

Full-length article

Catalysing decentralised renewable energy investment in Nigeria: Investor-focused risk evaluation and de-risking strategies

Z.Y.I. Abba , N. Balta-Ozkan ^{*} , G. Drew

Faculty of Engineering and Applied Sciences, Cranfield University, College Road, Cranfield MK43 0AL, United Kingdom

ARTICLE INFO

Keywords:

Decentralised renewable energy investment risks
Investment risk evaluation
Risk mitigation
Holistic risk management
Analytical hierarchy process

ABSTRACT

Scaling up private investment in Decentralised Renewable Energy (DRE) is crucial for achieving universal electricity access in sub-Saharan Africa. Tailored de-risking actions based on investors' risk perceptions can facilitate investment. However, current literature provides a fragmented perspective of investor-specific DRE investment risks. Through a multi-step participatory approach involving an online survey, focus groups, and interviews, 40 multidimensional risk factors across six categories were evaluated using the analytical hierarchy process, to establish their significance among four investor groups: development finance institutions, domestic finance institutions, developers, impact investors. Overall, economic and financing risk categories emerged as most critical, while social and environmental risks were least prioritised. However, risk factor priorities varied among different investor groups, highlighting key mutual high-priority risk factors amounting to 37–58 % of risk weighting including currency volatility, low access to low-cost capital, revenue risk, and insecurity. Limited awareness of existing risk mitigation practices, cultural and behavioural barriers to energy use, and path dependence were identified as influential risk drivers. Evidence-based risk mitigation strategies such as priority sector lending mandates, portfolio aggregation, stronger policy implementation, social interventions, collaboration, and capacity development are recommended to facilitate DRE investment. This study serves as a reference for decision-makers to prioritise actions for catalysing DRE investment.

Abbreviations

AHP	Analytical Hierarchy Process
DFI	Development Finance Institutions/Multilateral Agencies
DisCo	Distribution Company
DomDFI	Domestic Development Finance Institution
DomFI	Domestic Finance Institution (Local Bank)
DRE	Decentralised Renewable Energy
E1	Revenue risk
E2	Collection losses
E3	Foreign exchange volatility
E4	Inability to achieve single off-taker or cluster effect
E5	Non-cost reflective tariff
EPSRA	Electric Power Sector Reform Act
F1	High cost
F2	Inadequate access to low-cost capital
F3	Short loan terms
F4	Limited local financial sector experience
F5	Limited financial capacity and experience of developers/ local investors
F6	Difficulty accessing/repatriating Foreign Exchange
FiT	Feed-in-Tariff

(continued on next column)

(continued)

FGN	Federal Government Nigeria
FX	Foreign Exchange
GW	Giga Watt
HC	Hard currency
IEDN	Isolated Electricity Distribution Network
IMG	Interconnected mini-grid
IPP	Independent Power Plant
M1	Sensitivity of RE to fossil fuel prices
M2	Low competitiveness of RE due to subsidies on alternatives
M3	Lack of competitive hardware and labour market
M4	Poor data availability
M5	Barriers due to regulations
M6	Uncertain market growth potential
MW	Mega Watt
MYTO	Multi-year tariff order
NBET	Nigeria Bulk Electricity Trader
NERC	Nigerian Energy Regulation Commission
P1	Insufficient policy/legal support framework
P2	Unclear regulations/guidelines
P3	Policy changes

(continued on next page)

* Corresponding author.

E-mail address: n.ozkan@cranfield.ac.uk (N. Balta-Ozkan).

(continued)

P4	Lack of policy implementation
P5	Duplicative policy development
P6	Inconsistent policy application
P7	Uncertainties in IMG regulations implementation
P8	Grid extension uncertainty
P9	Political changes/instability.
P10	Inadequate political will
P11	Adverse political events
PI	Public institutions
PP	Policy and Political Risks
REFiT	Renewable Energy Feed-in-Tariff
RPS	Renewable Portfolio Standard
RPO	Renewable Purchase Obligation
SAS	Stand-alone system
SE	Social and Environmental Risk
SE1	Lack of social acceptance
SE2	Poor consumer awareness
SE3	Lack of integration of RE systems
SE4	Difficulty in acquiring land
SE5	Insecurity
SHS	Solar Home System
SSA	Sub-Saharan Africa Countries
T1	Limited training and Research and development (RD)
T2	Technical skills limitation
T3	Limitations in developer's capability
T4	Limitations in quality control (QC) and manufacturing capacity
T5	Uncertain load profile
T6	Inadequate infrastructure
T7	Uncertainty in site characteristics
WTP	Willingness to pay

1. Introduction

The deployment of decentralised renewable energy (DRE) is crucial to achieving universal electricity access and climate change targets in sub-Saharan African countries (SSA), where over 550 million people lack reliable electricity [1]. DRE involves small-scale off-grid, electricity generation and distribution from RE sources near consumers. Examples include solar mini-grids and standalone systems (SAS). DRE offers economically and environmentally favourable solutions for 60 % of this population — primarily due to the distance of the population from existing grid infrastructure or its unreliability and the abundance of renewable energy (RE) sources [2–4]. Despite the significance of DRE achieving the sustainable development goal (SDG) 7 agenda of ‘universal access to affordable, reliable, sustainable and modern energy for all’, IRENA [1] reveals DRE investment is inadequate, especially in SSA, where only 25 % of the 2021 need was met.

Nigeria, accounting for >23 % of the SSA population without reliable access, illustrates SSA countries’ broader challenges in bridging the gap between ambitious SDGs and the requisite DRE investment levels. The government aims to address electricity access alongside climate commitments by targeting a 17–20 % RE contribution to the electricity mix, allocating 5–12 % to solar photovoltaic (PV) technology, including solar mini-grids [5]. Solar mini-grids represent up to 40 % of the US\$35 billion DRE investment needs in Nigeria’s energy transition plan (ETP) [6]; nearly equivalent to Nigeria’s 2022 budget, highlighting the need for increased private investment amid competing development needs [1]. This study focuses on solar mini-grids due to their prominence in Nigeria. Despite abundant solar irradiation, policy developments and funding programs such as the Nigeria Electrification Program (NEP), the expansion of mini-grid investment remains constrained; limited by barriers such as high cost of capital and poor consumer affordability. Consequently, <10 MW was installed in 2022, falling short of the planned 2.6GW for mini-grids by 2030 [6,7].

The necessary level of investment mobilisation requires increased participation of various private investor groups [8]. Investment in developing countries are perceived as high risk, driven by location-specific factors and uncertainties, which impact costs and

competitiveness [9–11]. Studies have thus identified unattractive risk-return profiles contributing to low private investment in SSA [12–14]. Risk-return profiles can be improved through holistic risk management (RM) [15], encompassing identifying, analysing, and evaluating multidimensional risks and their interdependencies, followed by identifying effective risk mitigations, which can enhance investor appetite [16–18].

Consequently, there is extensive risk evaluation literature for renewable energy (RE) in developing and developed countries [15,19]. However, DRE risk literature in SSA countries is scant and presents a fragmented approach to RM [15]. The studies often overlook multidimensional perspectives encompassing technical, policy, political, market, economic, financing, social, and environmental risk perspectives, and their interdependencies [20–22]. Furthermore, the difference in risk priorities across geographical locations [23,24] and among actors [25–27], highlights the need for location- and investor-specific risk studies. Yet, there is limited empirical data on evaluating diverse investor perspectives of risk priorities and potential mitigations towards mobilising investment especially in SSA countries such as Nigeria [15, 23–25].

Many studies have identified risks and barriers to RE deployment in Nigeria. These include regulatory and policy uncertainty [20–22, 28–30]; market, political and economic constraints associated with rentierism and their interactions [31]; economic and financing barriers, such as non-cost reflective tariffs [20,29], collection losses [29], high cost [20,29,30], limited access to financing [21,28,29,32]. Others include social and technical barriers such as social acceptance and insecurity [20,21], low technical skills [20,28] and potential for infrastructure underutilisation [29]. The existing literature often addresses these risks within specific, limited risk dimensions—technical [20,28, 29], economic [20,29–31], policy [20–22,28–30], financing [28–30, 33], political [28,29,31] and social perspectives [20,21]. Additionally, the criticality of risks —though acknowledged in the literature — are not systematically evaluated from the Nigeria DRE investor perspective. The lack of holistic and systematic risk prioritisation among investor groups can limit the development of targeted policies [34]. This study seeks to address the questions: (i) what are the key risks for DRE investment in Nigeria and how do they vary by investor group? (ii) how can the most significant risks be effectively mitigated?

This study aims to apply a holistic RM framework [15] to evaluate risks and identify mitigation strategies as perceived by four distinct investor groups and other key DRE actors in Nigeria. It enriches the understanding of investor risk perceptions in Nigeria’s DRE sector through a participatory approach involving investors and other actors and offers three contributions. Firstly, this study confirms relevant DRE investor risks in a mixed-methods research and presents new empirical data on the differences in risk priorities among investors (and other actors). In contrast, the previous risk studies [20,35–37] predominantly reviewed risks from a single investor perspective. Secondly, it reveals empirical data on high priority risk factors for DRE investors in Nigeria. Lastly, it enriches the literature by providing a nuanced understanding of the shift in the risk landscape, risk drivers, and their potential mitigations. For example, unlike previous studies [20,21] which found social and technical factors among the prominent risks, this study found economic and financial risks as the high-priority risks. These outputs can be valuable for policymakers, researchers, and investors offering insights into priority risk mitigation actions as perceived by the investors.

1.1. Nigeria electricity sector

Nigeria’s electricity mix consists of a centralised grid supply (86 % from thermal and 14 % from hydroelectric sources), alongside decentralised generation from fossil and RE sources [38]. Of the 13 GW installed grid capacity, actual supply is limited to 4–6 GW due to challenges such as gas supply, transmission, distribution, and revenue issues [39,40]; while peak electricity demand, currently 24 GW, is projected to

increase fivefold by 2030 [5]. Consequently, 127 million people—66 % of Nigeria's population, mainly in remote, rural, and peri-urban areas—experience either no (43 %) or unreliable (23 %) electricity access, making DRE a viable solution (Fig. 1). The electrification gap is partly addressed by private fossil fuel generators, providing an estimated 10–15GW of backup power annually, impeding net-zero goals [41]. Whilst a relatively minor component of the current electricity mix, DRE deployment is expanding, supported by the ETP and evolving landscape of policies and programs.

1.1.1. Policy landscape

The ETP has set ambitious targets for electrification aiming to achieve a clean energy transition towards carbon neutrality by 2060 and SDG7 in conjunction with sustainable economic growth [6]. Within the ETP framework is the strategy to deploy 6.3GW of DRE by 2030. DRE in Nigeria include mainly solar PV isolated mini-grids, SAS and interconnected mini-grids (IMG), which operate in underserved areas with unreliable grid connections. In this study, isolated solar mini-grids and IMGs are collectively called mini-grids. The ETP allocates 2.6GW for solar mini-grids, equivalent to electrifying approximately 600,000 new households annually [6].

The prior unbundling and subsequent privatization of Nigeria's power sector, initiated by the National Electric Power Policy of 2001 and the Electric Power Sector Reform Act of 2005 (EPSRA), resulted in an administrative structure that includes an independent power sector regulator, the Nigerian Electricity Regulatory Commission (NERC), responsible for regulating generation, transmission, and distribution for grid and off-grid systems [43]. The Act facilitated policies, regulations, and programmes supporting DRE deployment as illustrated in the policy evolution timeline in Fig. 2. Key supporting regulations include the 2016 mini-grid regulations [44], which provided guidelines addressing investor concerns such as licensing, consumer and investor protection, and compensatory terms for grid arrival and cost-reflective tariffs, facilitating private off-grid generation of up to 1 MW [20,45]. The EPSRA established the Rural Electrification Agency (REA), which aims to promote electrification through off-grid and grid extension in unserved and underserved communities, offering technical and financial assistance via the Rural Electrification Fund (REF). In 2017, the REF guidelines were operationalised, implementing programs¹ such as the Nigeria Electrification Project (NEP), which offers capital subsidies and technical assistance through competitive tenders for least-cost technologies. Recent regulatory developments include the Mini-Grid Regulations 2023, which update and consolidate regulatory procedures for isolated and interconnected mini-grids [46]. The Electricity Act 2023 [47], which replaced the EPSRA 2005, provides a comprehensive legal framework for Nigeria's electricity sector including integration of RE. This act grants Nigerian states the autonomy to enact laws, issue licenses, and establish power markets for electricity generation, transmission, distribution, and supply within their respective jurisdictions. This encourages the decentralisation of electricity and empowers states to develop strategies to meet their respective electricity demands.

1.1.2. DRE Funding

Before 2005, power projects in Nigeria were predominantly government-funded and politically driven [48,49]. Today, mini-grid

funding is a blend of public and private sources, primarily consisting of grants and concessional debt facilities enabled by factors such as lower technology costs, advancement in business models and the implementation of policies such as mini-grid regulations [1,36,49]. Grants are primarily financed through national budget allocations, regulatory fines, and development agencies. Concessional debt facilities are provided by domestic or international development finance institutions (DFIs) [50]. Impact investment from international organisations offers an additional funding source, encompassing equity, grants, and concessional debt. Domestic finance institutions (DomFIs) also provide local currency debt financing, while project developers contribute equity. Consequently, this study broadly categorises DRE investors in Nigeria into four types: DFIs, Impact investors, DomFIs, and developers.

1.2. Risk evaluation literature

Multi-criteria decision analysis methods such as Analytical Hierarchy Process (AHP) have been widely utilised to evaluate risk perceptions due to their capacity to incorporate multiple actors' perspectives [15, 19]. For instance, Kul et al. [35] employed AHP to determine that economic and market risks were the most significant factors affecting RE investment in Turkey. Conversely, AHP analysis in India [26] highlighted political, technical, financing, and environmental risks as prominent, while in Nepal [37], economic, and political and policy (PP) risks were deemed most crucial. These varying outcomes may be attributed to differences in technological maturity, demographics, resource availability, and country-specific risks influenced by geopolitical factors, policy frameworks, and macroeconomic considerations [9, 16,35–37], emphasising the location-specificity of DRE risks. The risk evaluation studies presented in Table 1, which assess risks from multiple perspectives such as public agencies and industry experts, predominantly treat investors as singular entities. This study, however, broadens the scope to encompass a diverse range of investors.

Adopting Painuly's approach [51] to identifying risks involving literature survey and participatory stakeholder interaction, this study builds on risk factors identified in Abba et al. [15]. This was supplemented by further literature survey using the search terms 'renewable energy risk OR barrier Nigeria' in the Scopus database revealing 40 risk factors which were found to be potentially relevant to DRE in Nigeria (Table A- 1). Fig. 3 presents the identified risk factors, in six risk categories: technical, economic, financing, policy and political (PP), social and environmental (SE), and market risks, according to definitions in previous studies [15,35].

2. Methodology

Effective stakeholder engagement and communication are crucial for the success of RM, as per ISO 31,000 guidelines [52]. A participatory approach was thus employed, creating an iterative framework involving DRE actors to collect and evaluate data, and discuss its implications; thereby increasing the relevance and acceptance of the analysis [53]. This participatory process could reconcile risk perspectives of diverse groups, enabling a transition from subjective risk perceptions to evidence-based and enhanced understanding of risk perspectives among investors.

2.1. Data collection

Primary data collection for this study was conducted in two stages. First, an online survey targeting investors (impact investors, developers, DFI, and DomFI) and other stakeholders, including public agencies, development agencies, engineering service providers, utilities and consultants, was administered between August and September 2021 (Fig. 4). A purposive sampling strategy identified individuals with at least five years of DRE sector experience (Fig. 5) through LinkedIn, email

¹ US\$350 million World Bank and US\$200 million African Development Bank facilities, through the Nigeria Electrification Project (NEP) implemented by the REA 1. Launch of the 1 billion Naira Bank of Industry Solar Energy Fund to finance access to RE for micro, small and medium scale enterprises. 2. The 140 billion Naira Solar Connection Intervention Facility from Central Bank of Nigeria to facilitate 5 million new, solar-based electricity connections in off-grid communities. 3. Award of competitive tenders under the mini-grid acceleration partial grant scheme funded by German Agency for International Development through Nigerian Energy Support Programme (NESP)

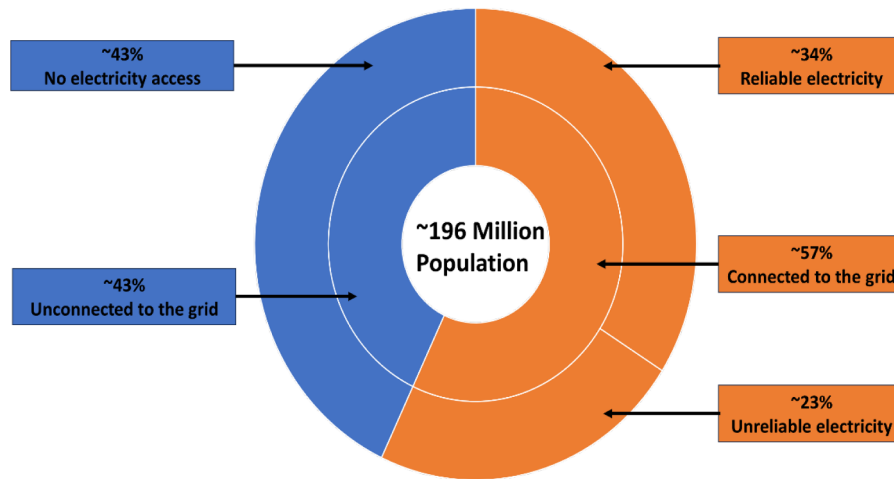


Fig. 1. Electricity Access Status in Nigeria.
Source: Data is from the World Bank [42].

