DRIVING MOBILITY FOR EUROPE

The used vehicle market for low-emission Light Duty Vehicles in Europe

Dynamics, policies & system-level implications

Quantalyse

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Preface

This research paper is the outcome of a collaboration between the management consultancies QUANTALYSE and STH Consulting. It has been prepared at the request of the European Automobile Manufacturers' Association ACEA, to provide an independent, system-level analysis of the used-vehicle market for low-emission passenger cars and light commercial vehicles in Europe. The purpose of this work is to deepen the understanding of how the second-hand market functions, how it interacts with the new-vehicle market, and how their interdependencies have a substantial impact on Europe's transport decarbonisation pace.

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Contents

1 Executive Summary

The **used vehicle market** constitutes a **secondary market** that originates from the **primary market for new vehicles**. Its existence and evolution are determined by the **stock–flow dynamics** of the overall vehicle fleet: new vehicle sales add to the stock, while retirements and resales redistribute it over time. The **supply** of used vehicles thus depends on the **historical flow of new vehicle registrations**, while **demand** reflects the heterogeneous preferences and budget constraints of consumers who enter the market at later ownership stages.

From an **economic equilibrium perspective**, the two markets are **mutually interdependent** with an inherent feedback system. While the used market is supplied by the primary market, the **viability of new vehicle sales** is, in turn, **anchored in the liquidity and price stability** of the used market. Residual values established in the secondary market feed back into **leasing rates, depreciation expectations, and total cost of ownership (TCO)** calculations for new vehicles. A well-functioning used market therefore **reduces perceived risk** for both consumers and financiers, enabling **higher transaction volumes** and **shorter replacement cycles** in the new market.

Conversely, when the secondary market suffers from **illiquidity, valuation uncertainty, or thin demand**, it depresses residual values and raises ownership costs for new vehicles—especially under leasing and fleet renewal schemes. In dynamic models of the vehicle stock, such as **fleet turnover and diffusion frameworks**, the used market acts as a **stabilizing mechanism** that ensures continuity in the flow of vehicles between user segments and across time. Hence, the **health of the secondary market** is not merely a byproduct but a **prerequisite for the sustainable functioning and diffusion potential** of the primary new-vehicle market.

The interaction between the **new and used vehicle markets** forms a **complex, dynamic system**, in which **policy interventions in one segment inevitably generate cascading effects** in the other. Market mechanisms such as **pricing, depreciation, and fleet turnover** transmit shocks and incentives across both domains, shaping the overall pace and equity of technological diffusion.

Within the broader context of the **transition to net-zero**, the transport sector remains one of the **hardest to decarbonize**, given its structural dependence on long-lived assets and the heterogeneity of its user base. Current policy frameworks in the European Union and beyond have primarily targeted the **new vehicle supply**, through regulatory standards, manufacturer obligations, and fiscal incentives. However, this **supply-centric approach** overlooks the pivotal role of the **used vehicle market** in determining the actual environmental trajectory of the circulating fleet.

This study therefore aims to **broaden the analytical horizon** by situating the used vehicle market within the **systemic dynamics of decarbonization**, emphasizing that progress toward net-zero requires a **nuanced, multi-layered policy architecture**. Such an approach must extend beyond the regulation of new vehicle supply to encompass the **circularity, affordability, and longevity** of vehicles already in circulation—factors that ultimately determine the **real-world carbon outcomes** of transport electrification. In other words, true progress begins with enabling conditions.

2 Introduction

The transition to a zero-emission vehicle fleet represents one of the most complex and consequential transformations facing European policy today. While major progress has been achieved through CO_2 standards, purchase incentives, and industrial strategy, the **pace of decarbonization** remains insufficient to meet 2030 and 2050 climate targets.

This shortfall does not stem from a lack of ambition, rather the application of an analytical lens that is too limited in focus: policies have largely been designed around **technology and cost**, focusing almost exclusively on the inflow of new vehicles. This supply-side, compliance-driven paradigm treats electrification primarily as a price-based substitution problem: make low-emission vehicles cheaper, push them into the market, and diffusion will follow.

This study aims to broaden that lens. It reframes transport electrification as a **multi-dimensional behavioural transition** embedded in physical flows, financial equilibria, and contextual enabling conditions. It provides a conceptual foundation for understanding *why* adoption rates deviate from model expectations and *how* targeted, context-aware measures can accelerate change with greater efficiency and fairness.

2.1 Ten pathways

There are essentially **ten main pathways** (in random order) through which the regulatory framework can decarbonize the vehicle stock:

1. **Inflow** – Ensure new vehicle purchases are of lower-emission vehicles.
2. **Outflow** – Encourage scrapping or export of the highest-emission vehicles.
3. **Replacement** – Steer used-vehicle transactions toward cleaner options.
4. **Allocation** – Match low-emission vehicles to long-distance users and vice versa.
5. **Mileage** – Reduce kilometres driven with high-emission vehicles, e.g. through fuel pricing or mobility management.
6. **Modality** – Shift travel to low-carbon alternatives, such as public transport, cycling, or shared mobility.
7. **Load** – Increase occupancy or payload per vehicle, e.g. carpooling or fleet optimization.
8. **E-fuel** – Introduce low-carbon fuels that decarbonize the incumbent fleet immediately.
9. **Circularity** – Cut embedded emissions via clean materials, processing, recycling, and end-of-life innovation.
10. **Intelligence** – Organize data & digitalisation to minimize energy waste and unnecessary travel through e.g. routing, predictive maintenance, global uniform payment, traffic, or dynamic pricing.

These can be structured in three leverage domains:

- control over stock flows,
- governing usage patterns, and
- drive ecosystem efficiency.

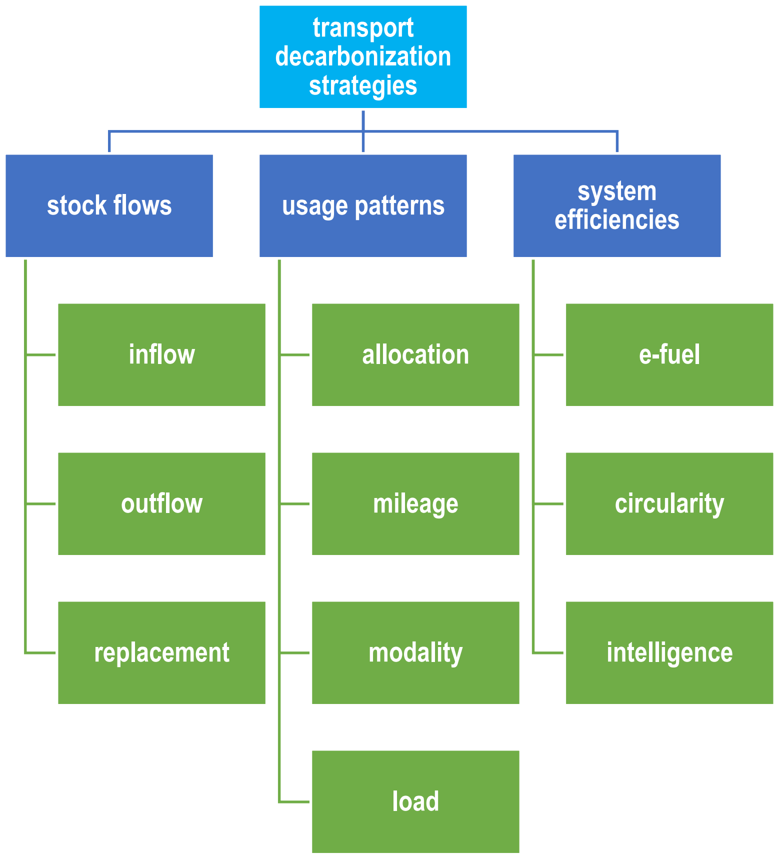

Figure 1: Low-emission policy achieves impact through ten mutually reinforcing strategic levers. They are structured into three domains: control over stock flows, governing usage patterns, and drive ecosystem efficiency. They shape how vehicles are produced, used, and renewed across the fleet. Decarbonisation is not a product problem. It is a system management problem.

The overarching objective of transport decarbonization in the European Union is to accelerate the **diffusion of low- and zero-emission** vehicles (passenger vehicles and light commercial vehicles).

Each pathway represents a lever through which regulators can influence the rate and pattern of diffusion—whether by shaping entry and exit flows, managing usage intensity, or improving systemic efficiency. Together they translate the abstract ambition of “net-zero mobility” into a set of concrete mechanisms through which cleaner technology can propagate through Europe’s vehicle ecosystem.

While the ten outline the complete set of strategic levers through which policy can influence the decarbonization of the vehicle stock, their implementation depends on how these levers are embedded in existing regulation.

2.2 EU Vehicle Policy

In the European Union (EU), motor vehicles are regulated by a complex but coherent framework of laws intended to ensure safety, environmental performance, and market integrity for vehicles placed on the EU market.

From the viewpoint of Original Equipment Manufacturers (OEMs), **three pillars** define the core environment in which BEV adoption unfolds:

- Vehicle type approval,
- CO_2 performance standards applicable to new passenger cars and vans, and
- the forthcoming 2025 Automotive Package (to be adopted on 16 December 2025).

2.2.1 Vehicle Type-Approval Legislation

The vehicle type-approval system in the EU is designed to ensure that before a new vehicle model (or variant) is placed on the market, the manufacturer must obtain a “type-approval” certificate confirming that the vehicle meets all applicable regulatory requirements.

- Directive 2007/46/EC provided the original framework, now replaced by Regulation (EU) 2018/858.
- As of 1 September 2020, this was further extended to harmonise emission and safety requirements. The new framework introduced the WLTP and real driving emissions (RDE) procedures, empowering the Commission to suspend technical services for non-compliance.
- Regulation (EU) 2018/858 now ensures that a single EU type-approval allows the sale of a vehicle across all Member States, guaranteeing compliance with environmental, safety and technical standards.

For Original Equipment Manufacturers, this system guarantees EU-wide market access through a single approval process but also creates a compliance frontier for emerging BEV-specific standards—battery safety, data access, and digital monitoring now being central compliance domains.

2.2.2 CO_2 Emission Performance Standards (Cars & Vans)

A second major regulatory strand concerns fleet-average CO_2 emission limits for new passenger cars and vans, primarily governed by Regulation (EU) 2019/631. This regulation sets binding CO_2 emission performance targets for manufacturers, measured in grams per kilometre (g CO_2/km).

- For 2020-2024, the target for passenger cars is 95 g CO_2/km.
- Amendments, such as Regulation (EU) 2023/851, establish a 100 % reduction target—effectively zero tailpipe emissions—from 2035 onwards. The WLTP procedure replaces older NEDC tests, and excess-emission premiums apply when manufacturers exceed targets.

- Type-approval ensures individual vehicle compliance, while the CO_2 regulation governs manufacturers' fleet performance, combining safety and environmental objectives.
- A revision of the CO2 regulation is currently under discussion.

For manufacturers, these fleet targets link directly to corporate strategy, capital allocation, and model portfolios. Yet, because they operate exclusively at the point of first registration, they influence the **inflow** of vehicles but not their **circulation** or **reuse**—a limitation increasingly recognized as a barrier to whole-fleet decarbonization.

2.2.3 The New Automotive Package

The European Commission plans to adopt a comprehensive automotive package on 16 December 2025. Building on the 2025 Automotive Action Plan, this package will integrate existing type-approval and CO_2 frameworks with new policies addressing digitalisation, data access, and industrial competitiveness.

Key elements likely include a proposal for a corporate fleets regulation (see section X), enhancing surveillance for autonomous vehicles, simplifying the regulatory framework (automotive omnibus), and new rules for circular-economy principles such as battery recycling and life-cycle assessments.

The package also anticipates amendments to the CO2 Regulation, allowing averaging of 2025-2027 targets. For the industry, this package signals a structural shift from compliance-based to **system-based regulation**, where lifecycle performance, data flows, and material circularity become as decisive as tailpipe emissions.

As noted by the International Road Transport Union (IRU), enabling conditions for older vehicles and second-hand markets are missing from the plan.

