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Original article

Economic feasibility assessment of manufacturing solar panels in South Africa – A case study of Steve Tshwete Local Municipality

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ABSTRACT

South Africa has developed one of the most successful renewable energy development programs in the world. However, the establishment of a South African solar Photovoltaic (PV) manufacturing localisation agenda has fallen behind. This study assesses the financial feasibility for local manufacturing of solar panels in South Africa using the Generally Accepted Accounting Principles (GAAP) method to determine a Minimum Sustainable Price (MSP) for a local production plant. Our findings show that local manufacturing of solar panels can play a role in supporting a "just energy transition", particularly, in regions that are phasing-out the coal economy. We observed the financial feasibility of solar panel local manufacturing and found that the Internal Rate of Return (IRR) was 1.75%. When sensitivity analysis of +15% was applied, the IRR increased to 3.51%. The study also determined that without any subsidies local manufacturing of solar panel is not economically feasible when the MSP is used. Lastly, the probable negative impacts of coal phase-out can be prudently mitigated by the creation of alternative economic opportunities which promotes a just energy transition in coal phase-out regions like Steve Tshwete Local Municipality (STLM).

Introduction

The ongoing energy transition will result in changes in how electricity is generated in South Africa. The expected changes introduce a variety of energy technologies like solar photovoltaics (PV), wind, biomass and hydropower. Local manufacturing of energy components is important for stimulating economic growth, job creation as well as contributing to the principles of a just energy transition. This study employs economic feasibility assessment, engineering economics as well as the General Accepted Accounting Principles (GAAP) to determine the Minimum Sustainable Price (MSP) for local manufacturing of solar panels in South Africa. The financial feasibility assessment of solar panels manufacturing will ensure that South Africa understands whether a technology like solar PV can be produced locally.

The South African solar resource is the third-largest internationally, this translates to an average of more than 2500 h of sunshine per annum and average solar radiation levels ranging between 4.5 and 6.5 kWh/m^2 in one day [1]. According to [2], photovoltaic is used to transform the free energy from the sun to electrical current using the photovoltaic effect. This process can be defined as a potential generation when the area in or near the built-in potential barrier of a semiconductor gets ionized by radiation [2]. This is recognised as a self-generated current and electromagnetic field that can transfer power [3]. There are various types of PV solar cells, including mono and polycrystalline silicon, cadmium telluride (CdTe), gallium arse-nide (GaAs), and triple-junction photovoltaic solar cells composed of indium gallium phosphide (InGaP) are among the most common solar cells used globally [4]. This study assesses the economic feasibility of manufacturing solar panels in South Africa.

Photovoltaics has demonstrated the most rapid cost decline among sustainable energy technologies. This means that this technology will continue to increase its share in the global energy system. According to [2], limited economic models are available to evaluate the economic profitability of solar PV panel manufacturing.

According to [5], economic models have been widely utilised in both research and industrial sectors to assess the financial feasibility of projects, therefore this study deploys an economic model to determine whether South Africa can manufacture solar panel at competitive prices compared to leading solar panels producers. As such, the study calculates Discounted Cash Flows (DFC), Net Present Value (NPV) and

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Internal Rate of Return (IRR) for a 1 GW solar panel production plant. Several methods that can be used to conduct economic feasibility assessments, these may include DFC, NPV, IRR, discounted payback time (DPBT), annual costs (AC) and annualised life cycle cost (ALCC) among others [5–7]. The NPV is used to assess financial performance for financial products or capital projects with cash flows that are spread over long-term. The IRR is a measure used for capital budgeting and evaluation project's profitability [2]. Other parameters used to measure economic feasibility include the DPBT, this is a capital budgeting process used to evaluate the project's breakeven point. The Profit Index (PI) is the ratio of payback off to potential project investment [5]. The total cash flow is the net amount represents the projects cash inflows and outflows. This study ran the DCF to assess NPV and IRR as the two main indicators that are used to assess the economic feasibility of manufacturing solar panels in South Africa.

Other countries such as the United States (US) has set a goal of reducing the cost of solar electricity production to about 6 USc/kWh by 2020 [8]. As such, [9] shows that solar PV is one of the cheapest forms of electricity generation globally. The Renewable Energy Independent Power Producers Program (REI4P) shows that South Africa will procure 6 814 MW of utility scale solar PV between 2020 and 2030 [10]. This means that it is important for South Africa to realise whether local manufacturing of solar panel is feasible.