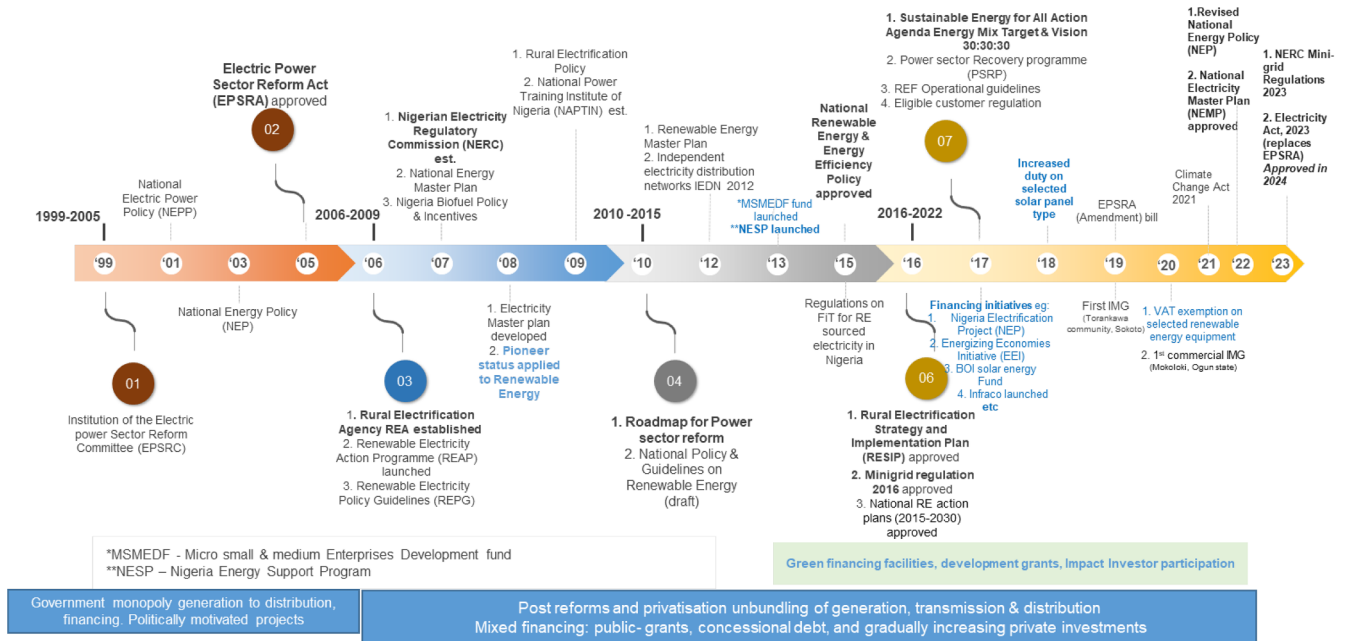


Fig. 2. Nigeria Power Sector Policy evolution and relevant facilitating programs for RE.
Source: Developed by the authors

outreach, and snowball sampling. The survey achieved a 59 % response rate out of $N = 138$. After quality checks,² $N = 70$ responses were analysed. While purposive sampling allowed targeted engagement, a limitation of this study is the lower representation of impact investors. This was mitigated by corroborating results in the interviews.

Second, semi-structured interviews ($N = 17$) and focus groups ($N = 3$) were conducted in July and August 2022; drawing from a subset of willing survey respondents with a minimum of senior management level experience and reflecting PIs and investor groups in the survey (see Table A- 2). Additional participants ($N = 3$), such as the domestic development finance group (DomDFI), were recruited through snowball

sampling further improving investor representation.

2.2. Methodological steps

This study used a mixed-methods approach [15,54] comprising three steps depicted in Fig. 6: Online survey to establish risk factors, AHP to evaluate risks, and a thematic analysis of interviews and focus groups transcripts.³ This study draws on interviews and focus groups to gather feedback on AHP results and gain insights into risk drivers, interdependencies, and mitigations thereby providing qualitative evidence to support the quantitative results and corroborate findings.

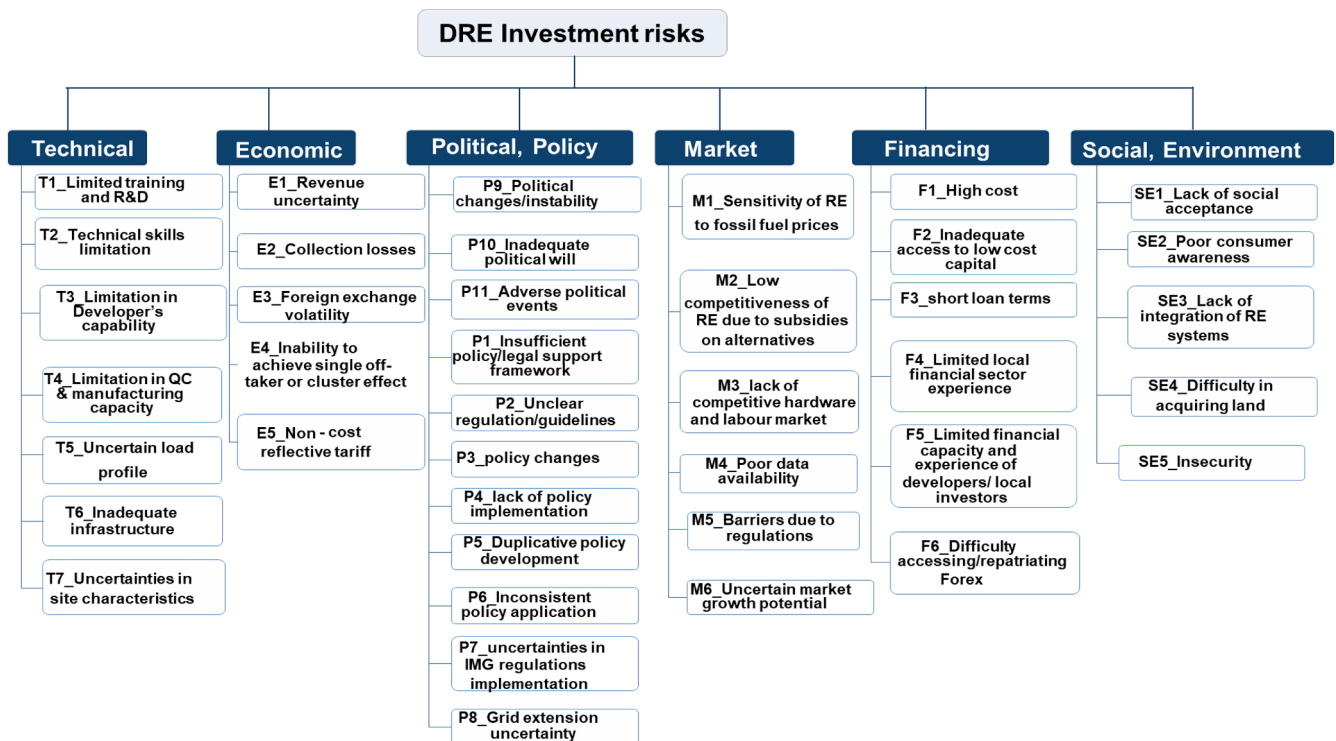
² Excluded responses in quality checks: $N = 8$ did not meet the experience level criteria and $N = 4$ surveys had significantly lower (1-5 minutes) than the expected survey (15-20 minutes) completion times potentially impacting the reliability of responses.

³ While initially only focus groups were planned, some participants' unwillingness to participate in them necessitated using one-to-one interviews. The use of focus groups alongside other qualitative methods in such instances has been demonstrated in the literature (102).

Table 1

Comparison of the number of RE risks or barriers and investor types evaluated in the literature.

Reference	Region	Risk evaluation method	Number of risk or barriers categories and (risk factors)	Number of actors (including investors)	Investor type covered in the study						Investor-specific risk evaluation carried out in the study?
					Private investor type						
					Developer	DomFI	DFI	Impact investor	Type not specified	Utility (public, *public-private)	
[26]	India	AHP	4, [17]	1							x
[35]	Turkey	AHP and Fuzzy weighted aggregated sum product assessment	6, [23]	4	x						
[36]	Ghana	AHP	5, [22]	6							x
[37]	Nepal	AHP	6, [22]	3					x		
[27]	South Korea	AHP	3, [13]	3					x	x	Yes
This study	Nigeria	AHP	6, [40]	8	x	x	x	x		x*	Yes

**Fig. 3.** The hierarchical structure of DRE investment risks in Nigeria.

Source: Abba et al. [9] The following sections present the methodology for establishing the risk priorities (Section 2), Section 3 presents and discusses the results of risk priorities among different investors and recommends mitigations for the priority risks. Section 4 offers conclusions.

In the first step, survey respondents were asked to rate the six risk categories and forty risk factors on a 5-point Likert scale according to their relevance and importance (considering probability and impact) to DRE investment in Nigeria (A.1 details the survey questionnaire). The second step involved using AHP to evaluate survey results and establish the importance of risks and risk factors (elements). AHP has been applied, focusing on country risk studies [26,35] and country barrier studies [36,37]. AHP involves pairwise comparisons of elements in a hierarchical structure representing their relationships (Fig. 3) to establish weighted priorities among them. This study employs the alternative AHP approach proposed by Kallas et al. [55] to assess preferences by collecting direct ratings from respondents using a Likert scale. These ratings were transformed into simulated pairwise comparisons using a formula that approximates the traditional AHP scale. The weighting

process was performed using the traditional AHP geometric mean approach based on these transformed comparisons as detailed in A.3. While the authors [55] highlight weight differences from traditional AHP results, priority levels were the same. Additionally, this method significantly simplifies complex and time-consuming pairwise comparisons by respondents [55].

In the final step, interviews and focus groups were conducted physically and online, lasting 1–1.5 h each, and were audio recorded and transcribed, ensuring informed consent was obtained. The participants were asked the same questions (detailed in Table A- 4) to ensure consistency. Interview responses⁴ were anonymised and identified by a

⁴ Focus group and interview responses are termed 'interview responses'.

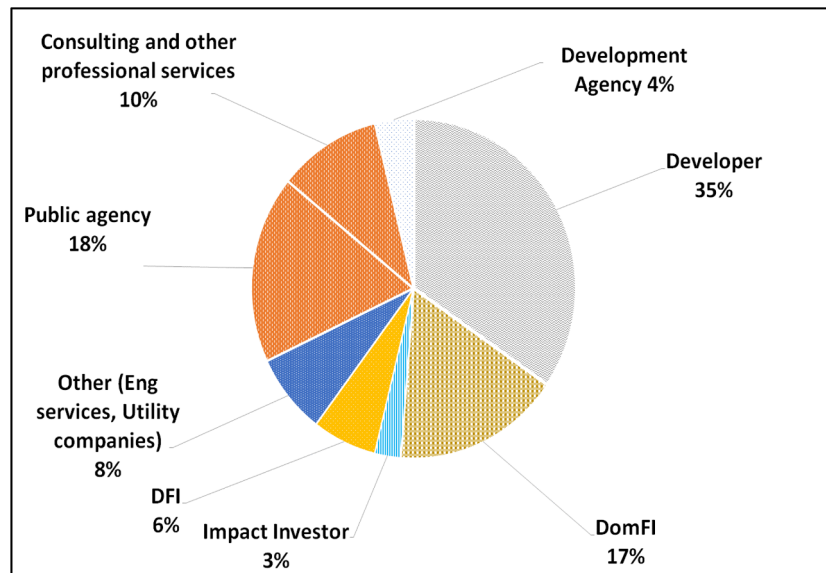


Fig. 4. Survey respondents.

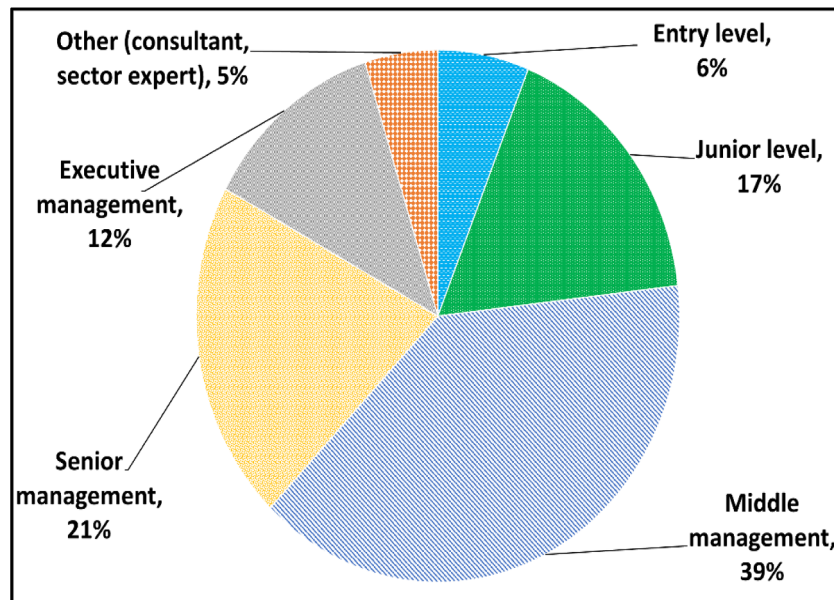


Fig. 5. Survey respondent experience profile.

serialised acronym of the interviewee's group. Data analysis followed a reinforcing approach [36], alternating between interview transcripts and literature to corroborate and contextualise AHP results.

Additionally, the mitigation actions proposed by interviewees were coded and thematically analysed following steps outlined by Braun and Clark [56]; using NVivo software version 14. The coding framework was informed by literature-based mitigation strategies and was adapted to include emergent themes discussed by interviewees.

The analysis (detailed in A.4) involved identifying and assigning codes to text segments related to actionable risk mitigation insights within the transcripts. Subsequently, individual codes were aggregated into broader thematic categories based on investor types, mitigation strategies, and risks. Emergent themes were reviewed to identify patterns, relationships, and discrepancies, leading to the refinement of similar themes. The final themes were: (i) navigating currency risks, (ii) enhancing financing mechanisms and capacity building, (iii) strategies for improving project revenues and viability, and (iv) policy

implementation and enhancements.

3. Results and discussions

3.1. Prioritisation of risk categories

This section outlines the prioritisation of risk categories for the collective group, representing the combined perspective of all survey respondents, and individual investor groups. The CR of <0.1 reflects consistency in the responses. From a collective standpoint, the economic (28.8 %) and financing (28.8 %) risk categories took precedence, followed by PP risks (17 %), technical and market risks (9.8 % each), and SE risks (5.9 %) (Fig. 7).

While individual groups agreed on the low significance of the SE risk category, variations emerged in other categories. For example, economic risk was emphasised among international investors (DFI (44 %) and impact investors (37 %)). Meanwhile, PP risks were additionally

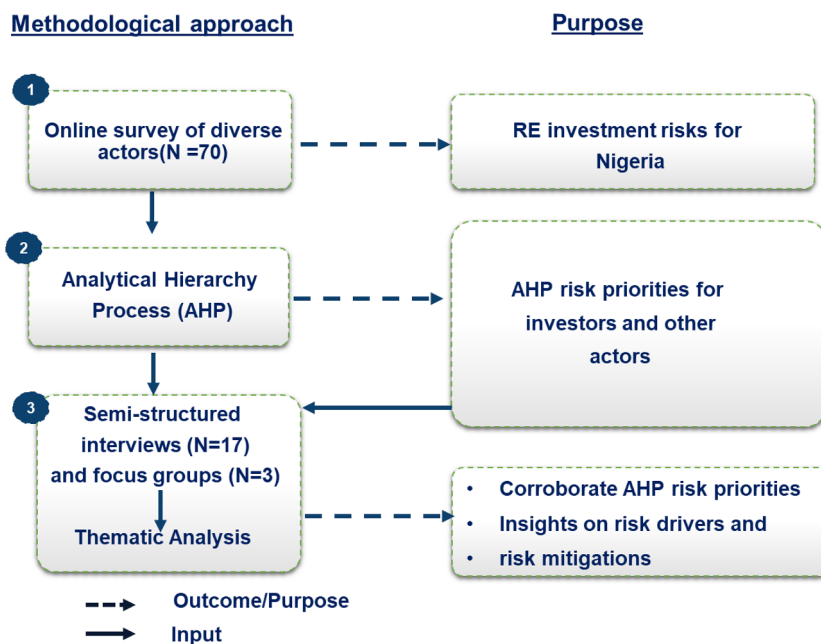


Fig. 6. Three-step methodological approach.

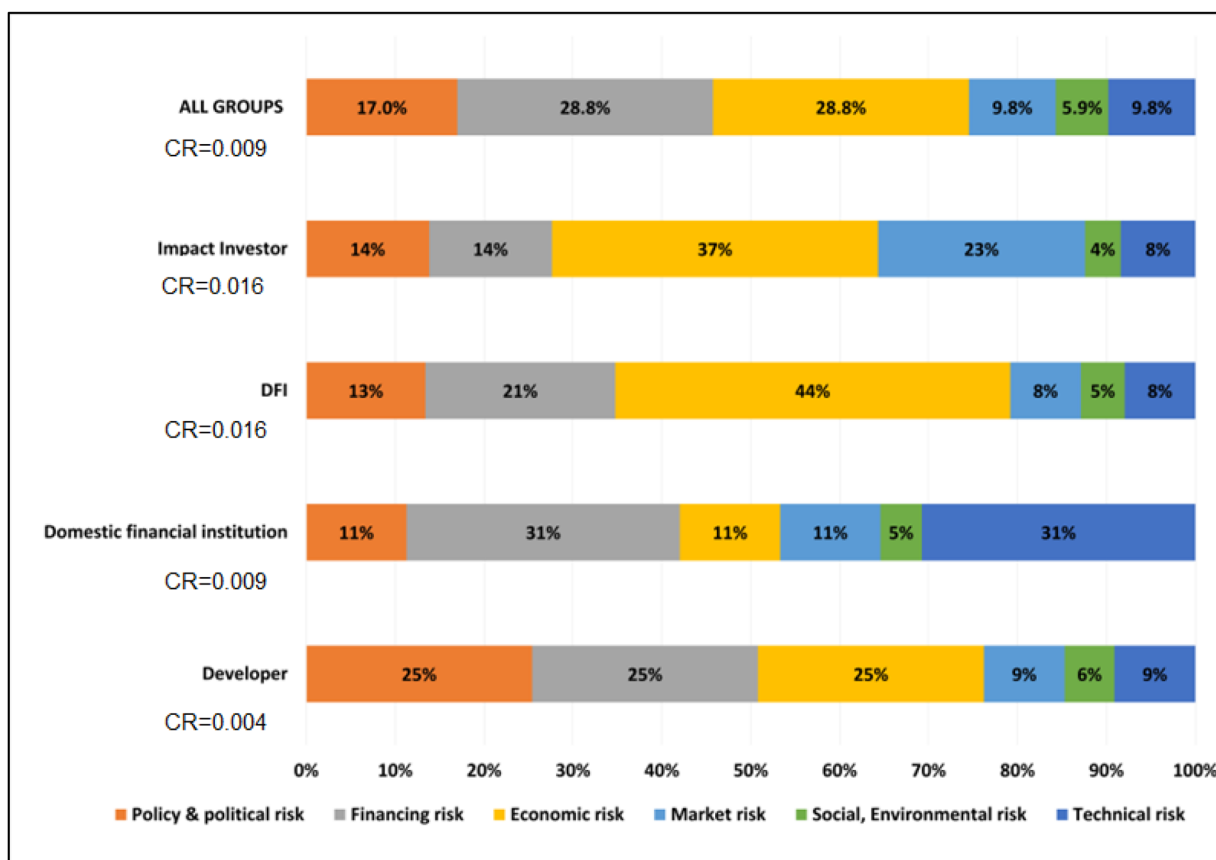


Fig. 7. Prioritisation of risk categories for collective (all respondents) and individual groups.

highlighted by developers (25 % each). In contrast, finance and technical risks (31 % each) were identified as the most crucial investment risks for DomFI. Among other groups, the consulting group closely aligned with DomFI risk perception (29 % each). PI identified economic, financing, technical, and market risks (21 % each) as equally highest priority.

The collective findings depicted in Fig. 7 contrast with results from other countries. For instance, in Ghana, another SSA country, the primary barriers to mini-grid investment were within the political category

[36]. This divergence could be attributed to Ghana's mainly public sector-led approach to mini-grid deployment, contrasting with Nigeria's involvement of both public and private sectors. Furthermore, the Nigerian government's political stability, and commitment, evident through targets and advancements in RE policy development, may contribute to reduced political uncertainty, therefore interviewees didn't see '[policy and political (PP) risks] becoming a future problem' (D1001).

