Modelling the spatial *DRE investment decisions using system dynamics and agent-based modelling

**Decentralised renewable energy*

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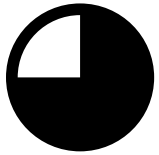
Outline

- Context
- Conceptual Model Framework
- Introduction of the Case Study
- Case Study Inputs
- Results – Model Validation
- Scenario Setting
- Results – Scenarios
- Conclusion

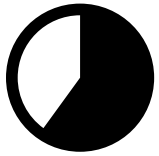
Context

Motivations

*Sub-Sahara Africa Statistics

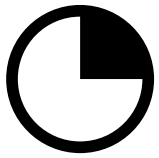


~ 53% of SSA is unelectrified



**DRE is viable for ~60% of the unelectrified SSA

<2% of global RE investment (2010-2020)



25% of DRE investment needs were met in 2021

***SSA **Decentralised renewable energy**

Gaps

- DRE is highly location-specific and can have heterogeneous decision-making investors
- Existing models mainly consider location attractiveness and levelized costs to identify potential locations
- But how likely are investment decisions in the locations, and how can investment be supported?
- A spatially explicit approach accounting for location attractiveness, investor heterogeneity, risk attributes, interactions, and feedback to analyse DRE investment choices has not been implemented

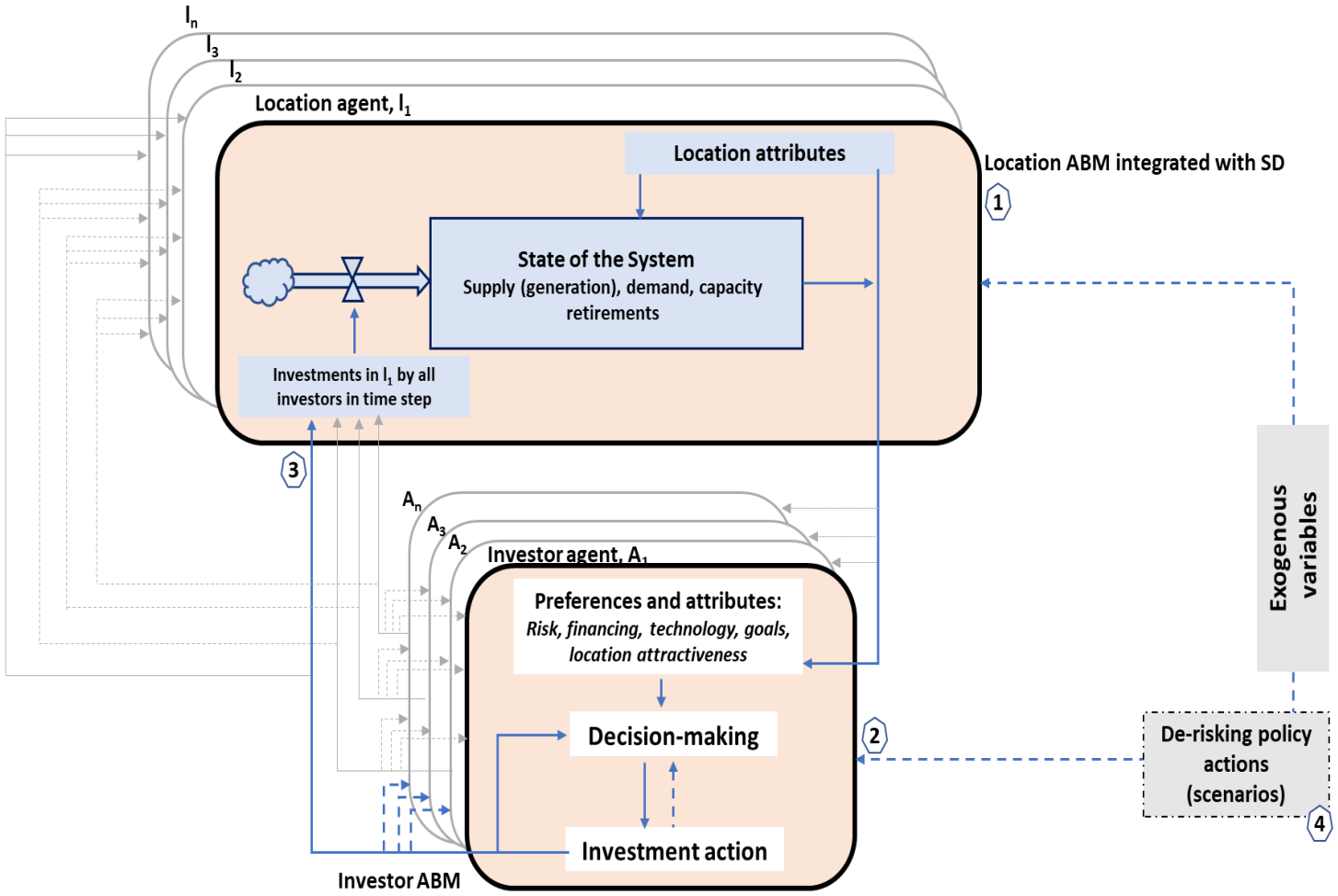
Can identify: *'Key incentives and actions to enhance DRE investment'*

