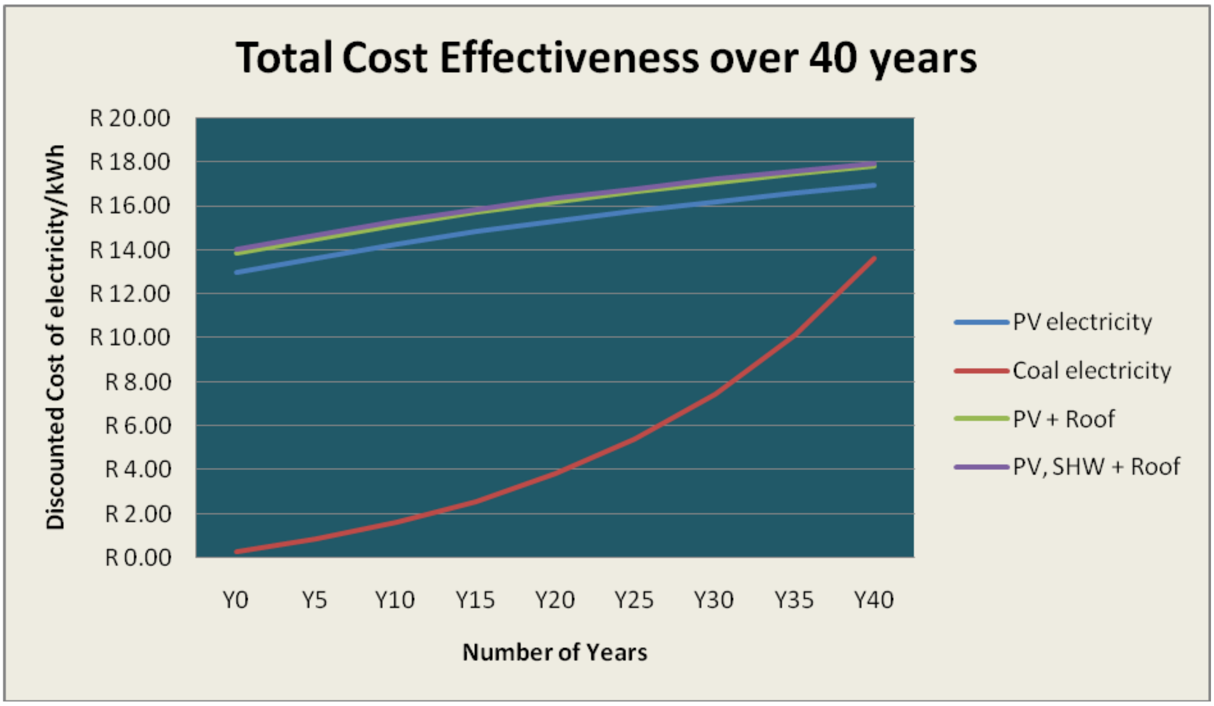

Figure 5: Effect of uncertainty in energy yield from the 5 kW PV roof tile system resulting in an actual outcome of 4 906 kWh, differing from the estimated outcome of 10 038 kWh on a 40-year LCC in kWh

Figure 6 shows the effect that the revenue from carbon credits has on the 40-year LCC of a residential solar power system (PV and SWH, including roof) compared with that of coal-based electricity.