Notwithstanding the emphasis on political stability, the relevance of

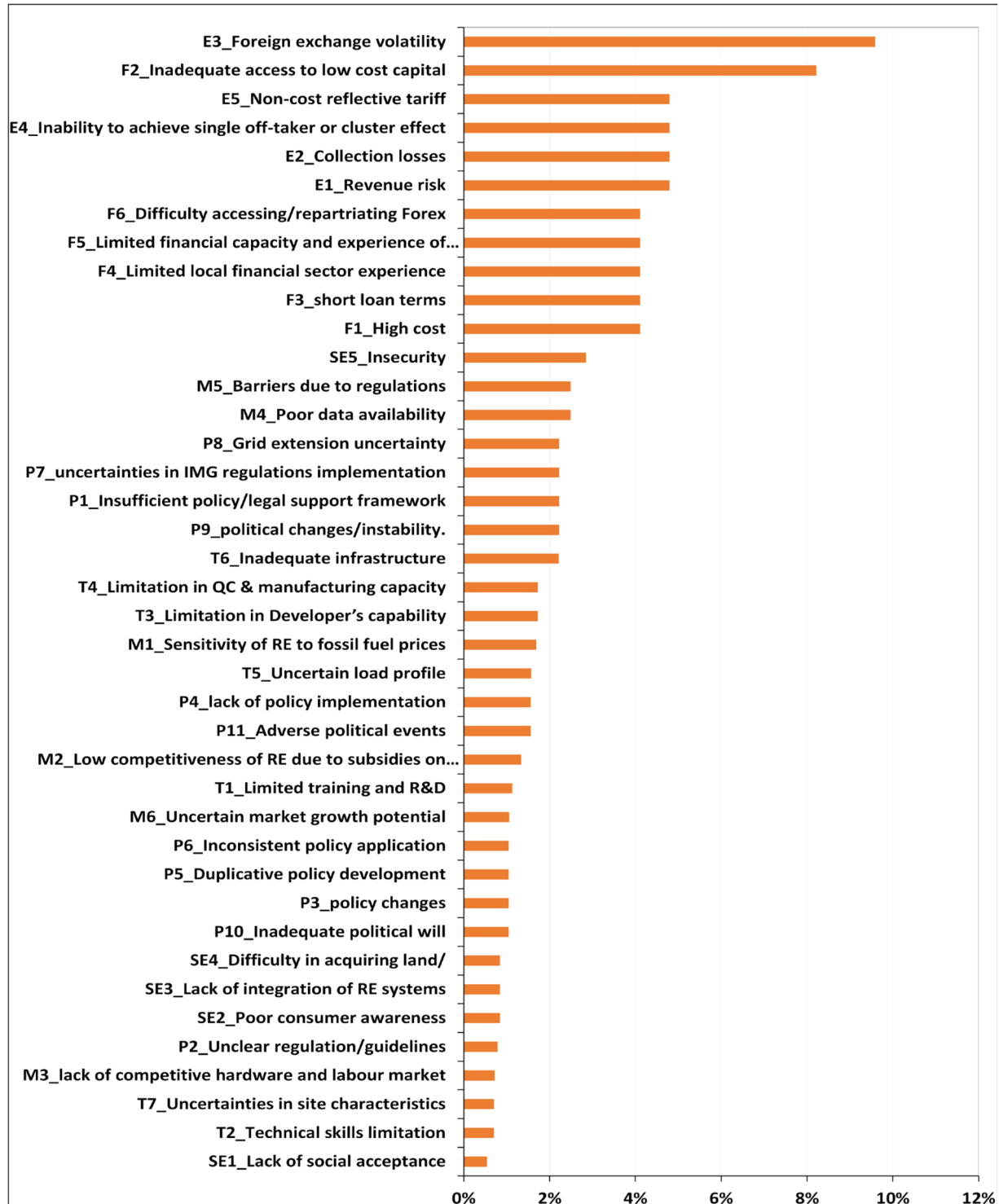


Fig. 8. Overall prioritisation of risk factors by collective (all respondents)).

PP risks persists. Despite the presence of policy frameworks, their inconsistent and bureaucratic implementation is underscored by poor synergies between government agencies, as highlighted by:

'Policy [implementation] is a challenge'...agencies are rarely on the same page so it's a struggle.' (D2001).

Consequently, poor policy implementation has led to value erosion of up to '30 % of grants' (D5001); highlighting the need for its improvement.

The identified variations in risk priorities across countries align with other studies [15,23,35–37], emphasising that risks are contingent on location and necessitate location-specific mitigation strategies. Additionally, diversity of priorities among investors aligns with a previous study [27], which evaluated solar PV investment risks in Korea from the perspectives of two investors (financial investors and private utility companies). The authors [27] revealed economic risk, encompassing financing risks, was the most significant for both investors. However, utility companies found policy risks as the second most significant compared to technical factors for financial investors [27]. This underscores the importance of policymakers considering investor-specific risk priorities when formulating policies to attract investment.

3.2. Overall prioritisation of risk factors

Following precedents [35–37], the overall AHP weights were derived by multiplying a category's weight by each risk factor's weight within that category. This section presents the collective perspective on the overall relative importance of the 40 risk factors (Fig. 8). Additionally,

Table A-5 presents the risk factor priorities for both the collective and individual groups within each risk category and overall.

Overall, FX volatility (9.59 %) was ranked as the first most significant investment risk factor, followed closely by inadequate access to low-cost capital (8.22 %). Revenue risk, collection losses, inability to achieve a single off-taker effect and non-cost reflective tariffs were

ranked equally in third place (4.80 % each). Apart from insecurity (2.85 %), the top five risk factors are rooted in the economic and financing categories, collectively constituting over 50 % of the overall risk factor weightings.

These findings diverge from extant literature in Nigeria [20,21,33, 57], which underscores technical and social risk factors, such as limitations in quality control (QC) and manufacturing capacity (T4), limited training and technical skills (T1), and low adoption. The disparities could be attributed to advancement in the DRE landscape since the previous studies, such as the development of policies facilitating DRE [44], the introduction of standards for solar equipment, and the impact of programmes e.g., capacity building through technical assistance grants [58]. These shifts highlight the necessity of re-examining the risk landscape to identify pertinent mitigations.

Following AHP evaluation, the results were discussed and corroborated in interviews. The following section analyses the top 50 % risk factors overall, their variations among investor groups, and the underlying risk drivers, interdependencies, and mitigations.

3.3. Qualitative discussion of the top 50 % risk factors

3.3.1. FX volatility (E3)

E3 emerged in the top two risk factors in the economic category (Fig. 9), and for all groups excluding DomFI. Specifically, E3 ranks high for international investors '*[considering] lending dollars to an entity that earns Naira and the ability of that entity to change that Naira into foreign currency to pay back [international obligations such as debt]*' (DFI2001). This effect is amplified by the long-term nature of DRE projects. Additionally, the procurement phase is impacted by E3, as imported hardware can contribute to as much as 49 % of mini-grid costs [59]. This impact is notably felt by local developers '*who import.*' (DFI3001). However, E3 is less important '*... if a lender is a local bank [DomFI], it is somebody else's risk as to what that volatility is because you [debtor] are paying them back in any case.*' (DFI2001).

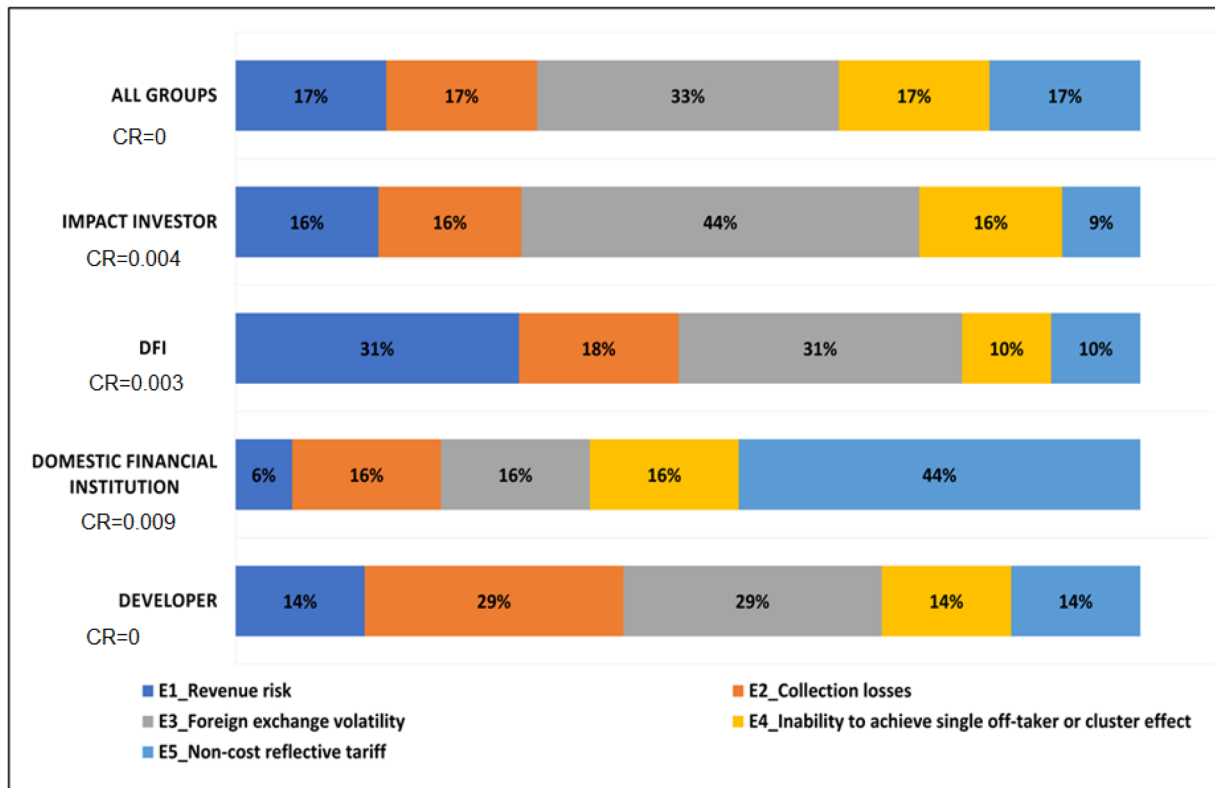


Fig. 9. Prioritisation of economic risks collectively and by investor groups.

These insights show that the importance of E3 for investors is contingent upon factors such as the source of financing, currency denomination, and the entity assuming the risk. This explains why E3 was not ranked as the top factor by DomFIs. While increasing access to domestic financing, as proposed in the literature [9,60], may mitigate exposure to E3 by addressing the currency mismatch challenge, it does not eliminate the residual risk associated with the cost of imported hardware, although a one-time occurrence.

3.3.2. Revenue risk (E1)

Collectively, E1 ranked as the third most crucial risk factor overall (4.80 %) and second in the economic category (see Fig. 9). E1 may arise from a low willingness to pay (WTP), collection losses (E2), the inability to achieve a single off-taker effect (E4), and an uncertain load profile (T5). This uncertainty in demand can be attributed to a poor understanding of customer usage patterns, 'mainly because there isn't data enough [for] a load profile' (DFI2001). Further, while low demand may escalate project unit costs, rendering tariffs unaffordable, higher-than-anticipated demand can significantly impact a project's long-term sustainability. This is because unmet supply expectations may prompt customers to explore alternatives, resulting in lower adoption rates [11]. Additionally, T5 may be influenced by macroeconomic conditions, socioeconomic factors, behaviours, and the ability to pay [11,60]. Macroeconomic factors such as high inflation rates and socioeconomic factors e.g., low commercial activities, can diminish purchasing power [11,60,61]. In situations of limited financial resources, households tend to prioritise more immediate needs, such as food and rent, over electricity, resulting in reduced investment revenues [62].

Furthermore, in rural areas, where mini-grid projects are predominantly implemented, communities often rely on 'seasonal farming and seasonal revenues' (D2001), leading to irregular income [62] and, consequently, unsustainable revenues can occur 'in the first one or two years [of operations].' (D2001). Moreover, some interviewees suggested that behaviours, lifestyle, and cultural practices contributed to low electricity utilisation, thus reducing demand and revenues. One interviewee illustrated this point regarding rural residential customers:

'I think it is more of their lifestyle; maybe some are minimising their usage. For example, instead of using a blender, they prefer the manual means they are used to. Some have TVs, but you find that they barely use a 1-kW load'. (P1001)

However, the interviews also show that while rural consumers 'desire the energy solution', 'they don't have a lot of commercial activity' (D1001) to support productivity and affordability leading to the observed low energy use behaviour. Consequently, an interviewee observed decreased utilisation 'as low as 20 % [...] because consumers "manage" [ration] electricity' (DomFI2001).

These findings align with research [63–65], which suggest generational scarcity—where individuals grow up in environments constrained by limited resources—reinforces cautious consumption patterns. This scarcity mindset can create a sustained cycle of low demand and energy underutilisation, hindering productive use, even when electricity is accessible. Another factor influencing E1 is WTP for electricity, which can vary across locations and is influenced by factors such as education level, income, productive activities, price of alternative sources of electricity [11,66] and conflicting demands of greater urgency [62]. Because of existing subsidies on alternative sources (grid and fossil fuels), there is low awareness of the actual cost of electricity, as '[customers] know the government says [grid electricity tariff] is 30–50 Naira/kWh' [...]; they do not understand 'why [mini-grid tariff] is 180–200 Naira/kWh' (D2001). This preconceived expectation of a low tariff can affect the WTP for electricity. Additionally, some interviewees noted that in instances where mini-grids were implemented as politically influenced constituency projects, there was an expectation within the community that 'electricity is free' (PF1001–1), as noted in the literature [66,67]. Nevertheless, other interviewees indicated variation

in this attitude as while 'some [consumers] know that they should pay', others still believe it is 'the government's responsibility.' (PF3001–7).

The above findings highlight the relevance of E1 and its interdependencies with T5, E4, and E2. Improving these interdependent factors can positively impact E1.

3.3.3. Collection losses (E2)

The survey results revealed that overall, E2 ranked third (4.8 %) aligning with DFI and Impact investor groups (Fig. 8). Similarly, within the economic category, E2 ranked either second or third for all groups, excluding the developer group, which ranked E2 as the most significant (Fig. 9). However, a developer pointed out that 'it used to be an issue' (D3001), indicating disagreement regarding the current importance of E2.

Additionally, interviews identified factors contributing to E2 such as technical losses from the distribution system alongside 'parasitic loads' (D2001) such as metering equipment. Another cause of E2 is commercial losses, which occur when projects are vulnerable to cash-payment misappropriation because 'everything is done [in] cash' (D2001). However, the risk has subdued over the years due to advancements in financial technology, 'metering and extension of telecoms infrastructure' (PF3001–7).

Another contributor to commercial losses is electricity theft [68]. For example, developers recognised 'bypassing meters' (PF3001). This problem is frequent as 'there was one time out of 27 connections in [location], 20 were bypassed.' (D1001). Nevertheless, mini-grids offer developers an advantage in facilitating easier system performance monitoring for prompt intervention facilitated by their smaller scale, 'the intimate knowledge of the customer and the ability to track [...] the energy they use' (DFI1001) compared to the centralised grid, where electricity theft is more prevalent. However, despite measures, such as 'smart meters [...] to reduce [E2]' (D4001), the risk remains considering actions are taken retroactively. Moreover, according to an investor, E2 is still relevant because of the lack of demonstration of consumer 'WTP' and 'ability to pay' (DFI1001) by developers. While the AHP results indicate that E2 is perceived as a high priority for investors, interviews with developers suggest best practices inherently integrated into the projects mitigate E2. This discrepancy highlights a potential lack of awareness among investors regarding the effectiveness of existing risk reduction practices, leading to an inflated perception of risks. To address this, historical project data demonstrating effective risk mitigation could be made available to investors.

3.3.4. Inability to achieve single off-taker effect (E4)

Overall, E4 ranked third (4.8 %), equal to E1, E2, and E5. Among the groups, only the impact investor group aligned with the overall result (Fig. 8). In the economic category (Fig. 9), E4 ranked second among all groups except the DFI group (E4 ranked third).

The creditworthiness of the off-taker, whether residential customers, businesses, or communities, can impact a project's viability [69,70]. Additionally, 'depending on whether an identified cluster [off-taker], for example, has productive use of power, [...], that has a large impact on demand [and] the ability to pay' (DFI001). This means varied off-taker financial capacities and demand uncertainty levels, especially in rural areas, can pose significant revenue risks and diminish the attractiveness of the potential investment. Some developers have mitigated E4 risk by structuring long-term 'PPAs [power purchase agreements] to guarantee revenues' (D6001) with financially capable off-takers, such as industrial customers and public sector institutions, a practice identified in the literature [18,70]. PPAs are perceived to have a lower risk level than the pay-as-you-go models deployed in rural communities, where limited information on customers' credit history is available. For such models, the 'cluster effect' (D4001) could be achieved by selecting locations with a 'sufficient customer base, with some demonstrable ability to pay' (DFI1001) e.g., commercial and industrial activities that may serve as anchor loads.

3.3.5. Non-cost reflective tariff (E5)

E5 ranked third overall (4.8 %). Meanwhile, the developer group considered it a lower priority, placing it sixth overall. Interestingly, E5 took precedence for DomFI in the economic category (Fig. 9). This high importance for DomFI group may be attributed to their experience in centralised grid financing, where non-cost reflective tariffs and low revenue collection negatively impacted performance [40]. Additionally, many projects in rural areas are subsidised by grants and concessional financing, as such, the tariff structure of such projects may not reflect the actual cost of development and operations [61].

In striving to achieve cost-reflective electricity tariffs, investors need to balance timely cost recovery, sustainable operations, and reasonable returns against customer expectations of affordable and fair electricity tariffs [11]. Achieving this balance is challenging due to factors such as high unit costs, and low intensity of use driven by low population density, demand, and affordability [11,70]. Nevertheless, developers highlighted that mini-grid tariffs compare favourably, especially for last-mile consumers ‘who pay more for [alternatives] such as petrol and diesel generators’ (D3001) when considering cost and generation efficiency holistically. However, this ‘benefit is not apparent to customers’ and suggests the need for developers ‘to demonstrate the cost reduction opportunities’ (D3001).

Additionally, most developers considered E5 a low priority. This is because the Nigeria mini-grid regulations [44] outline ‘cost-reflective tariff’ (D4001) provisions for mini-grid capacities up to 1MW. For mini-grids with capacities lower than 100 kW, the regulation requires developers to sign agreements with off-takers. However, negotiating tariffs poses challenges for developers, because while ‘[some] rural communities have never heard about or negotiated tariffs’ [...] ‘peri-urban [customers] are aware of the subsidised grid tariff, and it is difficult to convince them to pay more’. (D2001). Further, registered and permitted mini-grids of up to 1MW are subject to a multi-year tariff order methodology. The methodology makes provision for cost-reflective tariffs, considering up to 10 % technical and non-technical losses and 6 % profit; thus allowing ‘for cost recovery’ and

‘standardisation to the sector – [providing] a uniform plain field for financiers, developers, [and] government’ (D3001). However, the regulation [44] lacks explicit details on the tariff calculation process, potentially undermining investor confidence.