2.2.4 Adjacent frameworks

Beyond these pillars, BEV diffusion also depends on adjacent frameworks, partially integrated into EU vehicle regulation:

- **Battery Regulation (2023/1542):** introduces lifecycle footprint reporting, due diligence, and recycled-content targets, directly impacting design and sourcing decisions.
- **Alternative Fuels Infrastructure Regulation (2023/1804):** ensures adequate charging coverage—an essential complement to fleet CO_2 compliance.
- **Industrial and Raw Materials Acts (NZIA, CRMA):** affect BEV cost competitiveness and supply security.
- **Digital and Data Acts:** shape OEM access and third-party use of vehicle data—crucial for the emerging software-defined BEV ecosystem.

Together, these 3 pillars and frameworks define the current and forthcoming *operating envelope* for OEMs.

2.2.5 Mapping

From the viewpoint of the existing European regulatory framework, only a small subset of the ten decarbonization pathways is directly addressed today:

- CO_2 Regulation & Type Approval affect mainly
    - (2) Inflow, (9) Circularity (*partially*), (10) Intelligence (*partially*)

- Almost untouched by EU regulation today
    - (1) Outflow, (3) Replacement, (4) Allocation, (5) Mileage, (6) Modality, (7) Load, (8) E-fuels

Whereas the 10 pathways describe the **full decarbonisation space**, the EU regulatory framework covers **only a narrow slice** of it.

More importantly, the current framework remains overwhelmingly focused on **supply-side compliance**—ensuring that new vehicles meet prescribed standards—while paying little attention to the **decarbonization of the existing fleet**. Currently, policy heavily favours **composition change at entry**. OEMs thus operate within a compliance regime that tightly governs vehicle inflow but leaves the downstream dynamics of circulation, resale, and withdrawal in the used market largely unregulated.

This **asymmetry** is more than a gap in regulatory coverage; it represents a **structural imbalance** in how policy engages with the automotive system. By concentrating effort on the inflow of new vehicles while neglecting the mechanisms of **outflow and replacement**, EU regulation risks distorting the equilibrium of the vehicle market—particularly the feedback loops that connect new and used segments through prices, liquidity, and residual values. In effect, compliance is ensured at the factory gate, but decarbonization is left unresolved on the road.

The following chapters therefore examine how this imbalance can be corrected. By describing **three structural 'bridges'** between the new and used markets, the study proposes ways to restore coherence across the system—broadening the policy toolbox and aligning decarbonization with the practical constraints faced by consumers, fleets, and manufacturers alike.

2.3 Three bridges

In the next three chapters, the **Flux Bridge**, the **Depreciation Bridge**, and the **Utility Bridge** constitute a **comprehensive systems framework** for understanding the interdependence of the new and used vehicle markets within the broader mobility transition. These bridges capture the three fundamental transmission channels through which economic, behavioral, and policy dynamics interact: the **flow of quantities**, the **formation of prices**, and the **shaping of utility**.

- The Flux Bridge represents the **physical and temporal linkage**—how vehicles move through the stock–flow system, connecting production, ownership, and disposal.

- The Depreciation Bridge captures the **financial interdependence** between markets through residual values and price expectations, which mediate affordability and investment confidence.

- The Utility Bridge integrates the enabling conditions and context variables—those behavioral, infrastructural, and institutional **factors that modulate** perceived utility and determine how rapidly technological change diffuses across both markets.

Together, these three bridges form an **interlocking feedback architecture**, where shifts in one domain propagate through the others, influencing fleet composition, consumer behavior, and policy effectiveness over time. This triadic framework highlights that sustainable decarbonization of the transport sector cannot be achieved through isolated supply-side regulation of new vehicles alone.

It requires **coordinated action across all three domains**—balancing flows, stabilizing values, and enabling conditions—to ensure a **resilient, equitable, and self-reinforcing transition** toward a zero-emission vehicle ecosystem.

Beyond the bridge framework, the same system can also be viewed through the metaphor of three interdependent gears that keep the transition machinery in motion. The **Stock Flow Gear** reflects turnover and determines how rapidly the fleet can renew itself; the **TCO Gear** reflects depreciation and residual-value formation, which govern affordability and confidence across ownership cycles; and the **Utility Gear** reflects real-world utility, shaped by charging access, convenience, and behavioural context.

Like mechanical gears, these components must rotate in synchrony: if one slows or seizes, the overall system loses traction. This complementary lens reinforces that decarbonisation is not driven by any single policy lever but by the coordinated functioning of (i) physical flows, (ii) financial signals, and (iii) user experience across both the new and used markets.

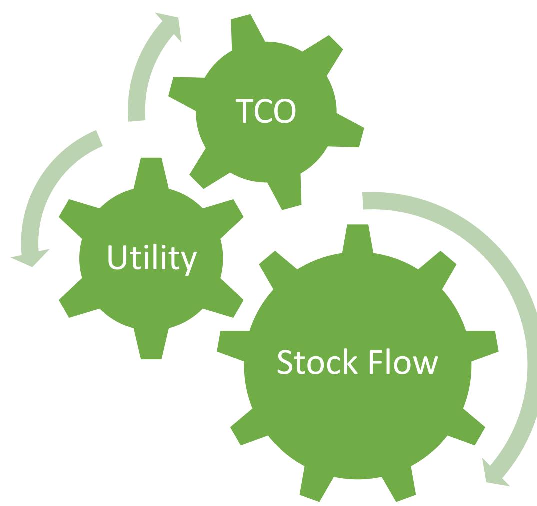

Figure 2: The automotive machine only runs when all three gears turn smoothly. A system level perspective tells that a stuck second-hand vehicle market is a stuck transition.

In short, this work calls for a more complete, multi-layer next-generation EU policy vision of transport: one that combines the ten systemic decarbonization pathways with the behavioural realism of **utility dynamics**, spanning **both** *new and used* market. Such an integrated framework empowers policymakers to move beyond cost-reduction logic, design context-aware interventions, and trigger faster, more equitable and self-sustaining decarbonization of Europe's vehicle fleet.

3 Stock flow dynamics

This section deals with concepts and metrics that underpin a structured view on the vehicle market. Understanding starts with the most basic question: "**How many cars are where**?". From an abstract viewpoint, the used vehicle market of a region at some (company, region, or state) level, can be described as a **stock flow system**.

Flow dynamics are particularly informative when evaluating **fleet stability**, **technology diffusion**, or **market maturity**, where both rapid flow (innovation) and high retention (legacy inertia) have strategic implications for transition dynamics.

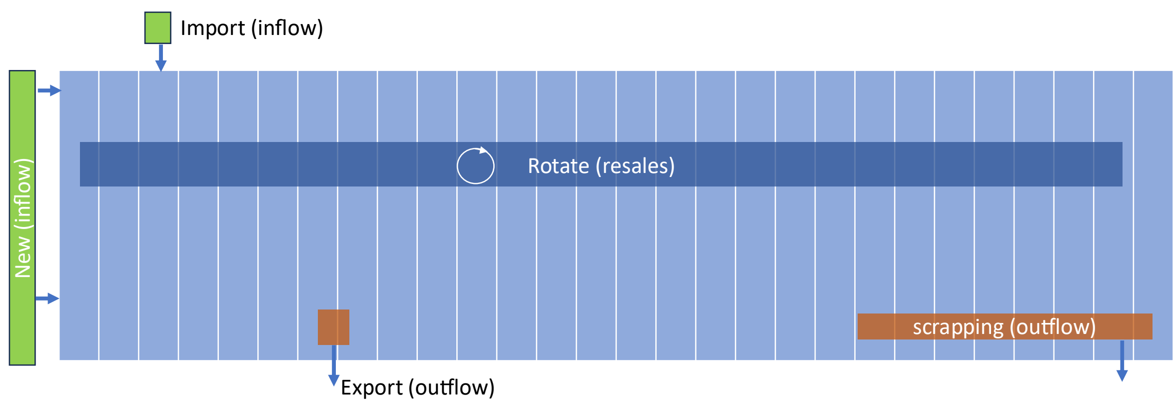

Figure 3:Vehicle stock in all age bands is undergoing inflows (new and import) and outflows (export and scrappage). The internal flow of resales is largely overlooked, but is actually one of the main drivers of diffusion speed for low-emission adoption.

We bring forward fundamental insights to the idea that the used market is essential in the decarbonization target and to diffuse new technology (like EVs) by making them accessible to more buyers. In this sense, the used vehicle market is currently a **blindspot** of which the relevance is only recently becoming recognized[1] in literature[2].

3.1 Stock and flows

Most decarbonization policies primarily target **inflow levers** — such as purchase subsidies for new electric vehicles, manufacturing quotas, or OEM imposed CO_2 fleet emission standards. From a system dynamics viewpoint, these instruments operate in a **closed stock–flow system**, and in this section, we go to the heart of it, to put the current and future automotive regulatory policy approach more in perspective.

[1] Diouf, Boucar. “The Second-Hand Market in the Electric Vehicle Transition.” World Electric Vehicle Journal (2025).

[2] Zacharof, N., Nur, J., Kourtesis, D., Krause, J. and Fontaras, G., A review of the used car market in the European Union, Publications Office of the European Union, Luxembourg, 2025, JRC140203.

Consider the tracked quantity of the stock to be the 'vehicle units'. Let S_0 be stock at period start, S_1 at period end. We recognize the fact that there are 2 (net) flows: one inlet (source) and one outlet (sink). Let N = count of **new** registrations inflow per period, O = count of scrap or export **outflow** per period. Then conservation of units in operation prescribes that:

$$S_1 = S_0 + N - O$$

Stock S_0 is the 'surviving' stock after accounting for all previous entries and exits in earlier periods. For convenience, one considers the flow counts relative to the stock at begin of period S_0, to express the amounts rather as a percentage per period:

$$n = \frac{N}{S_0}\ (new\ inflow\ rate), \qquad o = \frac{O}{S_0}\ (outflow\ rate)$$

In mature markets like the EU, inflow and outflow volumes are quite balanced, otherwise referred to as a **steady state**,

$$S_1 \approx S_0 \leftrightarrow o \approx n$$

In the EU, inflow is marginally larger than outflow in 2025, with indeed similar figures in the order of 5%,

$$n = 4.5\%,\ \ o = 4.2\%$$

which implies that replacement (turnover) is almost constant. This fact is also reflected in very low **net growth rate** of stock that is observed in EU (confirming the steady state):

$$\gamma = \frac{S_1 - S_0}{S_0} = n - o \approx 0.3\%$$

An important observation is that, in a stable or slowly growing market, **inflow (N)** and **outflow (O)** are tightly linked through a **feedback loop,** that maintains the total stock at equilibrium. The macro state of the economy governs that a slow inflow matches a slow outflow:

$$S_1 \approx S_0 \quad \leftrightarrow \quad N \approx S_0 . o$$

This relationship implies that every vehicle leaving -literally- creates the pull for a vehicle entering the stock. They are just separated by a long time lag of many periods, which makes it less evident to see the intrinsic coupling.

In a steady-state system, **inflow and outflow are symmetrical determinants** of the fleet's net size. Both inflow **and** outflow operate on equal footing: increasing either the entry of new vehicles or the exit of old ones can alter the total stock or its composition. Policies typically focus on **stimulating inflow** — through subsidies for new EV purchases, production mandates, or tax incentives — to accelerate the adoption of cleaner technologies.

However, the same overall fleet renewal effect can also be achieved by **acting on the outflow side**. For instance, increasing the **rate of vehicle retirement** (scrappage, export, or early decommissioning) opens space within the stock for new, cleaner vehicles to enter.

This may appear paradoxical: focusing on vehicle removal can *promote* innovation uptake. Yet, in a steady-state system, **every additional inflow must be balanced by a corresponding outflow**;

therefore, without inflow *push* matching with an adequate outflow *pull*, policies aimed solely at boosting inflow face structural limits. In practice, policymakers often treat outflow as a passive outcome of vehicle aging, rather than a controllable lever. This underutilization represents a missed opportunity: targeted outflow policies can **increase replacement demand** and thereby **amplify the diffusion rate of low-emission technologies**.

