Operating the Distribution Grid Through the EV Transition

Every EV that plugs in at home is disguised behind the consumer's meter, its load blended into ordinary household consumption. Undetected, that demand can drive coincident peaks far beyond what the local transformer was ever sized to carry. This paper sets out how NILM separates that hidden EV load from the rest, sees where it concentrates, and turns it into decisions the network can act on before the peak arrives.

www.impresa.ai

Table of Contents

Executive Summary

Electrification is a visibility problem before it is a capacity problem

The distribution grid is absorbing electric-vehicle load faster than it was built to carry it. Yet for most utilities the binding constraint is measurement rather than megawatts. A single home charger can draw as much as a small block of houses, but it hides inside an ordinary residential meter. A retail charging hub concentrates that same draw onto one feeder. Across a city, thousands of these loads switch on within the same evening hour, and the first signal many operators receive is a transformer running hot.

You cannot plan for, price, or protect against load you cannot see or predict, so the EV challenge begins as a problem of observability. The data required to solve it already exists, scattered across systems that were never designed to talk to one another. The meter knows the load shape. SCADA knows the transformer. The charge-point operator knows the session, the OEM knows the battery, and the billing system knows the tariff. The work lies in connecting them into one semantic picture, then converting that picture into governed action.

WHAT THIS PAPER ARGUES

1. **See the invisible load.** Non-intrusive load monitoring (NILM) separates EV charging from household consumption using ordinary smart-meter interval data, with no sub-meter and no survey. An invisible residential population becomes one the grid can address directly.
2. **Attribute it to the asset, bottom-up.** Where a utility has no transformer or feeder metering, EV load is rolled up to each asset by coincident, time-aligned summation. This reveals which transformers are stressed, by how much, and whether EV is the cause.
3. **Act on the cheapest effective fix first.** Managed charging, commercial throttling and time-of-use migration re-time demand before capital is committed. Every action is triggered by a measured signal, bounded by consent, and reversible.
4. **Govern every number and every action.** Estimated quantities are labelled as estimates, monetary figures inform prioritization rather than billing, and every field intervention is verified against measured data before it is called resolved.

The Blind Spot

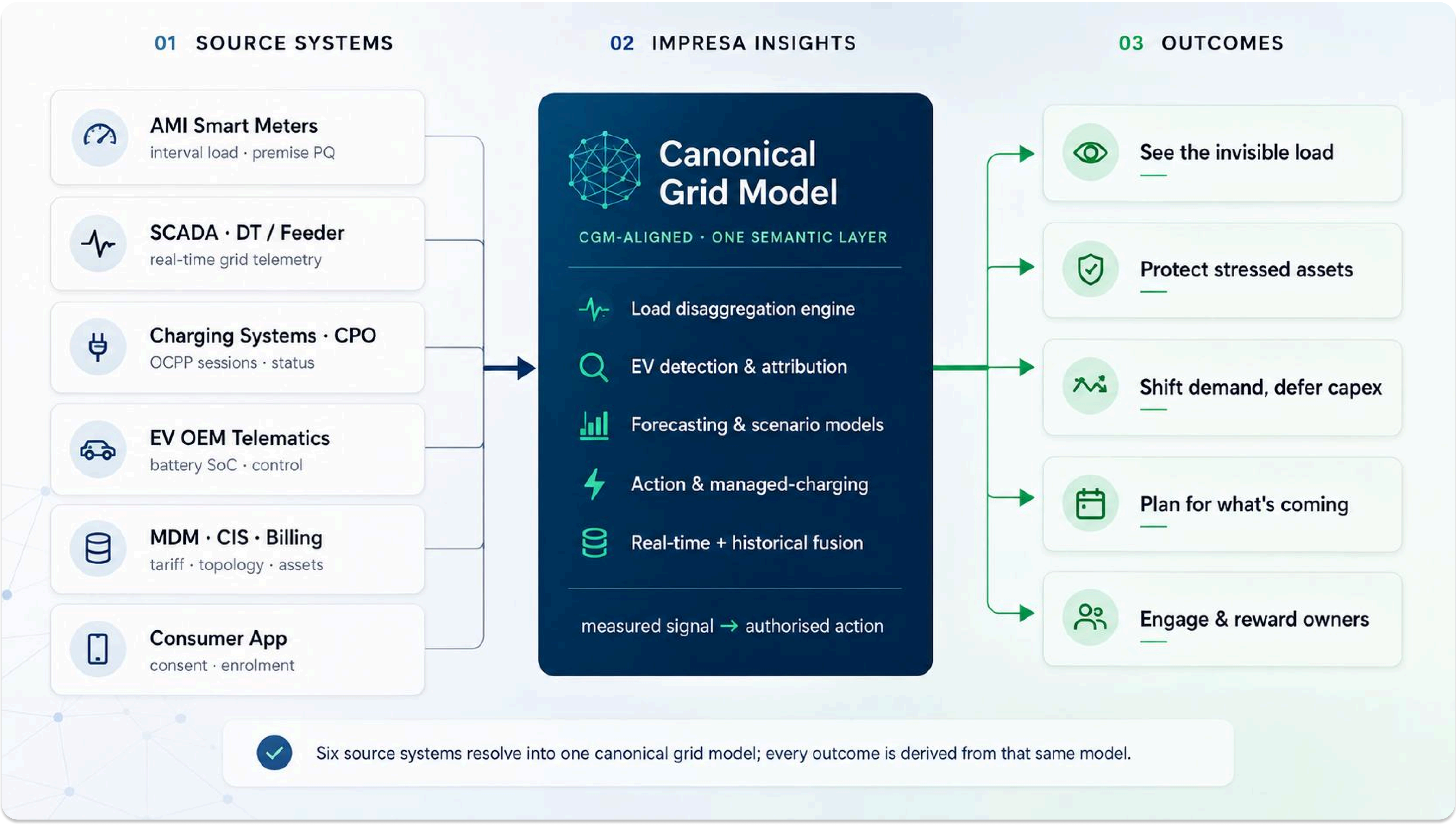
Why the transition outruns the network's ability to see it