3.3.6. Financing risk factors (F1, F2, F3, F4, and F5, and F6)

In the financing category (Fig. 10), collectively, inadequate access to low-cost capital (F2) ranked first while high cost (F1), short loan terms (F3), limited local financial sector experience (F4), limited financial capacity and experience of developers/local investors (F5), and difficulty accessing or repatriation FX (F6) all ranked second. Meanwhile, overall, F2 ranked as the second (8.22 %) while F1, F3, F5 and F6 ranked as the fourth (4.11 %), collectively. These risk factors are discussed together due to their interdependencies.

Financing risks can hinder the ability to attract affordable finance or recover investment [9]. DRE projects often face limited access to capital (F2), which typically comes at a high cost (F1) with short loan tenors (F3) [15,60,71,72]. Interviewees highlighted the importance of F2. Challenges in securing domestic and ‘international capital’ (D3001) were ascribed to investors’ high-risk perception [9,11,73], domestically prevalent low ‘sleeping funds [liquidity] available’ (DomFI2001) and ‘high [interest] rates’ (D2001) [32,50,60]. High costs (F1) can be attributed to high capital expenditure (CAPEX). Factors driving F1 can include costs related to inflation, financing, insecurity, FX transaction, importation and handling, and inefficiencies in policy implementation, thus, ‘increasing [developer] overhead costs’ (PF3001–7). Furthermore, interviewees indicated barriers impacting F1, such as high collateral requirements for financing whereby ‘[developers] are unable to provide tangible collateral, and [...] mini-grid assets] do not have a secondary market’ (DomDFI1001). This statement also emphasises the significance of the limited financial capacity and experience of developers/local investors (F5) and the financial sector (F4) [9,60].

Interviewees noted that domestic banks have a low willingness to invest in DRE projects. DomFIs tend to take the perspective of investment preservation by limiting their risk exposure, offering short – ‘two

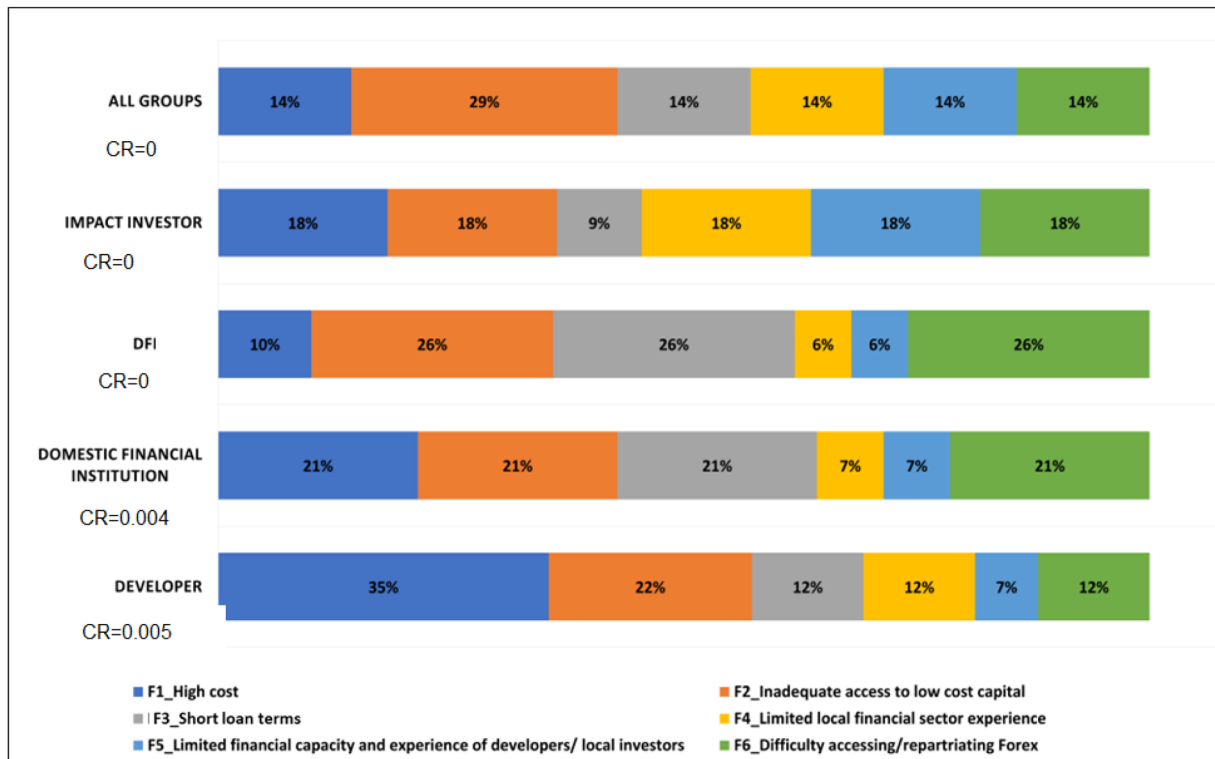


Fig. 10. Prioritisation of financing risk factors overall and by investor groups.

or three years' (P1001) – loan terms (F3), which are unfavourable for long DRE project life cycle. According to an interviewee, 'past negative experiences [of DomFIs and private equity investors]' (DomFI2001), such as low revenue collection and an inability to recover costs, from the centralised power sector privatisation have led to low interest in DRE projects. The distinction between the DRE sector and the grid power sector is often overlooked. DRE projects are perceived and appraised as similar to centralised grid power transactions. The interviewee suggested a 'need to repack the DRE sector' (DomFI2001) to garner more interest. While the literature reports the challenge of low liquidity impacts on Nigeria's grid sector [40], its impact on DRE remains underreported.

Additionally, the scarcity of data on the performance of DRE projects hinders the establishment of benchmarks for mini-grid success. This lack of benchmarks leads to situations whereby financiers 'depend on their [subjective] experiences' (DomFI1001). Consequently, DomFIs may categorise DRE similarly to grid power projects, resulting in biased viability assessments. This bias results in the application of higher risk premiums, reflected in interest rates of '23–25 %' (DomFI2001). Such practices can impact project costs and, tariffs, subsequently affecting the affordability and sustainability of projects. These circumstances further underscore the influence of path dependence on the risk attitude of some investors – where historical decisions and interactions may impact the evolution of a system e.g., historical investments in fossil fuel-based technology may impact RE investment decisions [74,75].

Interviews underscored the importance of F6, particularly in the execution of FX conversion and transfer obligations such as importation, hard currency (HC) debt repayment and repatriation for international investors, 'who provide long-term concessional financing' (DFI1001). Although the DomFI group ranked F6 as among its most important risk factors, an interviewee disagreed with the result as F6 'does not apply to local entities' (DFI2001). Nevertheless, local investors are affected by challenges in sourcing FX from the government apex bank (CBN) for obligations such as hardware importation. F6 has manifested in Nigeria's aviation sector, where an estimated US \$464 million was pending repatriation [76]. This situation persists despite existing fiscal policies, such as the Nigerian Investment Promotion Commission Act No 16 of 1995.⁵ Hence, it is recommended that such policies' implementation be strengthened to instil confidence among investors.

3.3.7. Insecurity risk (SE5)

In the SE category, insecurity ranked the highest (Fig. 11) collectively and within individual groups. However, despite its prominence in specific groups, insecurity ranked fifth overall. Some interviewees perceived 'insecurity should also have a high number [ranking]' (D1001) because of heightened insecurity at the time of the interviews and its adverse consequence on investor appetite. Furthermore, insecurity can affect all project phases, thus escalating costs through 'additional insurance, like security insurance, [...] which was not part of our cost structure prior' (D3001).

A developer indicated 'I won't do a mini-grid in [state] for example' because '... my team was ... attacked [there]. So, for now, for me [that] state is no' (D1001). This suggests the absence of security intervention can lead to persistent underinvestment. Security intervention is thus crucial for achieving access targets.

3.4. Investors' risk priorities – comparisons and interdependencies

To facilitate a comparison of individual group perspectives regarding the most significant risk factors overall, Table 2 presents a normalised scale of risk weightings. The rankings follow a qualitative scale – very

low, low, moderate, high, and very high – prioritised based on normalised AHP weightings assigned to each group.

Notably, as with the collective view, all groups except DomFI found E3 very high to high priority. Additionally, while high cost (F1) was a low priority for DFI and Impact investor groups, the developer and DomFI groups found F1 very high and high priority, respectively. This discrepancy may be explained by the association of F1 with other economic and financing risk factors such as revenue risks and short loan tenors leading to variations in respondents' views of F1.

The findings indicate that priorities differ among investor types due to their distinct mandates, sources of financing, path dependencies, operational scale, and risk appetites. For example, developers primarily emphasise high costs, FX volatility affecting equipment importation costs, and revenue risks arising from low ability to pay, collection inefficiencies. These risk factors are immediate and project-specific, reflecting their frontline position in market operations and limited access to affordable capital. DFIs and impact investors typically prioritise long-term developmental outcomes and may tolerate lower returns. However, they are more sensitive to macroeconomic conditions and currency volatility due to hard currency funding. Notably, only DomFI found technical risk factors a high priority among the investors. This distinction could be attributed to advancements in DRE in Nigeria, which DomFI may be unaware of due to their limited participation in the sector.

Although risks depend on project scope, phase, resources, and objectives, Hu et al. [77] additionally emphasise that psychological, behavioural, or institutional attributes and experiences can influence risk perception. Such factors contribute to diverse risk perceptions among groups. For instance, previous power investment experiences have negatively impacted DomFI's appetite for DRE projects (Section 3.3.6). The differences in risk priorities among investors emphasise the importance of considering risks not only from a collective perspective as done in previous studies [36,37] but rather, by incorporating investors' specific views. This approach can enable the identification of the most important risks to mitigate.

Therefore, in dealing with investments supported by multiple funding sources, decision-makers should address intersecting and mutually exclusive risk factors (depicted in Fig. 12). For example, while SE5, E1, F2, F3, and E5 are important to both DomFI and DFI groups, a broader range of risk factors, which are individually important to DFI (E4, F6 and E3) and DomFI (T1, T3, T4, T6 and F1), need addressing.

Furthermore, the interactions and dependencies between risk factors (see Section 3.3.2) and feedback mechanisms can reinforce or exacerbate risks. For instance, an increase in investment risk can elevate risk premiums and consequently project costs [16]. These can be further exacerbated by insecurity and ineffective policy implementation, contributing to financing risks and, consequently, higher investment risk. This feedback loop, unless disrupted, can reinforce risk levels. Another example is revenue risk—stemming from limited affordability and non-cost-reflective tariffs—directly undermining debt serviceability, particularly for developers lacking concessional finance. This, in turn, increases their reliance on short-term or expensive capital, thereby reinforcing limited access to affordable local finance.

Risk interdependencies may evolve with the dynamic nature of risks. For instance, the priority of social acceptance could increase in the future because of the limitation of QC, whereby unmet customer expectations might lead to reduced adoption rates [11]. These considerations could facilitate more strategic identification of risk drivers and relevant mitigations, providing a more sustained impact on multiple risk factors. An emerging risk is increased market uncertainty amplified by policy and regulatory fragmentation — potentially arising from the decentralisation provisions of the Electricity Act 2023. When implementation timelines, tariff guidelines, or licensing terms vary across states, developers could incur additional transaction costs when operating in multiple jurisdictions. This can impede project deployment or investment. These interactions underscore the necessity for a

⁵ The Nigerian Investment Promotion Commission Act No. 16 of 1995, ensures investors' free importation and unrestricted foreign currency convertibility with a certificate of capital importation (82).

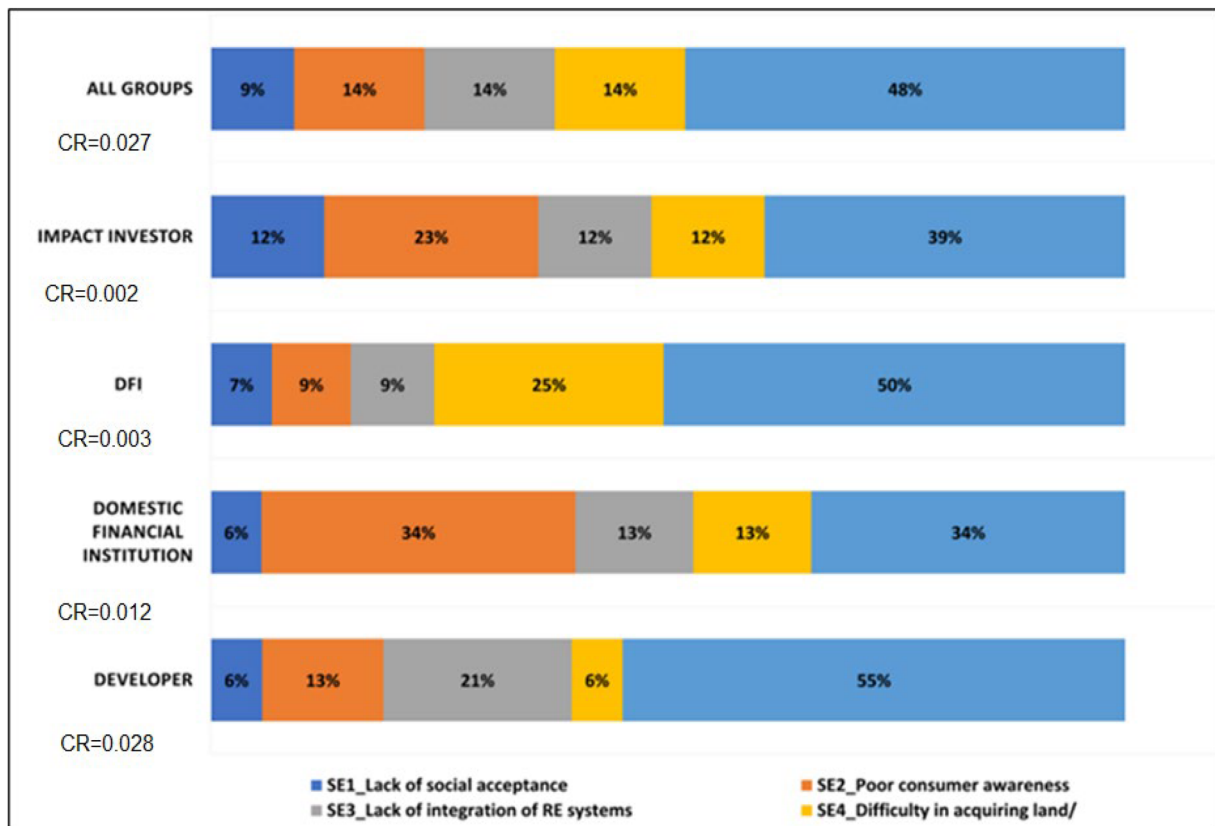


Fig. 11. Prioritisation of SE risk factors overall and by investor groups.

coordinated approach to policy design and implementation that considers risk interactions.

3.5. Investment risk mitigations and policy implications

Four main risk mitigation themes emerged from the thematic analysis of interview findings. Table 3 summarises the risk mitigation actions, highlighting interdependencies, identified from literature and interviews, along with their enablers and potential to enhance competitiveness for the moderate-to-very-high priority investor risk factors (identified in Table 2). These risk factors account for 37–58 % of the individual investor groups' AHP risk weightings. The following discussions focus on the mitigation actions for risks that at least two investor groups deemed moderate priority or higher. These risk factors comprise 37 %–58 % of the individual investor groups' AHP risk weightings.

3.5.1. Navigating currency risks

In this study, currency risks comprise FX volatility (E3) and difficulty accessing and repatriating FX (F6). Policies that support local manufacturing can reduce the impact of E3. Additionally, E3 can be 'hedged' (D1001) by adopting financing mechanisms that inherently mitigate its effects such as concessional local funding [1,2] and through tariff indexing to hard currencies or inflation rates via PPAs [9]. However, the latter option is typically reserved for 'commercial customers' (D6001).

Currency risk guarantee funds are another E3 mitigation where the government covers the difference in exchange rates over a period [10, 78] using public funds or by charging fees to participants to access guarantee funds. This approach can be used in small-scale projects but may be expensive in the event of currency depreciation [79].

F6 has been managed via monetary policies such as guarantees of convertibility and repatriation [10]. Other means of reducing F6 include parent company cross-currency swaps [78], and cross-country portfolio diversification [80]. Among the stated measures, enabling concessional local financing and local manufacturing is crucial for DRE deployment. Additionally, project aggregation may facilitate scaling and access to mitigations such as hedging and guarantees.

3.5.2. Enhancing financing mechanisms and capacity building

Increased participation from the local finance sector could offer more affordable financing options [9,10,60,70]; however, DomFIs have limited experience and appetite to finance DRE projects (3.3.6). The Nigeria Bureau of Statistics data [86] showed that <4 % of loans were disbursed to the power sector in 2021, suggesting a reluctance to fund power projects. Efforts should be made to differentiate between the grid and DRE sectors, providing benchmarked performance data to instil investor confidence and eliminate bias. Furthermore, 'a policy statement from CBN [requiring] that a portion of your loan portfolio as a bank must be green' (D4001) can be explored. Such policy, the Priority Sector Lending (PSL) applied in India, where local banks allocate 40 % of their lending to priority sectors, including RE, could be adopted [60,87].

Aggregating a spatially diverse portfolio across [88] or within [23, 66] countries, coupled with document standardisation [9,23,60], can improve the risk profile by addressing financing and economic risks and diversifying finance sources. However, an interviewee noted the limitations of aggregation due to developer financial 'capacity' (D1001) constraints. Co-lending can provide the opportunity to pool funds and distribute risks among diverse investors interested in larger-scale projects.

Portfolio aggregation enabled by collaboration among developers or with distribution companies (DisCos) additionally presents

Table 2

Comparison of risk factor priorities among investor groups.