'The most attractive risk-adjusted locations by investor type (within consumer willingness to pay)'

Conceptual SD-ABM Model Framework

Framework
- Complex system theory
- Bounded rationality

Key Inputs
- Economic parameters
- Location attributes
- Investor attributes, goals and decision rules
- Exogenous variables – funding, demand, risk attributes, fuel cost, etc



Objective
- Maximise expected utility for the most attractive location
- within consumer willingness to pay

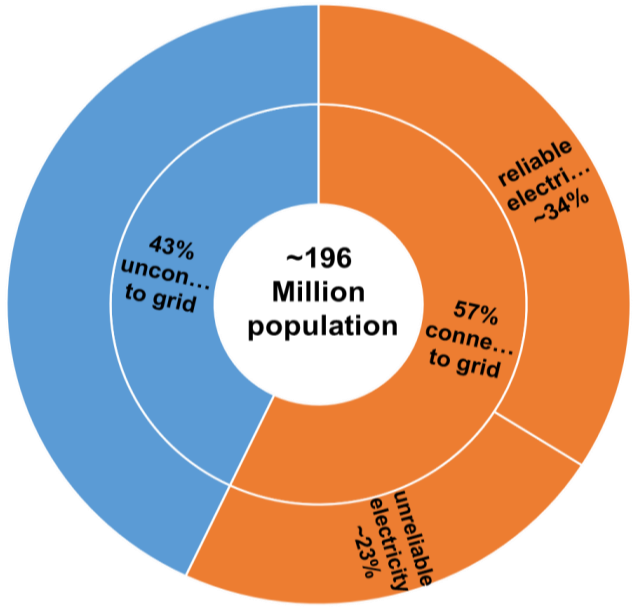
Key Outputs
- Spatial capacity additions and retirements
- Investment by investor type
- Electricity access level
- Potential CO_2 avoidance
- Economic variables (tariff, cashflows, NPV, IRR, LCOE, DSCR etc)

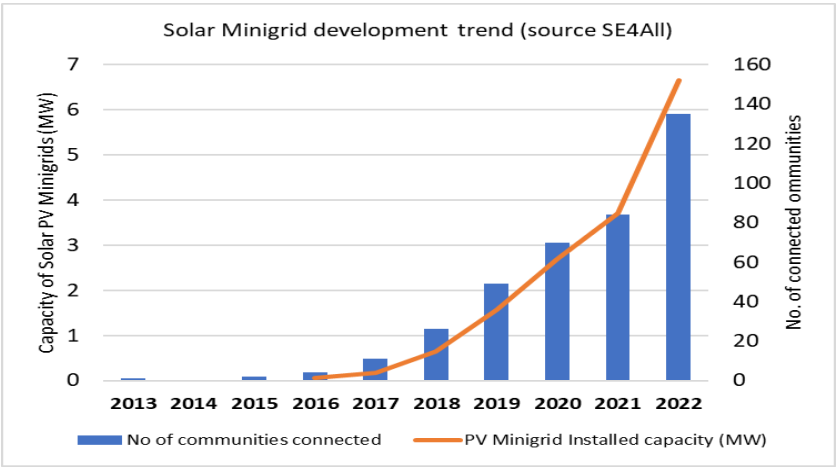
System Dynamics model (SD) **Agent-based based model (ABM)** **Exogenous variables**

Case Study

Nigeria Background

- Targets:
  - 90% electricity access by 2030,
  - 100% electricity access by 2040 and
  - Net zero by 2060
- The most prominent DRE technology is solar PV mini-grid
- Policy developments such as the 2016 mini-grid regulation have catalysed private investment. However, investment is still not to scale
- The Energy Transition Plan 2023 has estimated that ~$USD 35 billion is required for solar PV mini-grids
- Existing planning studies have identified potential solar PV mini-grid locations considering only levelized cost of electricity.