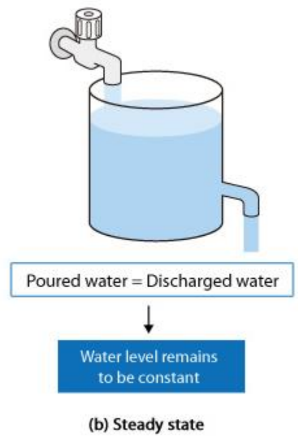

Figure 4: Outflow governs the stock system's capacity for renewal. Inflow determines what kind *of vehicles enter, but outflow determines* how fast *the stock can be refreshed. The apparent independence of inflow and outflow is an illusion created by time delays—the vehicles that enter today only leave many years later—but system dynamics establishes that they are tightly coupled.*

In summary, **inflow cannot expand faster than outflow permits**. The two are inherently linked within a **feedback loop**, where the pace of vehicle removal determines the system's capacity for renewal. A decarbonization strategy that targets only the inflow side is therefore **fundamentally incomplete**. Decarbonization policy that focuses solely on inflow stimulation (e.g., purchase grants for EVs) targets **only half of the system's renewal mechanism**.

3.2 Stock size

In the previous section it was illustrated how both sides of a stock deserve equal attention, those entering and leaving. Focus on **magnitudes** also matters.

Let us look into the **relative sizes** of the stock, based on 2025 figures from ACEA. The S_0 portion of the stock that remains on the road, consists of circa 250M passenger vehicles and about 30M light commercial vehicles, together this group of 'light duty vehicles' represents about **280M units**.

One notes immediately that the annual number of new vehicles *N*, circa 10M new passenger vehicles and almost 2M vans, together circa **12M** vehicles, is **incredibly small compared to the incumbent stock** S_0:

$$O \approx N \approx 12M \quad \ll \quad S_0 \approx 280\ M$$

The mismatch in scale is quite remarkable. With roughly 280 million vehicles already in circulation versus only 12 million new registrations per year, policy that targets only the inflow operates on **less than 5 % of the system**, while **95 % of the fleet remains untouched each year**.

This asymmetry elevates the used vehicle market from a secondary consideration to the **primary arena of decarbonisation**. Any measure that shifts behaviour, incentives, or technology uptake within the existing stock acts on a **base more than twenty times larger** than new-vehicle policy alone.

As a result, euro-for-euro, well-designed used-market interventions can deliver **order-of-magnitude higher system leverage** than inflow-only measures, in terms of vehicles and decision points affected per policy euro. This is not a marginal efficiency gain, but a **structural *multiplier effect* inherent to stock–flow systems**.

This does not diminish the necessity of strong inflow regulation; rather, it highlights that **without *complementary* stock-side measures, the pace of fleet decarbonisation is structurally bounded**.

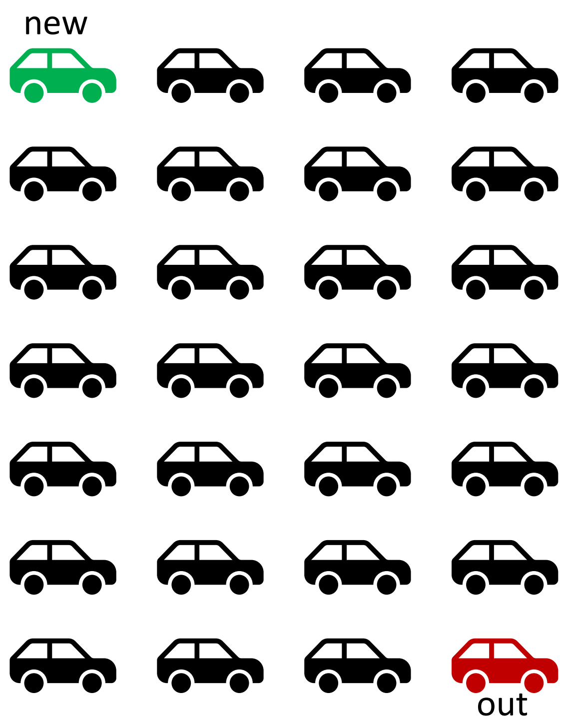

Figure 5: New vehicle inflows have a very limited impact on the overall stock on the road. The used vehicle is more than twenty times larger than the new market. Any incentive or regulatory signal applied there is automatically amplified by scale (multiplier effects). Decarbonisation that ignores the incumbent stock is decarbonisation by drip feed.

3.3 Outflow dynamics

The large stock of $S_0 - O$ escapes *any* change in each period. It behaves like a giant *counterflow*, that we can express relative to the stock S_0at begin of period, and is called the friction or **retention rate**:

$$f = \frac{S_0 - O}{S_0} = 1 - o \approx 96\%$$

It quantifies the **inertia** inherent in a stock, typical for durable goods. And this term indeed **dominates** the stock, and makes transitions in stock fundamentally slow. As such, we obtain the standard format of the stock system dynamics equation that describes the evolution of fleets:

$$S_1 = (1 - o)\, S_0 + N$$

There is no need to go into solving the difference equation. It suffices to make three structural observations regarding its components:

The role of used vehicle stock S_0: the lobsided potential

- In analysing the transition, two stock variables matter: the existing ICE stock S_{ICE} and the much smaller EV stock S_{EV}. Policies that act only on the inflowing EV stock target the *solution*, but not the *source*. By contrast, interventions applied to the **large** incumbent ICE stock operate on a far bigger **problem base**, and therefore have **much greater** potential impact on total fleet emissions.

- Consequently, even small percentage changes affecting the friction, turnover, or utilisation of the large ICE stock can generate larger aggregate decarbonisation effects, than much larger percentage changes in the EV inflow alone. This insight reinforces the strategic importance of the outflow and replacement pathways, which act on the **largest multiplier** in the system.

The role of inflow N: the visible lever

- **Inflow** is the result of **supply-side market function** and supporting policies (subsidies, mandates, manufacturer offerings).
- Inflow determines the **supply-side constraint** and the **maximum potential** for new technology diffusion. It is the visible lever and rightly the primary focus of policymakers for *introducing* innovation, because it's actionable.

The role of outflow rate o: the structural lever

- **Outflow** is the rate at which vehicles exit stock. The retention factor fundamentally governs **how fast the existing stock turns over.**

- If o is **low** (e.g., 5% per year), it will take decades to replace 95% of the stock, regardless of if even 100% of new sales are EVs, the fleet only turns over at the rate of o. Therefore, the **speed of the transition is structurally bound[3] by o**. New BEVs only change the stock *after* an ICE is gone. This additional insight prioritizes o because it is the lever for *acceleration*.

[3] In *transition*, outflow becomes the binding constraint. Its asymmetry with inflow emerges *from physics, economics, and stock-flow arithmetic*, not ideology. The key insight is that marginal payoff per unit outflow is much higher than per unit inflow, as it acts on the large incumbent base.

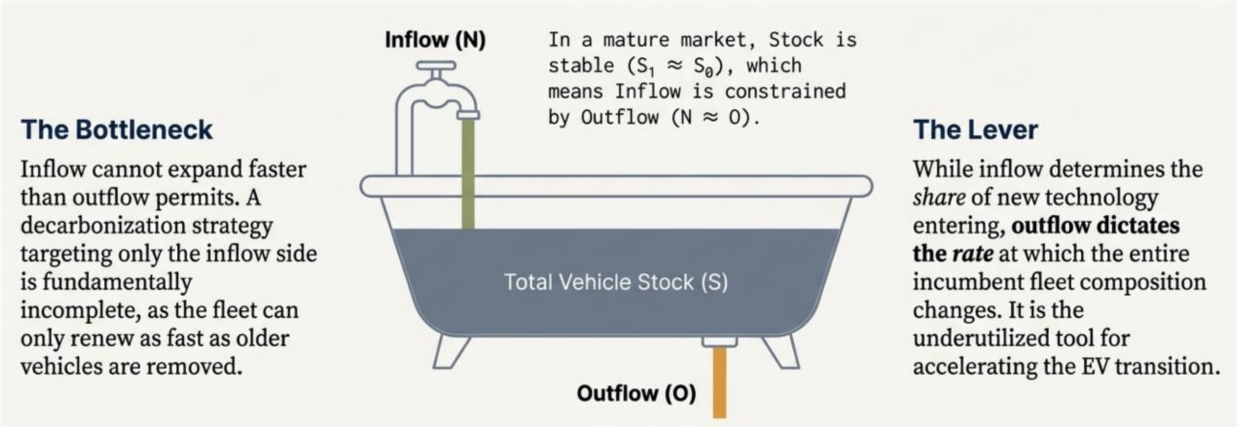

Figure 6: Boosting the clean-vehicle inflow is necessary—but on its own, it will not deliver system change. Ignoring outflow is like pouring clean water into a clogged bathtub: without clearing the drain, the system cannot renew.

While **inflow** determines the *share* of new technology entering the fleet (the kind of vehicle), **outflow** dictates the *rate at which the entire incumbent fleet composition changes (the gate)*. Even massive forced inflows cannot rapidly change the total stock if the existing vehicles remain on the road. In other words, inflow is the **visible policy lever**, but outflow is the **hidden structural lever** that truly determines the system's responsiveness, by increasing fundamentally **adoption speed** of clean technologies.

Understanding the coupling, taking advantage of multipliers and seeing what brings velocity leads to a plea for effective management of **outflow dynamics as** the **more powerful and underutilized tool for accelerating the EV transition.**

3.4 Stock composition

Besides the fact that the used market is huge, its composition also matters in order to understand why outflow management is so relevant for decarbonization.

When discussing the transition, the problem is often framed in terms of two stock variables:

- S_{ICE} (the stock of polluting vehicles one wants to eliminate)
- S_{EV} (the stock of low-emission vehicles one wants to grow)

with the objective of shifting the balance such that:

$$S_{ICE} \ll S_{EV}$$

Steering new production toward low-emission vehicles is therefore a logical starting point.

Yet **from a whole-fleet perspective**, this raises a structural efficiency question: should policy effort be concentrated where emissions are already lowest, or where they are highest? Decarbonisation gains are largest when interventions target vehicles with the **greatest emissions *intensity*** - typically older ICE vehicles, which in real-world use emit roughly **1.5–2× more CO_2/km** than new vehicles on average, with much larger differentials for the oldest passenger cars and light commercial vehicles due to obsolete emission standards, mechanical wear, and high utilisation.

This asymmetry creates **a strong leverage effect on the outflow side**. Retiring one high-emitting, late-life ICE vehicle delivers an immediate emissions reduction comparable to the effect of introducing several additional low-emission vehicles into the fleet, because it removes a disproportionate share of emissions at once. Ignoring this **multiplier** inherent in stock–flow systems, risks structurally constraining the pace of fleet decarbonisation, regardless of how ambitious inflow targets may be.