RISK FACTOR	Developer	Domestic financial institution	DFI	Impact Investor	ALL Groups
E1_Revenue risk	3.63%	0.71%	13.92%	5.79%	4.80%
E2_Collection losses	7.26%	1.86%	7.83%	5.79%	4.80%
E3_Foreign exchange volatility	7.26%	1.86%	13.92%	16.12%	9.59%
E4_Inability to achieve single off-taker or cluster effect	3.63%	1.86%	4.38%	5.79%	4.80%
E5_Non-cost reflective tariff	3.63%	5.00%	4.38%	3.16%	4.80%
F1_High cost	9.01%	6.59%	2.13%	2.51%	4.11%
F2_Inadequate access to low-cost capital	5.55%	6.59%	5.54%	2.51%	8.22%
F3_short loan terms	3.04%	6.59%	5.54%	1.26%	4.11%
F4_Limited local financial sector experience	3.04%	2.20%	1.30%	2.51%	4.11%
F5_Limited financial capacity and experience of developers/ local investors	1.72%	2.20%	1.30%	2.51%	4.11%
F6_Difficulty accessing/repartriating Forex	3.04%	6.59%	5.54%	2.51%	4.11%
P1_Insufficient policy/legal support framework	2.36%	1.68%	0.50%	1.18%	2.23%
P2_Unclear regulation/guidelines	1.33%	0.69%	0.34%	1.18%	0.79%
P3_Policy changes	1.25%	0.69%	0.78%	1.18%	1.05%
P4_lack of policy implementation	2.36%	0.77%	1.49%	1.18%	1.55%
P5_Duplicative policy development	1.29%	0.69%	0.82%	1.15%	1.05%
P6_Inconsistent policy application	0.79%	0.67%	2.71%	2.23%	1.05%
P7_Uncertainties in IMG regulations implementation	2.47%	2.01%	1.49%	2.13%	2.23%
P8_Grid extension uncertainty	2.36%	2.07%	1.49%	2.13%	2.23%
P9_Political changes/instability.	4.02%	0.67%	1.49%	0.69%	2.23%
P10_Inadequate political will	1.29%	0.67%	0.82%	0.32%	1.05%
P11_Adverse political events	5.92%	0.65%	1.49%	0.45%	1.55%
T1_Limited training and research and development	0.72%	6.15%	0.66%	0.45%	1.13%
T2_Technical skills limitation	1.31%	2.05%	0.38%	0.74%	0.71%
T3_Limitation in Developer's capability	1.31%	6.15%	0.66%	1.36%	1.73%
T4_Limitation in QC and manufacturing capacity	0.72%	6.15%	0.66%	1.36%	1.73%
T5_Uncertain load profile	3.27%	2.05%	2.47%	1.36%	1.58%
T6_Inadequate infrastructure	1.31%	6.15%	2.47%	2.38%	2.21%
T7_Uncertainties in site characteristics	0.44%	2.05%	0.66%	0.74%	0.71%
M1_Sensitivity of RE to fossil fuel prices	2.03%	3.38%	0.86%	3.27%	1.69%
M2_Low competitiveness of RE due to subsidies on alternatives	1.10%	1.13%	1.64%	3.27%	1.34%
M3_lack of competitive hardware and labour market	0.62%	1.13%	0.52%	3.27%	0.72%
M4_Poor data availability	1.41%	1.13%	1.64%	6.12%	2.49%
M5_Barriers due to regulations	2.82%	3.38%	1.64%	6.12%	2.49%
M6_Uncertain market growth potential	1.10%	1.13%	1.64%	1.26%	1.06%
SE1_Lack of social acceptance	0.31%	0.26%	0.33%	0.50%	0.54%
SE2_Poor consumer awareness	0.74%	1.60%	0.42%	0.94%	0.84%
SE3_Lack of integration of RE systems	1.15%	0.60%	0.45%	0.50%	0.84%
SE4_Difficulty in acquiring land	0.31%	0.60%	1.24%	0.50%	0.84%
SE5_Insecurity	3.08%	1.60%	2.49%	1.58%	2.85%

Ranking/colour coding is defined by a normalised qualitative scale of green (very low priority <1.92 %), yellow (low priority >1.93–3.84 %), orange (moderate priority >3.85–5.75 %), dark orange (high priority >5.76–7.67 %), red (very high priority >7.68 %). Table A-5 additionally provides results for the surveyed non-investor groups.

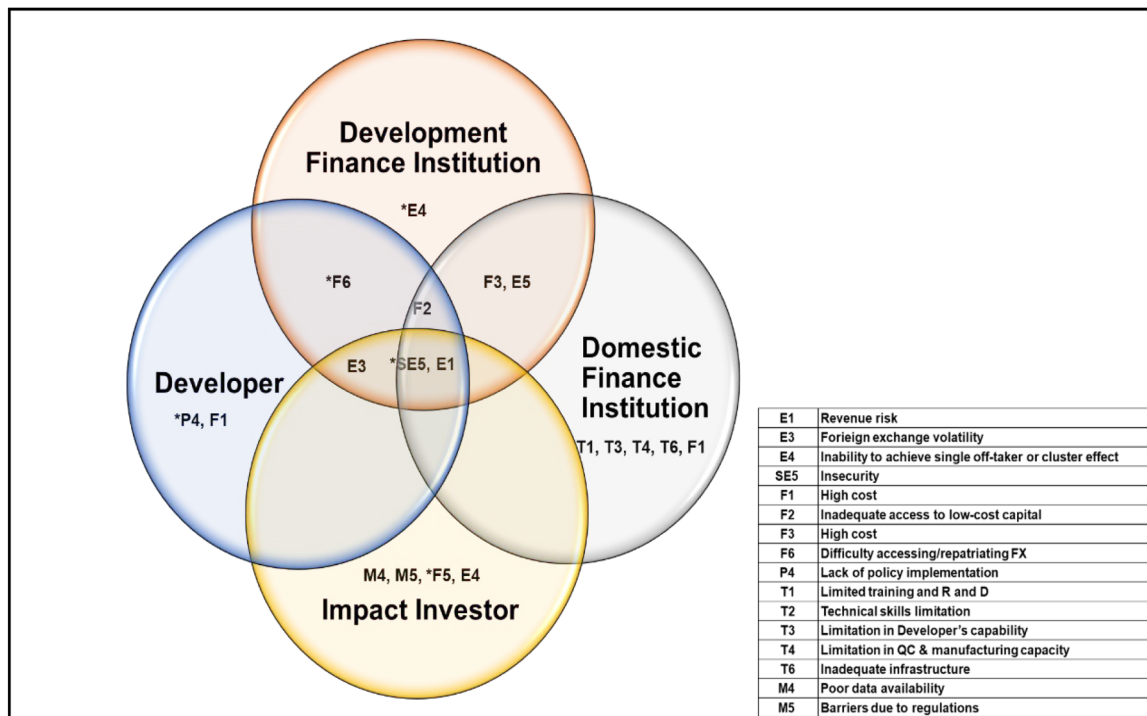


Fig. 12. Focusing on the moderate to high-risk priorities among investors.

opportunities to overcome single developer capacity constraints, facilitating access to a wider pool of capital and experience. Furthermore, government mini-grid tenders, which allocate single and aggregate sites to bidders could be specially designed to aggregate project sites with diverse socioeconomic characteristics. This approach can facilitate regional portfolio diversification and reduce risks (E1, F1, F2, F5, T3, and F3).

Moreover, concessional loans and technical assistance provided by DFIs through DomFIs via on-lending structures have reduced exposure to E3 and F1 whilst building local developers' and banks' capacity [1, 87]. However, access to concessional loans is constrained by 'collateral requirements' (DomDFI1001). Collateral barriers can be alleviated by developing an asset-backed finance lending facility, where the asset or future cashflows can be used as collateral. This scheme requires the local financial sector to assess the value of assets as collateral [79] and develop a 'secondary [asset sales] market' (DomDFI1001). Further, to enhance increased local developers' participation, the government could reduce entry barriers for new developers by providing a special funding and technical support category while implementing monitoring and evaluating efforts to ensure compliance.

3.5.3. Improving project revenues and viability

Interviews revealed that low energy utilisation, primarily due to affordability and behavioural factors linked to generational scarcity, impact E1. These behavioural implications are often overlooked in demand and cost forecasts. To mitigate demand uncertainty, 'robust analyses' (D3001) are crucial for informed investment decisions. Addressing energy underutilisation requires considering cultural and economic contexts that shape consumer behaviour through targeted policies and strategies. Economic policies should promote rural commercial development through subsidies and financing for productive-use equipment. Tailored 'business development models' (D2001), such as securing anchor customers and implementing the 'key maker model' (D2001) and 'energy efficiency practices' (P1001), could stimulate productivity and improve affordability. Targeted social interventions, like 'training and

awareness [campaigns]' (PF3001–7), can shift mindsets towards productive energy use—reducing E1. Another 'business development' strategy, securing 'community partnerships to improve asset security' (D2001), could mitigate E1 and insecurity risks.

Additionally, leveraging international carbon markets can unlock new revenue streams [60,89]. However, realising the benefits necessitates supportive policies and institutional capacity, aligned with the Nigeria Climate Change Act of 2021. Financial incentives, such as grants allocated to rural areas, enhance a project's viability and attractiveness [60,73,90]. However, some interviewees raised concerns about the sustainability of grant-funded projects, noting instances of nonfunctional mini-grids within a few years of operation. Causal factors for non-operational mini-grids include lack of a sustainability plan, poor maintenance, and low utilisation [61]. This suggests that grant-funded projects initially deemed viable for mini-grids might be more effectively served by standalone systems. Therefore, in selecting technologies, project locations and allocating incentives, the outcome of the least-cost studies must be weighed against location attractiveness and risk factors. This approach can guide targeted policy and inform site selection for developers.

3.5.4. Policy implementation and enhancements

This study recommends that policymakers focus on improving incentives and enhancing consistency in implementing and enforcing existing policies. Although incentives are specified in the existing policies [50], the application is inconsistent in supporting the DRE electrification targets. For instance, under the Customs Excise Tariff Act, custom duty exemptions are limited to a few solar components [50]. Specifically, while solar panels without diodes are exempt, solar panels with diodes are subject to import duties. To promote DRE, taxed components such as solar panels and batteries (with taxes of 27.5 % [91]), could be incentivised and reviewed periodically to stimulate domestic manufacturing.

Additionally, the development of institutional capacity and inter-agency cooperation within government could improve policy

Table 3

Suggested mitigation measures for high priority risk factors (Source: 1- literature [17,81–85], 2- interviews and focus groups, 3- literature [17,81–85] and interviews).

Mitigation Instruments and Strategies		Reference	Relevant mitigation themes	Mitigation applicability to DRE	Mitigation deployed in Nigeria for DRE?	Impact on risk factor																	Impact on competitiveness/return	Enablers and improvements to existing mitigations
						E1	E3	E4	E5	F1	F2	F3	F5	F6	P4	SE5	M4	M5	T1	T3	T4	T6	Other risk factors	
Fiscal & financial instruments	RE Feed-in-Tariff (indexed)	1	T3–4	P	N	+	+	+		+	+							+					+	Increase minigrid threshold and implement REFiT for IMGs
	Public Investments, concessional loans, grants, capital subsidy, financing for productive-use equipment	3	T1–2	Y	Y					+	+	+	+										+	Enable new developers through technical support and less stringent funding criteria
	Guarantees, Insurance e.g., for payment and currency	1	T1–2	P	N	+		+		–	+			+		+		+						Portfolio aggregation could enable required transaction size to enable this instrument.
	Incentives/ tax reductions, e.g., VAT/ import waivers	3	T2–4	Y	Y					+			+		+			+					+	Review and extend the application of tax incentives across RE components
	Currency hedging	1	T1–2	N	N			+		±	+												±	Applicable to large-scale projects for short-term. Could be enabled by aggregation
Market-based	Free transferability of foreign investor returns	3	T1	Y	Y					+	+			+	+									Establish RE as a priority sector for transfers
	Carbon certificates/ Carbon Market	1	T2–4	Y	N	+				+			+					+					+	Develop emissions trading framework and alignment with existing policies and institutions
	Carbon Tax	3	T2–4	Y	N	+				+			+					+					+	Requires enforcement of existing RPO regulation
Regulation/ guideline	Renewable Portfolio Standards or obligations, Tradable RE certificates	1	T4	Y	N	+									+								+	Incorporate spatial diversification and portfolio aggregation in tender design
	Tendering	3	T2–3	Y	Y	+			+	+			+										+	Requires update in regulation and supporting infrastructure
	Net metering/ Virtual Net metering	1	T2–3	Y	N	+				+			+										+	
	*Administrative/ legal provisions	2	T3–4	Y	Y										+			+						
	Technical standards	3	T3–4	Y	Y					+												+	+	Enable procurement aggregation

(continued on next page)

Table 3 (continued)

Mitigation Instruments and Strategies		Reference	Relevant mitigation themes	Mitigation applicability to DRE	Mitigation deployed in Nigeria for DRE?	Impact on risk factor																	Impact on competitiveness/return	Enablers and improvements to existing mitigations
						E1	E3	E4	E5	F1	F2	F3	F5	F6	P4	SE5	M4	M5	T1	T3	T4	T6		
Non-traditional financing	On-lending, local financing	3	T1–3	Y	Y ⁻					+	+		+										+	Implement priority sector loan mandate for RE Portfolio aggregation and diversification Secondary market and financial sector capacity development
	Co-lending, blended finance	3	T2–3	Y	Y ⁻		+			+	+		+										+	
	Asset-backed finance lending facility	3	T2–3	Y	N					+	+		+										+	
Other	**Institutional and manufacturing capacity development and Infrastructural investment	2	T2–3	Y	Y ⁻					+					+		+	+	+	+	+	+	+	+
	Social intervention campaigns for demand stimulation	3	T3	Y	Y ⁻																			
	Partnerships-community, disco-developer, financiers	2	T1–4	Y	Y ⁻		+	+	+		+	+		+	+	+	+		+	+			+	
	***Business models	3	T2–3	Y	Y ⁻		+		+	+	+	+											+	+
	Spatial portfolio diversification and aggregation	3	T2–4	Y	N		+		+	+	+	+											+	
Medium-Very High risk for	Developer						•	•			•	•		•	•	•								
	DomFI						•			•	•	•						•	•	•	•			
	DFI						•	•	•		•	•		•										
	Impact Investor						•	•					•			•	•	•						

Mitigation Themes: T1- Navigating currency risks, T2-Enhancing financing mechanisms and capacity building, T3-Improving project revenues and viability, T4-Policy implementation and enhancements.

Y -applicable, P -applicable in some instances, N -not available/ applicable, Y⁻ -available requires improvement.

+ positive, - negative, ± mixed impact, • applicable.

* Administrative and legal provisions e.g., regulation, licensing, grid arrival, land use,.

** Capacity development: awareness, training, manufacturing, benchmarked performance data.

*** Business models: Productive use, demand stimulation, robust forecasting, anchor customers, cross-subsidy, segmentation, site and technology selection.

implementation consistency. Some interviewees recommended a dedicated ‘service desk’ (D3001) in each agency where issues are reported, tracked, and promptly resolved to reduce bureaucracy. This approach has enhanced licencing efficiencies within the ‘regulatory agency’ (D3001).

While the mini-grid regulations offer a promising avenue for expanding electricity access in underserved areas through existing DisCos’ distribution networks, Pls noted implementation challenges. DisCos, with their concession rights, often exhibit reluctance ‘to deal with mini-grid developers’ (PF3001–3). However, as one interviewee noted, DisCos could play a crucial role in reducing investment costs by ‘socialising distribution cost’ (PF3001–3). To aid synergy between developers and DisCos, a review of the existing regulations is recommended. For instance, the lack of enforcement of renewable purchase obligation (RPO) regulations [92] which stipulates a 50 % RE target for DisCos and generation companies diminishes its potential impact to encourage such synergies. India’s experience demonstrates the effectiveness of a strict renewable RPO policy, resulting in 42–65MW of incremental DRE and large-scale solar capacity for every percentage point of RPO [85].

Despite the mini-grid regulations’ allowance for cost-reflective tariffs, revenue risks persist. Feed-in-tariffs (FiTs) have been globally employed to incentivise investment in higher-cost RE technologies by guaranteeing reasonable returns [20]. The RE FiT 2015 (REFiT), applicable to new grid or distribution network-connected RE technologies (1–5MW), ensures grid access and purchase obligations by the bulk electricity trader and DisCos. While REFiT doesn’t directly cover mini-grids, extending REFiT to aggregate portfolio interconnected mini-grids (IMGs) exceeding 1MW could make them eligible for REFiT, mitigating E1. However, Ozeogwu et al. [57] caution that high solar FiTs can hinder adoption and recommend subsidising them.

4. Conclusion and policy recommendations

This study addresses the paucity of empirical data on risk priorities among diverse DRE investor groups — developers, DomFI, DFI, and impact investors. In contrast, previous risk studies primarily focused on a single investor perspective. Employing a participatory and mixed method approach facilitated the identification and evaluation of 40 risk factors across six categories, including 13 risk factors including revenue risk and FX volatility— not previously high-graded in the published literature for Nigeria [20,21,33,57].

This study highlights the high priority of economic and financing risks. It reveals distinct variations in risk prioritisation among investor groups, necessitating tailored de-risking strategies. Common high-priority risks, such as currency risks, revenue risks, insecurity, and policy implementation, collectively account for 37–58 % of the risk weighting. While the recent Electricity Act 2023 aims to encourage investments, its decentralisation provisions could introduce increased market uncertainty due to policy and regulatory fragmentation during implementation. This study offers a nuanced understanding of risk factors’ drivers from the investor perspective, highlighting critical

influencing factors such as low energy utilisation linked to affordability and generational scarcity, low awareness of the effectiveness of risk mitigation practices and path-dependence informed by past experiences of DomFIs. To address these challenges, there is a need the dissemination of benchmark DRE performance data to investors, and the enhancement of energy utilisation through interventions that extend beyond economic policies to include targeted social awareness programs aimed at shifting mindsets toward productive energy use.

Further evidence-based policy mitigation measures and enablers include:

- Improving access to FX and managing FX volatility through domestic financing mandates and local manufacturing support.
- Enhancing policy implementation and inter-agency coordination to reduce barriers.
- Implementing policies e.g., enabling RPO, portfolio aggregation and regional diversification.
- Fostering collaboration among DisCos, developers, financiers, and communities.
- Enabling carbon markets and implementing robust planning and risk-adjusted technology and location selection.

An important area for future research is quantifying the impact of these mitigation measures on investment decisions and electricity access targets, considering system interactions. This approach could equip policymakers with a tool to test proposed measures before implementation. Overall, this study provides valuable insights for decision-makers to understand investment risks and prioritise actions to catalyse DRE investment, a crucial step towards improving electricity access.

CRedit authorship contribution statement

Z.Y.I. Abba: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **N. Balta-Ozkan:** Writing – review & editing, Supervision, Conceptualization. **G. Drew:** Writing – review & editing.

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.

Acknowledgement

The first author thanks the Petroleum Trust Development Fund (PTDF) Nigeria for supporting this research through its scholarship programme. Additionally, the authors would like to express their gratitude to the various experts for their insightful comments and support. Partial research time for Balta-Ozkan is funded by UK Engineering and Physical Sciences Research Council award EP/V006592/1.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.rset.2025.100112](https://doi.org/10.1016/j.rset.2025.100112).

Appendix

Risk categories and risk factors

Fig. A1, Fig. A2, Figure A3, Table A1, Table A2, Table A3, Table A4, Table A5

Table A-1

Risk factor definitions and a comparison of risk factors in this study with previous studies. Adapted from [15].

