



WFER IX

When Balance Is Achieved



IX WORLD FORUM
ON
ENERGY REGULATION

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Training Day. Module 1C

Grid Integration of Electric Vehicles

Tbilisi 21 September 2026

Electric vehicles and the grid: why this training, why now



Transport electrification has become an electricity-sector question, and therefore a regulatory one.

- EV charging is the largest new source of electricity demand growth in most member countries
- Its impact on networks depends on WHEN and WHERE vehicles charge, not only on how much energy they use
- Almost every mitigating measure - tariffs, metering, connection rules, flexibility markets - sits with the regulator
- Decisions taken before the load arrives are far cheaper than those taken after it

The content of this lecture



- 1 EV market realities and the regulatory agenda
- 2 Charging fundamentals and market structure
- 3 Grid impacts and load forecasting
- 4 Network tariffs and smart charging

Where does your authority stand?



How does your authority currently view load growth from electric vehicles in the next 5-10 years?

- A** Minimal - not a priority in the 5-10 yrs horizon
- B** Moderate but manageable
- C** Significant planning challenge
- D** High uncertainty and difficult to plan for



01

EV market realities and the regulatory agenda

Global adoption, regional evidence and what it means for energy regulators

The scale question, in three IEA numbers



709 TWh

Global EV electricity demand in 2030 (Stated Policies Scenario)

2.7%

Average share of total electricity generation

29 TWh

EV battery capacity expected available by 2030

- **EV energy demand** is modest nationally, but **charging power** can create significant local grid constraints.
- **EV integration** largely depends on **local capacity** and **charging timing**, not overall generation adequacy.

Source: IEA (2023), *Grid Integration of Electric Vehicles: A manual for policy makers*

Where the constraint really appears



The main constraint from EV charging may appear in local distribution networks, not in national generation capacity.

- In the Netherlands, around 3 000 neighbourhoods with at least 100 EVs were expected to exceed network capacity by 2025
- In California, one distribution utility found it would need to upgrade five times more feeders than planned to accommodate EVs by 2030
- Concurrent electrification of heating and cooling can equal or exceed the impact of EVs on the same networks

Source: IEA (2023), Grid Integration of Electric Vehicles: A manual for policy makers

The global market is shifting at very different speeds



Markets adopt EVs at different rates, but they follow strikingly similar adoption pathways.

- EVs now represent a major share of new vehicle sales in leading markets: the global EV fleet is approaching 80 million vehicles
- Carmakers are shifting investment towards electrification and supply chains are scaling globally
- Electric mobility is also taking hold in emerging economies - in India, electric three-wheelers reached 46% of segment sales in 2021-22
- For a regulator, the key question is **how fast EV adoption will grow** – and **which segment of EV charging** will lead (next module).

Not all EVs are the same: vehicle classes and battery sizes



Vehicle class	Battery capacity	Typical charging power	Why it matters for the grid
Two- and three-wheelers	0.5 - 20 kWh	0.5 - 3.3 kW	Low-power charging; battery swapping is an option
Light-duty vehicles	10 - 100 kWh	1.9 - 22 kW; en route 5–350 kW	Home and workplace charging offer high flexibility
Light commercial vehicles	35 - 76 kWh	22 kW at depots	Depot-based charging for commercial fleets
Buses	50 - 550 kWh	22 – 50 kW depot; 150+ kW fast charging at bus stops/terminals	Concentrated charging at depots or along routes
Trucks	100 - 800 kWh	Depot <350kW; en route 1-3.75 MW	Very high-power charging can create major local grid impacts

Priority segments differ by country — in Indonesia the 2030 target is 13M electric motorcycles versus 2M passenger light-duty vehicles

ERRA regions what 25 regulators reported in 2025



The 2025 ERRA E-Mobility Survey updates the 2020 and 2022 ERRA studies.