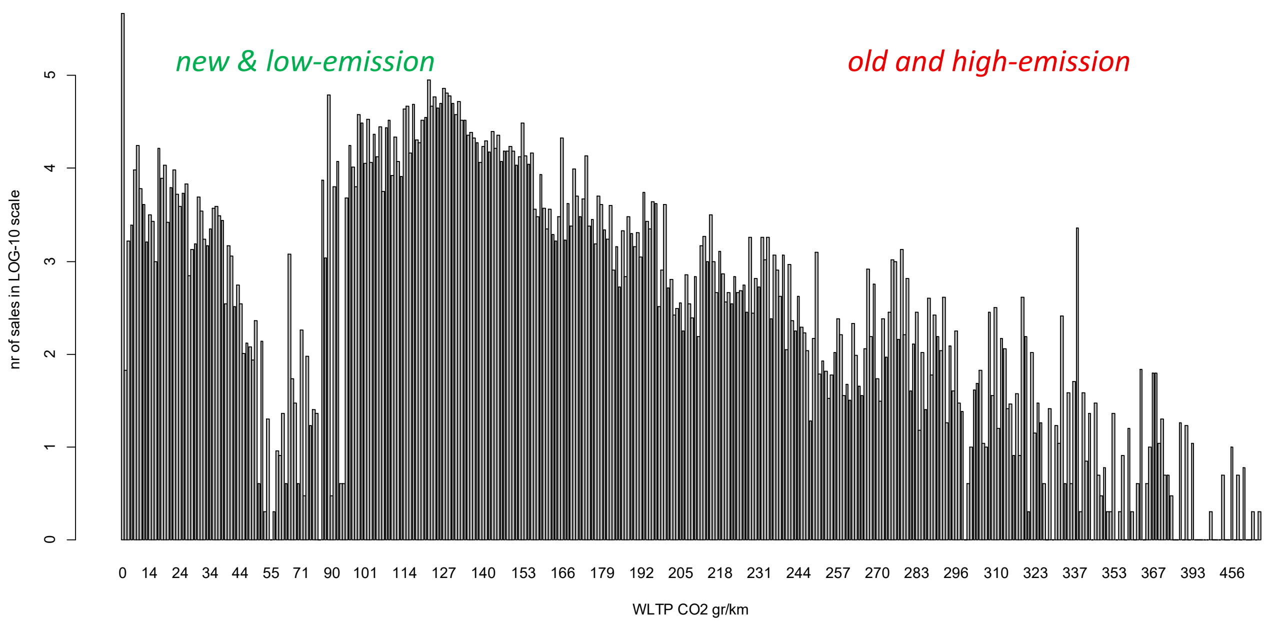

Figure 7: A stylized example of the distribution of the EU light duty vehicles fleet in terms of CO2 emission. A real histogram with age on one axis and CO_2/km on the other will reveal a very strong concentration of high emissions in the older, high-emission part of the stock. The largest environmental impact can be found in the tail of the age distribution. That distribution reveals immediately where intervention yields the highest return, if CO2 is the concern. Scrapping one 18-year-old ICE is equivalent to pushing in 3 or 4 extra low-emission vehicles in terms of immediate CO_2 reduction: this powerful multiplier effect is ignored.

Working on both, *including outflow* —e.g. through accelerated fleet turnover, scrappage incentives, and recycling or export pathways- is significantly more **effective** because (i) it directly shrinks the oldest part of the ICE stock, and (ii) generates replacement demand, which is then fulfilled by pull on newer cleaner vehicles (the feedback loop).

3.5 Transactions

Resales are largely invisible in the fleet equation, since these don't change the global stock. As such, **transaction flow accounting** reveals market dynamics *within* the stock, showing that resales are *central to the functioning and stability* of the vehicle market.

Consider the market activity by 'sale transactions' that create flow within. Let T = total transactions during period. We recognize the fact that there are two contributory sources, N = new sales during period, and R = nr of used resales during period. Then the tally of transactions in the period requires:

$$T = N + R$$

which gives in relative terms the **market penetration** fractions, as currently in the EU:

$$n_T = \frac{N}{T} \approx 25\%\,, \qquad r_T = \frac{R}{T} \approx 75\%$$

The **relationship between stock and sales** becomes clear when we simply contemplate that the rate of sales, say *turnover rate t*, actually moves vehicles through stock, because the base S_0 upon which a transaction rate operates, is the stock:

$$transactions\ T\ =\ physical\ stock\ S_0\ \times\ transaction\ rate\ velocity\ t$$

What this relationship tells, is far-reaching. Transactions in the vehicle market represent moments of potential renewal — each exchange of ownership creates an opportunity for technological upgrading within the fleet. A market characterized by **many** transactions facilitates these ownership transfers, enabling vehicles with newer technologies to circulate **more rapidly** among users.

A high number of transactions is thus highly desirable for EV adoption, as it creates more opportunities for fleet renewal, which according to above relationship can occur through two main channels:

- **Stock growth (increase S_0):** In mature economies such as the EU, the total vehicle stock continues to expand modestly each year as mobility demand increases. A larger stock naturally generates a higher absolute number of transactions. However, vehicle stock volumes are relatively stable and slow-moving, offering limited policy leverage in the short term. This is not the right lever.
- **Transaction rate growth (increase t):** Increasing the turnover rate t of existing stock provides a more dynamic lever.
    - This requires, first, maintaining a balanced and sufficiently strong **outflow (O)** — ensuring that older vehicles exit the system at a pace that allows new inflow (**N**) to enter.
    - Second, it depends on sustaining a healthy level of **used resales (R)**, which provide liquidity to current vehicle owners and lower the barriers to replacement.

In summary, **more *used transactions*** *R* move low-emission vehicles through ALL segments:

Increase used market resales → increase EV adoption

The additional fluidity not only sustains economic activity but also **accelerates** the diffusion of innovation: as more consumers gain access to advanced drivetrains through used transactions, awareness, trust, and network[4] effects grow. Secondary effects propagate broadly, as well as deeply, into the used market: vehicles reach more diverse owners, across geographic/demographic boundaries. **Resale transactions are not peripheral, but visceral to fleet transformation strategy.**

3.6 Resales

In this section, we will illustrate that resale transactions in the used market are not merely a by-product of market activity, but **a key enabler of technology diffusion**. Frequent resales increase likelihood of adopting new technologies, creates liquidity, and thereby **amplify** the social and economic diffusion of (PH)EV innovation through repeated reallocations of the existing stock. There are two main arguments.

First of all, in mature markets like EU, one observes that used sales outmatch new sales by a factor of 3 (flow ratio), because a used vehicle can be sold multiple times across its lifetime. On average in EU:

$$R \approx 3 \times N$$

Resales are far from irrelevant. On the contrary, used resales are dominating the flow in automotive market activity, having a **critical operational surface three times larger**, which implies any incentives benefit directly from that volume multiplier (amplification). The flow ratio shows that **new car incentives alone are insufficient** because they only influence a quarter of the total market activity.

In a tunnel vision of the new market, one looks at

$$Fleet\ transformation \propto (BEV\ share\ of\ new\ sales) \times (New\ sales\ volume)$$

Here, we point out that the used market is an integral part of the transition:

$$\begin{aligned} Fleet\ transformation &\propto (Total\ market\ transactions) \times (BEV\ share) \\ &\propto (New\ sales\ N + \boldsymbol{used\ sales\ R}) \times (BEV\ share) \end{aligned}$$

Under constant preferences, a marginal increase in resale activity (R) yields a multiple of the EV conversion opportunities obtained from the same marginal increase in new registrations (N), proportional to the resale-to-new flow ratio. In the EU, where used transactions outnumber new registrations by a factor of three to four, this creates **a systematic policy multiplier**. Yet policy attention remains disproportionately focused on the smaller new-vehicle flow, despite the used market being the dominant locus of turnover.

[4] Network Effect: While typically applied to products whose value increases with the number of users (like social media or a video game console), one can argue for the automotive sector that a large, active, and healthy secondary market adds value to the primary market (new product) by guaranteeing liquidity and a smooth exit strategy.

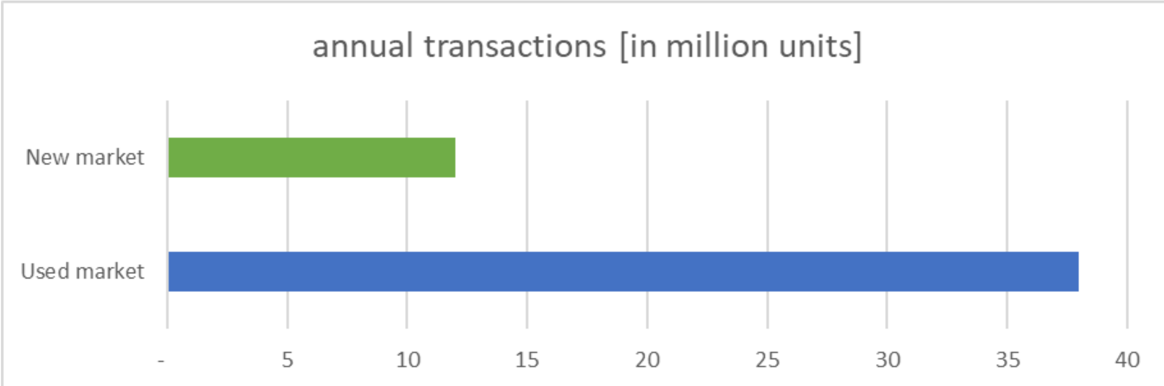

Figure 8: Three to four times more vehicles change hands in the used market than enter via new sales- annually. What resales really do is enable inflow by freeing ownership capacity. It is another underused lever to rebalance the transition in the system level perspective. One that shows that mobility of ownership is as important as technology choice.

Secondly, resales are opportunities: each time a vehicle changes owners, a decision moment arises—and the more of these moments, the greater the **potential for conversion**. The resale flow is therefore a chain of renewal forks, where the transition is repeatedly either reaffirmed or redirected.

Define the specific transaction rates relative to the whole vehicle stock S_0 at begin of the period, n as defined before, and

$$r = \frac{R}{S_0}\ (used\ resale\ rate),\ \ t = \frac{T}{S_0}\ (turnover\ rate)$$

These represent market **liquidities**: how actively the specific physical stock is being utilized or traded.

A higher used market liquidity implies faster turnover or greater churn, which means *better and more* transaction opportunities for substitution with new[5] EV, or used EV.

- Better, because it renders the new car purchase more attractive because the buyer knows they will get more money back when they sell it, as the rate is high and

- more, because it increases chance that the used car purchase will be EV. Liquidity maximizes the *number* of these decision points AND the *probability of conversion* at each point. In this sense, **market liquidity functions as an accelerator of transition speed.**

So, if policymakers care about electrified powertrains increasingly **substituting** combustion engines, a highly relevant quantity is the **used resale rate r.**

[5] A healthy used market paradoxically nurtures the new automotive market, an example of "demand externalities". This is sometimes used in academic literature to describe how the existence of a secondary market can, surprisingly, increase the demand for the new product, rather than cannibalize it, especially for durable goods.

The *reciprocal* of r measures how many periods *a used vehicle* on average cycles through the whole stock, i.e. time between change-of-ownership events, or average holding time[6]:

$$\tau_{used\ holding} = \frac{1}{r}$$

In policy analysis, **cycle time[7]** is particularly useful to compare among countries and all segments: a long cycle indicates structural inertia (e.g., slow fleet renewal), while a short cycle suggests rapid technological diffusion or high churn.

Short holding time in used market increases **market liquidity**—it can speed adoption if used market supplies EVs or if trade-in channels favor BEV replacement. A **lower turnover rate** means long holding times — diffusion slows even if new sales grow. Short vehicle holding time by owners increases **fleet renewal** directly, allowing new technology to replace old stock faster.

To give an idea of the order of magnitude, a publication of 2021 in European Transport Research Review[8] evidences that average vehicle lifespans (total time on road) range from 8.0–35.1 years across 31 European countries, with a mean of 18.1 years in Western Europe and 28.4 years in Eastern Europe. This reflects shorter initial holding (3–5 years for new/first owners, often via leasing) and longer subsequent ownership (5–10+ years for used vehicles in secondary markets), due to cross-border flows from West to East.

In summary, the **pace and liquidity of resales** determine the system's effective capacity for renewal: the more frequently vehicles change hands, the faster the overall fleet can absorb new technologies, *even if the inflow of new units remains constant*. Consequently, fostering transparent, low-friction secondary markets is not merely an economic objective, but a **structural enabler** of decarbonization.

Policies that improve used market liquidity directly **support** EV diffusion: for example,

- **Transferable warranties and battery certificates** reduce information asymmetry and resale risk.
- **Trusted digital resale platforms** shorten time-on-market and make BEVs more tradable.
- **Financial products** (availability of affordable financed mobility solutions (leasing and rental)) enhance perceived liquidity.
- **Transaction cost reduction** (e.g. waive sales tax on used purchases, facilitate trade-in programs, lessen registration fees for subsequent used BEV transfers) ease exit for current owners.
- **Support dealership** (e.g. tax credits for dealers turning over used BEVs, training subsidies) build dealer competence, reduce reluctance.

[6] On the level of a dealer, this metric is known as the Market Days Supply (MDS), the number of days it takes to sell the current inventory of used cars of a certain type (=stock) at the current daily sales rate (=outflow). Lower MDS means higher demand, as one cycles faster through stock.

