Towards a Blockchain Special Purpose Vehicle for Financing Independent Renewable Electricity Projects in Sub-Saharan Africa

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***Abstract*—Sub-Saharan Africa requires affordable, reliable, and sustainable electricity to boost its economic, social, and human development. The main challenge posed to the region's electricity sector is the large investment gap needed to finance new power projects. The employment of new and innovative financing options is required to bridge this investment gap. Independent power projects have become one of the fastest-growing sources of new finance in the region. However, their development is constrained by the limited availability of debt finance for project implementation. The limited capital and bureaucratic burden of traditional financial institutions coupled with the high risks in the region ensures that the debt finance required by independent power projects is raised only after an arduous voyage and at high interest rates. We address these challenges by proposing a novel decentralized finance instrument, a blockchain special purpose vehicle that streamlines the processes in the financial layer of a traditional special purpose vehicle – finance mobilization, revenue collection, and revenue disbursal. Specifically, the proposed decentralized finance instrument facilitates the mobilization of finance for the special purpose vehicle from a location-independent crowd, revenue collection from the electricity offtaker in a risk-mitigated manner, and disbursal of eventual project revenues to investors.**

***Key words*—Decentralized Finance, Blockchain, Smart Contracts and Renewable Electricity**

I. Introduction

SUB-Saharan Africa's electricity sector experiences Herculean challenges. It presently has the lowest installed electricity generation capacity per region across the globe, which is apparent in its slow pace of industrialization and economic growth [1]–[6]. To put the gravity of the region's electricity hurdles into context, a single European nation – Italy (130 GW) – has more installed electricity generation capacity than the whole of Sub-Saharan Africa (120 GW). The apportionment of power is also not uniform in the region, as one country – South Africa (50 GW) – possesses almost half of the region's installed electricity generation capacity [5]. The meagre generation capacity is also obvious in the accessibility of electricity in the region. Presently, more than half of the region's population lack access to reliable and affordable electricity. Electricity access is relatively high in the south but overall, the pace of electrification is currently insufficient in the region [1]–[6].

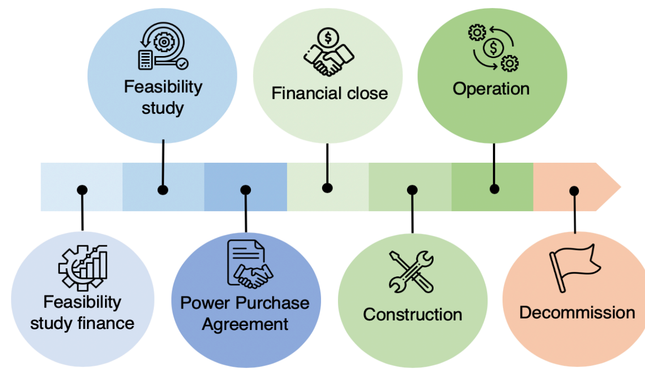

Fig. 1. Key phases of an independent power project in a typical jurisdiction in Sub-Saharan Africa

Although the region's electricity sector has seen a surge in investment in the last decade, this has been inadequate to meet the exponentially growing demand. Essentially, the financing requirements of the electricity sector in the region surpasses most nations' public budget [3], [5], [7]. An average annual investment of US$230 – US$310 billion until 2025 is required in the region for universal electricity access, whereas, an additional US$190 – US$215 billion is required for the period 2026 – 2030 [8]. Obviously, for Sub-Saharan Africa to meet these targets, new and innovative financing options are needed.