According to [9], the cost of solar PV has progressively declined in the past years, this makes the adoption of solar PV technology practical. As such, understanding the country's solar panel manufacturing feasibility is critically important. Most scholars have focused their solar PV economic feasibility assessments on solar thermal, solar PV electricity generation, solar PV techno-economic performance, grid-connected studies, stand-alone systems, economic and environmental solar PV studies, as well as parameters such as water pumping, levelised cost of electricity (LCOE), hybrid micro-grids and storage costs techno-economics [11–15]. However, the economic feasibility assessment for manufacturing renewable energy components is limited in South Africa. Moreover, manufacturing of solar PV panels techno-economic assessments is generally non-existent in South Africa as well as in many African countries [16–19]. This is an essential gap that this study has identified and aims to address thus make a significant contribution towards renewable energy component manufacturing through a solar panel manufacturing case study in a coal phase-out town such as STLM. Moreover, this will support just the energy transition. Scholars studying the South African energy transition have hitherto only focused their localisation research around the South African REI4P that has Local Content Requirements (LCRs) targets. The LCRs that the REI4P programme expected has not materialised into local manufacturing of solar panels but assembling plants [16,20–31]. More challenging, the World Trade Organization (WTO) describes LCRs as an uncompetitive practice, while domestically it is used as an Industrial Policy (IP) tool that stimulates local manufacturing [23]. Moreover, the Agreement on Trade-Related Investment Measures (ATRIMs) explicitly bans LCRs. Irrespective of trade policies that discourage LCRs, no study has tested the financial feasibility for local manufacturing of solar panels in South Africa. The study main contribution aims to assess whether South Africa can manufacture solar panel at competitive prices compared to global solar panel manufacturers.

According to the [32], "Just Transition is a vision-led, unifying and place-based set of principles, processes, and practices that build economic and political power to shift from an extractive economy to a regenerative economy. This means approaching production and consumption cycles holistically and waste-free". The energy transition needs to be just and equitable, it must redress previous harms and create innovative relationships for the future through reparations. The just energy transition outlines the route towards a fair energy transition as well as guidelines on how to get there [32].

The socio-technical transition theory has become a dominant body of work that tries to understand the transition of societies and technological systems, especially in the energy, transport and water sector [33]. The South African transition juncture is characterised by the adoption of a clean energy system that is carbon-free (in other words a transition from coal to a low carbon economy). To date, South Africa does not have any independent analysis of the socio-economic impacts of transitioning away from coal. The socio-economic impacts of phasing-out coal power stations are often perceived as a barrier to the energy transition [34]. Shows that an average miner in Mpumalanga[1] province supports a minimum of three individuals. Therefore, the loss of income due to the energy transition poses a threat to the economic emancipation of the citizens residing in Steve Tshwete Local Municipality (STLM), in the Mpumalanga province. Nonetheless, South Africa has been grappling with triple challenges, which are poverty, inequality and unemployment. The triple challenges were accelerated by the failure to achieve six out of the nine Millennium Development Goals (MDGs) in South Africa [35]. In 2009, approximately 47% of households in Mpumalanga province lived below the poverty line. For this reason, [34] indicates the importance of alternative economic diversification opportunities in regions that are dependent on the coal economy. As a result, local manufacturing of solar panels in Steve Tshwete will contribute to curbing perceived potential job losses.

Finally, coal power is regarded as one of the principal causes of anthropogenic climate change. The later has forced a global decline for coal utilisation in countries like China, United State and India. Moreover, the Asian and European coal exports are also expected to decline in the long-run due to climate change commitments while the adoption of technologies like solar PV is expected to increase [36]. It is estimated that over 80% of global coal reserves might need to remain unexploited to keep up with international climate change objectives [37]. South Africa is not exempted from this transition since there is a need to minimise environmental degradation and accelerate the energy transition from a coal-based power system to a carbon free future. The 2018 South African coal exports target of 77 million tons declined by 4.55% to 73.5 million tons already. Moreover, the price of coal reached an all-time high of $100 suggesting that coal costs continue to be expensive [38]. However, solar PV costs decreased by more than 80% between 2010 and 2017 [39]. Therefore, investments in cleaner technologies like solar PV have the potential to create jobs.

Although the adoption of cleaner energy sources like solar PV is necessary, local manufacturing of solar panels remains a cause for concern in South Africa, as the importation of solar panels does not assist curbing the unemployment difficulties that the country has faced for the past few years. [40] Shows that South Africa recorded an all-time unemployment rate of 29% in July 2019. Henceforth, the need to create green jobs in the solar PV value chain is significant.

Literature shows that localisation has been facilitated through IP instruments that encourage local production at costs that might not be competitive. This was evidenced in Brazil during the 1980 s where a microcomputer corporate applied economic protectionism as a tool to advance localisation [22]. However, this study will assess the level of competitiveness for local manufacturing of solar PV.

The solar PV manufacturing process

According to [41], the kind of solar PV modules produced depends mainly on the manufacturing process and materials used for the solar cell such as monocrystalline, polycrystalline, or thin film. The process of manufacturing solar modules is illustrated in Fig. 1.