[7] Flow rate is a churn (speed), which is quite abstract. Time periods are more cognitively natural for human decision-making, so for convenience we express the rate rather as a frequency (nr of cycles), as that emphasizes the duration (each cycle takes time) rather than velocity. Both views refert to the same ratio. "BEV churn rate increased from 0.2 to 0.3 transactions/vehicle/year" is equivalent to "Average BEV ownership duration decreased from 5 to 3.3 years".

[8] Held, M., Rosat, N., Georges, G. et al. Lifespans of passenger cars in Europe: empirical modelling of fleet turnover dynamics. Eur. Transp. Res. Rev. 13, 9 (2021) paper.

- **Facilitate cross-border vehicle flows** (e.g. remove migration barriers, harmonized data and export rules) beyond inflow and outflow, linking regional stock equilibria to equalize stock turnover.

Such instruments make EV ownership less of a long-term commitment, effectively shortening the issues with strongly prolonging[9] used holding time τ and therefore increasing willingness to purchase a new EV.

3.7 Conditionality

Stimulating the used-vehicle market does not imply using a one-size-fits-all approach. Each regional market has distinct structural characteristics—such as fleet age distribution, household income profiles, market liquidity, and the age composition of inflows and outflows—that require careful diagnosis before intervention.

Effective policy is to be designed as a multi-layered **targeted instrument**, calibrated to strengthen market functioning (liquidity, transparency, financing, trust) while **preserving the health of the new-vehicle inflow**, which is the essential channel through which technological innovation enters the fleet.

The used and new markets coexist in a **competitive but interdependent equilibrium**. Each used sale satisfies a portion of current mobility demand that might otherwise have been met by a new vehicle. Formally, if the share of used transactions in total vehicle transactions is r_T, the penetration rate of new vehicles can be expressed as its complement:

$$n_T = 1 - r_T$$

This highlights the **intrinsic coupling** between both markets: they **share the same pool of buyers**, constrained by overall mobility needs and affordability limits.

A **high resale share** (r_T) indicates that most vehicle demand is being met by the secondary market (demand substitution). When resale activity intensifies without a corresponding expansion in total transactions or stock, the effective demand for new vehicles tends to decline.

Over time, this creates a **negative feedback mechanism** for new-vehicle growth: a more vibrant used market, while desirable for liquidity and accessibility, can inadvertently dampen new inflows unless total mobility demand increases or vehicle lifetimes shorten. In such a scenario, resales do not generate net fleet renewal—they merely **recycle the existing stock more rapidly**.

[9] Gabriel Möring-Martínez, Murat Senzeybek, Samuel Hasselwander, Stephan Schmid, Quantifying the impact of fleet turnover on electric vehicle uptake in Europe, Transportation Research Part D: Transport and Environment, Volume 147, 2025.

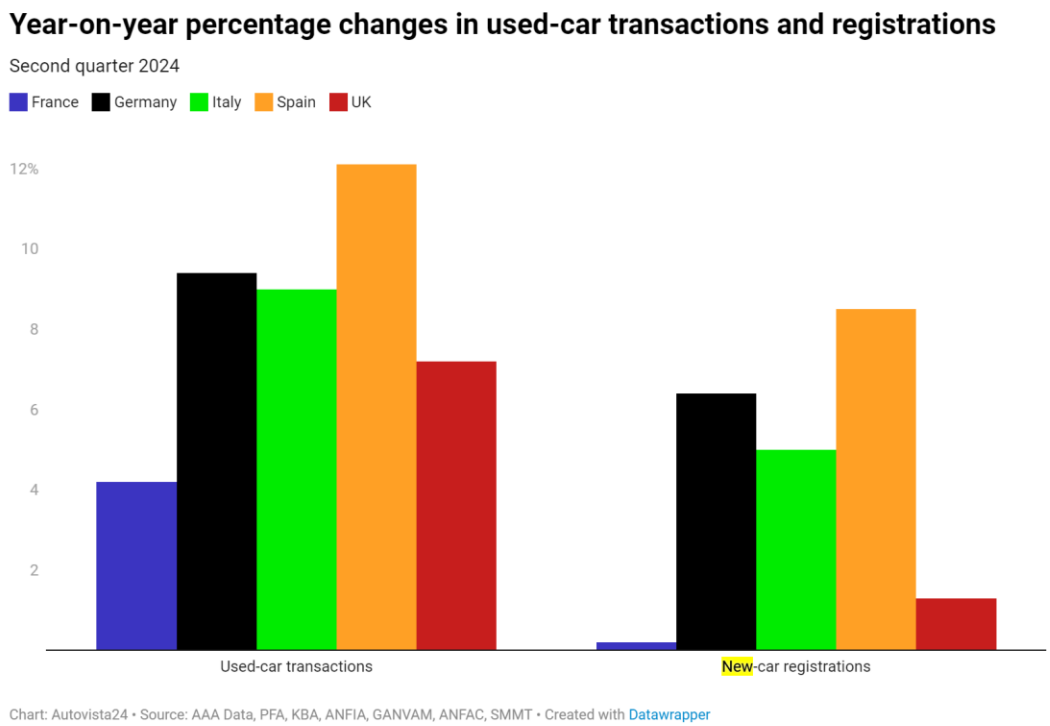

Figure 9: In each period, the demand for vehicles can be met either by new sales or by resales. However, since both address the same mobility need, they are in partial competition: every used vehicle resale satisfies a buyer who might otherwise have purchased a new vehicle.

Nevertheless, this substitution mechanism is **not fixed**. A well-functioning used market can also play a **complementary role** in technology diffusion when resale liquidity and confidence increase the **expected resale value of new electric vehicles**, thereby stimulating new purchases. This *demand externality*—where secondary-market strength enhances primary-market appeal—is particularly relevant for emerging technologies with uncertain residual values, such as BEVs.

From a policy design standpoint, used-EV incentives must therefore be handled with precision. Unconditional subsidies that directly lower used-EV purchase prices risk **cannibalising new-EV demand**, especially when applied to relatively young vehicles. Instead, **eligibility conditions** should be designed to:

- target **older vehicles** (e.g. ≥5 years old) or **low-income households** where new-EV purchase remains unattainable;
- differentiate by **battery degradation and age class** to avoid upward price distortion in the near-new segment;
- combine **used-EV incentives with scrappage or trade-in requirements**, ensuring that new inflows are indirectly stimulated rather than displaced.

In short, the used and new segments are two halves of a complex **renewal system**, not independent markets. Policies that recognise and manage this feedback—stimulating liquidity and accessibility in the used segment while safeguarding innovation inflow in the new segment—will achieve a more balanced and sustainable acceleration of the EV transition.

3.8 Policy implications

The stock–flow perspective on the vehicle market reveals that most regulatory and incentive tools deployed across Europe have focused on inflow stimulation through subsidies, tax incentives, or manufacturing mandates, which target only half of the system's renewal process. Because inflow and outflow are inherently coupled, policies that neglect the exit rate of older vehicles (outflow) face structural limits: the total fleet can only decarbonize as fast as vehicles are removed from circulation.

A more balanced strategy must therefore manage *both sides* of the equation:

- **Inflow policies** (purchase incentives, CO_2 standards, OEM compliance) introduce cleaner technology into the fleet.
- **Outflow policies** (scrappage programs, export regulation, or accelerated retirement incentives) create the physical and economic space for new low-emission vehicles to enter.

The above stock flow dynamics shows that the **outflow lever is the hidden accelerator** of fleet transition. Increasing vehicle turnover directly determines the system's responsiveness; without sufficient outflow, even a 100% share of BEVs in new sales cannot rapidly change the overall stock composition. Policymakers should thus integrate outflow management—through early decommissioning schemes, recycling credits, or targeted retirement incentives—into decarbonization frameworks. Especially during downturns it is a stabilizing measure for both markets, while simultaneously upping the decarbonization pace.

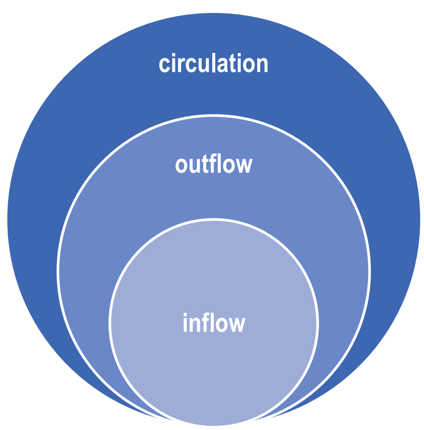

Figure 10: Managing inflow alone is insufficient for low-emission diffusion, outflow is a structurally different and far greater lever to influence adoption, while mass-market access is made possible by a healthy liquid circulation flow in the used market.

Equally critical is recognizing the **used vehicle market** as a major vector for technology diffusion. With a transaction volume roughly three times larger than the new market, the used segment offers a natural multiplier effect for policy impact. Measures that **increase resales** or 'market liquidity'—such as transferable battery warranties, standardized certification, digital resale platforms, and lower transaction costs—help shorten vehicle holding times and increase resale confidence. This liquidity enhances both affordability and the speed of BEV adoption across income segments and regions.

However, used-market support must be **conditional and well-calibrated** to avoid undermining the new-vehicle market. Since both segments share the same pool of buyers, strong used-EV incentives can cannibalize new sales if poorly designed. To avoid this, policy should **shift focus from sales shares to (used market) system metrics**, as to ensure coherence between inflow and outflow instruments to maintain systemic balance and long-term fleet decarbonization of the ***total*** fleet:

- Treat outflow as an active policy lever, not a passive outcome.
- Combine used-EV support with scrappage or trade-in requirements to maintain inflow.
- Leverage used-market liquidity as a cost-effective multiplier for BEV diffusion.
- Apply conditionality to align used-market support with innovation and fleet renewal objectives.
- Target older vehicles or lower-income households, not only new BEVs.

Ultimately, **new and used markets form an interdependent ecosystem**. Policymaking that views them as complementary—stimulating the accessibility, liquidity, and trust in the used segment while safeguarding innovation inflow—will yield the most sustainable acceleration of the EV transition.

3.9 Conclusion

At its most basic level, the used vehicle market is an accounting book of units moving from here to there over time. The **quantity relationship** between the new and used vehicle markets is best understood through the concept of **flux**—the dynamic flow of vehicles entering and exiting the circulating stock. The **supply of used vehicles** at any point in time is a **direct function of past new vehicle sales**, as vehicles transition from first to subsequent ownership stages. In this sense, the **new vehicle market feeds the used market** through the continuous outflow of maturing vehicles.

Conversely, the **used vehicle market sustains the vitality of the new market** by providing **liquidity and an exit channel** for existing owners. Without an efficient secondary market, potential buyers face higher resale uncertainty, which suppresses new vehicle demand. The **flux—defined as the rate of change in vehicle quantities over time—constitutes the bridge** that connects the two markets. This "**flux bridge**" encapsulates the intertemporal dependency between inflows and outflows, linking stock evolution to market stability.

The **balance between inflow and outflow** is therefore crucial for the health of both markets:

- **Inflow:** A robust new vehicle market today ensures a sufficient supply of used vehicles in the future. The **COVID-19 supply chain disruptions** vividly demonstrated how a contraction in new vehicle inflows can stimulate excess demand and price inflation in the used market.

- **Outflow:** Elevated disposal or scrappage rates reduce the total stock of durable vehicles, generating demand for replacement through both new and used channels. Conversely, **frictions in resale or disposal processes**—such as export barriers, regulatory uncertainty, or high transaction costs—can suppress turnover and dampen new vehicle demand.

These reciprocal flows form a **quantity-based feedback loop** that binds the two markets into a single **stock–flow system**.

Beyond its role in balancing volumes across ownership cycles, **circulation—the rate at which vehicles change hands—plays a decisive role in the diffusion of low-emission technologies**. Each resale transaction is not merely a transfer of ownership; it is a *new adoption opportunity*.

A high circulation rate enables BEVs and other low-emission technologies to cascade from early adopters to the mass market. As these vehicles progress through second and third ownership cycles, they reach consumers with more constrained budgets—precisely the segment where the largest remaining decarbonisation potential lies. In this sense, **circulation is the mechanism that transforms early-stage inflow into broad-based adoption**, allowing the benefits of technological innovation to diffuse across the entire fleet.