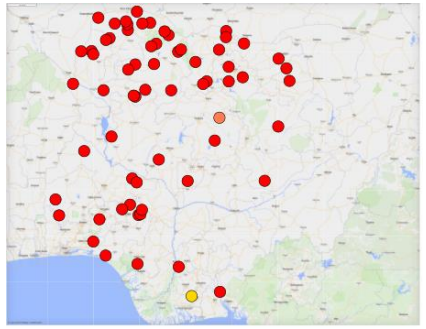




Case study inputs for model validation and implementation

Agents

Location agents



Potential/existing mini-grid locations from literature

Investor agents

9 investor agents defined based on the financing mix

Investor type	Investor Sub-groups	Stylised attributes

Primarily Equity (Equity)	Equity (E)
	Equity (EG)
		• Financing mix
		• Investment preferences and goals
		• Investment thresholds
		• risk attributes
		  • risk priorities
		  • risk aversion
		• discount rates
		• decision criteria

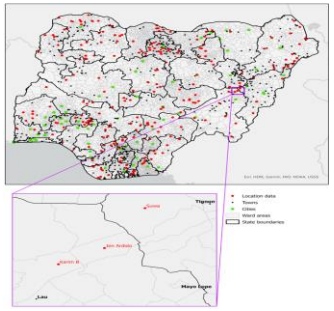
Domestic finance institution debt (DomFI)	DomFI (DEG) DomFI (DE) DomFI (DG)	
Primarily concessional debt (Concessional)	Concessional (DEG) Concessional (DE)	
Primarily Development Finance Institution debt (DFI)	DFI (DEG) DFI (DE)	

E – Equity
D – Debt
G – Grant

Input Data

Spatially differentiated location factors

Accessibility



Solar potential

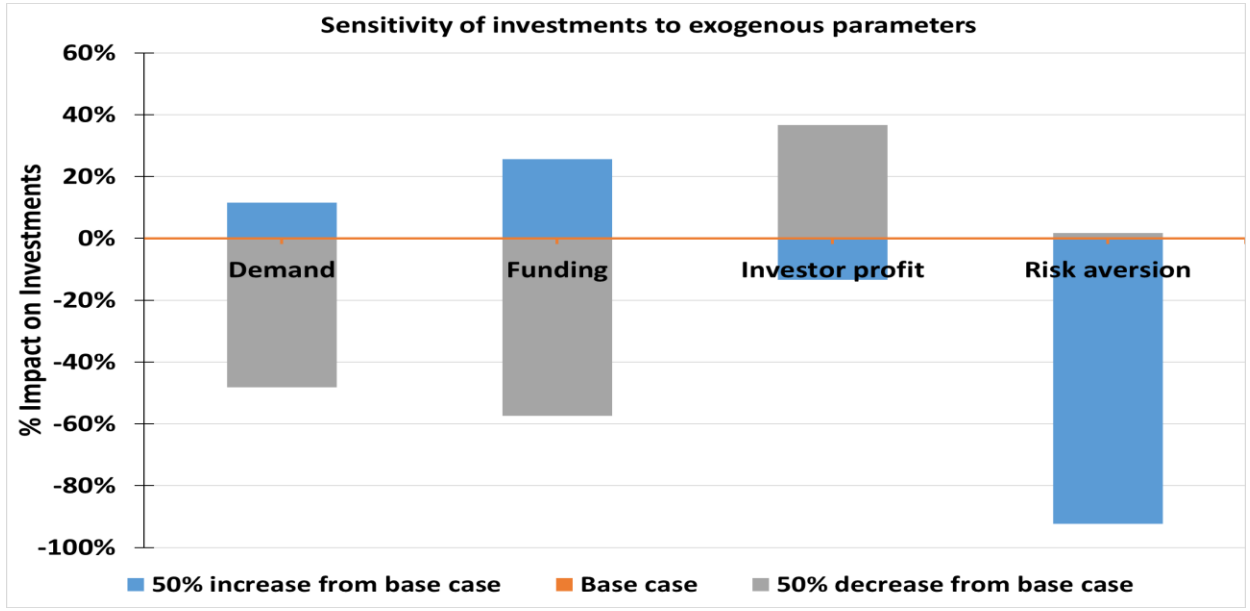
Poverty rate (affordability)