EVs are arriving on the distribution network faster than the network was built to absorb it, and for most utilities the difficulty lies less in the additional demand than in the fact that the demand goes unobserved. Residential charging is buried inside metered household consumption. Public and fleet charging concentrates onto specific feeders and specific hours. Adoption clusters geographically, so the stress is never spread evenly; it lands on the transformers of the neighbourhoods that adopt first.

The question that matters is no longer how much energy was sold. It is which asset is now exposed, by how much, and what can be done about it tonight.

The result is a structural gap between what the grid is experiencing and what its operators can measure. Planning cycles assume a load forecast that no longer holds. Connection approvals are granted against headroom that has quietly been consumed. Power-quality complaints rise without an obvious cause. Because the load is invisible, none of this surfaces until it presents as a physical symptom: a thermal alarm, a voltage excursion, a customer call.

Reframing electrification as a problem of observability changes where the work begins. The data needed to run the grid through the transition is fragmented rather than missing. Each source system holds one true fragment of the picture, and none holds the whole. The value comes from fusing those fragments into a single, canonical model of the network and its behaviour, then turning that model into a ranked set of decisions with the recommended moves attached to each.



What EV Intelligence does

From the meter signature to the charging decision

EV Intelligence is an operating capability that follows EV load from the moment it appears disguised on the consumer meter to the moment it is brought under control, across both the homes a utility cannot see into and the public infrastructure it can.

Sense & Understand

Detect
Disaggregate Home EV Load

Attribute
Map Load to the asset

Forecast
Find tomorrow’s Hotspots

Act & Engage

Act
Managed Charging Throttle

Engage
Reward Participation

It starts behind the meter

A load-disaggregation engine reads ordinary AMI interval data and separates EV charging from the rest of a household's consumption, with no sub-meter and no survey. It infers each home's charger class from the load signature, whether light, medium or heavy, quantifies the EV energy and the peak draw, and maps every detected EV to the transformer it sits under. Invisible residential load becomes a grid-addressable population, and a confidence band travels with every detection so that downstream figures carry their provenance honestly.

It sees the visible network too

For commercial and fleet charging, the platform integrates charge-point telemetry to monitor capacity, availability and uptime, and relates each station to the feeder and transformer that supply it. A hub's growth then shows up where it matters to the operator, as asset headroom consumed rather than energy sold, and vendor performance and contracted-capacity utilisation become first-class operational signals.

And then it acts

When a transformer approaches its limit, EV Intelligence orchestrates relief. Managed charging works through OEM integration for consented home vehicles, and commercial chargers are throttled through the charge-point operator, always triggered by measured grid stress, bounded by consent, and reversible. The same intelligence migrates households toward off-peak time-of-use windows, so that the cheapest remedy, re-timing demand, is tried before reinforcement is scheduled.