Independent power projects, financed, built, owned, and operated by the private sector have become one of the main sources of investment in Sub-Saharan Africa's electricity sector. Recently, they have eased the burden of financing large power projects on the public sector. With independent renewable electricity projects also offering record-low electricity generation prices, it is evident that they present one of the fastest means of achieving clean and low-cost new generation capacity in the region [5]–[7]. The typical life cycle of an independent power project in the region is presented in Fig. 1 [5]–[7], [9]. At the *feasibility study* phase, projects usually require *feasibility study finance* to undertake technical and financial feasibility studies and detailed environmental and social impact assessments. Projects that proceed past the feasibility study phase typically go-ahead to sign a *power purchase agreement* with the offtaker – the buyer of the electricity generated by the project, after which they will strive to reach *financial close* and commence *construction*. Following construction, these projects

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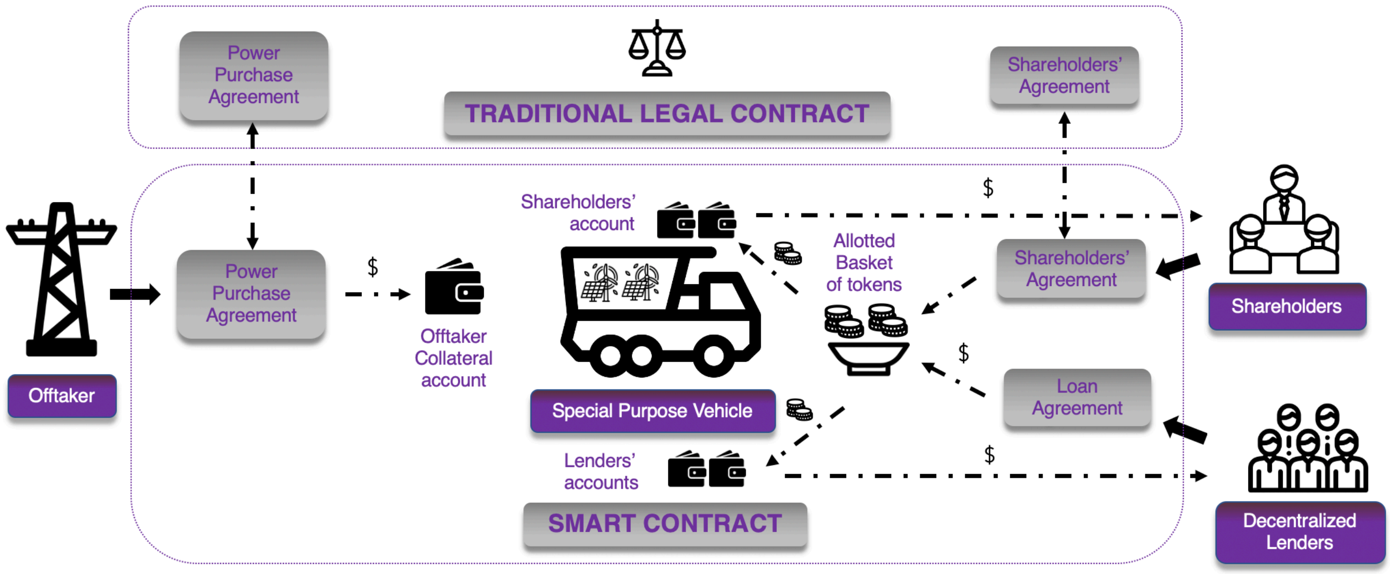

Fig. 2. Ecosystem of the blockchain special purpose vehicle

aim to sustainably *operate* to earn a return on investment before they are decommissioned [5]–[7], [9].

The development of independent power projects in the region remains constrained by the limited availability of debt finance for project implementation [5]–[7]. Moreover, the limited nature of the available capital from the handful of development finance institutions or commercial banks and the high risk typical of most electricity markets in the region ensures that debt finance is raised at high interest rates. The administrative inefficiencies inherent in these traditional financial institutions also ensures that independent power projects obtain the required debt finance for project implementation only after an arduous and long voyage [5]–[7], [9], [10].

