Virtual Power Plant Residential

Executive Summary



Pilot Project for Technical, Regulatory, and Behavioral Assessment of Virtual Power Plant (VPP) Operation with Prosumers in Brazil

March, 2026

FLORIPA NIT auren BASE INTEGRATE TO ZERO ANEEL

EXECUTIVE SUMMARY

September 2025 – March 2026

Project led by Auren | Technical coordination: FloripaBit | International articulation: BASE | Support: Integrate to Zero

Project Overview

This document presents an Executive Summary of the Residential Virtual Power Plant (VPP) Methodology Report, covering the period from September 2025 to March 2026. The project is an ANEEL-regulated Research and Development initiative led by Auren, with technical coordination by FloripaBit, international articulation by BASE, and support from Integrate to Zero.

The pilot assessed the technical, operational, and behavioural feasibility of aggregating residential consumers to participate in demand response events, generating the empirical evidence needed to advance residential flexibility markets in Brazil.

Context and Motivation

Brazil's power system is undergoing structural transformation: more than 85% of installed capacity already comes from renewable sources, distributed generation has surpassed 36 GW across more than 2.5 million consumer units, and the low-voltage retail electricity market is expected to open to residential consumers by 2028[1]. This convergence creates the conditions for Virtual Power Plants to become a commercially and operationally relevant mechanism for flexibility aggregation.

Three structural barriers have historically limited VPP deployment in Brazil: the absence of a regulatory framework recognising residential aggregators; limited smart meter penetration; and low consumer awareness of energy flexibility programmes. The pilot was designed to generate evidence on all three fronts simultaneously.

The project is also strategically positioned within Brazil's regulatory experimentation landscape. While the ANEEL Tariff Sandbox tests price-signal mechanisms and the ONS Demand Response Sandbox focuses on large-consumer dispatch, neither addresses the full challenge of coordinating and verifying aggregated residential flexibility as a service. This pilot fills that empirical gap.

International Benchmarking

The pilot's design drew on international demand response programmes. A consistent finding across the UK, US, and Australia is that incentive values in flexibility events must be significantly above the residential tariff (typically 5 to 20×) to generate the concentrated economic signal needed to shift or reduce consumption.

1 *Brazil's electricity retail market is currently structured around regulated distribution concessions: residential consumers purchase electricity exclusively from their local distribution utility at regulated tariffs, with no freedom to choose their energy supplier. The planned retail market opening (Mercado Livre de Energia) will progressively allow residential consumers to contract electricity directly from competing retailers and generators at freely negotiated prices, introducing commercial relationships between residential consumers and non-distribution agents such as energy retailers, generators, and aggregators. This transition, expected to reach residential consumers by 2028, is a prerequisite for most commercial VPP and demand response aggregation models. .*

Programme	Incentive (USD/kWh)	Reference Tariff	Incentive / Tariff	Verification
Demand Flexibility Service, UK (NESO)	~USD 3.80/kWh (£3/kWh)	~£0.27/kWh	~10–11×	Smart meter
Power Saver Rewards, USA (PG&E, CA)	USD 1–2/kWh	~USD 0.15–0.20/kWh	~5–12×	Smart meter
Smart Usage Rewards, USA (Con Edison, NY)	USD 1–3/kWh + USD 18–25/kW/mo	~USD 0.15/kWh	~15–20×	Smart meter
This Pilot, Brazil (metered group)	USD 0.15–8.28/kWh	~USD 0.10/kWh	~10–20×	Smart meter
This Pilot, Brazil (non-metered group)	USD 1.91–3.83/event (fixed)	~USD 0.10/kWh	~5–7× (proxy)	WhatsApp photo

The pilot's incentive design is aligned with international benchmarks in relative terms. The higher absolute cost per kWh (USD 5.01/kWh average) is primarily a scale effect: with 30 metered participants, fixed costs are distributed over a small energy volume. At 1,000 participants, the cost is projected to fall to USD 0.50–0.80/kWh, within commercial range for peak demand applications.