Risk Factor	Definition	Risk identified for Nigeria in literature	Risk identified in this study	Reference
Economic risks				
E1 Revenue risk	Results from default by off-taker, unwillingness to pay, low affordability, seasonal income etc		•	[11,23,24,27,29, 69,93]
E2 Collection losses	This could be a result of technical, financial, and behavioural factors that lead to non-revenue-generating consumption.		•	[11,29]
E3 Foreign exchange (FX) volatility	FX volatility results in a mismatch between revenues denominated in local currency and hard currency-denominated obligations		•	[9,23,24,68,69, 94,95]
E4 Inability to achieve single off-taker or cluster effect	Limited creditworthy off-takers impacting project viability and revenues		•	[11]
E5 Non-cost reflective tariff	Unattractive regulated tariff	•	•	[11,20,29,66,77]
Finance risk				
F1 High cost	High initial cost, unaffordable tariff	•	•	[20,29,30,71,93, 95–97]
F2 Inadequate access to low-cost capital	limited access to affordable finance due to factors like liquidity constraints, experience, high interest rate	•	•	[9–11,21,27,28, 71,93,98]
F3 Short loan terms	A mismatch between short loan tenors and project lifetime.			
F4 Limited local financial sector experience	Limited experience in the financial sector	•	•	[9,93,96,97]
F5 Limited financial capacity and experience of developers/ local investors	Limited financial capacity and execution capabilities of developers. Domestic investors' lack of familiarity with RE	•	•	[9,93,96,97]
F6 Difficulty accessing/repatriating Forex	1. Inability to convert local currency into hard currency due to Government action or inaction 2. restrictions to repatriate funds add uncertainty to investors		•	[71,94]
Policy and Political risks				
P1 Insufficient policy/legal support framework	Insufficient supporting policy frameworks and incentives. Complex Institutional structures with overlapping responsibilities	•	•	[20–22,28,31, 77,96–99]
P2 Unclear regulations/guidelines	Impact of unclear guidelines	•	•	[21]
P3 policy changes	Legislative changes/ retroactive change in policy	•	•	[21,24,28,88,98, 100]
P4 lack of policy implementation	Policy and regulatory uncertainty due to non-implementation of existing policy	•	•	[11,21,93,101]
P5 Duplicative policy development	Impact of duplicative policies and institutions		•	
P6 Inconsistent policy application	Policy and regulatory uncertainty due to inconsistent policy application	•	•	[11,21,28,71,93, 100,101]
P7 Uncertainties in IMG regulations implementation	Uncertainties in implementing interconnected mini-grid regulations (IMG)		•	[101]
P8 Grid extension uncertainty	Uncertainty in grid extension plans and technical regulations for integration of mini-grids into the main grid	•	•	[11,22,23,71,93]
P9 political changes/instability.	Effect of political changes, e.g., reshuffling of institutions, changes in Government	•	•	[21,22,24,93]
P10 Inadequate political will	Political decision-making and target-setting impacted by political will	•	•	[71,97]
P11 Adverse political events	Political events that adversely impact the value of investment (e.g., war, breach of contract)	•	•	[9,94,97]
Technical risk				
T1 Limited training and R&D	limited training and R&D in RE	•	•	[21]
T2 Technical skills limitation	Limited technical skills and capacity in operations and maintenance	•	•	[9,11,20,21,23, 28,66,97,99]
T3 Limitation in Developer's Capability	limitations in developers' experience in executing projects		•	[23,66]
T4 Limitation in QC & manufacturing capacity	Limitations in the quality control and availability of hardware	•	•	[20,23,28,97]
T5 Uncertain load profile	Poor understanding of customer needs or usage patterns leading to variability in demand		•	[66,71]
T6 Inadequate infrastructure	lack of supporting infrastructure, and facilities and inadequate access to project locations		•	[71]
T7 Uncertainties in site characteristics	Uncertainties in estimating power potential and its variability	•	•	[9,20,24,27,68, 71,96]
Market risk				
M1 Sensitivity of renewable energy (RE) projects to fossil fuel prices	Sensitivity of competitiveness of RE to changes in prices of conventional energy sources	•	•	[20,68,69,71,95, 99,100]
M2 Low competitiveness of RE due to subsidies on alternatives	Impact of subsidies on alternatives on RE competitiveness	•	•	[24,98,99]

(continued on next page)

Table A-1 (continued)

	Risk Factor	Definition	Risk identified for Nigeria in literature	Risk identified in this study	Reference
M3	lack of competitive hardware and labour market	Limitations in the availability of competitive labour and equipment locally		•	
M4	Poor data availability	Limited market and consumer data availability	•	•	[10,22,93]
M5	Barriers due to regulations	Regulatory barriers to market access and competitiveness	•	•	[21,28,31,98]
M6	Uncertain market growth potential	Uncertainty in market growth potential due to uncertain demand, market size and potential		•	[98]
Social and environmental risk					
SE1	Lack of social acceptance	Public resistance to adopting RE technology	•	•	[21,23,24,96]
SE2	Poor consumer awareness	Poor awareness of solar benefits	•	•	[21,71,96,97]
SE3	Lack of integration of RE systems	Poor integration of RE into the energy mix	•	•	[21]
SE4	Difficulty in acquiring land/	Difficulty in acquiring land, competition with land uses	•	•	[20,24,69,97]
SE5	Insecurity	Instability caused by security and social events, e.g., riots. Insecurity of infrastructure	•	•	[20,24,94,97]

Online survey questionnaire

Name:

Email:

Organisation:

PART A: General information

- Which of the following best describes your organisation?
 - Developer
 - Financial institutions such as development finance institution, commercial bank etc.
 - Investor – Equity provider
 - Investor – Debt provider
 - Consulting and other professional services
 - Public agency e.g., Regulator, Ministry, legislative
 - Other – please state.
- What is your age range?
 - 18 – 25 years
 - 26 – 35 years
 - 36 – 50 years
 - 51 – 60 years
 - > 60 years
- What is your gender?
 - Male
 - Female
 - Prefer not to say.
- What is the length of your industry experience?
 - 0 – 5 years
 - 5 – 10 years
 - 10 – 15
 - 15 – 20
 - > 20 years
- How would you describe your position in your organisation?
 - Entry level
 - Junior level
 - Middle management
 - Senior management
 - Executive /board member Other (please specify)
- Which of the following best describes your organisation?
 - Developer
 - Domestic financial institution e.g. commercial banks, microfinance banks etc.
 - International financial institution e.g. commercial banks, microfinance banks etc.
 - Private equity firm
 - Development finance institution / Multilateral development bank
 - Impact Investor
 - Consulting and other professional services
 - Public sector institutions e.g., Regulator, Ministry, legislature. Please indicate.
 - Other – please specify.

PART B

Private investor risks

Several risks that need to be considered in renewable energy system investments have been identified in the literature. These risks can be specific to location and application. In this section, you will be asked to rate the applicability of risk factors grouped into 7 categories in terms of their importance to investments in DRE in Nigeria

1. Please identify the applicable system to which you will be ranking risk factors in the next set of investment risk questions.
2. Please rate each of the following risk factors in terms of the extent to which they impact DRE investments in Nigeria (*Please rate from 1- not important to 5-extremely important*)

A	Risk categories	Importance					N/A
		1	2	3	4	5	
a	Technical risk (These are risks that impact the design and therefore efficiency, cost, longevity, and profitability of the project)						
b	Policy/regulatory & political risk These are uncertainties in revenue, cost or development of the project due to changes in legislation, policies or regulations, political events						
c	Financing risk These may arise from barriers in the financial environment e.g., low access to low-cost capital, inability to source local currency funding etc. that affect the revenue, cost and sustainability projects						
d	Economic risk (These may arise from changes in the economic environment e.g., currency fluctuation, ability to pay etc. thereby affecting the sustainability of the project)						
e	Market risk (These may arise from uncertainties brought by variation or limitations in markets such as market access barriers, competition etc.)						
f	Social and environmental risk (These may arise due to changes in social conditions and potential impact on the environment)						

3. Please rate each of the following risk factors in terms of the extent to which they impact DRE investments in Nigeria (*Please rate from 1- not important to 5-extremely important*)

A	Technical risk factors	Importance					NA
		1	2	3	4	5	
a	Limitation in training, research and development capacity.						
b	Low availability of technical skills during construction, operations and maintenance phases.						
c	Limitation in developer's capability to effectively execute projects.						
d	Limitation in the quality control of hardware and manufacturing capacity.						
e	Uncertain load profile due to variability in demand, uncertainties in population distribution patterns etc.						
f	Inadequate infrastructure and collection systems e.g., roads, mobile payment technologies.						
g	Site characteristics such as gradient, resource variability						
h	Other, please specify						
B	Social and Environmental risk factors	Importance					NA
		1	2	3	4	5	
a	Lack of social acceptance or resistance to change.						
b	Poor consumer awareness of renewable energy benefits						
c	Lack of integration of renewable energy systems to support the development of host communities						
d	Difficulty in acquiring land/ competition with land uses						
e	Insecurity						
f	Other- Please specify						
C	Market risk factors	Importance					NA
		1	2	3	4	5	
a	Sensitivity of competitiveness of renewable energy to prices of traditional fossil sources.						
b	Low competitiveness of renewable energy due to subsidies on alternatives e.g., grid electricity						
c	Market access barriers - lack of competitive hardware and labour market						
d	Poor market and consumer data availability						
e	Market access barriers - regulations e.g., taxes, tariffs						
f	Uncertain market growth potential						
g	Other- Please specify						
D	Financing risk factors	Importance					NA
		1	2	3	4	5	
a	High initial investment cost						
b	Inadequate access to low-cost capital						
c	A mismatch between short loan terms and long project lifecycle						

(continued on next page)

(continued)

D	Financing risk factors	Importance					
		1	2	3	4	5	NA
<i>d</i>	Limited local financial sector experience in renewable energy						
<i>e</i>	Limited financial capacity and experience of developers/ local investors in renewable energy						
<i>f</i>	Difficulty in accessing foreign exchange and repatriation of funds to foreign investors						
<i>g</i>	Other- Please specify.						
D	Economic risk factors	Importance					
		1	2	3	4	5	NA
<i>a</i>	Revenue uncertainty due to low affordability, demand variability, lack of willingness to pay etc						
<i>E</i>	Collection losses due to line tampering, theft, and non-payments.						
<i>c</i>	Foreign exchange volatility leading to cost-revenue mismatch.						
<i>d</i>	Inability to achieve single off-taker or cluster effect for off-takers to diversify and achieve scale						
<i>e</i>	Inability to charge cost-reflective tariff						
<i>f</i>	Other- Please specify.						
E	Political risk factors	Importance					
		1	2	3	4	5	NA
<i>a</i>	Effect of political changes or political instability						
<i>b</i>	Inadequate political will to diversify into renewable energy.						
<i>c</i>	Political events that adversely impact the value of investments (e.g., war, civil disturbance, currency inconvertibility, breach of contract, non-honouring of obligations)						
<i>d</i>	Other- Please specify						
F	Policy/regulatory risk factors	Importance					
		1	2	3	4	5	NA
<i>a</i>	Insufficient or undefined policy/legal frameworks to support investments e.g. tax incentives, efficient processing of permits, licences & approvals, strong regulator, competing incentives.						
<i>b</i>	Unclear regulations with inadequate guidelines)						
<i>c</i>	Retroactive policy changes						
<i>d</i>	Poor/ lack of policy implementation						
<i>e</i>	Duplicative policy development through institutions with overlapping responsibilities						
<i>f</i>	Inconsistent policy application						
<i>g</i>	Uncertainty in the implementation of regulations for the interconnection of mini-grids into the main grid						
<i>h</i>	Uncertainty in grid extension plans						
<i>i</i>	Other- Please specify						

Please respond to the following question before finishing the survey.

Would you be open to participating in a follow-up interview on this topic?

Yes, contact me via the email provided in the earlier part of this survey

Yes, contact me via this email, **No**

Table A-2

Classification of interview and focus group participants.

Group	Description of interviewees	Focus group participants. % (N = 3)	Interview participants % (N = 17)
Developer	Chief executives/founders	-	6
PI (2 groups)	Senior and management officials of public agencies for policy development, regulation, implementation	10 4	3
DFI	Senior management officials of international development finance institutions involved in risk management and infrastructural development	-	5
DomDFI	Middle and Senior management officials of domestic development finance institutions involved in infrastructural development	3	
DomFI	Senior management officials of domestic finance institutions involved in RE and power financing	-	2
Impact Investor	Executive management officials of impact investment firms involved in financing RE impact investment in Nigeria	-	1

AHP methodology: Calculation of AHP risk priorities (weightings)

The alternative AHP methodology [55] entailed collecting preference data via a 5-point Likert scale, wherein respondents provided direct ratings of the importance of risks and risk factors. Ratings ranged from 1 (Not Important) to 5 (Extremely Important). These scores were subsequently transformed to simulate the judgement, $\hat{a}_{ij}$ of the traditional AHP pairwise comparisons through the formula:

$$\hat{a}_{ij} = |Sc_{ik} - Sc_{jk}| + 1$$

Where:

Sc_{ik} : Score assigned by respondent k to risk or risk factor descriptor i

Sc_{jk} : Score assigned by respondent k to risk or risk factor descriptor j

The transformation results in simulated pairwise comparison values, which are then utilised to calculate weights, w_{ik} via the geometric mean approach:

$$w_{ik} = \sqrt[N \times P]{\prod_{i=1}^{N \times P} a_{ijk} V_{i,k}}$$

Where:

a_{ij} : is the pairwise comparison value between attributes (risk categories) and levels (risk factors)

N: is the number of attributes (risk categories)

P: is the number of levels (risk factors)

The calculated weights are normalised to ensure that their sum equals 1. This approach offers a substantial reduction in the number of required comparisons to relative to the traditional AHP methodology, thereby streamlining the evaluation process. The employed approach provides a viable alternative to the traditional AHP method, offering simplicity. Although the method yield comparable rankings, discrepancies in weight estimates indicate areas for methodological refinement [55].

The consistency of weight estimates was determined using Eqs. (1) and 2.

$$Aw = \lambda_{max} \times w \quad (1)$$

where A is the comparison matrix, w is the Eigenvector of size $n \times 1$ or priority vector, and λ_{max} is the maximum Eigenvalue.

The degree of consistency of the estimation (consistency ratio, CR) was determined using Eq. (2).

$$CR = CI/RI \quad (2)$$

Where $CR \leq 10\%$ indicates an acceptable level of consistency in judgements.

$CI = (\lambda_{max} - n)/(n-1)$, and the random index (RI) is used as the consistency index when the matrix entries are random [37]. The standard values of RI are shown in Table A-3.

Table A-3

Standard values of random index.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0	0.52	0.89	1.25	1.35	1.4	1.45	1.49

Table A-4

Interview and focus group questions.

Purpose	Question
General	Can you tell us about your background and expertise?
Validation	The outcome of risk priorities in relation to their impact on DRE investment in Nigeria is presented. Do you agree with the priorities and why? If not, what other factors are important and why?
Risk drivers	What are the possible drivers for these risk factors?
Interdependencies	What are the interactions between the factors?
Mitigations	How could the top risks discussed be mitigated?

Qualitative Analysis

Following a previous approach [1], data was analysed by alternating between interview transcripts and the literature to provide context to quantitative AHP results. Additionally, the mitigation actions proposed by interviewees were coded and thematically analysed. The thematic analysis of interview transcripts was conducted in accordance with the steps outlined by Braun and Clark (142). This process was initiated by an extensive review of the transcripts, focusing on risk mitigation strategies, with the aim of understanding and contextualising the responses provided by the interviewees. Following this initial review, the coding phase was executed using NVivo software version 14. The coding framework was initially informed by mitigation strategies outlined in the literature, serving as a preliminary guide. Additionally, the analysis was receptive to emergent strategies discussed by interviewees, ensuring that further codes and insights were captured. Coding involved identifying and assigning codes to texts specifically related to actionable insights for risk mitigation within the transcripts.

The subsequent phase involved the aggregation of individual codes into broader thematic categories. This process was guided by the interviewee types, the nature of the mitigation strategies proposed, and the specific risk categories addressed. By comparing codes, identifying connections and commonalities, similar codes were grouped together to form broad themes. In the fourth stage, the emergent themes were reviewed. This involved an examination of patterns, relationships, and discrepancies within and between themes. This facilitated the refinement of themes, where similar themes were merged and appropriately renamed to reflect the underlying data. The final themes were: (i) navigating currency risks, (ii) enhancing financing mechanisms and capacity building, (iii) strategies for improving project revenues and viability, and (iv) recommendations for policy implementation and enhancements. These themes were reflective of the diverse DRE risk mitigation strategies and insights shared in the interviews.

Table A-5

Risk factor priority overall ranking (AHP results) by respondent groups and indications of priority changes identified in interviews.

RISK FACTOR	Developer	Domestic financial institution	DFI	Impact Investor	Consulting and other professional services.	Public sector institution	Other - Eng. Services and utilities	Development agency	ALL Groups
E1_Revenue risk	3.63%	0.71%	13.92%	5.79%	0.96%	5.98%	2.54%	7.58%	4.80%
E2_Collection losses	7.26%	1.86%	7.83%	5.79%	1.50%	2.99%	2.54%	2.53%	4.80%
E3_Foreign exchange volatility	7.26%	1.86%	13.92%	16.12%	8.47%	5.98%	8.97%	7.58%	9.59%
E4_Inability to achieve single off-taker or cluster effect	3.63%	1.86%	4.38%	5.79%	2.43%	2.99%	2.54%	2.53%	4.80%
E5_Non-cost reflective tariff	3.63%	5.00%	4.38%	3.16%	3.91%	2.99%	0.99%	7.58%	4.80%
F1_High cost	9.01%	6.59%	2.13%	2.51%	11.10%	2.99%	1.88%	2.31%	4.11%
F2_Inadequate access to low-cost capital	5.55%	6.59%	5.54%	2.51%	3.94%	5.98%	1.13%	6.94%	8.22%
F3_short loan terms	3.04%	6.59%	5.54%	1.26%	2.12%	2.99%	3.11%	6.94%	4.11%
F4_Limited local financial sector experience	3.04%	2.20%	1.30%	2.51%	3.94%	2.99%	5.16%	6.94%	4.11%
F5_Limited financial capacity and experience of developers/ local investors	1.72%	2.20%	1.30%	2.51%	3.94%	2.99%	5.16%	2.31%	4.11%
F6_Difficulty accessing/repatriating Forex	3.04%	6.59%	5.54%	2.51%	3.94%	2.99%	1.13%	2.31%	4.11%
P1_Insufficient policy/legal support framework	2.36%	1.68%	0.50%	1.18%	1.32%	1.20%	3.52%	2.43%	2.23%
P2_Unclear regulation/guidelines	1.33%	0.69%	0.34%	1.18%	0.40%	1.23%	1.22%	2.43%	0.79%
P3_Policy changes	1.25%	0.69%	0.78%	1.18%	0.70%	0.38%	5.83%	2.43%	1.05%
P4_lack of policy implementation	2.36%	0.77%	1.49%	1.18%	1.32%	1.20%	0.81%	0.86%	1.55%
P5_Duplicative policy development	1.29%	0.69%	0.82%	1.15%	0.70%	0.85%	3.52%	2.43%	1.05%
P6_Inconsistent policy application	0.79%	0.67%	2.71%	2.23%	0.70%	1.11%	2.03%	0.86%	1.05%
P7_Uncertainties in IMG regulations implementation	2.47%	2.01%	1.49%	2.13%	1.32%	1.09%	2.03%	2.43%	2.23%
P8_Grid extension uncertainty	2.36%	2.07%	1.49%	2.13%	1.32%	0.62%	5.83%	2.43%	2.23%
P9_Political changes/instability.	4.02%	0.67%	1.49%	0.69%	1.32%	1.20%	3.52%	6.65%	2.23%
P10_Inadequate political will	1.29%	0.67%	0.82%	0.32%	0.40%	1.20%	2.03%	2.43%	1.05%
P11_Adverse political events	5.92%	0.65%	1.49%	0.45%	0.70%	1.20%	1.22%	2.43%	1.55%
T1_Limited training and research and development	0.72%	6.15%	0.66%	0.45%	6.24%	4.04%	0.56%	0.51%	1.13%
T2_Technical skills limitation	1.31%	2.05%	0.38%	0.74%	2.14%	1.29%	2.33%	0.51%	0.71%
T3_Limitation in Developer's capability	1.31%	6.15%	0.66%	1.36%	3.73%	1.29%	2.33%	0.51%	1.73%
T4_Limitation in QC and manufacturing capacity	0.72%	6.15%	0.66%	1.36%	9.65%	4.04%	0.90%	1.52%	1.73%
T5_Uncertain load profile	3.27%	2.05%	2.47%	1.36%	2.14%	4.04%	0.90%	0.51%	1.58%
T6_Inadequate infrastructure	1.31%	6.15%	2.47%	2.38%	3.73%	4.04%	2.33%	1.52%	2.21%
T7_Uncertainties in site characteristics	0.44%	2.05%	0.66%	0.74%	1.34%	2.20%	0.37%	0.51%	0.71%
M1_Sensitivity of RE to fossil fuel prices	2.03%	3.38%	0.86%	3.27%	1.00%	4.81%	5.75%	1.04%	1.69%
M2_Low competitiveness of RE due to subsidies on alternatives	1.10%	1.13%	1.64%	3.27%	1.91%	4.81%	1.73%	1.04%	1.34%
M3_lack of competitive hardware and labour market	0.62%	1.13%	0.52%	3.27%	1.00%	1.46%	3.31%	1.04%	0.72%
M4_Poor data availability	1.41%	1.13%	1.64%	6.12%	3.33%	4.81%	1.73%	1.04%	2.49%
M5_Barriers due to regulations	2.82%	3.38%	1.64%	6.12%	1.00%	2.53%	3.31%	1.04%	2.49%
M6_Uncertain market growth potential	1.10%	1.13%	1.64%	1.26%	1.91%	2.53%	1.73%	0.35%	1.06%
SE1_Lack of social acceptance	0.31%	0.26%	0.33%	0.50%	0.32%	0.39%	2.23%	0.62%	0.54%
SE2_Poor consumer awareness	0.74%	1.60%	0.42%	0.94%	0.54%	1.20%	0.80%	0.62%	0.84%
SE3_Lack of integration of RE systems	1.15%	0.60%	0.45%	0.50%	0.94%	0.67%	0.48%	0.62%	0.84%
SE4_Difficulty in acquiring land	0.31%	0.60%	1.24%	0.50%	0.54%	0.67%	1.22%	0.62%	0.84%
SE5_Insecurity	3.08%	1.60%	2.49%	1.58%	2.14%	1.98%	1.29%	3.09%	2.85%