Once the production process is concluded, the solar PV module is then passed through an automatic machine for lamination and trimming. After this process, the framing machine is used to put the Aluminium frames around the module. Once this process is concluded the voltage (V) and current (I) of the module are tested by an EL tester

[1] Steve Tshwete Local Municipality is located in Mpumalanga Province.

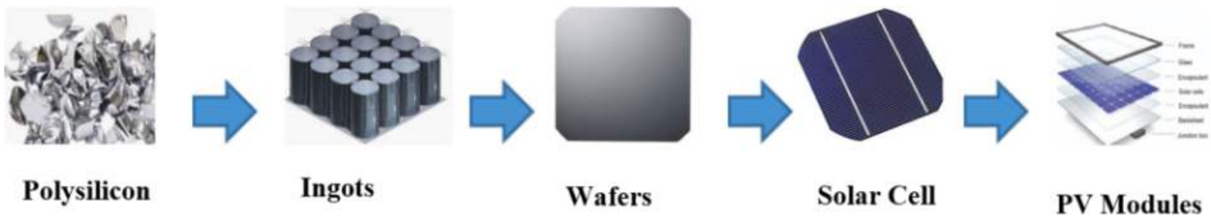

Fig. 1. Solar PV manufacturing process [41].

[41]. According to [42], the bottom-up cost models for solar PV can be deployed to evaluate the impact of low cost PV material. In this study, we follow we develop a bottom-up cost model to assess the economic feasibility for manufacturing solar panels in STLM. The process of manufacturing solar panels utilises two main methods for converting raw polysilicon feedstock into complete wafers. The monocrystalline method utilises Czochralski (Cz) process, and the multicrystalline process uses the directional solidification (DS) route [43]. The main difference between these two methods is in how the polysilicon is heated, how it is converted to ingot, the diameter of the block bar, and how the block of steel is moulded into bricks for wafer cutting. The Cz method generates a cylindrical bar, and this is followed by various stages of band and wire cutting to produce wafers [44]. For this study, we focused on monocrystalline solar panel manufacturing due to the high efficiency it has. Moreover, South African temperatures can be extreme, as such integrating technologies such as lithium accumulators can play a significant role in cooling and balancing airflow in the solar PV infrastructure [45].

The passivated emitter and rear cell (PERC) manufacturing offer patterns for the materials, labour, and electricity costs as well as the capital investment needed for new manufacturing plants. The methodological know-how and the equipment required to produce standard solar panels in large volumes with guaranteed and highly regarded efficiencies are currently commonly accessible. If an enterprise can source solar panel material and has funds to make the required investment, sizeable cell conversion can occur anywhere in the world. Insignificant differences in the production cost would be a currency exchange, input material, and minor logistics cost. Electricity and labour costs are the only variables that can make substantial modification [44]. Numerous companies offer solar panel module assemblage services since it is easy for potential module assemblage businesses to find various cell suppliers. Nonetheless, this route will not demonstrate the full potential of the South African solar panel industrialisation pathway, therefore, this study quantifies the financial viability of a fully scaled 1 GW annual solar panel manufacturing plant that [44] shows to be large enough to realise maximum profits available from economies of scale. This study proposes a solar panel manufacturing plant study in STLM due to the 4900 MW of coal power stations that will be decommissioned in this region [10]. Additionally, local manufacturing of solar panels also means that waste that will be generated would need to be recycled soon [7].

Economic feasibility theoretical framework

GAAP

According to [46] the term "Generally Accepted Accounting Principles" came to effect in 1932 where reports of public accountants were certified. The opinion in the form of the balance sheet, income statement or profit-and-loss of an investment represents the financial position of any operation. The purpose of accounting is to provide comprehensive reliable information needed by decision-makers or management to fulfil their responsibilities to either government or shareholders [46]. [47] Recognises GAAP as a better financial management standard than the cash basis accounting. Moreover, [48] shows that GAAP analysis provides a systematic investment analysis that reflects the real-world facts relating to business transactions. This study employs GAAP to ensure that the economic feasibility and investment analysis is a true representation of how local manufacturing of solar panels plant would financially perform.

Engineering economics

Engineering economics is a financial appraisal method that is generally deployed in engineering investment projects to determine their financial viability using the concepts of compound interest, amortisation and DCF to consider the time value of money under the principle of economic equivalence. Historically, financial analysis has been used to determine a project's economic feasibility [28,29]. This study employs financial feasibility, engineering economics and GAAP to determine a MSP for the local manufacturing of solar panels.