Report: <https://erranet.org/erra-report-e-mobility-status-update-development-plans-and-related-regulatory-issues/>

- Legal frameworks are strengthening, though national approaches still differ substantially
- Market entry is largely open, with some countries applying licensing or tailored models
- Charging prices are mostly market-based, with limited targeted regulation
- DSO ownership approaches vary, balancing speed of roll-out against competition concerns
- Fair-access rules are expanding, with clear potential for further consolidation

Source: ERRA E-Mobility Survey 2025 Report, ERRA Energy Transition Committee

ERRA survey: infrastructure roll-out and system effects



Roll-out

- EV uptake rising steadily across the region
- Deployment more geographically widespread than in 2022
- Mostly market-driven, municipalities central in planning
- DSOs largely confined to grid connection

Funding and plans

- National plans and support schemes remain unevenly widespread
- Funding still primarily private
- Mixed public-private models emerging but limited

System effects

- Charging is beginning to affect load patterns
- V1G and V2G remain mostly at the analysis and planning stage.
- Operational V2G largely absent across ERRA
- Dedicated EV tariffs still limited (require separate metering for private charging)

Source: ERRA E-Mobility Survey 2025 Report, ERRA Energy Transition Committee

NRA roles in e-mobility remain limited



- NRA roles in e-mobility remain limited and differ widely across countries
- Many NRAs still have no clearly defined e-mobility mandate
- Structured roles in licensing, tariffs and market monitoring remain limited
- EV-specific tariff regulation remains rare
- Cross-sector coordination remains weak and uneven
- Price transparency, consumer protection and data collection remain underdeveloped

Source: ERRA E-Mobility Survey 2025 Report, ERRA Energy Transition Committee

Main barriers reported by ERRA members



Insufficient grid capacity

- Currently less prominent, but likely to grow with EV uptake

Regulatory uncertainty

- Uncertainty over market structure and DSO roles

Administrative burdens

- Slow permitting and connection processes

Absence of ToU tariffs

- Limited time-variant price signals

Lack of incentives for developers

- Weak business case for early charge point operators

Gaps in spatial planning law

- Planning rules may not reserve space for charging infrastructure

Source: ERRA E-Mobility Survey 2025 Report, ERRA Energy Transition Committee

Module 1 - key takeaways



- 1 EV adoption varies, but the overall direction is clear**
Electrification of transport (both individual and collective) is going on.
- 2 National energy demand is manageable; local grid capacity is the challenge**
Local transformers and feeders can face constraints before the overall power system does.
- 3 Local clustering drives grid impacts**
EVs aren't evenly distributed, so grid impacts are concentrated too.
- 4 Different segments of EV imply different charging impact**
Not only electric cars! The speed and vehicle mix differ across countries
- 5 ERRA countries are progressing, but maturity remains uneven**
Legal frameworks are strengthening, many NRA roles remain unclear.

02

Charging fundamentals and market structure

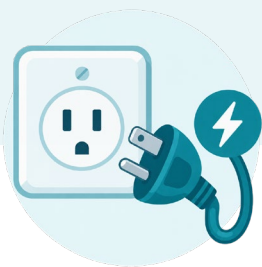
What is actually being charged, where, by whom - and who the electricity customer is

Charging types by power level



Level 1 - standard socket

- About 1.5 - 2 kW
- Overnight to multi-day for a full charge
- No dedicated equipment needed (some safety risks)
- Household-scale impact



Level 2 - dedicated AC

- 7 to 20 kW AC
- Several hours for a full charge (modulable kW)
- The workhorse of home and workplace charging
- Where most managed charging value sits



DC fast charging

- 50 to 350 kW for cars
- MW-scale charging for heavy trucks
- 30 minutes to a few hours
- Commercial, high power, low flexibility



Charging locations and charging behaviour



Residential

- Single-family homes
- Multi-unit dwellings
- Overnight / long-dwell charging
- Highest flexibility potential



Work and destination

- Workplace charging
- Public Level 2 at destinations
- Retail, leisure and other destinations
- Daytime, often solar-aligned



Travel and commercial

- Public DC fast on corridors
- Depot charging for fleets
- On-route commercial charging
- Shorter dwell times, higher power