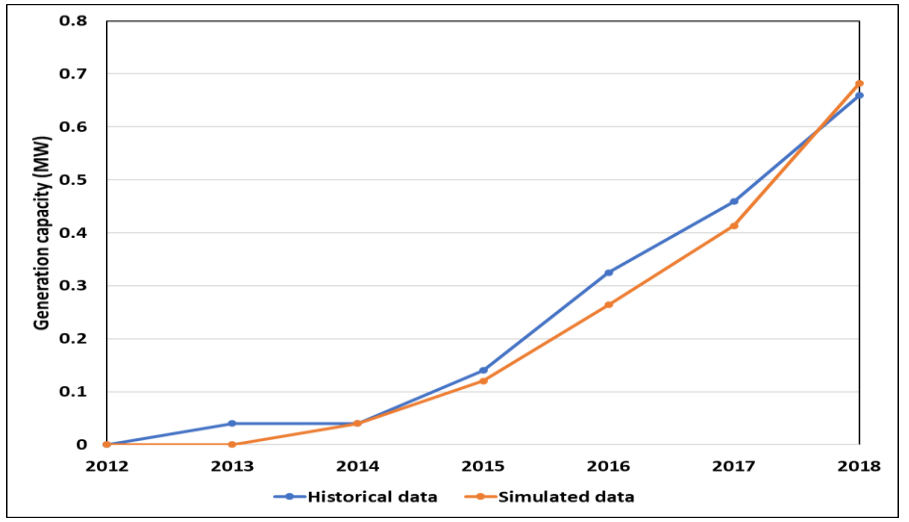
Population

- Others: historical conflict data, consumer willingness to pay, dynamic peer effect, dynamic supply-demand gap

Model Validation

- Model was validated with existing 16 solar mini-grids data in Nigeria (2012-2018)
- The model-generated data (generation capacity, IRR and electricity tariff) showed a close fit to historical data
- Model highly sensitive to parameters:





Variable	MSE (units²)	RMPSE (%)
Generation capacity	0.002	0.582
Electricity tariff range	0.003	0.155
IRR range	0.001	0.182

MSE – Mean Square Error,
RMPSE – Root Mean Per Cent Square Error
IRR – Internal Rate Of Return

Scenario setting

Base case

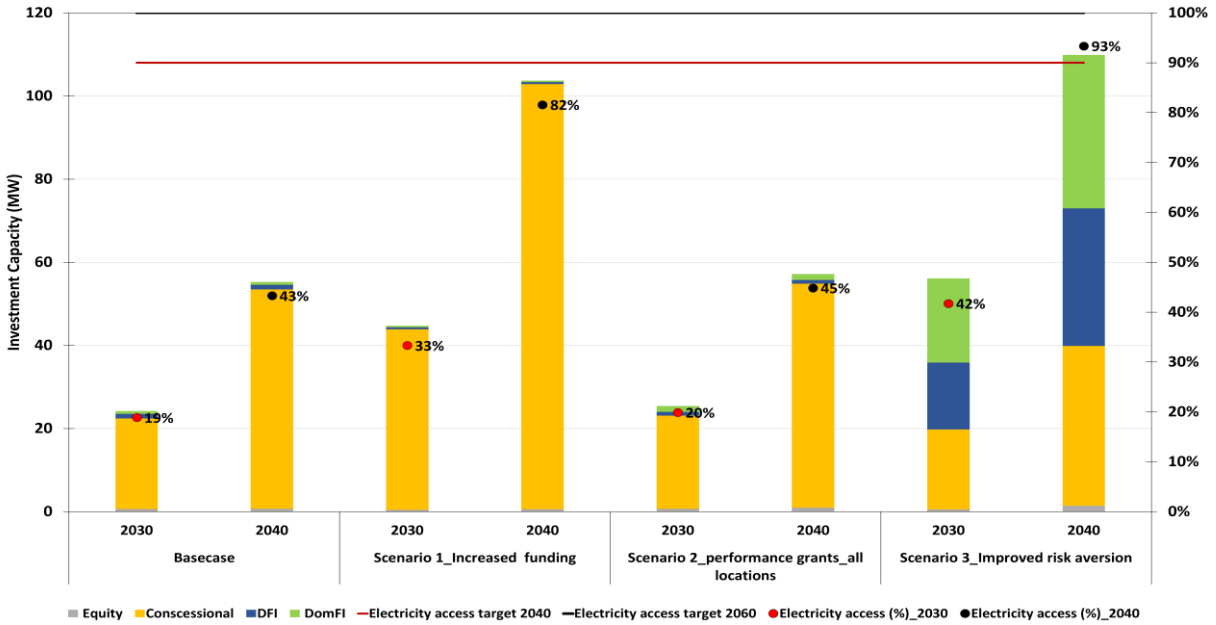
- 66 potential mini-grid locations identified in the literature
- 9 investor groups characterised by
  - Goals – cost, impact
  - Risk aversion – low, medium and high
  - Risk priorities; discount rate
  - Funding limits
  - Decision criteria
- Investors can charge cost-reflective tariffs
- Investment decisions are made when criteria are met, and consumers are willing to pay