According to [49], the engineering economist Arthur Lesser distinguished engineering economics as a special discipline and initiated its application in the evaluation of engineering projects in 1955. In the finance analysis domain, engineering economics is regarded as the capital budget decision-making process. Engineering economics is the principal technique for investment decision-making for manufacturing plants projects and financial management plans. The investment assessment method employed in capital investment decision-making solves manufacturing challenges and achieves financial feasibility [49].

Engineering economics merges construction planning and economic theory. Lifetime financial analysis is recommended for future manufacturing and operations in engineering plants like solar panel manufacturing. The financial programming and risk sensitivity analysis of solar panel local manufacturing under different possible discount rates, times, and risks can provide financial criteria for finance- and operation-related decision-making in the localisation of solar panels [49].

Financial feasibility theory

Financial feasibility analysis is an analytical tool employed to appraise the economic viability of an investment. It assesses the financial state and operational performance of an investment, as well as projecting future financial position of an investment. An investment decision is dependent on the expected return and expected risk. The financial feasibility assessment is an analytical process for examining returns expected and the associated investment risk [50,52,53].

Economic feasibility assessment should be conducted before an investment decision can be made. It is possible to develop a business idea into operational technology, however, if it is not economically feasible to produce, it can result in financial losses and waste of valuable time. Conducting a feasibility study outlines various implications on modelled scenarios and it shows strengths and weaknesses of a potential investment [29–31] Several methods can be used for capital investment analysis. These may include the IRR, NPV and DPBT [32,33].

NPV

$$\boldsymbol{NPV}(i) = \frac{A^0}{(1+i)^0} + \frac{A^1}{(1+i)^1} + \frac{A^n}{(1+i)^n}$$

$$\sum_{n=0}^{n} \left(\frac{A^n}{(1+i)^n} \right) \tag{1}$$

N = The lifespan of a project
A^n = Net cash flow
i = discount rate or return that could be earned in alternative investments.

The NPV is used to make investment-related decisions. An investment is accepted if cash inflows are greater than cash outflows, this means that the NPV needs to be greater than zero for the investment decision to be made [28,29]

IRR

$$\boldsymbol{IRR} = \sum_{t=1}^{T} \left(\frac{Ct}{(1+r)^t} - C0 \right) \tag{2}$$

Defined as:
C_t = net cash inflow during the period t
C_0 = total initial investment costs
R = the discount rate
t = the number of periods.

The IRR formula is founded on the principles of a return on invested capital [54]. The IRR is the interest rate charged for the project balance that might not be obtainable on an investment such that, when the project reaches the end of life, the unattained project balance is zero [50]. This means that the investment has zero NPV, however, the IRR serves as the benchmark interest rate and allows investors to be able to make an investment decision.

DPBT

The DPBT is a method that is used to determine when an investment will return the full-invested amount (i.e. breakeven). This method shows how long it will take an investment to recover all investment cost and start generating revenue. However, this method does not quantify profit, it only measures the time it takes to recover the initial investment. The payback method disregards all income stream and operational expenses after the payback time has been reached. As a result, it does not allow an investor to determine the long-term view performance of a project. Moreover, the method does not acknowledge the time value of money. Due to these identified shortfalls, this study utilises the NPV and IRR to assess the financial feasibility of local manufacturing of solar PV in South Africa. The payback method is regarded not suitable to assess financial feasibility, and will thus not be used further in this study [29,33].

MSP

Operational manufacturing plants need revenue that is higher than their operational expenses to remain profitable. However, for this study, we tried to determine the minimum selling price that will ensure that this investment break-even. We assumed that positive operating margin is required to sustain a business in long-term and calculated to the MSP[2] that can maintain positive margins for solar panel manufacturing. The MSP method is used to assess competitive against producers that leads the local manufacturing of solar panels globally. Sensitivity analysis is employed to understand the possible Internal Rate of Return for a 1 GW solar panel annual production plant. This study applied the financial feasibility assessment for local manufacturing of solar panels. This will assist the South African government in their decisions regarding potential investments and operations in support of a just energy transition.

For investors to be involved in a new investment project, the project needs to demonstrate economic viability. This means that any capital invested must indicate the potential to generate a positive IRR. The achievable IRR needs to benchmark against investment portfolios with similar risk and at least indicate an equal or higher return. A typical example would be a solar panel manufacturing plant that can make sufficient income to pay for all cost requirement of running the plant as well as recovering construction costs while the profitability might be lower than comparable production plants Financial appraisals of operations and maintenance cost for running a solar module manufacturing plant as well as income expected to be generated are essential parameters to determine the financial feasibility of any manufacturing plant [50].

Model implementation

To realistically examine the solar panel local manufacturing economic viability in STLM, we used the NPV, IRR analysis to evaluate the bottom-up cost modelling approach and the GAAP frameworks to estimate costs for a MSP for an economically viable solar PV localisation.