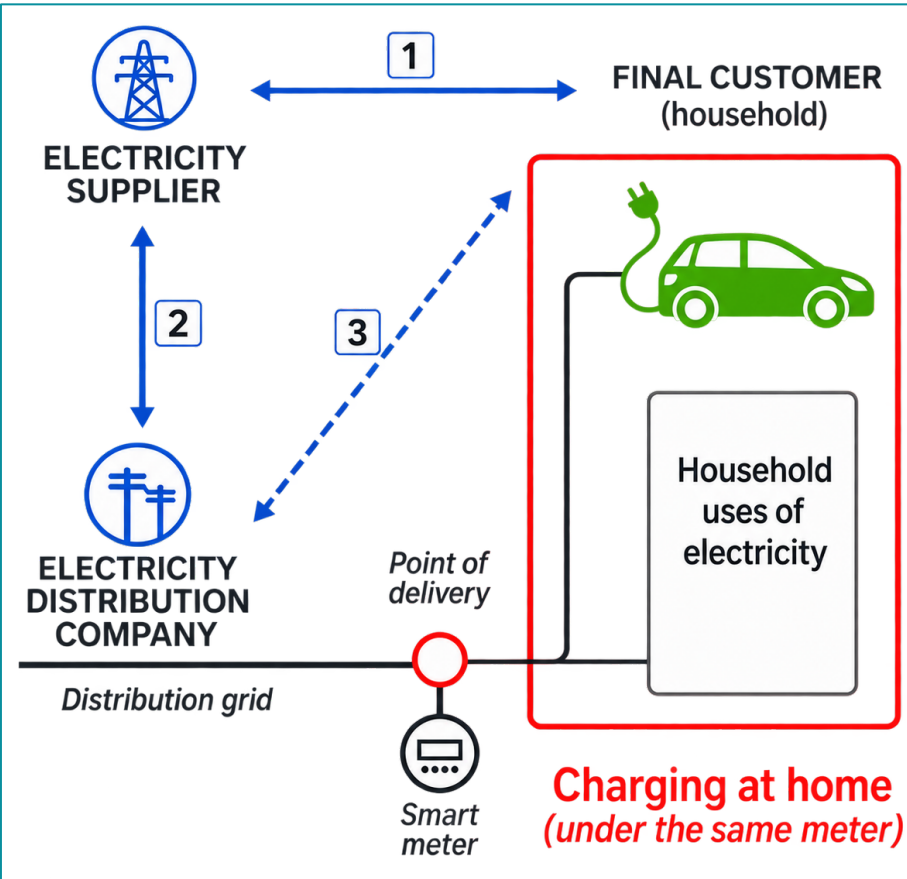
Charging behaviour depends on whether the driver («end-user») need a full recharge or top-up, how long the vehicle is parked, and price sensitivity.

EV charging is a multi-segment activity

Where charging happens determines the commercial and regulatory relationship.