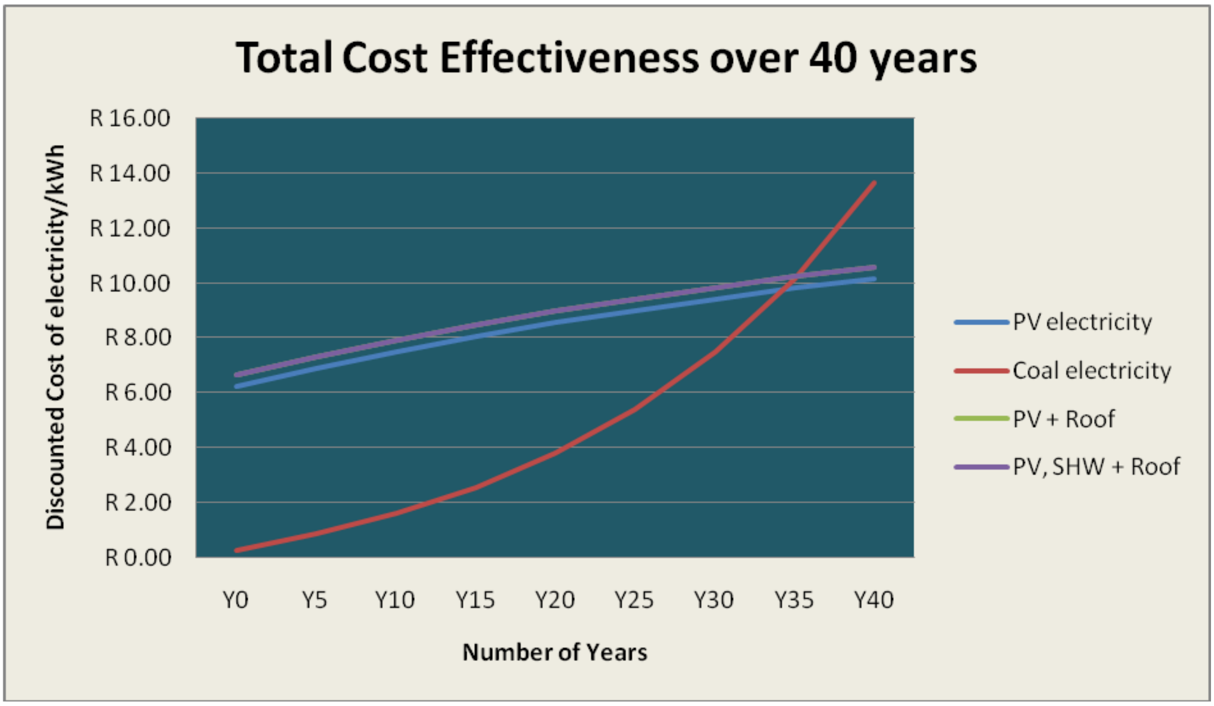

Figure 6: Effect of carbon credits on a 40-year LCC of solar power system (PV and SWH, including roof costs) electricity compared with coal-based electricity in R/kWh

The effect of carbon credits (CERs) at a price of €10/ton CO_2e on the LCC of Lynedoch RSPS is minimal. A Lynedoch RSPS has an LCC of R10.59/kWh. The Lynedoch RSPS breaks even in year 35 – this is similar to the case without carbon credits (where the LCC is R10.77/kWh). In this case, the high CDM registration costs would be more expensive than the value of the carbon credits. But the cumulative effect of a million or more houses with Lynedoch RSPS will result in more than 16 million tons of estimated annual carbon savings based on Eskom's emission factor of 1.2 kg CO_2/kWh for coal-based electricity. This is 4% of South Africa's annual carbon emissions.

8 Conclusion

Life-cycle costing (LCC) has indicated that operational savings could be sufficient to justify the upfront investment costs of Lynedoch RSPS (comprising a 5 kW PV roof tile system and 2.5 m^2 SWH), which are often greater than the upfront investment costs of coal projects (e.g. US$1–1.5/W) in terms of the project's functional unit, i.e. cost/kWh. It must be stated, however, that the LCC in this case used the estimated annual energy output of 10 038 kWh and not the actual annual output of 4 906 kWh. It is therefore clear from Figure 5 above that the actual annual energy output of Lynedoch RSPS is not enough for the LCC to break even with the LCC of Maluti coal-fired electricity in a 40-year life-cycle.

The LCC, using an estimated annual energy output of 10 038 kWh, reveals that the common belief that sustainable and renewable energy alternatives are too expensive is a false perception created by looking no further than initial capital costs. Lynedoch RSPS becomes a superior energy provision solution that promotes ecological, social and economic sustainability through less resource consumption, improved access to energy services and lowest life-cycle operating costs. The Lynedoch RSPS has, measured in NPV at a 9% discount rate, a lower life-cycle cost of R10.77/kWh than Maluti coal-fired power plant's life-cycle cost of R13.63/kWh over the 40-year technical design working life, with the potential to have an even higher LCC of R22.41/kWh when the coal price comes under upward pressure due to uncertainty in global markets. The LCC of Maluti coal-based electricity at R13.63/kWh is 27% more than that of Lynedoch RSPS, fully installed, i.e. including installation, replacement, import and storage and roof costs, at R10.77/kWh.

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