Model assumption

The assumptions adopted for calculating the cost of solar panels local manufacturing are contained in [44]. The capital investment assumed is \$30 million, with a 70:30 debt-equity ratio. Depreciation has been estimated to be \$90,000 over 10 year's straight line for this plant. The amortisation estimates have been calculated over 8 years with a 10% interest rate, which is equivalent to the South African lending rate. The electricity cost is calculated using the 2018 approved electricity tariffs for STLM that are available from the National Regulator of South Africa (NERSA), this is shown in Fig. 2. The exchange rate is adjusted by an average of 13.25 ZAR (average USD/ZAR exchange rate in 2018) for the base year 2018 [56]. For a 1 GW solar manufacturing plant, annual energy requirements are estimated to be 80,645,161 kWh for 1 GW solar panel manufacturing factory (60 cell module of 310 W, 3,225,806.45 modules), shown in Table 1. The input material cost was estimated as 1,000,000,000 Wp (1 GW) multiplied by 80% of \$0.13 as indicated by [44]. The lifespan of this plant is assumed to vary as suggested by [44], where 5–10 years for the manufacturing machines and 15–25 for the building infrastructure (see Table 2).

Steve Tshwete local municipality solar panel manufacturing case study

Labour costs are estimated by adjusting the direct labour expenses of workers and engineers in a similar plant in urban China into South African conditions. According to [57], labour costs in China were 104.80 index points, however, South Africa recorded an all-time high labour cost of 156.20 index points in the same period (2018). The labour cost index points shown in Fig. 3 were adopted to estimate solar panel local manufacturing labour costs. The index points indicate a 33% difference between South African and China, this was adjusted directly (see Fig. 3). Research and Development (R&D), sales and administration have been estimated to be \$0.010/W adjusted by South Africa and China labour cost index points.

A sound solar panel manufacturing plant means an ability of the investment to generate enough revenue to meet all financial obligations on a timely basis and command an adequate level of working capital for continued operations. The financial feasibility and MSP for manufacturing monocrystalline solar panels was calculated through the application of the GAAP. The NPV and the IRR were calculated for the local manufacturing of solar panels in STLM.

[2] MSP is equal to the minimum price a company would have to charge for a good or service in order to cover all variable and fixed costs and make enough extra money to pay back investors at their minimum required rates of return, but no more [44].

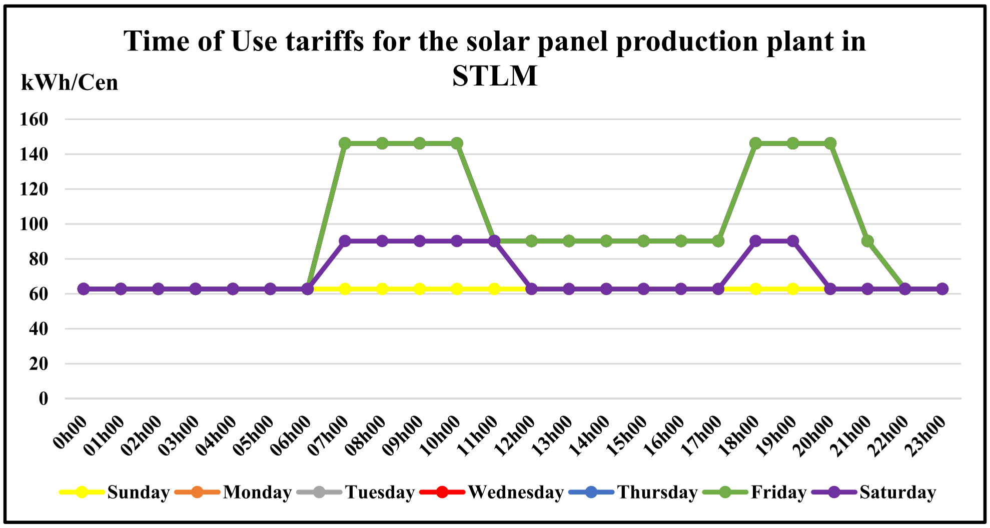

Fig. 2. Time of Use tariffs used for the solar module production plant [55].

Table 1
Solar panel manufacturing plant assumption.

Parameters	Evaluation inputs assumptions
Annual capacity	1,000,000,000 Wp
Plant life time	10 years
Building infrastructure	15–25 years
Exchange rate (2018 Average)	13.25
Cost per watt	$0.13

Table 2
Evaluation input assumptions.