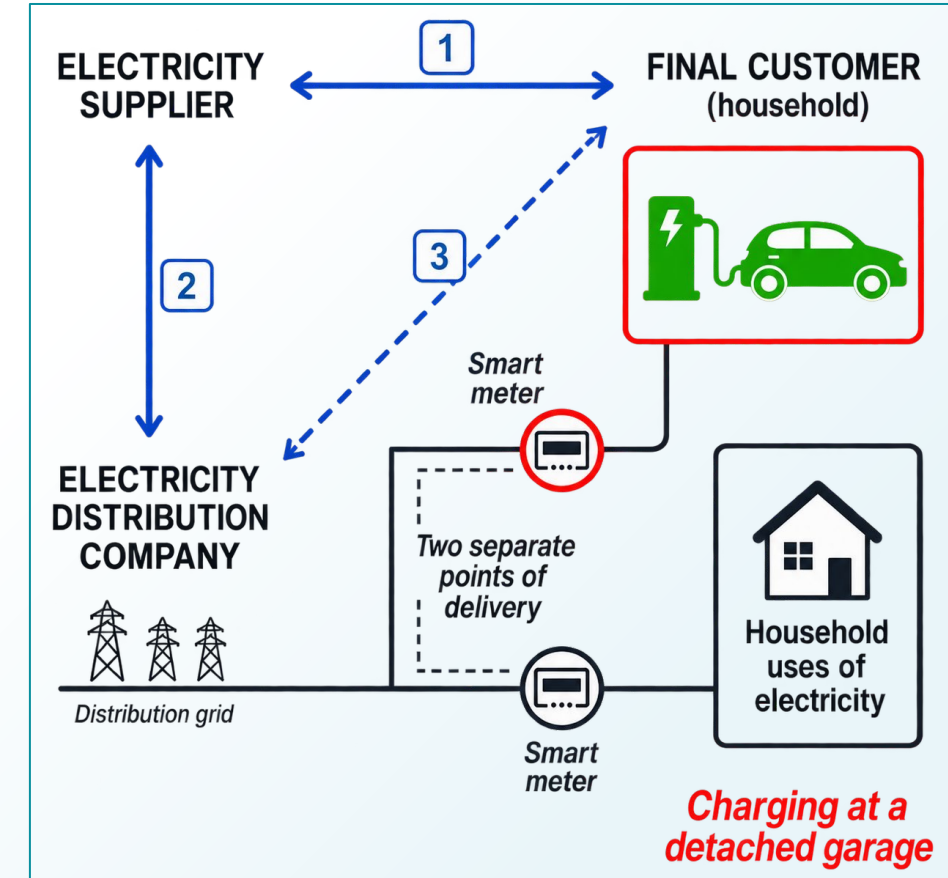


Private charging: EV user is (normally) the electricity customer



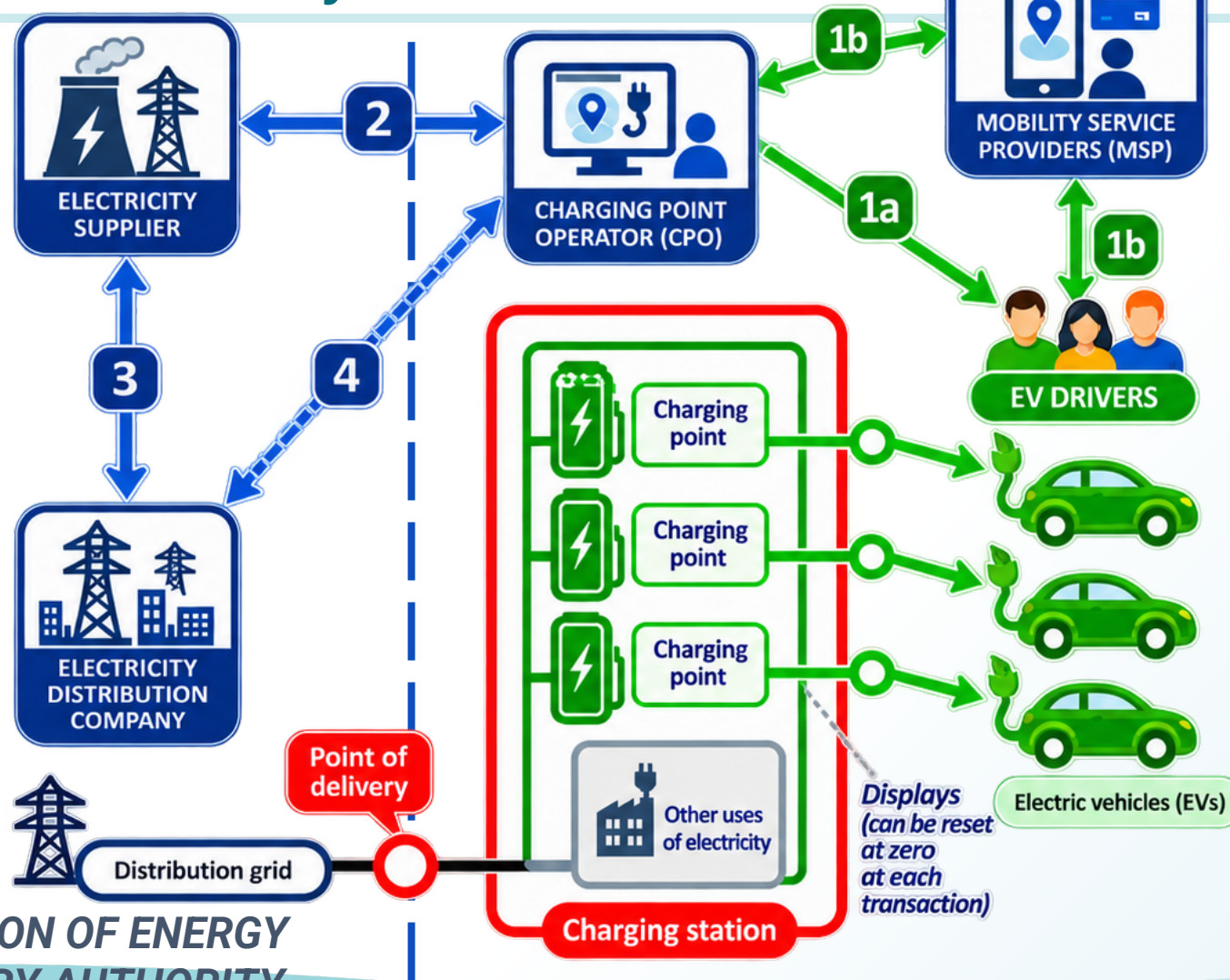
CONTRACTUAL RELATIONSHIPS

1. Customer – Retail Supplier
2. Retail Supplier – DSO
3. DSO – Customer
(only for new connections)



In these cases the «final customer» for the power system coincides with the «end user» for the e-mobility (i.e. the EV driver or EV owner)

EV charging in public places: EV user is NOT the electricity customer



**JURISDICTION OF ENERGY
REGULATORY AUTHORITY**

Where the energy actually goes



65 - 95%

Share of EV energy charged privately, at home or at work

5 - 35%

Share charged at publicly accessible charging points

1 - 8%

Typical utilization range for public charging points