NOTE: Ranking/colour coding is defined by a normalised qualitative scale of green (very low priority <1.92 %), yellow (low priority >1.93–3.84 %), orange (moderate priority >3.85–5.75 %), dark orange (high priority >5.76–7.67 %), red (very high priority >7.68 %).

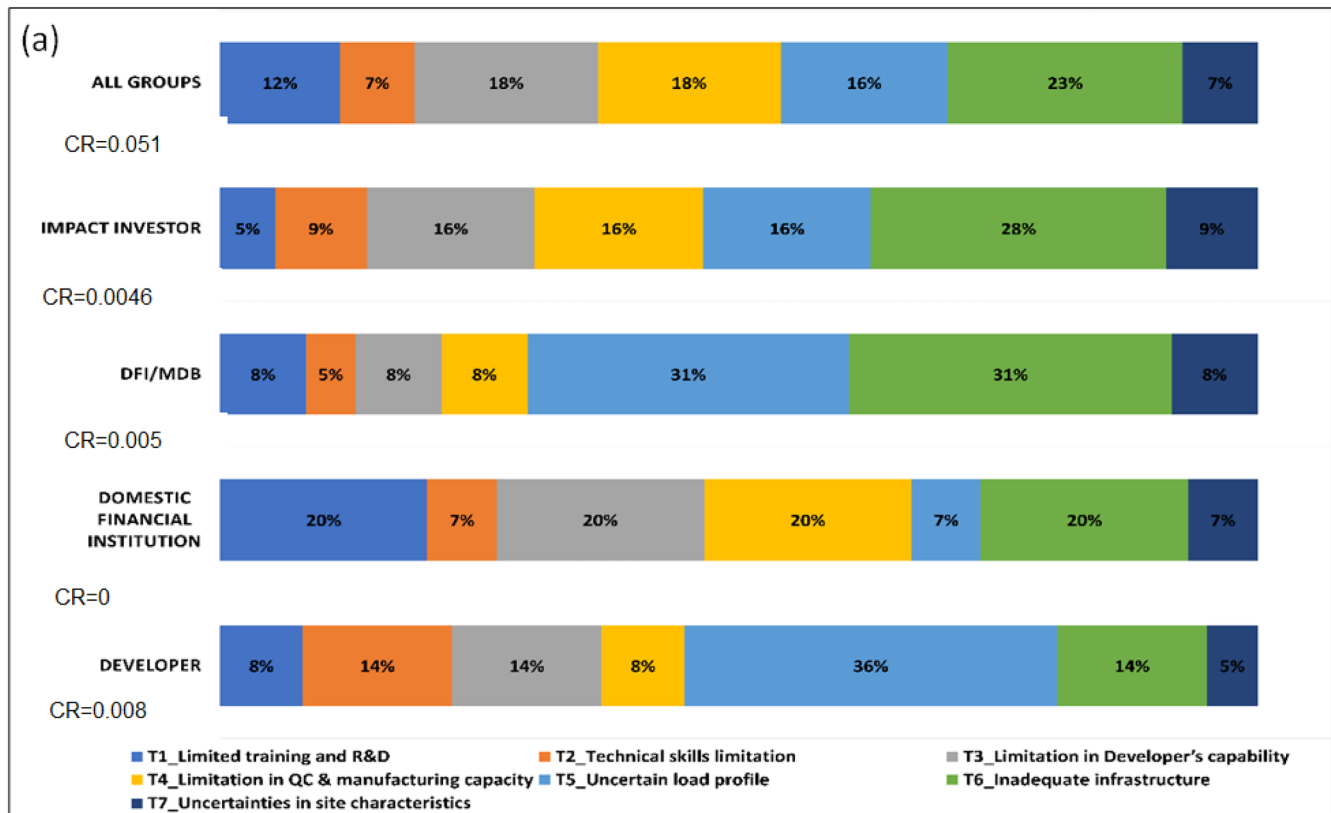


Fig. A-1. Prioritisation of technical risk factors overall and by investor groups.

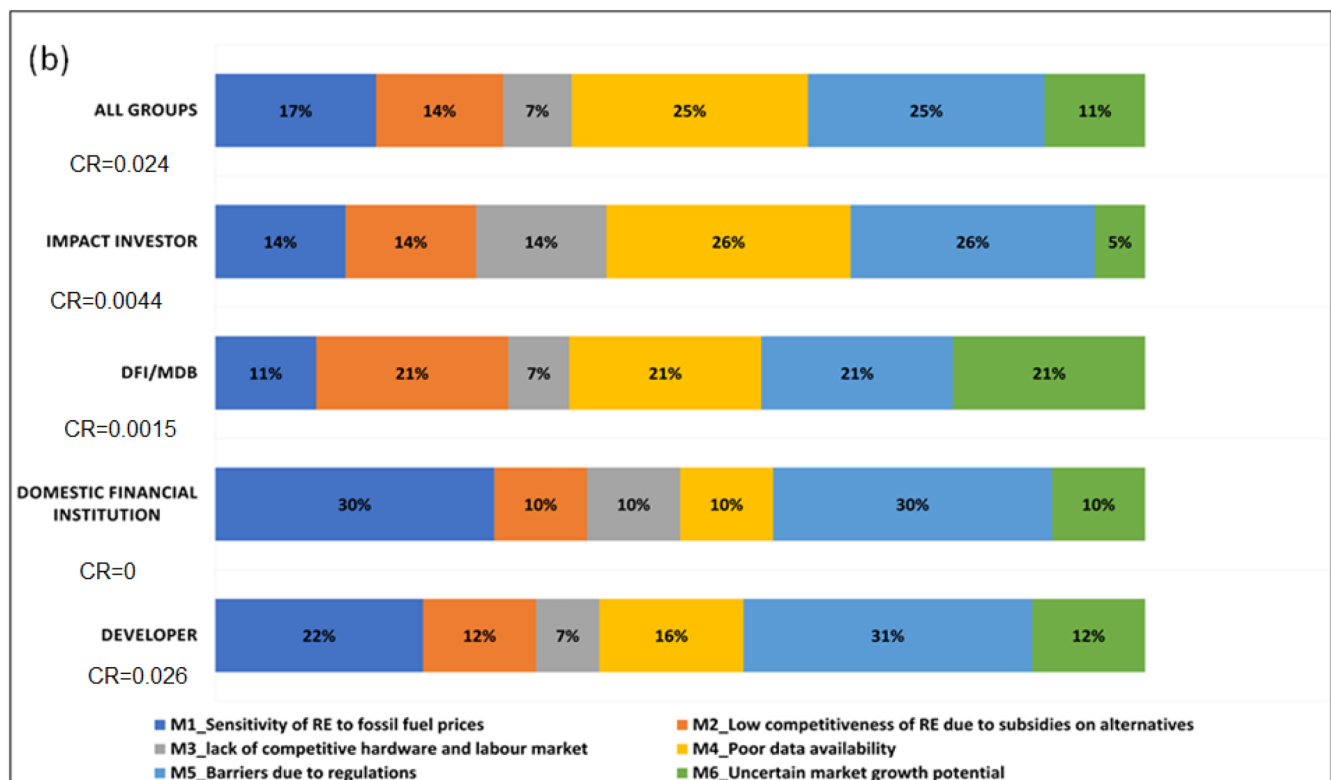


Fig. A-2. Prioritisation of market risk factors overall and by investor groups.

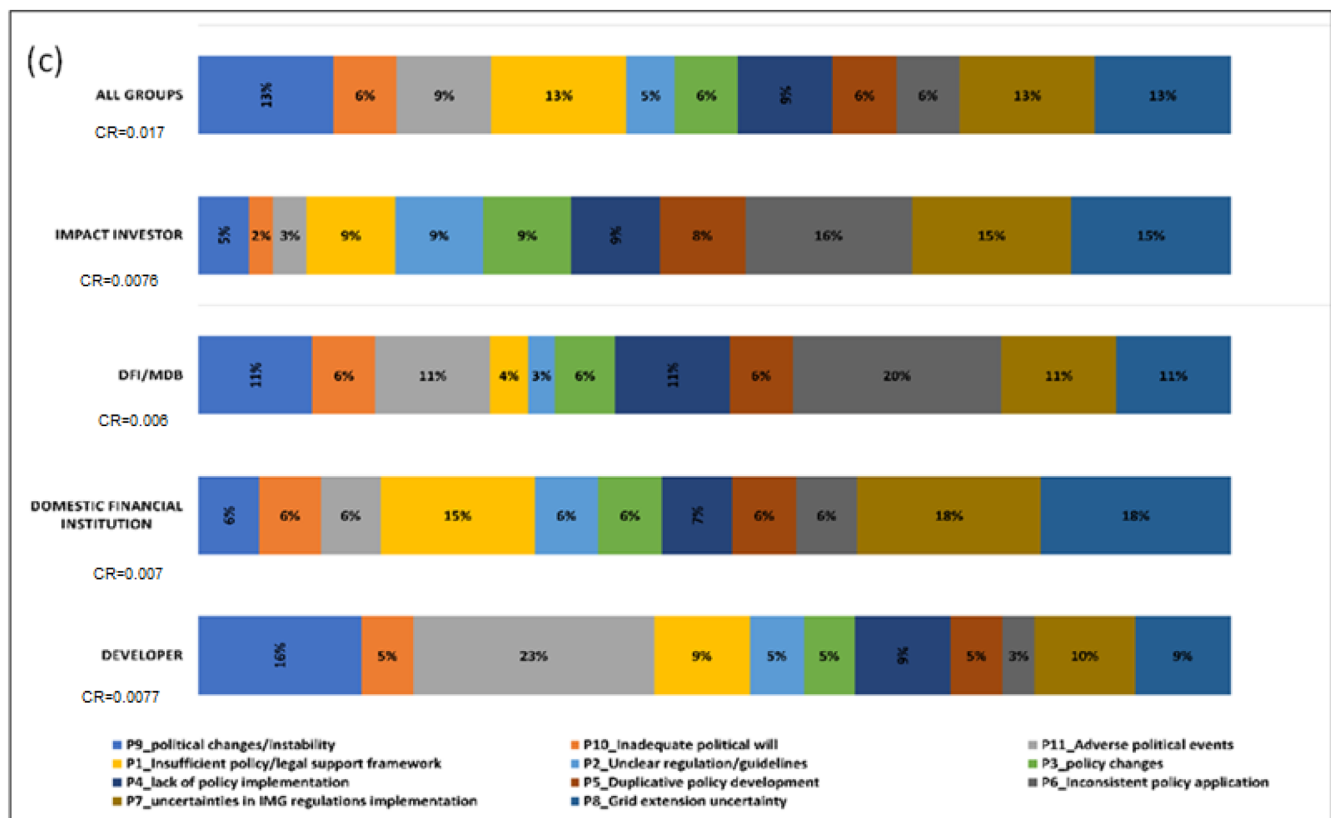


Fig. A-3. Prioritisation of PP risk factors overall and by different groups of investors.

Data availability

Data supporting this study are included within the article.

References

- [1] IRENA and CPI, Global Landscape of Renewable Energy Finance, 2023 [Internet], International Renewable Energy Agency, Abu Dhabi, 2023 [cited 2023 Dec 1]. Available from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/Feb/IRENA_CPI_Global_RE_finance_2023.pdf.
- [2] A. Bender, M. Moner-Girona, W. Becker, K. Bódis, S. Szabó, A.G. Kararach, et al., Dataset for multidimensional assessment to incentivise decentralised energy investments in Sub-Saharan Africa, Data Brief [Internet] 37 (2021) 107265, <https://doi.org/10.1016/j.dib.2021.107265>. Available from:.
- [3] D. Mentis, M. Welsch, F. Fuso Nerini, O. Broad, M. Howells, M. Bazilian, et al., A GIS-based approach for electrification planning-A case study on Nigeria, Energy for Sustainable Development [Internet] 29 (2015) 142–150, <https://doi.org/10.1016/j.esd.2015.09.007>. Available from:.
- [4] M. Moner-Girona, M. Solano-Peralta, M. Lazopoulou, E.K. Ackom, X. Vallve, S. Szabó, Electrification of Sub-Saharan Africa through PV/hybrid mini-grids: reducing the gap between current business models and on-site experience, Renewable and Sustainable Energy Reviews 91 (2018) 1148–1161.
- [5] ECN, National Energy Masterplan; Energy Commission of Nigeria [Internet], Energy Commission of Nigeria, Federal Republic of Nigeria, 2022 [cited 2025 Mar 20] Available from: https://www.energy.gov.ng/Energy_Policies_Plan/APP/ROVED_NEMP_2022.pdf.
- [6] Nigeria Energy Transition Office. Nigeria Energy Transition Plan. [cited 2023 Jan 6]. Nigeria Energy Transition Plan. Available from: <https://www.energytransition.gov.ng/power/>.
- [7] Federal Ministry of Power S. Installed capacity generated by mini-grids in Nigeria. [Internet]. 2022 Oct 22 [cited 2025 Mar 20]; Available from: <https://nigeria4all.gov.ng/mini-grids>.
- [8] A. Donastorg, S. Renukappa, S. Suresh, Financing Renewable Energy Projects in Developing Countries: a Critical Review, IOP. Conf. Ser. Earth. Environ. Sci. 83 (1) (2017).
- [9] IRENA. Unlocking Renewable Energy Investment: the role of risk mitigation and structured finance [Internet]. 2016 [cited 2024 Nov 30]. Available from: www.irena.org/publications.
- [10] O. Waissbein, Y. Glemarec, H. Bayraktar, T.S. Schmidt, Derisking Renewable Energy Investment. A Framework to Support Policymakers in Selecting Public Instruments to Promote Renewable Energy Investment in Developing Countries [Internet]. United Nations Development Programme, 2013 [cited 2022 Nov 9] Available from: <https://www.osti.gov/servlets/purl/22090458>.
- [11] N.J. Williams, P. Jaramillo, J. Taneja, T.S. Ustun, Enabling private sector investment in microgrid-based rural electrification in developing countries: a review, Renewable and Sustainable Energy Reviews 52 (2015) 1268–1281.
- [12] X.S. Musonye, B. Davíðsdóttir, R. Kristjánsson, E.I. Ásgeirsson, H. Stefánsson, Integrated energy systems' modeling studies for sub-Saharan Africa: a scoping review, Renewable and Sustainable Energy Reviews 128 (September 2019) (2020).
- [13] T. Schinko, N. Komendantova, De-risking investment into concentrated solar power in North Africa: impacts on the costs of electricity generation, Renew Energy [Internet] 92 (2016) 262–272, <https://doi.org/10.1016/j.renene.2016.02.009>. Available from:.
- [14] A.P. Troost, J.K. Musango, A.C. Brent, Strategic Investment to Increase Access to Finance among Mini-Grid ESCOs : perspectives from sub-Saharan Africa, in: Proceedings - 2018 2nd International Conference on Green Energy and Applications, ICGEA 2018, 2018, pp. 229–237.
- [15] Z.Y.I. Abba, N. Balta-Ozkan, P. Hart, A holistic risk management framework for renewable energy investments, Renewable and Sustainable Energy Reviews [Internet] 160 (March) (2022) 112305, <https://doi.org/10.1016/j.rser.2022.112305>. Available from:.
- [16] F. Egli, Renewable energy investment risk: an investigation of changes over time and the underlying drivers, Energy Policy [Internet] 140 (March) (2020) 111428, <https://doi.org/10.1016/j.enpol.2020.111428>. Available from:.
- [17] F. Polzin, F. Egli, B. Steffen, T.S. Schmidt, How do policies mobilize private finance for renewable energy?—A systematic review with an investor perspective, Appl Energy [Internet] 236 (May 2018) (2019) 1249–1268, <https://doi.org/10.1016/j.apenergy.2018.11.098>. Available from:.
- [18] C. Klessmann, M. Rathmann, D. de Jager, A. Gazzo, G. Resch, S. Busch, et al., Policy options for reducing the costs of reaching the European renewables target, Renew. Energy 57 (2013) (2013) 390–403.
- [19] A. Ioannou, A. Angus, F. Brennan, Risk-based methods for sustainable energy system planning: a review, Renewable and Sustainable Energy Reviews 74 (March) (2017) 602–615.
- [20] O.S. Ohunakin, M.S. Adaramola, O.M. Oyewola, R.O. Fagbenle, Solar energy applications and development in Nigeria : drivers and barriers, Renewable and