Pilot Design

The pilot operated two parallel participant groups, capturing complementary dimensions of residential flexibility:

Metered Group (30 units)	Instrumented with external smart meters. Enabled precise baseline calculation and verified load reduction. Primary output: quantitative energy flexibility data.
Non-Metered Group (100 units)	No additional hardware. Participation verified via WhatsApp photo submission. Primary output: behavioural engagement and programme scalability evidence.
Communication Channel	WhatsApp (primary), managed through an integrated platform handling event dispatch, participant messaging, automated Pix[2] payments, and a real-time monitoring dashboard.
Incentive Classes	Five event classes (Class 1 to 5) tested, ranging from 1-hour basic engagement events (USD 1–2 fixed) to consumption-shifting events and hybrid models (fixed + variable up to USD 4–6/event).
Events Conducted	10 flexibility events for the metered group and 8 for the non-metered group, between January and March 2026. Total pilot budget: USD 4,000.
Remuneration Models	Three models tested sequentially: fixed payment (Event 01), percentage-based/variable (Events 02–06), and hybrid fixed+variable (Events 07–10).
LGPD Compliance	Full compliance with Brazil's General Data Protection Law (Lei 13,709/2018). All data anonymised and used exclusively for R&D purposes.

2 *Pix is Brazil's instant payment system, operated by the Central Bank of Brazil (Banco Central do Brasil). Launched in November 2020, it enables real-time digital transfers between bank accounts and digital wallets at any time of day, at no cost to individuals. In the context of this pilot, Pix was used to transfer financial incentives directly to participants' bank accounts immediately after each flexibility event.*

Key Results

Metered Group: Energy Performance

70.6% **Average Event Acceptance Rate** *Above international range of 50–65%*	**80.1%** **Flexibility Delivery (among acceptants)** ≥30% load reduction vs. individual baseline	**56.3%** **Overall Conversion Rate** *From invitation to verified flexibility*
99.3 kWh **Total Verified Energy Reduction** *Across 10 events (metered group)*	**0.49 kWh** **Avg. Reduction per Acceptant/Event** *~490 kWh at 1,000 participants*	**7 / 10** **Events Meeting Dispatch Target** *70% (all 6 final events achieved target)*
USD 497.77 **Total Incentives offered (metered)**	**USD 5.01/kWh** **Average Incentive Cost**	**USD 2.48** **Avg. Payment per Accepted Event** *Per participant per event*

Non-Metered Group: Behavioural Engagement

87% **Activation Rate** *87/100 participants responded to onboarding*	**55.7%** **Average Confirmation Rate** *Per event (range: 47.1%–65.9%)*	**44%** **High-Engagement Core Group** 44 participants confirmed ≥6/8 events
19 / 100 **All-Events Participants** *19% confirmed all 8 events*	**385** **Total Confirmations** *Of which 83.1% from the core group*	**USD 1,655** **Total Incentives offered (non-metered)** *Fixed availability payments across 8 events*

Remuneration Model Comparison

The metered group tested three incentive structures in sequence throughout the pilot, generating directional evidence on how remuneration design influences load reduction performance. The non-metered group used only a fixed payment model throughout, as consumption was not measured and performance-based remuneration was not applicable.

Model	Events	Avg. Load Reduction (acceptants)	Payment Range / Participant	Key Characteristic
Fixed Payment	Events 01, 07–10	58.8% vs. baseline	BRL 10 (Event 01); hybrid in 07–10	Simple & predictable; no extra incentive for deeper cuts
Percentage-Based (variable)	Events 02–06	63.5% vs. baseline	USD 0.004–8.28/event	Highest variability; strongest performance alignment
Hybrid (fixed + variable)	Events 07–10	66.5% vs. baseline	Fixed floor + variable top-up	Best balance: accessibility + incentive effectiveness

Recommendation

The hybrid model, which combines a guaranteed fixed payment with a performance-based variable component, produced the most consistent results across the pilot, with all four events in this phase meeting or exceeding their dispatch targets. It is recommended as the default incentive design for future residential VPP programmes in Brazil, as it accommodates the heterogeneity of residential consumption profiles while maintaining motivation for deeper reductions.