It plans for the curve, and closes the loop with the customer

Adoption forecasting and scenario simulation translate today's detection trend into tomorrow's demand, projecting which transformers cross their limits and when, and separating what managed charging can defer from what genuinely needs reinforcement. Programs and engagement then turn EV owners from a risk into a resource, enrolling them, capturing consent, and rewarding the behaviour that keeps the network healthy. The owner saves, and the grid gains flexible capacity it can call on.

Methodology : Why the Numbers can be trusted

Measuring load nobody metered, without pretending to

The credibility of an EV-intelligence platform rests on one discipline: being precise about what is measured, what is derived, and what is estimated. Where a utility has no distribution-transformer or feeder metering, every asset-level figure, from loading and utilisation to imbalance, harmonic distortion, power factor, hosting capacity and incremental loss, is a bottom-up derivation rather than a direct measurement.

The connectivity model is the spine

Every roll-up depends on an accurate meter-to-transformer-to-feeder mapping. The platform maintains a versioned connectivity model with per-transformer coverage, the share of connected meters mapped and reporting, and flags any asset below threshold as low-confidence rather than presenting it as complete. Where the loading system of record and the GIS disagree on a meter's parent, the loading source governs and the discrepancy is logged for correction.

Attribution is coincident, never sum-of-peaks

EV-attributable load on a transformer is the time-aligned sum of the disaggregated EV component across all mapped meters, evaluated at each interval, and the EV contribution at peak is the EV component in the interval of the asset's own peak rather than the arithmetic sum of individual meters' peaks. The distinction is far from academic, because summing peaks that never coincide overstates stress and misdirects capital. An asset is classified as overloaded due to EV only when removing that coincident EV component would bring it back within its limit; otherwise, EV is recorded as a contributor rather than the cause.

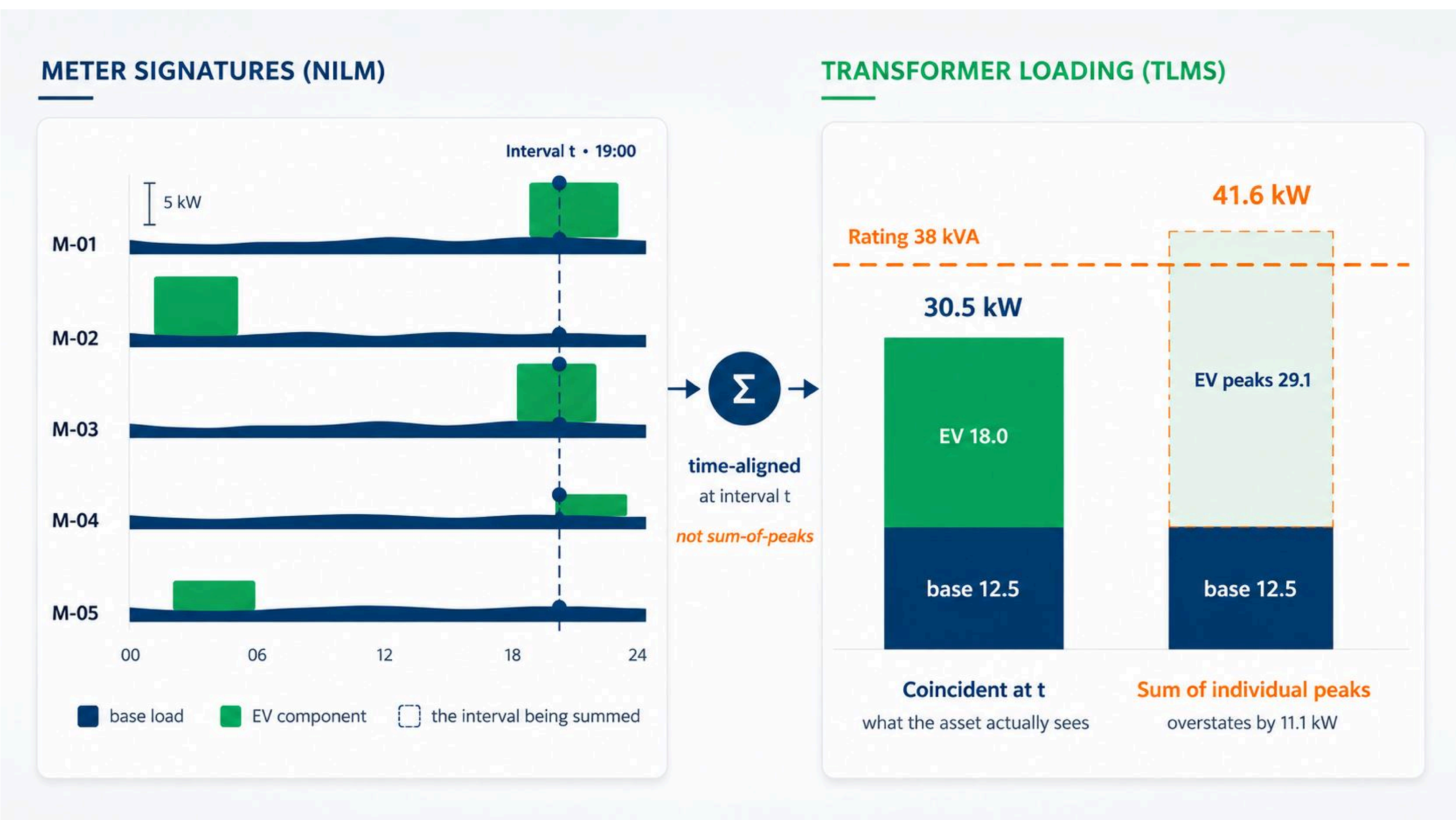
Provenance Discipline . Three Non-Negotiables