Decentralized Finance (DeFi), an umbrella term connoting blockchain-based financial services, provides compelling opportunities in electricity projects financing, which have historically been burdened by bureaucratic processes [10], [11]. DeFi instruments are essentially a second layer application developed on a – *blockchain* – an immutable and decentralized ledger that facilitates transparent and secure transactions between multiple, disparate and anonymous parties [6], [11]–[13]. DeFi instruments are underpinned by – *smart contracts* – self-executing chaincode governed by predefined terms and conditions for handling data and cryptographic assets [6], [11]–[13].

The employment of DeFi instruments to raise finance for electricity infrastructure projects are not new. In the electricity industry, DeFi instruments have been proposed to generate finance for small-scale renewable electricity projects via crowdfunding [14]–[17]. Early results here indicate that they can ease finance mobilization for project implementation [15], [16]. Although DeFi instruments are recording early successes in obtaining the finance required for implementing small-scale renewable electricity projects, they are limited in their design [14]–[18]. Essentially, they do not actually mitigate the investment risks of a venture, rather they distribute these risks amongst many lenders to achieve competitive interest rates [14]–[18].

To this end, we propose a novel blockchain-based special purpose vehicle (SPV) that automates and thus streamlines the processes in the financial layer of an SPV. Our approach facilitates seamless finance mobilization and revenue disbursal amongst two distinct types of investors: the shareholders who are the owners of the project and provide equity and the crowd known as the decentralized lenders who are incentivized to provide debt finance for the project. Further, it incorporates a collateralization mechanism into the revenue collection component of the blockchain SPV within the smart contract to hedge the credit risk posed by the offtaker, the entity that serves as the electricity buyer under a power purchase agreement. Our blockchain SPV is, therefore, a transparent, frictionless, risk-distributed, risk-mitigating, and autonomous DeFi instrument underpinned by the *crowd* to streamline the process of debt finance mobilization, revenue collection and revenue disbursal for independent renewable electricity projects in Sub-Saharan Africa.

II. Methodology

The development of independent power projects in the region is constrained by the limited availability of debt finance. Moreover, the limited capital and bureaucratic burden of traditional financial institutions along with the high risks in the region ensure that independent power projects mobilize the required debt finance only after a lengthy process and at high interest rates. Therefore, we propose a DeFi instrument, a blockchain-based SPV that addresses the root cause of the aforementioned development constraints. The DeFi instrument streamlines the processes in the financial layer of a traditional SPV – finance mobilization, revenue collection and revenue disbursal. Specifically, it facilitates the mobilization of finance for the SPV from a location-independent crowd, the revenue collection from the electricity offtaker in a risk-mitigated manner, and disbursal of eventual project revenues to investors.

The financial layer of the blockchain SPV is governed by two contracts: a traditional legal contract and a smart contract as in Fig. 2. A fundamental assumption made in this paper is that the smart contract has been integrated to a stablecoin[1] cryptocurrency service, in such a way that US$1 equals 1 stablecoin [11], [13]. Therefore, throughout the rest of this paper, the off-chain fiat currency US$ is equivalent to the blockchain stablecoin cryptocurrency.

There are two distinct types of investors in the project: the shareholders and the decentralized lenders. The shareholders are the legal owners of the project's physical assets and provide the project's equity. They are originally constituted off-chain under a traditional shareholder's agreement at the outset of the project. Although the shareholder's agreement is a traditional off-chain legal contract, the key terms of the agreement such as the stake of each shareholder in the SPV are immutably written into the smart contract following consensus by the shareholders.

We propose that at a later stage, the shareholders mobilize debt finance for the project on the blockchain from another type of investors known as decentralized lenders. Shareholders achieve this by issuing an initial coin offering program whose terms and conditions are embedded in a loan agreement. In such a scheme, the shareholders define the number and price of tokens that match the total investment cost of the project. Thereafter, they distribute the tokens amongst themselves as per the off-chain equity they provided at the inception of the SPV. Finally, they sell the remaining tokens in an open and public blockchain marketplace. Importantly, the remaining tokens match the quantum of debt finance they seek to mobilize for project implementation. Decentralized lenders are incentivized to purchase these tokens as holding them entitles them to future revenue streams, in a way fully governed by the smart contract.