In sum, **circulation is not a secondary phenomenon but a central lever of fleet transition**. It determines how effectively the stock of low-emission vehicles permeates the fleet, how rapidly consumer segments adopt new technologies, and how strongly used-market dynamics reinforce new-market incentives. Recognising circulation as a core diffusion mechanism is therefore essential for designing policies that move beyond narrow inflow targets and engage with the full stock–flow system through which fleet decarbonisation actually unfolds.

4 Price dynamics

In a stock–flow dynamics framework, the steady-state vehicle stock converges to the level where inflows and outflows are balanced. They are emerging macro level quantities in the system. Outflows are primarily determined by technological and physical resilience, as well as replacement norms (used holding period), while inflows depend on demographic growth, income levels, and consumer preferences.

On the **macro-level** each unit stock and flow have an associated total value that in principle emerges from tracking the value of its individual vehicles. In practice, one relies on estimates of the average value of a new vehicle to arrive at the total value, for example:

$$V_{new} = N.\bar{P}_{new}$$

The mean new price is a *market equilibrium outcome* (aggregate), that is itself driven by many sale transactions on the new market, but also through resales on the used market. In this section we see how price connects the new and used inventory. It is the bridge by which they constantly influence each other and create stock equilibrium.

The equilibration mechanism, operates at the **micro level** through **price-mediated adjustments**: resale values (internal flows) and repair costs shape scrappage decisions, while purchase and replacement choices respond to vehicle prices, credit conditions, and income constraints.

Thus, the steady state[10] of the unit stock is defined by structural (demographic and technological) fundamentals but achieved through market **price** adjustments.

4.1 Elements of TCO

In this section, the concept of Total Cost of Ownership (TCO) is built up. Besides widely used, it is a fundamental metric, in which the link between new and used market is embedded.

4.1.1 Sticker price

The sticker price for a new vehicle is an administered anchor, set by producers based on long-term structural expectations. However, the *actual* transaction prices for both new and used vehicles are emergent properties of a dynamic equilibration process.

[10] In the short to medium term, exogenous shocks—such as fuel price spikes or abrupt policy changes—can displace the system from this equilibrium, and prices then govern the transitional dynamics as the market rebalances.

The new vehicle market

The ‘sticker’ is a **macro signal**: the Manufacturer's Suggested Retail Price (MSRP) is set by manufacturers based on their long-term expectations of the structural fundamentals (production costs, target demographics, brand positioning (preferences), and projected income levels.

Market adjustment is the **micro equilibration**: The actual transaction price is realized in aggregate through micro-level interactions. If the vehicle stock is below the desired steady-state (e.g., due to strong demographic growth or supply chain issues), demand outstrips supply. This leads to market adjustments **above** the sticker price. Conversely, if the stock is too high relative to demand, manufacturers and dealers use incentives, discounts, and rebates to effectively lower the transaction price **below** the sticker price, accelerating inflows to clear inventory. Credit conditions, like interest rates, moderate this.

The Used Vehicle Market

No Sticker, only equilibrium: The used market has no administered price. Its price is **purely emergent** and is the most direct visible output of the stock-flow equilibration process.

Price as the balancing variable: The used vehicle price is the key mechanism that rations the existing stock and signals the need for replacement. It is determined by the intersection of two flows:

- **The scrappage decision (outflow):** A vehicle's resale value (its price) is continuously weighed against rising repair costs. The used price *falls* until it triggers the scrappage decision for the marginal vehicle, regulating the outflows from the stock.
- **The replacement decision (inflow to the *Used* Stock):** For buyers, the price of a used car is weighed against the price of a new car (itself a market-adjusted sticker price). A high new car price pushes demand into the used market, bidding up used prices until the inflow of used vehicle purchases matches the outflow from scrappage and aging.

The link: how the two prices co-determine each other

The new car price and the used car market price are inextricably linked in a feedback loop.

- **From new to used:** The market-adjusted new car price sets the **ceiling** for used car prices. A significant discount off a new car's sticker price exerts downward pressure on late-model used cars.
- **From used to new:** Strong used car prices make consumers more willing to pay a higher effective price (closer to sticker) for a new car, as their **trade-in** is worth more. Weak used car prices have the opposite effect, forcing new car stickers to be discounted more heavily to attract buyers.

Thus, the sticker price is the **opening bid** in a negotiation, but the final market price (actual purchase price) is the system's solution to the fundamental stock-flow equilibrium defined by technology, demographics, and consumer norms.

4.1.2 Capex

A vehicle looses at every time period value, which is reflected in an ever decreasing price

$$P_0 > P_1 > P_2 > \ \dots$$

The depreciation is a **capital cost** of holding an asset during a period (capital expenditure or capex), a rate which is readily observable from the price difference over the period:

$$D = P_0 - P_1$$

When expressing depreciation rate D against the price at begin of period, we get a percentage:

$$d = \frac{D}{P_0} \approx 14\% \qquad (depreciation\, rate)$$

The complement of depreciation, the retention rate, operates on the previous price at every period, generating the current market value:

$$P_1 = P_0(1 - d)$$

This relationship describes exactly the well-known geometric depreciation curve (price, time) that is empirically observed. The depreciation curve shows that a vehicle loses the largest percentage of its value early in its life, with the rate of loss slowing down over time.

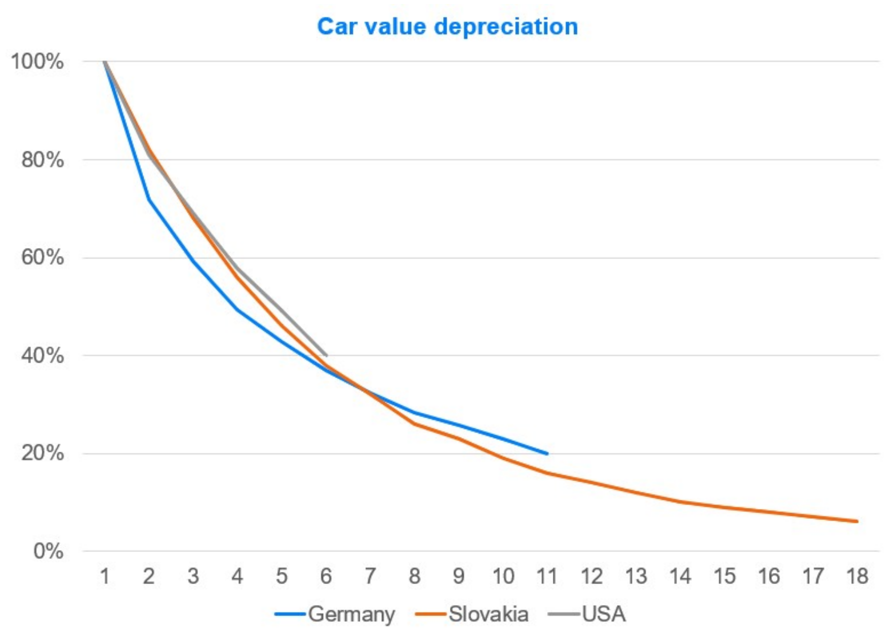

Figure 11: an example of vehicle depreciation in function of age. Also km is an important dimension.

New vehicle prices function as the ceiling (initial value), while used prices form a floor (residual value). The counterforce of depreciation operates period after period on the new car price, to lower it into a **"residual value"**, until it reaches the threshold of scrap value (value of sum of metal and other components). The relationship allows to project this price far into the future, which is why one says that the residual value is the *future expected resale price*.

CAPEX is the initial financial barrier to ownership. It is the core of the EV adoption challenge in the early days of electrification: a **high CAPEX** which can be offset over time by **lower OPEX**, a calculation that depends on the user's timeframe and access to incentives.

4.1.3 Opex

The **purchase price** of a vehicle represents only the initial outlay cost— the *ceiling* of its market value at the time of acquisition. **From that moment, the owner is faced with** continuous expenditure required to run it, keep the vehicle operational and compliant over its lifespan. Each vehicle component deteriorates with normal use, necessitating regular **maintenance and repair**, which together often amount to a total expenditure comparable to the initial purchase price over the vehicle's lifetime.

In addition to these mechanical costs, owners face further sources of depreciation and loss, including taxation, insurance, energy expenses, ease of resale, and exposure to regulatory or technological obsolescence.

The total of all types of operational costs can be lumped together in an amount, booked per period, to define a cost rate, that is itself a sum of diverse components:

$$\boldsymbol{C} = \boldsymbol{C_1} + \boldsymbol{C_2} + \dots$$

After the warranty period, the cumulative curve of cost C keeps quite linearly increasing.

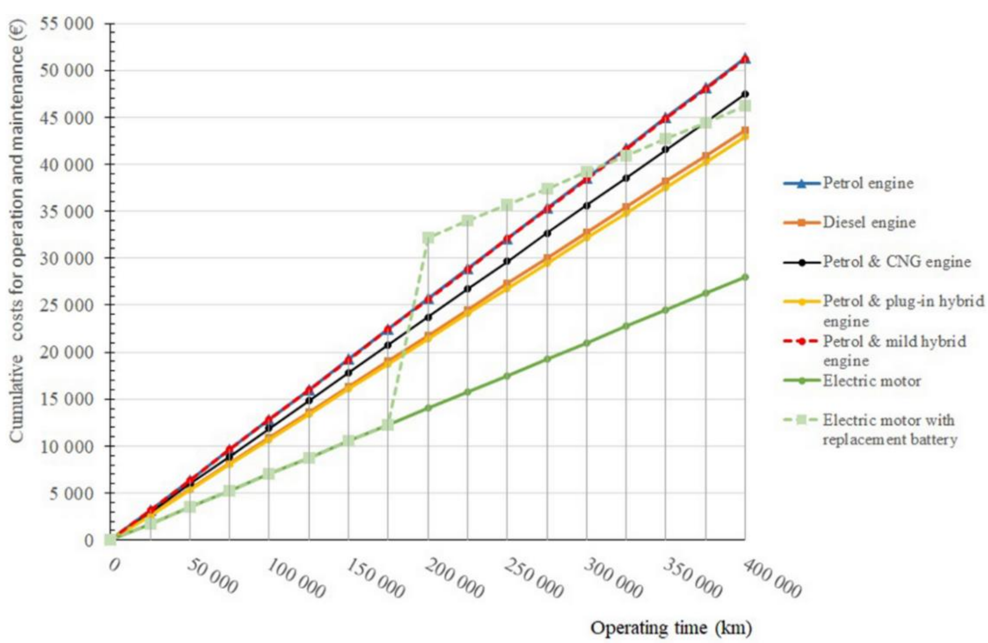

Figure 12: An example of the cumulative costs in function of powertrain choice. Credit of the plot to Furch, J., Konečný, V. & Krobot, Z. Modelling of life cycle cost of conventional and alternative vehicles. Sci Rep 12, 10661 (2022).

OPEX is the true cost of ownership after you drive the car off the lot. Understanding it is key to calculating the real affordability of a vehicle, where EVs often have a significant advantage over time despite a potentially higher sticker price.

4.1.4 TCO concept

When considering all costs, capex and opex, together in each period, one obtains the rate of **total cost of ownership**:

$$TCO = D + C = (P_0 - P_1) + C$$

TCO is a factual, but also dynamic variable. For example, fluctuations in raw material prices and labor costs can affect the vehicle's new retail price, while changes in the used car market can impact resale or “residual” value (RV).

Any vehicle operator, be it a consumer or a business, considers the cost of acquiring, operating and eventually disposing his vehicle. TCO is the most common decision metric: a rational agent wishes to minimize it. The vehicle with low TCO is preferred.