(Yearly Energy/Rated Power/8760)

- The large majority of EV energy is charged at home or at work, even where public networks are dense
- Drivers without their own private parking are structurally dependent on «public charging» (*charging in publicly accessible places*)
- Public charging is essential, but it is not where most kilowatt-hours flow (though, all drivers need public charging occasionally - for long journeys or local top-ups)

Energy needs for EV (duty light) charging: the basic arithmetic



1 Annual mileage
12,000 – 15,000
Km/year

Illustrative range



2 Energy consumption
15 – 16
kWh/100 km

Broader range: 13-23 kWh/100km



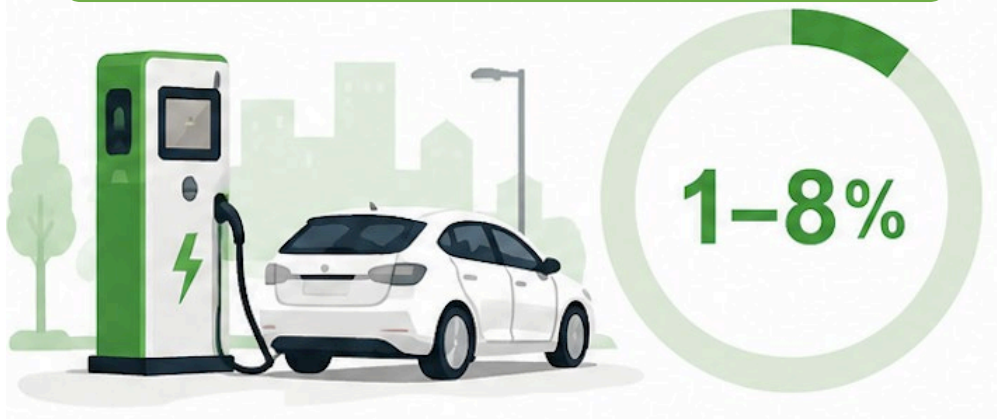
3 Annual energy per EV
1.8 – 2,4
MWh/year