Before an initial coin offering program can be issued, the revenue stream of the project must be secured. In this context, revenues for the project is mainly obtained from the offtaker, the buyer of the electricity generated from the project. A power purchase agreement between the shareholders and the offtaker is, therefore, used to secure the revenue stream of the project. Although the power purchase agreement is negotiated off-chain as in traditional legal contracts, the agreed terms needed to enhance autonomous revenue collection are immutably written into the smart contract prior to the issuing of the initial coin offering by the shareholders. Beyond leveraging a smart contract to facilitate seamless revenue collection from the offtaker, we employ a collateralization mechanism to mitigate the high credit risk posed by the offtaker.

As the project commences operation, the investors receive periodic revenue streams. The revenue disbursal to these investors is autonomously managed by the smart contract as detailed in the shareholder's agreement for the shareholders and loan agreement for the decentralized lenders. Therefore, the disbursement of cash flows in the SPV to the project's investors are frictionless. Overall, the three key players in the financial layer of our proposed SPV are the shareholders, decentralized lenders, and offtakers. The activities of these key players are managed by the smart contract. Hence, these entities need not directly interact with each other, rather they operate in accordance with the predefined agreements embedded in the business logic of the smart contract.

A. Finance Mobilization

The finance cost F for the project is obtained from two distinct types of investors: shareholders and decentralized lenders. On the one hand, equity funds E are provided off-chain by j^{th} shareholders at the outset of the project. On the other hand, debt contributions D for the project are mobilized by the shareholders on the blockchain at a later stage from k^{th} decentralized lenders. The composition of the total finance cost for the project is shown in Equation 1.

$$F = \sum_{j=1}^{J} E_j + \sum_{k=1}^{K} D_k \tag{1}$$

1) Coin Distribution: At the outset of the project, shareholders provide off-chain equity funds for the project and in return, they receive an ownership stake in the SPV. Their ownership stake is thereafter immutably written into the smart contract. The funds injected by the shareholders at the project inception are typically used to undertake feasibility studies for the project. However, for the project to advance to construction, the SPV must reach financial close[2]. To raise debt finance for the project and thus reach financial close, we propose the employment of an initial coin offering. Here, the shareholders allocate a number of tokens at a price that matches the total investment cost of the project. Thereafter, they assign tokens to themselves as per the equity stake provided by them. Finally, they publicly sell the remaining tokens in a blockchain-based marketplace. The buyers of these tokens, called decentralized lenders essentially provide debt finance for the project. They are incentivized to purchase these tokens, as a long-term holding will entitle them to future revenue streams that include their investment and interest, in a way fully governed by the smart contract. The token holdings of the lenders are immune to tampering and cannot be subsequently overridden by the shareholders [14]–[16], [18].

2) Shareholders: Shareholders are the legal owners of the project. They essentially invest in the project with the expectation of earning a return on their investment over the duration of the project's power purchase agreement. We propose that each year, the smart contract initiates a transaction to each of the shareholders. The distribution of these earnings is proportional to the stake of the shareholders in the SPV. The annual payments disbursed to each shareholder S by the smart contract over the duration of the project is as Equation 2. In Equation 2, p represents the profit due to the shareholder and y the number of years of the power purchase agreement.

$$S = \frac{E_j + p}{y} \tag{2}$$

[1]A cryptocurrency that is pegged to a fiat currency to limit the currency volatility risk inherent in blockchain native currencies.