If you **compute Total Cost of Ownership (TCO) as a function of vehicle age** (e.g. per month or per year), you don’t get a simple straight line — you get a **U-shaped or bathtub-like curve.**

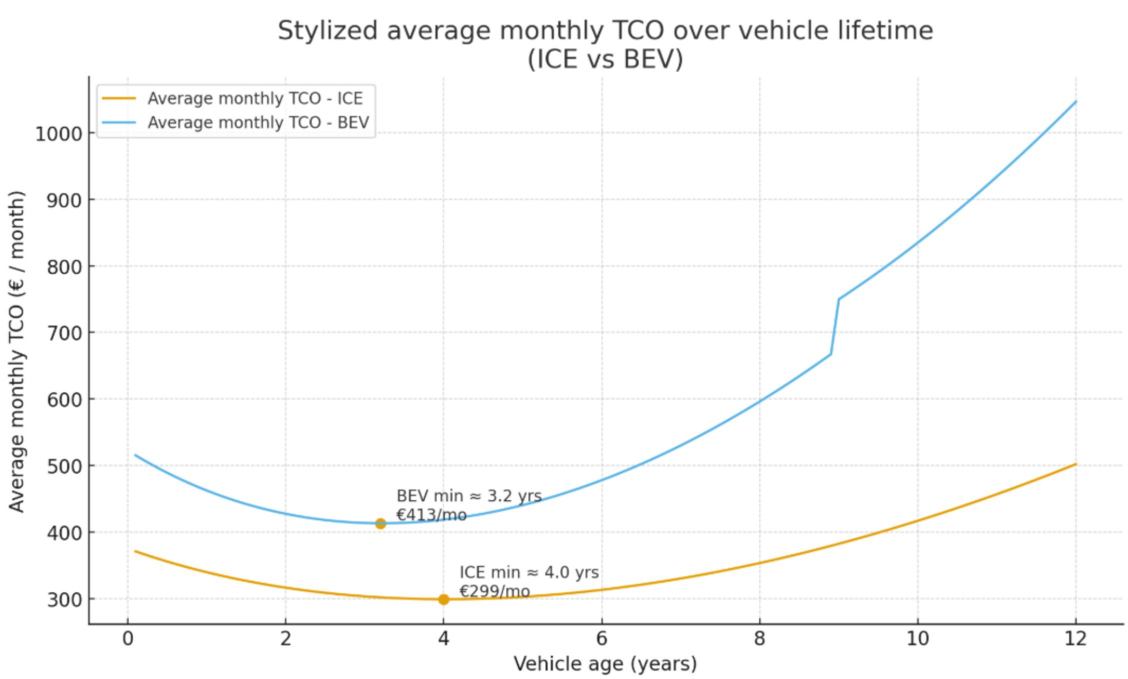

Figure 13: TCO levels – lower is better. For example, one can plot the typical TCO rate over time for EV vs ICE of similar specs, but with the EV premium price difference. One can notice that the price difference remains persistent, and the observed steeper depreciation rate of EV suggests a shorter optimal point for holding period.

The TCO U-shaped curve is a result of depreciation and opex, with two regimes, split around the 4 year mark:

- The cost of newness and warranty is the **economic premium** paid by the first owner, which manifests as the first **steepest part of the depreciation curve.** Around year 4, the car becomes the most liquid asset in the used market resales flow.

- The 5-year period turn out to be the minimum time required for the Annualized Depreciation Cost to become roughly comparable to the Annualized Running Cost. This connects to the **holding times** of new vehicles.

Instead of per period, one can of course also fix a desired holding horizon and annualize an average expected TCO rate. Or in a more financial way: summing TCO rate over h periods, and adding the **time value of money** (via discounting rate r), allows to arrive at the Net Present Value (NPV), useful for comparison purposes:

$$TCO_h = P_0 + \sum_{k=0}^{h} \frac{C_i}{(1-r)^t} - \frac{P_h}{(1-r)^h}$$

The list price of the vehicle, market dynamics in the used car market, market liquidity and monetary funding rates all play a role. The higher the expected residual value, the lower TCO, thus the higher willingness-to-pay becomes for a retail consumer at purchase (against higher trade-in), or the lower the rent lessors can charge for a leasing.

If you use **TCO as the decision metric** on a specific vehicle, EV adoption will increase if the drive train has the lower TCO:

$$TCO_{EV} < TCO_{ICE}$$

The percentage change in total cost of ownership (TCO) resulting from a 1% change in any cost component is approximately proportional to that component's share in total TCO. This implies that, structurally, TCO is most sensitive to changes in following ranking order:

- 90% Purchase price
- -50% resale price
- 30% energy cost
- 10% Repair and Maintenance
- 10% insurance
- 10% taxes

However, it says "where TCO is *most sensitive* to change," not "where policy is *most effective*." That's an important distinction one can formalize as:

$$Elasticity\ ranking \neq Policy\ leverage\ ranking.$$

The first is mechanical (based on TCO composition); the second is behavioral and temporal. The next sections will deal in more detail with the consequences of this insight.

The Total Cost of Ownership (TCO) provides an objective breakdown of vehicle expenses into capital (capex) and operating (opex) components. It is a forward-looking model of vehicle economics: future expectations determine today's purchase decisions between electric and non-electric powertrains.

TCO also represents the deep ***economic link*** between the new and used-vehicle markets. Buyers form **expectations** about future resale value, which directly influence the perceived cost of ownership. When expected used-car prices decline, the present value of resale decreases, effective TCO rises, and willingness-to-pay for new vehicles falls. Dealers then face lower demand and must adjust new-car prices downward to restore market equilibrium.

This **feedback loop** between the used and new markets is **central to fleet decarbonization policy making**. Stable and credible resale values for low-emission vehicles are therefore essential to sustain both consumer confidence and manufacturer incentives for electrification.

4.1.5 TCO discounting

Income moderates price perception. However, TCO also is altered by perception, as it is abstract and the arithmetic is universal ("same formula for everyone").

The **Total Cost of Ownership (TCO)** represents indeed an *objective*, context-dependent monetary measure of vehicle ownership and operation. As such, the TCO belongs to the **vehicle in a given environment**, since these costs are determined by technological characteristics, market conditions, and regulatory context — not by who owns or operates the vehicle.

However, **decision-making** regarding vehicle choice is not based purely on the objective TCO. The relevance and interpretation of each TCO component (e.g., upfront cost vs. running cost) vary substantially across buyer segments, reflecting differences in financial constraints, risk preferences, operational horizons, and accounting conventions.

One such major differentiator is the **Buyer-Type segmentation**, which one may stylize in two groups:

- **Professional customers**
    - **Business fleets** evaluate vehicles under *operational efficiency* and *cash-flow optimization*. They account for depreciation, fuel, and maintenance costs with a lower discount rate and often recover VAT and incentives. For them, TCO is a *strategic management variable* that directly enters procurement criteria.
    - **Leasing companies and lessors** take a more comprehensive *financial view* of TCO. They treat vehicles as assets, around which a mobility service package is created, prioritizing functionality, residual value, maintenance predictability, and secondary market risk. Their weighting emphasizes *residual uncertainty* and *lifecycle cost predictability (!)* rather than direct cost minimization.
- **Retail consumers** typically underestimate their *liquidity constraints*. They emphasize purchase price and immediate operating costs, while heavily underestimating long-term factors such as

depreciation or maintenance. Their TCO perception is thus *myopic*, sensitive to loan maturity and size of down payment, biased toward visible or salient expenditures or non-monetary attributes (range, charging time, brand).

For example, Dumortier[11] et al. find that fleet buyers' discount rate r ≈ 4%, while private buyers behave as if r ≈ 20%. The difference in the discounting parameter r is called a **risk premium** ε, which can be a positive or a negative add-on**:**

$$actual\ \frac{1}{1+r} \quad \rightarrow \quad perceived\ \frac{1}{1+(r+\boldsymbol{\varepsilon})}$$

And this premium manifests itself independently of any other variable in the TCO calculation. It is not anchored in cost, efficiency, or measurable performance attributes, but in subjective value, perception, and affective response.

As a result, it can **necessitate a fundamental adjustment of the entire decision function**: even when BEVs exhibit superior or comparable TCO, consumers may still prefer an ICE vehicle because the experiential or symbolic premium attached to it dominates economic rationality. Conversely, a strong positive premium can pull consumers toward BEVs even before TCO parity is reached. In both cases, the presence of this non-monetary premium can shift group preferences—and therefore aggregate market behaviour—**toward drivetrain choices that diverge from policymakers' expectations based solely on price or cost-based models**.

The degree of variance in assigning weights to TCO components has been analysed in a variety of studies, where for private individuals the following typically holds:

- Purchase price has an oversized impact, since it is immediately felt
- Costs are having a low weight of 10%–20% instead of 30%, thus people heavily underestimate fuel/electricity costs[12] Vehicle buyers (as opposed to lessees) **undervalue** lifetime fuel cost savings: they assume to only pay ≈ $0.29 today for every $1 of lifetime fuel cost savings[13]**.**
- Resale value is far away and uncertain, so people underestimate it strongly.

[11] Dumortier, J., Siddiki, S., Carley, S., Cisney, J., Krause, R.M., Lane, B.W., Rupp, J.A., Graham, J.D., 2015. Effects of providing total cost of ownership information on consumers' intent to purchase a hybrid or plug-in electric vehicle. Transp. Res. Part A 72, 71–86

[12] Ankney, Kevin & Leard, Benjamin, 2021. "How Much Do Consumers Value Fuel Cost Savings? Evidence from Passenger Vehicle Leasing," RFF Working Paper Series 21-27, Resources for the Future. The paper finds that vehicle buyers (as opposed to lessees) undervalue lifetime fuel cost savings: they only pay circa $0.29 today for every $1 of lifetime fuel cost savings.

[13] In the NHTSA/Cafe regulatory analysis they observe that: to equate vehicle price increases with discounted future fuel cost savings, discount rates above circa 24% would need to be assumed if consumers fully valued fuel savings.

Corporate priorities differ fundamentally:

Factor	Corporate	Private Used
Primary goal	Compliance/ESG	Affordability
TCO horizon	3-5 years	8-12 years
Risk tolerance	High (portfolio)	Low (single asset)
Infrastructure	Controlled	Variable
Uncertainty	Low	High
Charging cost	$0.02/kWh	$0.08-0.40/kWh
Negotiation power	High	None
Information	Expert	Amateur

Figure 14:TCO is a powerful lens to understand the buying behavior of automotive stakeholders, and effects of policies on TCO components and the difference between segments, are key to understand how to facilitate the transition.

TCO is an 'invisible' market force. Even if buyers don't consciously calculate TCO, the market behaves *as if they do*. Sellers competing for business are forced to offer attractive TCO packages, which often means competing on factors beyond just price (e.g., reliability, efficiency).

It is predominantly consumer decisions that are shaped by a **weighted TCO**, reflecting not only the objective cost components but also **context-dependent perceptions** of those costs. Variables such as **annual mileage, income, tax treatment, infrastructure access, and vehicle segment** can substantially **alter the relative importance of each TCO component**. Or alternatively, all of the gaps together form a giant Risk Premium in the perception of BEV buyers - in finance, one says the customer considers "the option value of waiting", and the Risk-adjusted price becomes effectively higher.

The bottom line is that the **same TCO calculation can lead to different decisions** because customers discount its components differently. This insight brings about a whole set of dynamics and policy implications.

4.2 TCO Segment dynamics

TCO may be individual, yet it **clusters** around similar values *within certain segments*. It this section we will see how crucial the fact that TCO does not mean the same thing across market segments, is for understanding adoption dynamics. The Total Cost of Ownership functions as a *gate* — **a hurdle** each buyer segment must clear before purchase becomes viable.

However, the characteristics of that gate differ sharply depending on **who** the buyer is and **where** it is evaluated. The transition must address the below working fields coherently, respecting market structure and buyer heterogeneity. We make three main observations on the TCO dynamics concerning the who and where.

4.2.1 Within New market

The new-vehicle market is composed of two very different buyer logics — **professional** versus **retail** — each operating under a distinct TCO gate.

- **Professional buyers (fleets, companies, lessors).** Their TCO gate is **lower** because they operate at high utilization rates, their customers can recover VAT, and evaluate vehicles on discounted lifecycle costs. They can rationalize a higher upfront price if running costs are lower and resale value predictable. *For them, BEVs can already pass the TCO gate under operational efficiency logic, provided the vehicle meets customers' demand as well.* Of course, ESG reporting, sustainability targets, brand image ("green fleet"), are emotional effects that can also play for companies, but economic calculus prevails.
- **Retail buyers (private individuals).** Their TCO gate is **much higher** because of liquidity constraints, short planning horizons, and a focus on visible costs. They rarely discount future savings strongly enough to offset the high upfront price of a BEV. Only the **top tier of new retail buyers** — those motivated by technology, status, or warranty benefits — participate meaningfully in the new BEV market. They are *least* TCO-sensitive and act more on non-monetary motivations.