- Sustainable Energy Reviews [Internet] 32 (2014) 294–301, <https://doi.org/10.1016/j.rser.2014.01.014>. Available from:.
- [21] D. Abdullahi, S. Suresh, S. Renukappa, D. Oloke, Key Barriers to the Implementation of Solar Energy in Nigeria: a Critical Analysis, *IOP. Conf. Ser. Earth. Environ. Sci.* 83 (1) (2017).
 - [22] N.V. Emodi, S.D. Yusuf, Improving Electricity Access in Nigeria : obstacles and the Way Forward, *International Journal of Energy Economics and Policy* 5 (1) (2015) 335–351.
 - [23] A. Malhotra, T.S. Schmidt, L. Haelg, O. Waissbein, Scaling up finance for off-grid renewable energy: the role of aggregation and spatial diversification in derisking investments in mini-grids for rural electrification in India, *Energy Policy* 108 (June) (2017) 657–672.
 - [24] Y. Wu, J. Wang, S. Ji, Z. Song, Renewable energy investment risk assessment for nations along China's Belt & Road Initiative: an ANP-cloud model method, *Energy [Internet]* 190 (2020) 116381, <https://doi.org/10.1016/j.energy.2019.116381>. Available from:.
 - [25] E. Côté, S. Salm, Risk-adjusted preferences of utility companies and institutional investors for battery storage and green hydrogen investment, *Energy Policy* 163 (January) (2022).
 - [26] S.P.A. Mohamed, N. Firoz, M. Sadihik, M. Dadu, Risk Analysis in Implementation of Solar Energy Projects in Kerala, *J. Phys. Conf. Ser.* 1355 (1) (2019).
 - [27] B.C. Kim, J. Kim, J. Kim, Evaluation model for investment in solar photovoltaic power generation using fuzzy analytic hierarchy process, *Sustainability (Switzerland)* 11 (10) (2019).
 - [28] A. Gungah, N.V. Emodi, M.O. Dioha, Improving Nigeria's renewable energy policy design: a case study approach, *Energy Policy* 130 (2019) 89–100. Jul.
 - [29] H.A. Daggash, N. Mac Dowell, Delivering low-carbon electricity systems in sub-Saharan Africa: insights from Nigeria, *Energy Environ. Sci.* 14 (7) (2021) 4018–4037.
 - [30] A. Isah, M.O. Dioha, R. Debnath, M.C. Abraham-Dukuma, H.M. Butu, Financing renewable energy: policy insights from Brazil and Nigeria, *Energy Sustain Soc [Internet]* 13 (1) (2023) 1–16, <https://doi.org/10.1186/s13705-022-00379-9>. Available from:.
 - [31] F. Adeniyi, A. Isah, Unlocking renewables amid rentierism: market constraints to Nigeria's energy transition, *Energy Res. Soc. Sci.* 104 (2023) 103248. Oct.
 - [32] C. Agutu, F. Egli, N.J. Williams, T.S. Schmidt, B. Steffen, Accounting for finance in electrification models for sub-Saharan Africa, *Nat. Energy* 7 (7) (2022) 631–641.
 - [33] D. Abdullahi, A Framework For Adopting Solar Energy Governance in the Nigerian power Sector [Internet], University of Wolverhampton, [Wolverhampton], 2021. Available from: <https://wlv.openrepository.com/handle/2436/624227>.
 - [34] M. Rasouli, A. Ayough, B. Khorshidvand, A. Alemtabriz, Evaluating risk factors in solar energy investments: a strategic approach for Iran's market, *Solar Energy* 262 (2023). Sep 15.
 - [35] C. Kul, L. Zhang, Y. Ahmed, Assessing the renewable energy investment risk factors for sustainable development in Turkey, *J Clean Prod [Internet]* 276 (2020) 124164, <https://doi.org/10.1016/j.jclepro.2020.124164>. Available from:.
 - [36] D. Bukari, F. Kemausuor, D.A. Quansah, M.S. Adaramola, Towards accelerating the deployment of decentralised renewable energy mini-grids in Ghana: review and analysis of barriers, *Renewable and Sustainable Energy Reviews [Internet]* 135 (November 2019) (2021) 110408, <https://doi.org/10.1016/j.rser.2020.110408>. Available from:.
 - [37] L.P. Ghimire, Y. Kim, An analysis on barriers to renewable energy development in the context of Nepal using AHP, *Renew Energy [Internet]* 129 (2018) 446–456, <https://doi.org/10.1016/j.renene.2018.06.011>. Available from:.
 - [38] Nigeria Energy, IRENA. Renewable Energy Roadmap Nigeria [Internet]. 2023 [cited 2025 Mar 20]. Available from: <https://www.nigeria-energy.com/content/dam/markets/emea/nigeria-energy/en/2023/docs/NE23-NigeriaEnergyRoadmap-Report.pdf>.
 - [39] PSRP. Federal Republic of Nigeria Power Sector Recovery Programme: 2017–2021 [Internet]. 2017 [cited 2025 Mar 21]. Available from: <https://rea.gov.ng/download/power-sector-recovery-implementation-program-2017-2021/>.
 - [40] B. Ugwoke, O. Gershon, C. Becchio, S.P. Corgnati, P. Leone, A review of Nigerian energy access studies : the story told so far, *Renewable and Sustainable Energy Reviews [Internet]* 120 (November 2019) (2020) 109646, <https://doi.org/10.1016/j.rser.2019.109646>. Available from:.
 - [41] M. Yetano Roche, H. Verolme, C. Agbaegbu, T. Binnington, M. Fischedick, E. O. Oladipo, Achieving Sustainable Development Goals in Nigeria's power sector: assessment of transition pathways, *Climate Policy [Internet]* 20 (7) (2020) 846–865, <https://doi.org/10.1080/14693062.2019.1661818>. Available from:.
 - [42] World Bank. World Development Indicators. 2023. <https://databank.worldbank.org/reports.aspx?source=2&series=SP.RUR.TOTL&country=NGA#>.
 - [43] K. Ley, J. Gaines, A. Ghatikar, The Nigerian Energy Sector, *Nigerian Energy Sector [Internet]* (2015) 1–152 [cited 2025 Mar 23];(June)Available from: <https://www.giz.de/en/downloads/giz2015-en-nigerian-energy-sector.pdf>.
 - [44] NERC. Nigerian Electricity Regulatory Commission Regulation for Mini-Grids 2016 [Internet]. 2016 [cited 2023 Oct 3]. Available from: <https://rea.gov.ng/wp-content/uploads/2018/07/NERC-Mini-Grid-Regulation.pdf>.
 - [45] NESG. Investment Report, Scaling the Nigerian Market [Internet]. 2018 [cited 2024 Jan 31]. Available from: <https://rmi.org/press-release/the-latest-rocky-mountain-institute-and-the-nigerian-renewable-energy-roundtable-report-shows-us20-billion-investment-opportunity-for-nigeria-in-scaling-minigrids/>.
 - [46] NERC, NERC MINIGRID REGULATIONS 2023 [Internet], NERC, 2023. Available from: <https://nerc.gov.ng/resources/nerc-minigrid-regulations-2023/>.
 - [47] Federal Government of Nigeria. Nigeria Electricity Act 2023 [Internet]. Available from: <https://www.power.gov.ng/download/electricity-act-2023/>.
 - [48] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Nigerian Energy Support Programme (NESP) The Nigerian Energy Sector An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification [Internet] (2015). Available from: www.gopa-intec.de.
 - [49] S.M. Ohiare, Financing Rural Energy Projects in Developing Countries: a Case Study of Nigeria [Internet], Energy. Leicester (2014). Jul [cited 2023 Feb 23] Available from: <https://dora.dmu.ac.uk/server/api/core/bitstreams/14965bf7-4df1-4d3e-9935-441fccce28c8/content>.
 - [50] FMPWH, Rural Electrification Strategy and Implementation Plan (RESIP) (July) (2016) 1–41. Available from: file:///C:/Users/debbi/Downloads/RESIP_APROVED.27.07.2016_Final.pdf.
 - [51] J.P. Painuly, Barriers to renewable energy penetration: a framework for analysis, *Renew. Energy* 24 (1) (2001) 73–89.
 - [52] ISO. ISO 31000:2009(en), Risk management — Principles and guidelines [Internet]. [cited 2020 Nov 7]. Available from: <https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-1:v1:en>.
 - [53] C. McGookin, B. Ó Gallachóir, E. Byrne, Participatory methods in energy system modelling and planning – A review, *Renewable and Sustainable Energy Reviews* 151 (2021) 111504. Nov.
 - [54] J.P. Painuly, Barriers to renewable energy penetration: a framework for analysis, *Renew. Energy* 24 (1) (2001) 73–89.
 - [55] Z. Kallas, Butchers' Preferences for Rabbit Meat, *Ahp Pairwise Comparisons Versus a Likert Scale Valuation* (2011) 1–6.
 - [56] V. Braun, V. Clarke, Using thematic analysis in psychology, *Qual. Res. Psychol.* 3 (2) (2006) 77–101. Jan.
 - [57] C.G. Ozogwu, C.A. Mgbemene, P.A. Ozor, The status of solar energy integration and policy in Nigeria, *Renewable and Sustainable Energy Reviews [Internet]* 70 (November 2016) (2017) 457–471, <https://doi.org/10.1016/j.rser.2016.11.224>. Available from:.
 - [58] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.giz.de/en/downloads/giz2021_NESP_II_Factsheet.pdf. 2021. Nigerian Energy Support Programme II.
 - [59] NESP, Nigeria Energy Support Programme G. DUE DILIGENCE GUIDELINES FOR MINI-GRID INVESTORS IN NIGERIA. 2017.
 - [60] Michoud B., Hafner M. Financing clean energy access in Sub-Saharan Africa: risk mitigation strategies and innovative financing structures [Internet]. 2021. 197 p. Available from: <https://www.dropbox.com/s/wprd5hv0eavycyb/978-3-030-75829-5.pdf?dl=0>.
 - [61] N. Edomah, Rural electrification in Africa: a case study of Yebu community solar minigrid, *Environmental Research: Infrastructure and Sustainability* (2022).
 - [62] E.O. Eludoyin, X. Lemaire, Work, food, rent, television: the role of lifestyles and experiences on household energy behaviour in rural Lagos, Nigeria, *Energy Res Soc Sci [Internet]* 71 (October 2020) (2021) 101820, <https://doi.org/10.1016/j.erss.2020.101820>. Available from:.
 - [63] M. Tesfamichael, C. Bastille, M. Leach, Eager to connect, cautious to consume: an integrated view of the drivers and motivations for electricity consumption among rural households in Kenya, *Energy Res. Soc. Sci.* 63 (2020) 101394. May.
 - [64] L. Lozano, E.M. Querikol, E.B. Taboada, The Viability of Providing 24-Hour Electricity Access to Off-Grid Island Communities in the Philippines, *Energies (Basel)* 14 (20) (2021) 6797. Oct 18.
 - [65] J. Zhao, B.M. Tamm, *Psychological Responses to Scarcity*. Oxford Research Encyclopedia of Psychology, Oxford University Press, 2018.
 - [66] T.S. Schmidt, N.U. Blum, Sryantoro Wakeling R. Attracting private investments into rural electrification - A case study on renewable energy based village grids in Indonesia, *Energy for Sustainable Development [Internet]* 17 (6) (2013) 581–595, <https://doi.org/10.1016/j.esd.2013.10.001>. Available from:.
 - [67] D. Akinyele, J. Belikov, Y. Levron, Challenges of microgrids in remote communities: a STEEP model application, *Energies (Basel)* 11 (2) (2018) 1–35.
 - [68] N.J. Williams, P. Jaramillo, J. Taneja, An investment risk assessment of microgrid utilities for rural electrification using the stochastic techno-economic microgrid model: a case study in Rwanda, *Energy for Sustainable Development [Internet]* 42 (2018) 87–96, <https://doi.org/10.1016/j.esd.2017.09.012>. Available from:.
 - [69] J. Barroco, M. Herrera, Clearing barriers to project finance for renewable energy in developing countries: a Philippines case study, *Energy Policy* 135 (August 2018) (2019).
 - [70] International Energy Agency (IEA). Financing Clean Energy Transitions in Emerging and Developing Economies. 2021.
 - [71] Ouedraogo NS, Opportunities, Barriers and Issues with Renewable Energy Development in Africa : a Comprehensive Review, *Current Sustainable/ Renewable Energy Reports* (6) (2019) 52–60.
 - [72] Schmidt T. Low-carbon investment risks and de-risking. 2015;(March 2014).
 - [73] REN21, Renewables 2022 Global Status [Internet], Ren21, 2022, p. 309, 2022Available from: <https://www.ren21.net/gsr-2022/>.
 - [74] C.S.E. Bale, L. Varga, T.J. Foxon, Energy and complexity: new ways forward, *Appl Energy [Internet]* 138 (2015) 150–159, <https://doi.org/10.1016/j.apenergy.2014.10.057>. Available from:.
 - [75] C. Hooker, Introduction to Philosophy of Complex Systems: A: Part A: towards a framework for complex systems, *Philosophy of Complex Systems* (2011) 3–90. Jan 1.
 - [76] Bloomberg. www.Bloomberg.com. 2022. Nigeria's aviation sector, p 1-1. 1 p.
 - [77] J. Hu, R. Harmsen, W. Crijns-Graus, E. Worrell, Barriers to investment in utility-scale variable renewable electricity (VRE) generation projects, *Renew Energy [Internet]* 121 (2018) 730–744, <https://doi.org/10.1016/j.renene.2018.01.092>. Available from:.
 - [78] UNDP and ETH Zurich. Derisking Renewable Energy Investment: off-Grid Electrification. 2018; Available from: www.epg.ethz.ch.

- [79] G. Falchetta, B. Michoud, M. Hafner, M. Rother, Harnessing finance for a new era of decentralised electricity access: a review of private investment patterns and emerging business models, *Energy Res Soc Sci* [Internet] 90 (August 2021) (2022) 102587, <https://doi.org/10.1016/j.erss.2022.102587>. Available from:..
- [80] H.H. Gandhi, B. Hoex, B.J. Hallam, Strategic investment risks threatening India's renewable energy ambition, *Energy Strategy Reviews* [Internet] 43 (January) (2022) 100921, <https://doi.org/10.1016/j.esr.2022.100921>. Available from:..
- [81] N.V. Emodi, K.J. Boo, Sustainable energy development in Nigeria: current status and policy options, *Renewable and Sustainable Energy Reviews* 51 (2015) 356–381.
- [82] Energy Commission of Nigeria E. Compendium of renewable energy investment incentives in Nigeria. 2019.
- [83] Commission E, DRAFT NATIONAL RENEWABLE ENERGY AND ENERGY EFFICIENCY POLICY (NREEEP), Federal Ministry of Science and Technology, 2014. March.
- [84] REN21, Global Status Report for Buildings and Construction: towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector, *Renewables 2020 Global Status Report* [Internet] (2020) 367. Available from: http://www.ren21.net/resources/publications/%0Ahttps://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf.
- [85] G. Shrimali, N. Agarwal, C. Donovan, Drivers of solar deployment in India: a state-level econometric analysis, *Renewable and Sustainable Energy Reviews* (2020) 133.
- [86] Nigeria Bureau of Statistics, Nigeria Bureau of Statistics data (2022). <https://nigerianstat.gov.ng/elibrary/read/1241238>.
- [87] International Energy Agency. Renewables 2021. 2021; Available from: <http://www.iea.org/reports/renewables-2021>.
- [88] N. Gatzert, N. Vogl, Evaluating investments in renewable energy under policy risks, *Energy Policy* [Internet] 95 (2016) 238–252, <https://doi.org/10.1016/j.enpol.2016.04.027>. Available from:..
- [89] Advisors CO grid. Unlocking Climate Finance to Accelerate Energy Access in Africa. 2021.
- [90] N.J. Williams, P. Jaramillo, J. Taneja, An investment risk assessment of microgrid utilities for rural electrification using the stochastic techno-economic microgrid model: a case study in Rwanda, *Energy for Sustainable Development* 42 (2018) 87–96.
- [91] The Mini-Grids Partnership (MGP), State of the Global Mini-grids Market Report 2020, *J. Chem. Inf. Model.* 53 (9) (2019) 1689–1699.
- [92] NERC, Nigerian electricity regulatory commission regulations on feed-in tariff for renewable energy sourced electricity in Nigeria 1, Regulations on feed-in tariff for renewable energy sourced electricity in Nigeria (2015) 1–21.
- [93] S.C. Bhattacharyya, Mini-grids for the base of the pyramid market: a critical review, *Energies*. (Basel) 11 (4) (2018).
- [94] D. Qiu, H. Dinger, S. Yüksel, G.G. Ubay, Multi-faceted analysis of systematic risk-based wind energy investment decisions in E7 economies using modified hybrid modeling with IT2 fuzzy sets, *Energies*. (Basel) 13 (6) (2020).
- [95] M. Kozlova, Real option valuation in renewable energy literature: research focus, trends and design, *Renewable and Sustainable Energy Reviews* 80 (May) (2017) 180–196.
- [96] Blaise K. Koua, Paul Magloire E. Koffi, Prosper Gbaha S. Present status and overview of potential of renewable energy in Cote d'Ivoire. *Renewable and Sustainable Energy Reviews*.:Pages 907–914.
- [97] E.O. Diemuodeke, TAB, Policy pathways for renewable and sustainable energy utilisation in rural coast line communities in the Niger Delta zone of Nigeria, *Energy Reports* (4) (2018) 638–644.
- [98] X. Liu, M. Zeng, Renewable energy investment risk evaluation model based on system dynamics, *Renewable and Sustainable Energy Reviews* 73 (November 2016) (2017) 782–788.
- [99] H. Gujba, S. Thorne, Y. Mulugetta, K. Rai, Y. Sokona, Financing low carbon energy access in Africa, *Energy Policy* [Internet] 47 (2012) 71–78, <https://doi.org/10.1016/j.enpol.2012.03.071>. Available from:..
- [100] Pegels A. Renewable energy in South Africa : potentials, barriers and options for support. 2010;38:4945–54.
- [101] M. Soshinskaya, W.H.J. Crijns-Graus, J.M. Guerrero, J.C. Vasquez, Microgrids: experiences, barriers and success factors, *Renewable and Sustainable Energy Reviews* 40 (2014) 659–672.
- [102] J. Sim, J. Waterfield, Focus group methodology: some ethical challenges, *Qual Quant* [Internet] 53 (6) (2019) 3003–3022, <https://doi.org/10.1007/s11135-019-00914-5>. Available from:..



DSPACE

<https://dspace.org/>

Catalysing decentralised renewable energy investment in Nigeria: investor-focused risk evaluation and de-risking strategies

Abba, Yahajja Zara Ibrahim; Balta-Ozkan, Nazmiye; Drew, Gillian H.

2025-06-01

Elsevier

<https://doi.org/10.1016/j.rset.2025.100112>

Abba ZYI, Balta-Ozkan N, Drew G. (2025) Catalysing decentralised renewable energy investment in Nigeria: investor-focused risk evaluation and de-risking strategies. Renewable and Sustainable Energy Transition, Volume 7, June 2025, Article number 100112