Parameters	Evaluation inputs assumptions
Total project development cost and production equipment	$30,000,000
Equity cost	$21,000,000
Debt	$9,000,000
Debt repayment duration	8 years
Discount rate	10%
Assumed subsidies	0%
Annual plant expense increase	6%

Results

Table 3 shows the main results for the DCF that the study ran to determine the economic feasibility of manufacturing solar panels in South Africa. The study assumed a 1 GW solar panel production line. This translated to 3,225,806.45 unit modules produced per year. The capex required for the case study is estimated to be $30 million. The equity assumed for the economic feasibility assessment is 30%. This means that that debt-equity ratio is 70/30 while the discounted interest rate use is 10%. The capacity factor for the solar panel manufacturing plant is 80%, 20% is assumed for plant time and maintenance. The infrastructure is assumed to depreciation straight over 10 years. The calculated labour cost is $0.00532/W, while input material, electricity cost in STLM, and R&D are assumed to be $110 500,000, $ 546,356.46 and $0.0133/W respectively. The solar panel's selling price is assumed to decline by 1% annually.

The economic feasibility assessment conducted in this case study found that it is not economically viable to manufacture solar panels in South Africa without any subsidies. The study used two economic indicators, namely the NPV and IRR to determine the MSP. The calculated MSP is $43 per 310 W module which translate to $0.14/W. However, the production plant does not break-even with these results. The solar panel manufacturing plant has an IRR of 1.75% and the NPV is estimated to be $ −252,152.

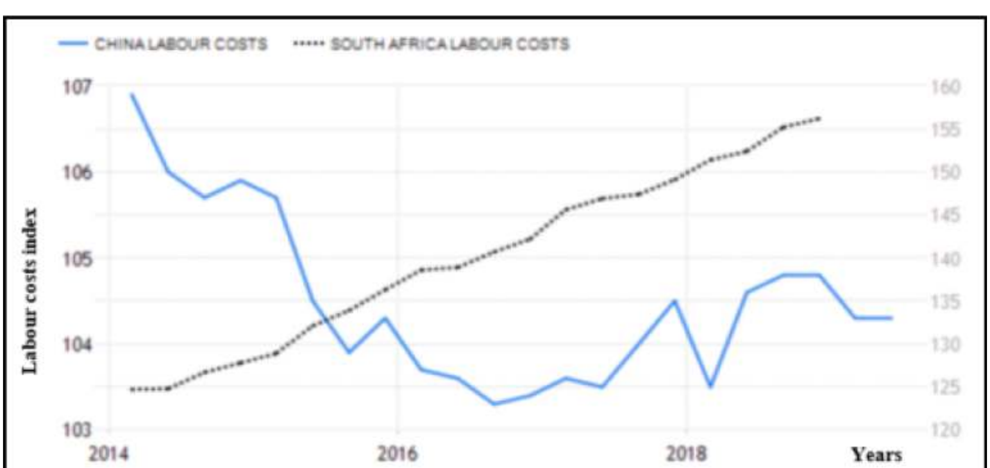

Fig. 3. Labour cost index points between South Africa and China [57].

Table 3
Solar PV localisation investment parameters and results.

Parameters	Economic cost evaluation inputs
Plant size	1 GW solar
Units produced p.a	3,225,806.45 (authors calculation)
Capital investment cost	$ 30 million
Equity	30%
Amortisation	70%
Interest rate	10% [58]
Capacity factor	80%
Depreciation	10 years straight line
Labour cost	$0.00532/W [44,57] author's calculation)
Input material	$110,500,000 [44] (author's calculation)
Electricity cost	$ 546,356.46 (author's calculation)
Research & Development, sales, general administration	$0.0133/W [44,57] (author's calculation)
Module costs prices projected to decline	1% p.a
Calculated MSP	$43 per 310 W module ($ 0.14/W)
IRR	1.75
NPV	$ −252,152

The study found that there is an opportunity for South African solar panel manufacturing to increase its selling price by 41% and still be competitive with the prices shown in Fig. 4.

Sensitivity analysis

Table 4 shows the IRR results from sensitivity analysis calculated using the base case scenario. The sensitivity analysis adjustment increased the IRR to 3.51%, 2.47% and 2.02% (15%, 10% and 5% sensitivity analysis). The NPV was lower than zero signalling that subsidies would be required for an economically viable solar panels manufacturing plant in STLM.

DCF sensitivity analysis results

Three additional scenarios are shown in Table 5. The scenarios that are calculated have been benchmarked against monocrystalline spot prices that are indicated in Fig. 4. Scenario 1, 2, and 3 have a selling price of $65, $75, and $122 per 310 W produced (i.e. $0.21/W, $0.24/W, and $0.39/W), this is the same as the spot price shown in Fig. 4. The annual plant expenses were assumed to be 6% for the scenarios shown in Table 5. The baseline scenario and the three additional scenarios indicate that solar panels manufacturing in South Africa would require subsidies. The results from the scenarios also indicate that solar manufacturing using the MSP to compete with the Chinese market price is not economically viable. As such, the subsidy requirements for the manufacturing plant to break-even are shown in Table 5 for all the scenarios under consideration.