Broader range: 1.3-2.7 MWh/year

x 1,000,000 EVs around 2,0 – 2,5 TWh/y

Rated Power utilisation rate: the number that drives the economics

PUBLICLY ACCESSIBLE CHARGING POINT



Utilisation rate for a 1.3 kW/EV
publicly accessible charging point

AFIR-based
assumption

SEPARATE HOME WALLBOX



Utilisation rate for a separate 7.4
kW wallbox

Charging infrastructure is connected to the grid continuously, but delivers energy for only a small fraction of the time

Who is who: operational stakeholders in vehicle-grid integration



Stakeholder	Main concern	Main motivation
EV users and fleet managers	Charger availability, range, privacy and security	Convenience and lower energy bills
Vehicle manufacturers (OEM)	Warranty claims; customer charging experience	Sales and market share
Charge point operators (CPO)	Grid connection, land, network tariffs	Higher utilisation and new revenue streams
Mobility service providers (MSP or EMSP)	Interoperability of charging points; roaming systems	Larger subscriber base; B2B contracts with CPOs
Distribution network and system operators	Grid security and quality of supply (esp.ly voltage regulation)	Reliable regulated network services and tariff revenues
Electricity suppliers and retailers	Portfolio balancing and energy-cost recovery	Customer acquisition, supplying electricity to customers
Aggregators	Access to flexible EV resources	Participation in flexibility and system services

Source: IEA (2023), *Grid Integration of Electric Vehicles: A manual for policy makers*

Module 2 - key takeaways



- 1 EV Charging is also segmented**
Power, location, dwell time and charging needs vary strongly by vehicle use
- 2 Follow the electricity customer**
In private charging, the EV user is the electricity customer; in public charging, the CPO is.
- 3 Most energy flows at home**
65 to 95% of EV energy is charged privately, with long dwell times
- 4 Charging capacity has low utilization factor**
Chargers are connected continuously but deliver energy for only a small share of time

03

Grid impacts and load forecasting

Where the impacts appear, how fast they arrive, and how to read a forecast critically

Your biggest concern



What is your biggest concern with electric vehicle growth?

- A** Forecast uncertainty
- B** Local grid impacts
- C** System peak impacts
- D** Cost to ratepayers
- E** Not a priority yet



Three ways EV charging affects the power system

Line and transformer loading

- Sustained loading beyond physical capacity
- Premature ageing or permanent damage
- May require reinforcement or upgrades



Power quality

- Single-phase charging may cause a voltage imbalance
- EV charging may cause harmonic distortion
- Lower power quality can affect nearby appliances
- Increasingly addressed through technical standards



System-wide effects

- Charging during peak periods can increase system peak
- Increases peak generation capacity requirements (e.g Reserve Dimensioning)
- Can ultimately increase generation requirements and system costs



EV load is different from a typical household load



Why EV load is challenging

- Unmanaged charging can align with the evening peak
- EV adoption occurs in local clusters
- Impacts can therefore be highly localised

What makes it valuable

- Vehicles are parked around 22 hours per day
- Plug-in time often exceeds charging time
- Average daily charging need is only 15-20% of a full battery
- Vehicles are often close to existing electrical infrastructure

The speed mismatch regulators must plan around



EV charging load can arrive 5 to 10 times faster than traditional planning cycles deliver capacity

- A charging site can be planned and deployed in roughly 6 to 18 *months*; distribution reinforcement typically takes 3 to 5 *years* to plan and construct
- This is why proactive planning and hosting capacity transparency matter more than accuracy of the central forecast
- *Speed to connect* is becoming the key performance question for DSOs

Peak impact forecasts: two national examples



+8% / +21% / +39%

UK system peak in 2030 / 2040 / 2050 from EV charging

+14% by 2030

Italian MV/LV contractual capacity, against 172 GW existing

- UK: National Grid Future Energy Scenarios projected steadily rising peak contribution over three decades
- Italy: the regulator's own consultation estimated about 23.9 GW of new peak demand, of which 8.2 GW from private recharge and 5.4 GW from public recharge
- Both studies show the same pattern: the distribution level absorbs the impact first

Forecasting the charging mix requires caution



Where charging happens depends on infrastructure availability - and expectations shift quickly.