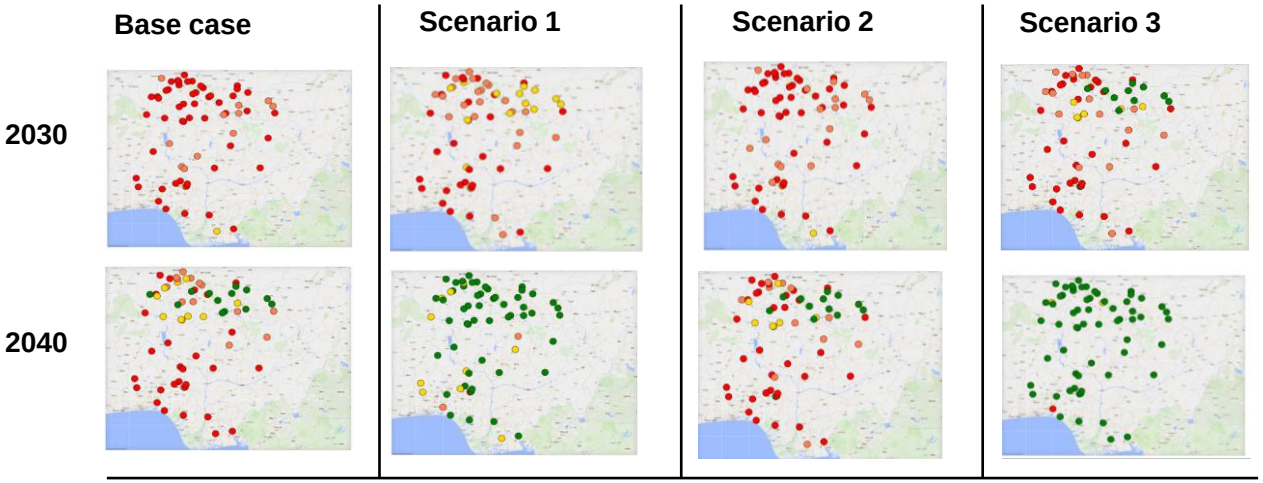
Scenario 1
Base case with increased (**double) funding** across all investor groups

Scenario 2
Base case **with performance-based grants** applied across all locations

Scenario 3
Base case + **improved investor risk aversion** (supported by mitigating risks such as revenue and currency risks)

Spatial outlook for potential locations under 4 scenarios





Key results

- 2030 and 2040 targets not met under base case and scenarios 1, 2 and 3
- Scenario 3 achieved 93% electricity access; investment is not sustained to meet 2040 target

Implications

- Only a few locations are attractive without incentives or risk mitigations for all investor types.
- An increase in funding without improving investor risk perception will primarily increase concessional investment
- As observed in Scenario 3, concessional investment remains important alongside improved risk aversion

>80% access >60-80% access >40-60% access <40% access

*Access (electricity) defined as supply, demand ratio

Conclusions

- Decision-makers can draw insights from the model to support DRE investment considering location attractiveness and investor heterogeneity (risk attributes, preferences and goals) alongside interactions and feedback.
  - Electricity access was significantly improved in Scenario 3 (low-risk aversion). This can unlock investments for all investor groups;
  - Concessional capital remains critical to driving DRE investment
  - Increase in funding in isolation primarily represents concessional-funded investment
- Improvement in DRE investment requires a combination of actions (risk mitigations, funding and incentives) that boost investor diversity beyond primarily concessional capital and encourage investment in less attractive locations.

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