[2]When the funds required for project implementation has been fully mobilized

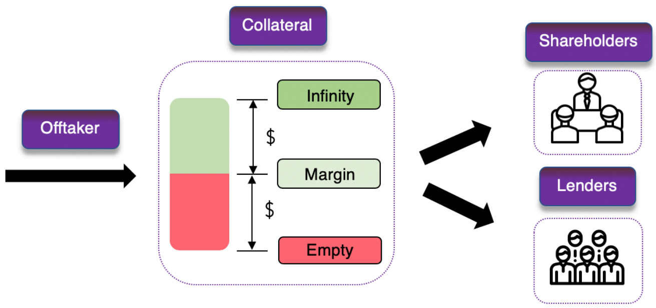

Fig. 3. Simplified revenue collection and disbursal of the SPV

3) Decentralized lenders: The decentralized lenders are critical players in the SPV because they typically provide the bulk of the project finance. We propose that the returns of the lenders are governed by a *mortgage amortization* debt service mechanism. In this method, the smart contract initiates a constant installment payment to the decentralized lenders all through the loan tenor t of the debt [9]. This payment comprises the debt principal L and interest I as indicated in the blockchain loan agreement between the shareholders and the decentralized lenders. The annual debt service Y paid to the decentralized lenders by the smart contract is represented in Equation 3. In Equation 3, r is the interest rate.

$$Y = \left(\frac{r \times L}{1 - (1 + r)^{-t}} \right) \tag{3}$$

It is important to note that while the annual debt service amount is uniform over the loan tenor, the principal and interest vary. Equation 4 shows the interest component of the annual debt service over the duration of the loan tenor. In Equation 4, B represents the beginning balance of the loan yet to be repaid and N is the number of payment periods.

$$I = B \times \frac{r}{N} \tag{4}$$

B. Revenue Collection and Disbursal

The offtaker is the buyer of the electricity and the principal source of revenue for the project. The revenue stream for the project is governed by the off-chain negotiated power purchase agreement between the offtaker and the shareholders. Power purchase agreements are essentially what makes an independent power project bankable since lenders rely on them to substantiate the cash flow forecasts that constitute the basis for loan repayment [9], [19]. For the project to be deemed bankable, the total revenue R due to the SPV and payable by the offtaker must satisfy the condition in Equation 5.

$$R \geq \Big((S \times y) + (Y \times t) \Big) \tag{5}$$

Offtakers in most electricity markets in Sub-Saharan Africa pose a high credit risk to independent power projects which often make debt finance mobilization more onerous and expensive. To mitigate the high credit risk, we propose the employment of a collateralization mechanism within the smart contract to hold the value of a pre-defined period's worth of power purchase agreement cash flow payable to the independent power project. Some financial institutions already offer this type of service to provide greater comfort for independent power projects [5], [7]. However, the SPV will totally eliminate the need for a third-party. The maintenance margin M requirement[3] of the offtaker in the smart contract becomes as in Equation 6. In Equation 6, h is a pre-selected percentage that defines the fraction of the total revenue due to the SPV that must be reserved as collateral by the offtaker in the smart contract.

$$M \geq h \times R \tag{6}$$

Revenues collected from the offtaker are autonomously disbursed by the smart contract to the investors, starting from the decentralized lenders, as is the usual practise in project finance [9], [19]. Hence, investors will not have a cause to contest financial transactions. Revenue collection and disbursal in the SPV could look like Fig. 3.

III. Results and Discussion

A. Results

To demonstrate the workings of our proposed blockchain-based SPV, we outline its potential implementation in the development of an independent renewable electricity project in Sub-Saharan Africa. The notional project is a 20MW solar PV power plant situated in Tororo, Uganda. Following the completion of pre-feasibility studies, it is concluded that the average daily duration of power delivery from the plant is 6 hours and that the total (feasibility study and construction) cost of the project is US$25 million. At an assumed gearing ratio[4] of 80:20, the equity funds that are required to be mobilized for project implementation amounts to US$5 million, while debt amounts to US$20 million. Of the total project cost, the feasibility study cost is US$1 million and the construction cost is US$24 million. The feasibility study cost is funded from the shareholders' equity of US$5 million contributed off-chain at project inception.