Behavioural Insights

Across both groups, the pilot identified consistent behavioural patterns with direct implications for future programme design:

- Stable engagement without direct load control: Although the metered group had smart meters installed for consumption monitoring and baseline calculation, there was no automated control of household appliances. Participants adjusted their own loads manually in response to each event notification (switching off appliances, postponing consumption). The consistent acceptance rates maintained across ten events demonstrate that meaningful behavioural response can be achieved through digital communication alone, without requiring smart plugs, home energy management systems, or any form of automated demand dispatch.
- Core group dynamics: In the non-metered group, 44% of participants became highly reliable contributors (≥6/8 events), and 19% confirmed every event. This indicates that residential VPP reliability depends more on cultivating a consistent core group than on maximising total base participation.
- Tangible payments drive organic diffusion: After the first Pix transfers, several participants spontaneously recommended the programme to family and friends, suggesting that visible financial reward acts as a strong secondary engagement driver.
- A learning curve improves targeting: The three events that missed targets (Events 01, 02, and 04) were concentrated in the first four weeks. All six subsequent events met or exceeded targets, reflecting operational maturation in both participant behaviour and target calibration.

Implications for the Brazilian Electricity Sector

The pilot provides three types of evidence directly relevant for policy, regulation, and commercial design:

Implication	Evidence from the Pilot
Residential flexibility exists and is measurable	99.3 kWh verified across 10 events; 0.49 kWh/acceptant/event. At 1,000 metered participants, this represents approximately 490 kWh (0.49 MWh) of dispatchable flexibility per event, commercially relevant at wholesale scarcity prices above USD 191/MWh.
Operational feasibility validated with existing technology	WhatsApp communication, smart meter baseline processing, photo-verification for non-metered participants, and automated Pix payments all functioned without additional consumer hardware.
Hybrid metered/non-metered model is viable	Combined operation of both groups allows verified energy flexibility (metered) and broad behavioural engagement (non-metered) to coexist, which is critical for Brazil, where smart meter penetration remains limited.
Positions Brazil for regulatory advance	Results feed directly into ONS and ANEEL demand response consultations, providing Brazilian-specific evidence for the design of aggregation frameworks and residential flexibility markets ahead of the 2028 retail market opening.

Market Potential for Post-Pilot Expansion

A TAM–SAM–SOM analysis was conducted to estimate the commercial opportunity for a scaled residential VPP in Brazil, using Auren's market position as the reference.

Market Level	Estimate	Basis
TAM: Total Addressable Market	82.9 million residential units	Full long-term universe post retail market opening (EPE data)
SAM: Serviceable Available Market	13.5 million households	Households with connected smart devices today (IBGE, 2024)
SOM: Serviceable Obtainable Market	~55,000 consumer units	Auren's ~6.3% market share × SAM × 6.5% DR adoption rate (ESIG reference)
Committed Firm Capacity (VPP)	55 MW	Based on 55,000 units at observed pilot flexibility levels
Annual Flexible Energy Potential	17.3 GWh/year	15% of the aggregated annual consumption of SOM (supported by technical literature)
Annual Revenue (capacity payments)	~USD 2.6 million/year	USD 4/kW/month benchmark (ONS Demand Response Sandbox)
Break-even Consumer Payout	USD 1.2/kWh	40 activation hours/year; USD 48/kW/year capacity revenue
Illustrative Gross Margin for Auren	~USD 550,000/year	10 critical + 30 regular events at calibrated payout below break-even

Key Insight on Market Constraints

The primary short-term constraint for residential VPP expansion in Brazil is not market size, but the pace of residential smart device penetration and the development of formal aggregation frameworks. The full retail market opening expected by 2028 is the single most important catalyst for accelerating the serviceable market, as it will allow energy retailers like Auren to establish direct commercial relationships with residential consumers.