70% / 55%

Residential share of charging: 2024 actual vs 2030 estimate

20% / 30%

Public share of charging: 2024 actual vs 2030 estimate

10% / 15%

Workplace share of charging: 2024 actual vs 2030 estimate

- The mix is a forecast output, not an input - and it drives where grid impacts land
- Charging location choice depends on housing, parking, commuting patterns and infrastructure provision
- Given the early stage of the sector, the future segment split remains genuinely uncertain

Source: IEA, Global EV Outlook 2024

Module 3 - key takeaways

- 1 Impacts are local before they are national**
Feeders and transformers bind long before generation does
- 2 Timing beats volume**
Coincidence with peak determines cost, not total kilowatt-hours
- 3 Speed is the real constraint**
Load arrives 5 to 10 times faster than reinforcement can be delivered
- 4 Forecasts are scenarios, not predictions**
Demand credible ranges, sensitivities and distribution-level detail
- 5 Flexibility is a must**
Learn from Anne Collyer

04

Network tariffs and smart charging

Cost-reflective pricing, the capacity-versus-volume problem, and regulatory experiments that worked

Capacity-based versus volumetric network tariffs



Capacity-based

- Charges follow contracted or measured kW
- Cost-reflective for LV and MV distribution, where capacity drives cost
- Works well for steady, high-utilisation loads
- Penalises assets used only a small share of the year

Volumetric

- Charges follow kWh withdrawn
- Simple to administer and forecast
- Favourable for low-utilisation charging stations
- Weak signal on peak if not ToU related
- DSO revenues erode if utilisation stays low

The Italian context: why this experiment was possible



Regulatory experiments depend on the metering and tariff design already in place.

- 29 million households out of 37 million total customers, with low average electric intensity (2 000 - 2 200 kWh/year)
- A contractual capacity limit applies to all households since the 1970s - typically 3 kW for 85% of them
- Capacity-based tariffs extended to households from 2017-18
- Smart meters for all customers: first generation from 2001 (with three time-bands on monthly basis), second generation from 2018 (with hourly metering)
- A breaker on board enforces the capacity limit remotely - the enabling technology for everything that follows

ARERA decision 541/2020: smart charging at home



The ordinary rule

- A customer wanting more power buys more contracted capacity
- The capacity-based tariff rises accordingly (distribution network cost are covered in euro/kW)
- The higher capacity limit then applies 24 hours a day, 7 days a week

The experimental regime

- EV owners get a free capacity increase up to **6 kW usable only 23:00 - 07:00 on weekdays and all day Sunday**
- They keep paying the tariff for a 3 kW limit
- Enforced through existing smart meter functionality

Why it works technically

- Most LV users on 3 kW contracts are physically connected to standards permitting about 6.6 kW continuously
- Almost all applications can be handled remotely by the DSO
- No site visit, no new hardware on the network side

Conditions to apply, and what counts as a smart charge point



Customer requirements

- Connected to the low-voltage network
- Contractual capacity limit between 2 kW and 4.5 kW
- Equipped with a working smart meter
- Explicit permission for on-site verification

Smart charge point definition

- Permanently installed (mode 3, EN 61851-1) - no portable devices
- Certified compliance with safety regulations
- Must be V1G functionality “ready”

V1G functionality means

- Monitor and record energy consumption
- Transmit it remotely to a third party designated by the customer
- Receive and process information and adjust the charging rate accordingly



What the regulator was trying to achieve

- Offer a genuine saving opportunity on private charging that is cost-reflective, not a public subsidy
- Gently push the newborn wallbox market towards smart devices
- Prepare customers to offer vehicle-to-grid services to a balancing service provider, or emergency services to the DSO
- Collect information to understand private charging behaviour better
- Create a template that can later be extended to other flexible technologies

The saving is cost-reflective: night-time, network capacity genuinely costs less.