Thereafter, a 20-year, build-own-operate and take-or-pay power purchase agreement at a tariff of US$c4/kWh is negotiated and signed off-chain with the state-owned offtaker Uganda Electricity Transmission Company Limited. In the power purchase agreement, a h value of 5% is selected for the maintenance margin determination of the offtaker. This h value selection implies that at least a year's worth of cash flow must be reserved by the offtaker in the smart contract. Following signing of the power purchase agreement, the shareholders proceed to raise the funds required for project implementation. Therefore, they issue an initial coin offering program on a blockchain marketplace, where they allot 2.5 billion tokens at a rate of US$cent1 per token. At this price, the total value of the tokens is US$25 million which is equal the total investment cost of the project.

Of these allotted tokens, the shareholders distribute 0.5 billion tokens (US$5 million) amongst themselves as per their

[3]The minimum financial asset value that must be reserved in a collateral account by a contracting counterparty to mitigate credit risk.

[4]Ratio of debt to equity in project finance

TABLE I.
SPECIFICATIONS AND KEY AGREEMENTS OF TORORO CASE STUDY

Project Specifications	Input
Renewable energy technology	solar PV
Location	Tororo, Uganda
Capacity	20MW
Feasibility study cost	US$1 million
Construction cost	US$24 million
Total cost	US$25 million
Average daily duration of power	6 hours
Loan Agreement	
Gearing ratio	80:20
Allotted tokens	2.5 billion
Token price	US$cent1
Loan tenor	20 years
Interest rate	3.1%
Number of payments per year	1
Power Purchase Agreement	
Duration	20 years
Delivery mechanism	build-own-operate
Supply agreement	take-or-pay
Tariff	US$4/kWh
h value for maintenance margin	5%

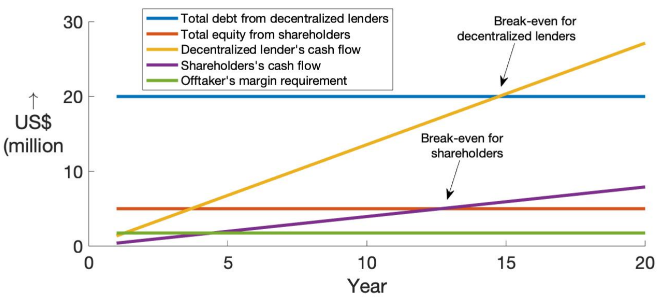

Fig. 4. Positive cummulative cashflows of the decentralized lenders & shareholders and maintenance margin requirement of the offtaker over the power purchase agreement duration

off-chain equity share in the SPV. Thereafter, they sell the remaining 2 billion tokens on an open and public blockchain market place. The sold tokens amount to US$20 million which is the debt finance amount required by the shareholders to reach financial close. The holders of these remaining tokens are called the decentralized lenders. With these tokens, they can directly redeem a share of the future revenues of the project by interacting with the blockchain-based smart contract. Other key terms of the debt obtained from the initial coin offering program include a loan tenor of 20 years and an average interest rate of 3.1% for all decentralized lenders. The agreed number of payments per year is one. The summary of our project specifications, power purchase agreement, and loan agreement assumptions are presented in Table I.

The smart contract autonomously disburses the earnings due to each investor as the revenues are paid by the offtaker. The distribution of the revenue to the investors in the smart contract is dependent on the number of tokens held by each investor in the smart contract. Hence, each year, investors can invoke

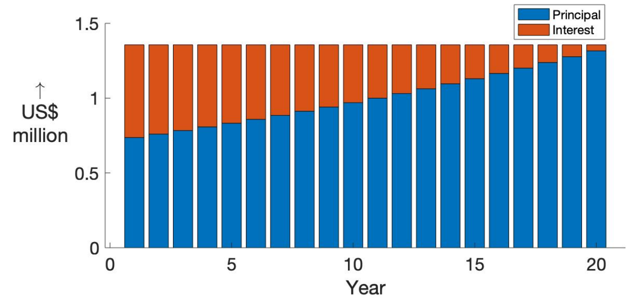

Fig. 5. Disaggregated components of the annual debt service due to the decentralized lenders