Key Lessons Learned

Recruitment & Engagement

- Minimise the gap between registration and selection: The 15–30 day interval between landing page registration and participant confirmation caused significant dropout. Immediate or same-day onboarding is recommended for future programmes.
- WhatsApp is essential; email alone is ineffective: Even among self-selected, motivated registrants, email yielded low open and response rates. WhatsApp was the critical operational channel throughout the pilot.
- Conversion funnels require buffer: Forming 30 metered participants required contacting ~55 individuals; 100 non-metered participants required ~213 contacts. Future recruitment plans should budget for a 2–3× outreach multiplier.
- Reduce bureaucracy to the minimum: Simplifying non-metered onboarding (removing non-essential validation steps) led to a substantial improvement in adherence rates. Lean operational models are a prerequisite for residential scale.
- Regional factors matter: Belo Horizonte showed markedly lower engagement than São Paulo and Florianópolis, suggesting that geographic targeting and local partnership strategies should be differentiated.

Communication & Platform

- WhatsApp template rejection (~10–15%): Meta's automatic rejection of templates designed for transactional messaging requires careful template architecture and maximum exploitation of the 24-hour active conversation window.
- Full messaging automation is a prerequisite for scale: Some event communications required manual batch sends during the pilot. Full automation, from invitation to payment notification, must be built before expanding beyond pilot scale.
- Partner with distributors: Participants consistently associated the project with CELESC and CEMIG (local distributors) rather than with Auren[3]. Formal distributor partnerships will increase programme credibility and participant trust.
- Move toward digital wallet payments: Per-event Pix transfers were effective for the pilot. A wallet model aggregating payments across events reduces transaction costs and enables consolidated participant statements, better suited for scaled deployment.

Incentive Design & Baselines

- Incentive calibration must be dynamic: The evolution from fixed thresholds to baseline-proportional and finally hybrid models was necessary to accommodate the diversity of residential consumption profiles. Rigid structures exclude low-consumption participants.

3 *Auren is an electricity generation and trading company with no distribution operations. In Brazil's current regulatory structure, residential consumers interact exclusively with their local distribution utility for billing, metering, and all electricity-related services — companies such as CELESC (Santa Catarina), CEMIG (Minas Gerais), and others. Generation and trading companies like Auren have no direct commercial interface with residential consumers today, making distributor partnerships strategically important for any residential-facing programme. This dynamic is expected to change with the retail market opening planned for 2028 (see footnote 1), which will allow energy retailers and generators to establish direct relationships with residential consumers.*

- Avoid December for baseline collection: Holiday-driven variability in December compromised baseline representativeness. Events should not begin before mid-January to ensure statistically robust individual baselines.
- Target alignment determines measured success: Events 01 and 02 had targets set on full enrolment, not actual acceptance. Adjusting targets to reflect expected participation significantly improved target attainment in later events.

***Note**: In this pilot, the baseline used to evaluate flexibility events is fixed, based on historical consumption, and does not change over time. The reference to a "dynamic" approach relates only to the evolution of the incentive design, as different models (Fixed Payment, Percentage-Based, and Hybrid) were tested to better accommodate diverse residential consumption profiles. As a result, the baseline remains stable, incentive values do not decrease with participation, and there is no risk of a negative engagement loop.*

Next Steps

Building on this pilot, the following priorities are defined for the next phases of the Residential VPP programme:

Priority	Action
Expand participant base	Target 1,000+ metered participants to reduce cost per kWh, improve statistical robustness, and approach commercially meaningful dispatch volumes.
Extend pilot duration	Minimum 12 months with weekly events to characterise seasonal flexibility patterns and build robust individual baselines across all days of the week.
Full platform automation	Eliminate manual intervention from the event cycle; automate invitations, reminders, confirmations, payment triggers, and reporting.
Digital wallet payment model	Transition from per-event Pix transfers to aggregated wallet payments with consolidated statements, optionally linked to the electricity bill.
Distributor partnerships	Formalise partnerships with local distribution utilities to leverage existing consumer relationships and improve programme reach and perceived legitimacy.
Regulatory engagement	Use pilot results as evidence in ANEEL and ONS demand response consultations, targeting the creation of a formal residential flexibility market framework ahead of the 2028 retail opening.