Table 4
Solar panel manufacturing plant sensitivity analysis.

Deviance	IRR corresponding			
of parameter	IRR Results	Price increase exps.	Annual Expenses	Solar Panels Sales
No change for Variable	1.75%	1.75%	1.75%	1.75%
−15%	1.32%	1.75%	0.64%	1.13%
−10%	1.43%	1.75%	0.76%	1.30%
−5%	1.57%	1.75%	0.98%	1.53%
0%	1.75%	1.75%	1.75%	1.75%
5%	2.02%	1.75%	1.75%	2.00%
10%	2.47%	1.75%	1.75%	2.26%
15%	3.51%	1.75%	1.75%	2.53%

Table 5
Profitability assessment scenarios.

Scenarios	Selling price per watt	NPV	IRR	Subsidy requirement
Baseline	$0.14/W	$ −252,152	1.75%	$ 640,542,886
Scenario 1	$0.21/W	$ −9,148,183	−0.1%	$ 281,663,290
Scenario 2	$0.24/W	$ −13,192,432	−13%	$ 188,054,774
Scenario 3	$0.39/W	$ −32,200,403	N/A	$ 8,603,576

Discussion

Given the results, the MSP for solar PV location is $0.14/W. This MSP is competitive for local manufacturing of solar panels in South Africa. The monocrystalline solar PV spot price quoted on the 7th of August 2019 (see Fig. 4), shows that China sold mono PERC modules with an average of $0.239/W. The financial analysis indicates that South Africa cannot breakeven at $0.14/W when localising solar panel manufacturing. This means that South Africa can charge an additional $0.12/W to maximise the profit margin when selling locally manufactured solar panels at a competitive rate with the Chinese spot price. As indicated earlier, loss of income due to energy transition to a low carbon economy in STLM requires alternative economic diversification pathways. As such, understanding whether South Africa can competitively

Solar PV Module Weekly Spot Price

Item	High	Low	Average	AvgChg	AvgChg %
Poly Solar Module	0.300	0.190	0.207	↓ -0.001	↓ -0.48%
Poly Module in China	0.240	0.190	0.204	↓ -0.003	↓ -1.45%
Poly High Eff / PERC Module	0.340	0.215	0.243	↓ -0.001	↓ -0.41%
Mono High Eff / PERC Module	0.390	0.235	0.260	↓ -0.001	↓ -0.38%
Mono High Eff / PERC Module in China	0.260	0.235	0.239	↓ -0.002	↓ -0.83%
ThinFilm Solar Module	0.330	0.230	0.245	− 0	− 0%
US Multi Solar Module	Visit here for more detail module price information				
Mono Silicon Solar Module	Visit here for more detail module price information				
India Poly Module	Visit here for more detail module price information				

Unit: USD / Watt   more   *Last Update:* 2019-08-07

Fig. 4. Solar modules spot price [59].

manufacture solar PV modules is critically important. The solar PV local manufacturing feasibility was evaluated using the model illustrated in Section 3.

The MSP for monocrystalline solar panel manufacturing is 50% cheaper than the Chinese spot price, however, the overall IRR is 1.75%. This is still a positive return although private investors are not likely to invest in such a facility due to a lower IRR, non-recoverable capital expenditure and negative NPV. When sensitivity analysis is applied, the IRR increased to 3.51%. However, this means that private investors might require a higher IRR than 3.51%. Nonetheless, the employment opportunities that can be created from a socially owned solar panel manufacturing plant can mitigate potential economic losses that will result from phasing-out coal power stations. The study by [60] found an IRR of 8% in the financial analysis conducted for the Canadian local manufacturing of solar PV. Moreover, [42] found an MSP of $0.41/W which is more expensive than what this study found. Furthermore, the study by [61] found an MSP of $0.19/W ($0.16/W margin required and 0$0.03/W maintenance cost). The result of this study demonstrates that South Africa is competitive when the MSP is applied, however, the cash flow required to keep a profitable plant is negative. This makes local manufacturing of solar PV in South Africa not competitive unless if it is highly subsidised. Lastly, the Perovskite solar cells case study indicated one of the cheapest PV technologies owing to low material usage, production processes and high efficiencies. The MSP was in the range of 0.32, 0.34, and 0.37 $/Wp for the modules manufactured [62].