Estimated is labelled.

Asset-level power-quality and loss figures carry a mandatory estimated flag, with confidence tied to coverage. Harmonic distortion, which is not summable across meters, appears as an indicative load-weighted signal, and breaches are counted only at the meter level, where they are measured.

Trends are not forecasts of record.

Short-horizon stress trajectories are statistical extrapolations with stated confidence, kept distinct from adoption forecasting and labelled as such wherever they appear.



Each meter's EV component is read at tha same interval and summed there - not by adding each charger's own peak.

Both panels are drawn to the same kW scale: Profiles and Values are Illustrative.

From Insight to Governed Action

It does not stop at the data. It says what to do next

Most analytics stop at the chart and leave the hardest part, judgement, to an operator already buried in alarms. The value of an EV-intelligence platform lies in the sentence that follows the chart: of everything happening on the network tonight, here are the few things worth attention, and here is what to do about each.

One risk population, three views

The derivation layer emits risk records across five categories, spanning contractual violation, overload, imbalance, harmonic distortion and power factor at both meter and transformer level, each carrying severity, affected assets and customers. That single population is rule-ranked by impact and urgency, and it surfaces consistently across the executive action queue, the breaches register and the intervention workspace: one population, three views, always reconciled.

The intervention loop closes on measured data

Opening a case presents an AI diagnosis, a root-cause chain that terminates in the required decision, a recommended workflow, and a multi-select set of interventions, each with its own confidence, expected relief and monetary value. The operator assigns an owning team, the platform raises a ticket in the field-workforce system, and a case is marked resolved only when two signals agree: the ticket is closed and the reduction is confirmed against measured AMI data. Verification is a two-signal check rather than a status update.

Insight, not just information

An AI insight layer reads across EV detection, asset loading, power quality and forecasts in real time, and asks the question an operator would ask. What is most exposed, by how much, what is it worth, and what is the cheapest effective response? It ranks the answers by financial impact and urgency, so the day opens with a decision queue rather than a data dump.

Tuned to the grid, by design

Generic large models do not speak distribution. Impresa trains and operates compact, specialized language models grounded in utility data, terminology and operating practice. Because they are purpose-built and run close to the data, they are faster, more economical, more private, and more reliable on the narrow questions a grid operator asks.

Illustrative - Today's Priorities, Ranked by Value & Urgency

Each item carries its reasoning, affected assets and recommended action. Figures illustrate the decision format rather than a specific deployment.

#	Exposure	Signal	Recommended move
1	Transformer overload risk in ~6 months	EV peak contribution ~21%, thousands of customers exposed	Enrol managed charging and demand response
2	Charging hub queueing at peak	Multiple chargers above 85%, headroom thinning	Load-balance or add ports
3	EV homes on the wrong tariff	~2 MW shiftable off the evening peak	Launch EV-TOU migration campaign

impresa.ai
Smart.Simple.Innovative

A staged Operating Model

See and diagnose today, anticipate and act next

Most analytics stop at the chart and leave the hardest part, judgement, to an operator already buried in alarms. The value of an EV-intelligence platform lies in the sentence that follows the chart: of everything happening on the network tonight, here are the few things worth attention, and here is what to do about each.