Public charging: the volumetric tariff derogation



Some regulators created an exception to their own cost-reflectivity principle - deliberately.

- Given low EV adoption and low utilisation, capacity-based tariffs can obstruct deployment of public charging
- As a early deployment measure, ARERA introduced a special volumetric-only tariff for LV connection points dedicated to EV charging (unlike the standard three-part tariff fixed, capacity, energy)
- The higher the connection capacity, the larger the saving for the operator
- Below a break-even volume the operator saves; above it the standard tariff would be cheaper

Module 4 - key takeaways



- 1 Capacity tariffs clash with low utilisation**
Cost-reflective for networks, , barrier for e-mobility development
- 2 Derogations need an exit condition**
Italy's volumetric tariff for public charging worked on deployment, not on utilisation
- 3 Smart charging: smart metering is a pre-requisite**
Not only volumetric ToU: also capacity limit modulation in presence of capacity charges
- 4 Night-time capacity is genuinely cheaper**
Which is why the Italian 6 kW experiment is cost-reflective, not a subsidy

Ten things to take home (1 of 2)

- 1 Timing beats volume**
When vehicles charge determines cost far more than how much energy they take
- 2 Impacts are local first**
Feeders and transformers bind before national generation does
- 3 Adoption clusters**
Spatially granular analysis is not a refinement, it is the analysis
- 4 Most energy is charged privately**
65 to 95% at home or work - that is where flexibility lives
- 5 Speed to connect is the new constraint**
Load arrives 5 to 10 times faster than reinforcement

Ten things to take home (2 of 2)

- 6 “Public charging”: capacity tariffs clash with low utilisation**
Cost reflective for networks, barrier for e-mobility development
- 7 Derogations need an exit condition**
Italy's volumetric tariff for public charging worked on deployment, not on utilisation
- 8 Smart charging: smart metering is a pre-requisite**
Not only volumetric ToU: also capacity limit modulation in presence of capacity charges (smart charging at home)
- 9 Night-time capacity is genuinely cheaper**
Which is why the Italian 6 kW experiment is cost-reflective, not a subsidy
- 10 Flexibility must be paid to exist**
(Spoiler for the next lecture)

Further reading and source materials



Source	What it gives you
IEA (2022), Grid Integration of Electric Vehicles: A manual for policy makers (www.iea.org/reports/grid-integration-of-electric-vehicles?utm_source)	The four-step policy framework and the four-phase grid integration framework
RAP & ICCT (2025), How to Unlock Benefits from Smart EV Charging (www.raponline.org/knowledge-center/how-to-unlock-benefits-from-smart-ev-charging/?utm_source)	Quantified savings from four global case studies and regional policy recommendations
ERRA (2026), E-Mobility Survey 2025 Report (https://erranet.org/erra-report-e-mobility-status-update-development-plans-and-related-regulatory-issues/)	Regional benchmark across 25 ERRA member regulators, barriers and recommendations
Lawrence Berkeley National Laboratory (2025), BCA for Managed EV Charging (https://emp.lbl.gov/publications/best-practices-guide-benefit-cost?utm_source)	Cost-effectiveness tests, nine-step BCA method and emerging best practices
Energy Systems Integration Group (2026), EV Load Forecasting Guide (https://emp.lbl.gov/publications/ev-load-forecasting-guide?utm_source)	Forecasting approaches, data requirements and forecast review criteria
CEER (2019), New Services and DSO Involvement (C18-DS-46-08) (https://www.ceer.eu/publication/conclusions-paper-on-new-services-and-dso-involvement/?utm_source)	Contractual relationships and the boundaries of regulatory jurisdiction



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