According to [63], the MSP for solar PV manufacturing would be approximately 0.97 beyond 2025, however, the MSPs/Wp shown in Fig. 5 are comparable with this study and the spot price shown in Fig. 4. The study by [64] shows that in 2015 an estimated solar PV production cost was $0.59/W while the MSP for the same production is estimated to be $0.78/W. The study results signal solar panel production costs decrease over the past 5 years. Moreover, the analysis by [64] suggested that a manufacturing cost of $0.65–$0.70/W would be achieved at production volumes of only 10 to 50 MW per year. In our results, we found a MSP of $ 0.14/W for solar panel production.

To supplement the South African solar PV MSP, the policy makers need to subsidise the capital requirements for local manufacturing of solar panels. This will increase the IRR and attract private sector investors to participate in the solar PV local manufacturing initiatives. Moreover, the local Finance Development Institutions (FDIs) need to reduce their lending rates to enabling local manufacturing of solar PV. Lastly, the energy transition policy maker's needs to consistently procure solar PV technologies to ensure that jobs that are created from local manufacturing are sustainable. This will be in line with the principles of a just energy transition.

Conclusion

The economic feasibility evaluation conducted in this case study found that it is not economically viable to manufacture solar panels in South Africa. The calculated MSP shows that South Africa can sell panels for is $43 per 310 W module, this translate to about $0.14/W. This means that South Africa has an opportunity to increase its selling price by 41% to try to improve the level of competitiveness. The calculated IRR was found to be 1.75%. When sensitivity analysis was applied the IRR increased to 3.51%. The main limitation is that the local manufacturing of solar panels is not subsidised. The amount of subsidies that might be required is shown in the study results, moreover, subsidising local manufacturing solar panels would be the discretion of the South African government.

The debt-equity ratio was assumed to be 70/30 with a plant operational capacity factor of 80%. This means that if a portion of the equity could be subsidised the investment analysis results might generate additional profitability. The annual price increase of modules has been kept constant even under the sensitivity analysis scenarios (see Table 5). The panel sales varied between 1.13% and 2.53% when sensitivity

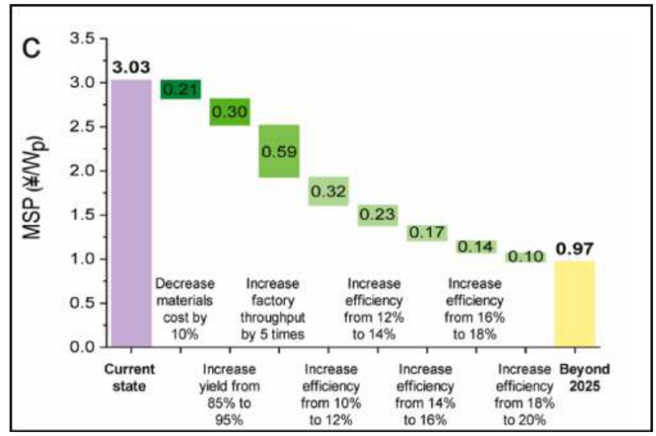

Fig. 5. MSP projection until 2025 [63].

analysis was employed.

One of the key questions that need to be unpacked is whether the lack of diversification pathways for coal phasing-out regions supports a "just" energy transition. Nonetheless, over $14 billion has been invested in the South African renewable energy sector. Europe and the US account for about 67% and 15% of the renewable energy Foreign Direct Investment (FDI) respectively [17]. This means a shift towards local manufacturing might require local investments from institutions like the African Development Bank, South African development funds and pension funds investment. This will ensure that those that are vulnerable to the energy transition are socially and economically protected.

This study calls for a dedicated policy that will deal with the implications of phasing-out coal in South Africa. Moreover, it is important to develop a road map for local manufacturing of energy components. South Africa needs to set energy components local manufacturing targets that can be monitored while we transition our energy system. Additionally, supporting a just energy transition should be driven with the acknowledgement that renewable energy technologies like solar PV do not have a broad value chain like the coal sector. For example, the coal sector employs a fair share of low skilled labourers in coal-mines as well as technical employees that run coal power stations. In addition to this, the transport sector services the coal power plants by transporting coal from mines to power station throughout the lifetime of a power station. As we transition to technologies like solar PV that are environmentally friendly compared to coal, it is important to ensure that employment opportunities available from renewable energy technologies like solar are earned optimally (i.e. throughout the value chain). South Africa cannot only focused on establishing renewable energy assembling firms, especially because the energy transition is going to deploy cleaner technologies like soar PV moving forward. Nonetheless, this study proves that when the MSP method is employed the IRR is 1.75, signalling a solar production plant that is not economically viable. The NPV shortfall makes local manufacturing not feasible without subsidies. This study shows that financial returns for local manufacturing of solar panels in South Africa is not economically attractive for investors. As a result, this study recommends that local manufacturing of solar PV should only be considered if it is subsidised to generate profitable results. Lastly, the South African energy system is relatively small in size, this contributes to economically unfeasible local manufacturing of solar panel.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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