Phase 1: the visibility and intervention base

Detection, bottom-up attribution, contractual and power-quality impact, hosting-capacity exhaustion and an AI-ranked risk register are each routed to a field intervention and verified against measured data. In this phase every intervention, including managed-charging enrolment, is executed by a human team through a governed ticket. Nothing on the grid is actuated automatically; the platform's authority is to see, rank, recommend and verify.

Phase 2: active management and engagement

Adoption forecasting and scenario simulation extend the trend into a planning horizon; EV-TOU and demand-response programs convert owners into flexibility; and automated control, whether a charger kW cap through the charge-point operator or a home-charging window through the OEM, actuates on a measured breach, with measurement and verification closing the loop. Vehicle-to-grid and conversational access round out the forward scope, each specified and retained so that the operator moves from insight to control on its own timeline.

Phase 1 - Deployed Today

See & Diagnose

- NILM detection + bottom-up attribution
- Contractual, PQ & Loss impact surfaced
- AI-Ranked risk register (8 categories)
- Intervention - SMOC/WFM ticket
- AMI-verified resolution & value

Phase 2 - Forward Scope

Anticipate & Act

- Adoption forecasting &scenario simulation
- EV-TOU & managed-charging programs
- Automated control via CPO / OEM
- Consumer app engagement & consent
- V2G & GenAI conversational access

EV Intelligence Modules

Module	What it delivers
Home Charging Intelligence	AMI load disaggregation, charger-class inference, and behind-the-meter EV detection mapped to the grid.
Charging Network Operations	Commercial and fleet charger monitoring: capacity, uptime and asset-overload attribution.
Grid Impact & Power Quality	Bottom-up EV attribution, contractual-violation cause, estimated power quality and incremental loss, and hosting capacity.
Action & Orchestration	Managed charging through the OEM, commercial throttling, and EV-TOU migration, all triggered by grid stress.
Forecasting & Planning	Adoption and demand models that surface stressed assets and separate deferral from reinforcement.
Programs & Engagement	Consent-based enrolment and rewards that convert EV owners into dependable grid flexibility.
EV Overview	An executive cockpit that ranks the whole picture by impact, showing what to act on first, network-wide.

EV Intelligence is one lens on a wider Grid Intelligence service

EV load never arrives in isolation. It lands on the same transformers that age, the same feeders that lose voltage, the same network that has to keep the lights on. For that reason EV Intelligence shares its foundation, the same canonical model and the same real-time and historical data, with the rest of the Grid Intelligence service. Each module is a different lens on one network.

Outage & Restoration Intelligence
Last-gasp outage detection, predictive outage risk, and customer-impact restoration analytics against SAIDI and SAIFI.

Demand & EV-Impact Forecasting
Forward demand modelling that folds EV growth into the planning horizon.

Transformer Health & Aging
Condition and loss-of-life tracking, so that EV stress is read against an asset's true remaining headroom.

Peak Load Intelligence
Real-time peak monitoring and transformer capacity and headroom, showing where the network is closest to its edge right now.

Voltage & Power-Quality Compliance
Harmonics, imbalance and EN 50160 compliance, including the distortion that EV charging introduces.

Phase, Power-Factor & Loss Intelligence
Phase rebalancing, intelligent power factor, and technical-loss attribution across the low-voltage network.

Grid Intelligence sits alongside the wider Impresa AI+ Suite, spanning Smart Meter, Revenue, DER and Asset Intelligence, all on the same Meter Data Hub foundation.

Conclusion

Make the utility ready for what plugs in next

The EV transition will not wait for the grid to catch up. What it demands first is not more steel but the ability to see, anticipate and act on electric demand as it arrives. That capability is built by turning the data already flowing through legacy grid systems, metering, charging networks, OEMs and consumer apps into proactive, defensible decisions, invisible load made visible, attributed honestly to the assets it stresses, ranked by what it is worth, and resolved through action that is verified against measurement. Operated this way, the network stops being caught off guard by electrification and starts being ready for it.

Smart.Simple.Innovative

Learn More

To schedule a live demo or find out more information, visit **www.Impresa.ai** or call **+1 510 824 3255**