TABLE II.
OUTPUTS FROM SIMULATION

Parameters	Output
Total revenue	US$35.040 million
Total debt service	US$27.135 million
Total payment due to shareholders	US$7.904 million
Break-even point for shareholders	Year 13
Break-even point for lenders	Year 15
Margin requirement of offtaker	US$1.752 million

a withdrawal of their dues from their accounts in the smart contract. We simulate the cashflows of the shareholders and decentralized lenders of the SPV and show the margin that must be maintained by the offtaker (see Fig. 4). For simplicity's sake, the time value of money due to inflation and other factors such as depreciation, etc. are ignored here. The annual debt service due to the decentralized lenders is disaggregated into the principal and interest components as in Fig. 5. The summary of the key outcomes of the simulation are shown in Table II.

B. Discussion

From the results, it is evident that our proposed blockchain SPV realizes the same final outcome of raising debt finance for project implementation as in traditional financial institutions and commercial banks. This debt could also be raised within a very short time since the bureaucratic burden of these traditional financial institutions are effectively sidestepped. Moreover, our proposed blockchain SPV is highly liquid because the initial coin offering scheme at the finance mobilization phase opens up a whole world of location-independent potential investors.

Our proposed blockchain SPV also reduces the cost of obtaining debt capital by distributing the investment risk amongst thousands or millions of people rather than concentrating the risk to one or few financial institutions as in the traditional financing system. Transactions are frictionless between the key financial players of the SPV because the smart contract autonomously handles coin distribution and revenue sharing amongst financiers. The investments and returns of the investors are fairly stable since a stablecoin is integrated into the smart contract of the SPV. The credit risk of the off-taker is also hedged to reduce the overall risk of the venture. This lowered risk is reflected in the low interest rate (approximately

TABLE III.
SUMMARY OF THE KEY BENEFITS OF A BLOCKCHAIN SPV

Features	**Blockchain SPV**	**Traditional SPV**
Finance cost	Low	High
Finance mobilization speed	Fast	Slow
Risk profile	Distributed	Concentrated
Risk level	Medium	High
Administrative efficiency	High	Low

3%) of our proposed blockchain SPV. The summary of the key benefits of a blockchain SPV is shown in Table III.

It is important to note that although the credit risks posed by the offtaker is reduced, the risk remains. This is due to the fact that at any point, the offtaker can cease to make payments into the smart contract, which will suspend the cash flow due to the investors. In this scenario, the offtaker only forfeits its collateral in the smart contract to the SPV. Further, our blockchain SPV introduces new risks to the key players of the SPV. First, the smart contract that governs the operation of these players following deployment on the blockchain can be vulnerable to new attack vectors. The integration of another DeFi instrument – the stable coin service – also makes the smart contract susceptible to *reliance risk*. Lastly, the key players of the SPV are vulnerable to account risks [20]. Account risks scenarios include funds transfer to an invalid or wrong public address[5], implying the loss of funds forever. It can also be the loss of a player's private key[6], which means that the funds associated with that key are irrecoverable [20].

IV. Conclusion

Sub-Saharan Africa faces a double challenge of achieving industrialization while taking into account the realities of the global environmental imperatives. Fortunately, the industrialization impetus in the region corresponds with the period where clean and renewable electricity is becoming mature and competitive. Although financing renewable electricity projects have been challenging, a number of independent power projects have navigated through the difficult terrain in the region to reach financial close and operate successfully. Therefore, the introduction of our proposed blockchain SPV will reduce independent power projects' reliance on traditional financial institutions and commercial banks. This new alternative will lead to the exponential development of independent power projects, thus bridging the electricity gap in the region. Future iterations of this project will involve further development of the collateralization mechanism and the employment of new incentive mechanisms to attend to other risks peculiar to electricity markets in the region.

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[5]Public address holds funds for users on a blockchain network.

[6]Private key is what grants a user ownership of the funds on a given public address.