It is key to realize that new-car buyers and **used-car buyers** are not just different income groups, but represent *structurally distinct populations* with **different demographics, psychographics, and decision criteria** — which ultimately strongly affects EV diffusion [e.g. Bigler and Radulescu, who find that in analysis[14] of new registrations in Switzerland, demand for EVs is positively related to income].

Fundamental economic analyses of the **Total Cost of Ownership (TCO)** consistently demonstrate that, under normal market conditions, the TCO of an Electric Vehicle (EV) is *structurally* lower for corporate and fleet buyers than for private retail buyers. This is expressed as:

$$TCO_{EV,company} < TCO_{EV,\ private}$$

This relationship is currently the baseline. The lower TCO for professional buyers is the primary driver for their typically higher EV uptake rates, as fleets can recover VAT, have predictable routes, benefit from superior financing (leasing and rental), have higher utilization rate (more fuel savings per km) and fully realize discounted lifecycle operational savings (e.g., lower energy and maintenance costs). Consequently, the expected adoption rate follows -***under normal market conditions***- the principle of economic rationality:

$$\%EV_{private} < \%EV_{company}$$

[14] Bigler P, Radulescu D (2022) Environmental, Redistributive and Revenue Effects of Policies Promoting Fuel Efficient and Electric Vehicles. *CESifo Working Paper No. 9645*

This is considered to be the *normal* market share order. It is not easy to quantify what is the typical percent point difference that one can expect. According to rough back-of the envelope calcs[15], a 30%-50% TCO difference creates a structural fleet adoption uplift of 4-6 percentage points at today's low market shares. Without incentives, we estimate an inherent baseline BEV adoption rate of about 5% is reasonable, such that one plausibly can take the assumption that companies exceed that level with a significant amount, say:

$$5\% \approx \%EV_{private} < \%EV_{company} \approx 9\%$$

The great diversity in packages of incentives and policy making across EU Member States, often driven by short term initiatives and lacking in long-term consistency, significantly impacts and **alters this *natural* TCO balance**, increasing market share segments often by a factor 3 to 4.

Abrupt subsidy cuts, one-sided unique corporate tax benefits, or strong private consumer grants, produce at times wild swings, with paradoxical EV adoption rates across the EU member states, resulting **in two extreme market situations** observed in the data.

1. **TCO Logic Amplified (**$\%EV_{private} \ll \%EV_{company}$)

Using their role as a facilitator of the uptake of affordable and cleaner mobility service providers, the leased and rented fleets achieved towards end 2024 overall in EU a circa 17% BEV penetration rate for PV, and 10% for LCV. That is a level achieved under periods of subsidies that influenced their TCO calculus, so we can assume this is a demand level on the high side of the spectrum.

The UK data strongly deviates in the professional segment: it shows 23% corporate (vs. a fairly normal 8% new Retail) uptake, which is a **clear confirmation** of the TCO gate principle, but also an exaggeratedly strong gap:

- **Corporate Buyers (23%):** This high rate is driven by extremely favorable TCO benefits, most notably the **Benefit-in-Kind (BiK) tax rate** for company cars in the UK. This policy drastically lowers the cost of ownership for employees and companies, pushing BEVs to become the cheapest option on a TCO basis for fleets, easily passing the "TCO gate."
- **Retail Buyers (8%):** This low rate reflects the struggle of the traditional private buyer, who focuses on the high initial **upfront price** and does not benefit from the same steep corporate tax advantages, thus facing the "much higher TCO gate."

The UK market, due to its specific tax structure favouring fleets, is the textbook example of the TCO-driven schism between professional and private buyers. Belgium (delta of 20%pp), an outlier due to its company car regime, joins this **corporate-demand-led group**, together with Austria (10%pp). This demonstrates that automotive policy is a very powerful force: if it targets demand of a particular group, it really strongly shifts its TCO, and influences adoption rates in a significant way.

[15] Assuming that professional are 3-4 times more sensitive to TCO difference, a logit response ratio is of order 1.80, which corresponds to almost double (at small market shares). This is close to the observed ratio of 1.64 in the Leaseurope Annual Market Report 2024.

2. **TCO Logic inverted ($\%EV_{private} \gg \%EV_{company}$)**

In 2023, Germany had a corporate BEV uptake rate that was 10%pp *lower* than private registrations, which was primarily caused by:

- **Corporate Collapse**: Germany abruptly ended the subsidy for corporate BEV registrations in August 2023. This immediately removed the major TCO advantage for fleets, leading to a 'demand cliff'. This decision coincided with manufacturers strategically prioritizing inventory for other markets (like the UK) where incentives were stable or better, causing a sudden drought in corporate registrations.

- **Private Resilience** (temporary): The subsidy for private BEV customers remained in place until December 2023 (when it was also abruptly cut). This created a "**pull-forward effect**" where private buyers rushed to register vehicles between August and December to secure the last of the grants, leading to a temporary surge and a higher recorded uptake rate than the corporate sector.

Germany's unusual market pattern was the result of abrupt and unbalanced policy adjustments: incentives for TCO-rational corporate buyers were withdrawn earlier than those for the less TCO-sensitive private buyers, temporarily inverting the expected relationship between both segments. By 2025, however, German figures already indicated a re-alignment toward more equal BEV shares across buyer types.

France (≈10%pp difference) and Denmark (≈27% pp difference) also belonged to this **private-demand-led group** of countries where private new demand temporarily led BEV uptake in 2023—largely due to substantial, sometimes near-total, tax exemptions for *private* BEV purchases.

Some industry stakeholders (e.g., 2023 T&E article) seized this short-term divergence to criticize corporate fleets and OEMs for "failing to lead" the transition despite benefiting from favourable fiscal treatment. Yet, a closer examination shows how overlooking the timing and design of national incentive schemes can lead to misplaced accusations at the address of companies and OEM, and even justify single-focus BEV mandates. Market figures must always be interpreted within the policy context that shapes them, and any *policy design that omits context, is destined to fail*. The strong TCO reversal and amplifying effects of various policies in member states demonstrate the great power of market intervention for the good, but it can also lead to bad with the same force.

TCO is a powerful lens for understanding EV adoption in the new-car segment. It reveals that current market dynamics are structurally driven by professional users and high-income private buyers, rather than by mass-market households.

4.2.2 Within Used market

The TCO gate in the used market is much higher, which is evidenced by an enormous drop in the used EV adoption rate. According to a Mckinsey report, the consensus figure is around 2% of all used vehicle transactions for the EU bloc. This stands in stark contrast to the **25% share in the new-car market**, revealing roughly a **twelvefold difference in EV adoption rate** between the two markets.

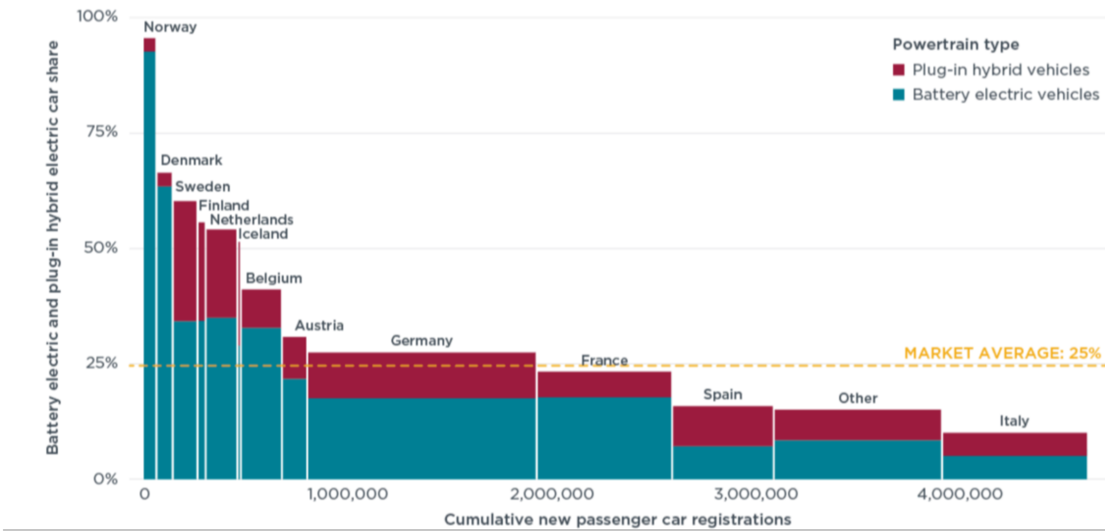

Figure 15: Total new car registrations and share of BEV and PHEV cars by country, January to May 2025. Media report abundantly on the new registrations share of low-emission, but the second-hand market adoption is underreported. Credit to the ICCT.

Of course, there is disparity between Member States. For example, in Spain, 2024 data from the **National Association of Vehicle Sellers (GANVAM)** show that electric cars represent **0.9%** of all used vehicle transactions, while plug-in hybrids are representing 1.5% of total sales in the second-hand market. In the UK in 2025, autovista reports that BEV have a record 3.3% share of all used-car transactions, HEVs 5%, while PHEVs 1.2%. In France, EV share of used transactions counts 3% in 2025, where it was 10% in 2024.

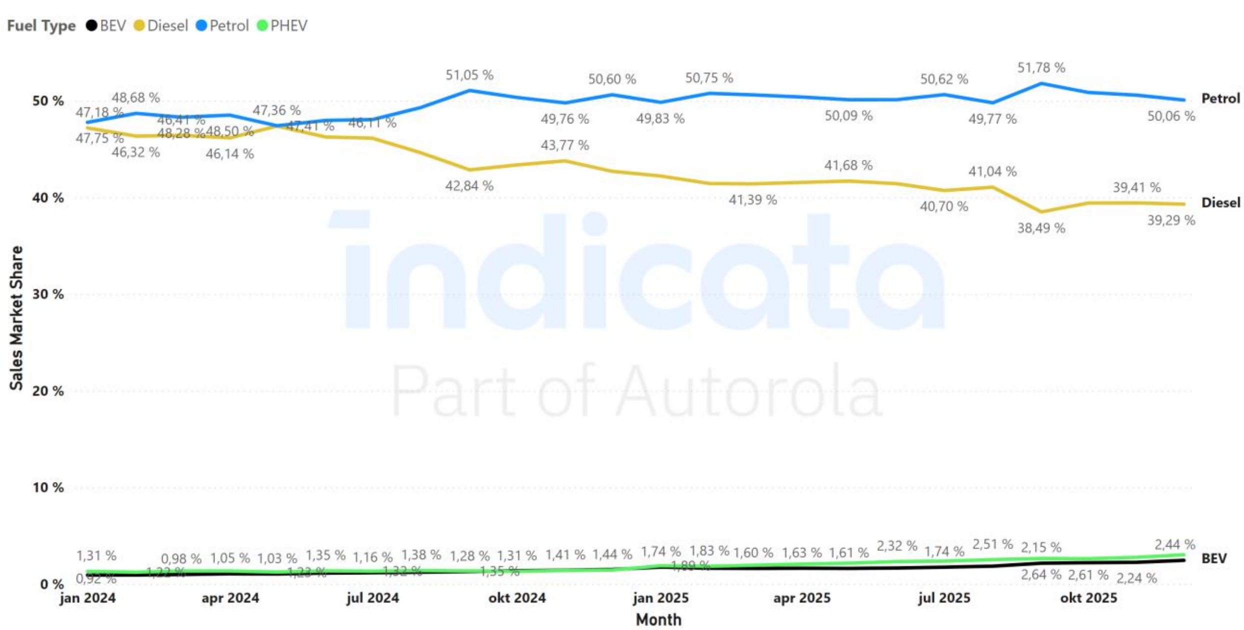

Figure 16: In the older segment +5years overall in Europe, the shares of EV transactions are very low. Credit of data sourcing to Andrew Shields from Indicata.

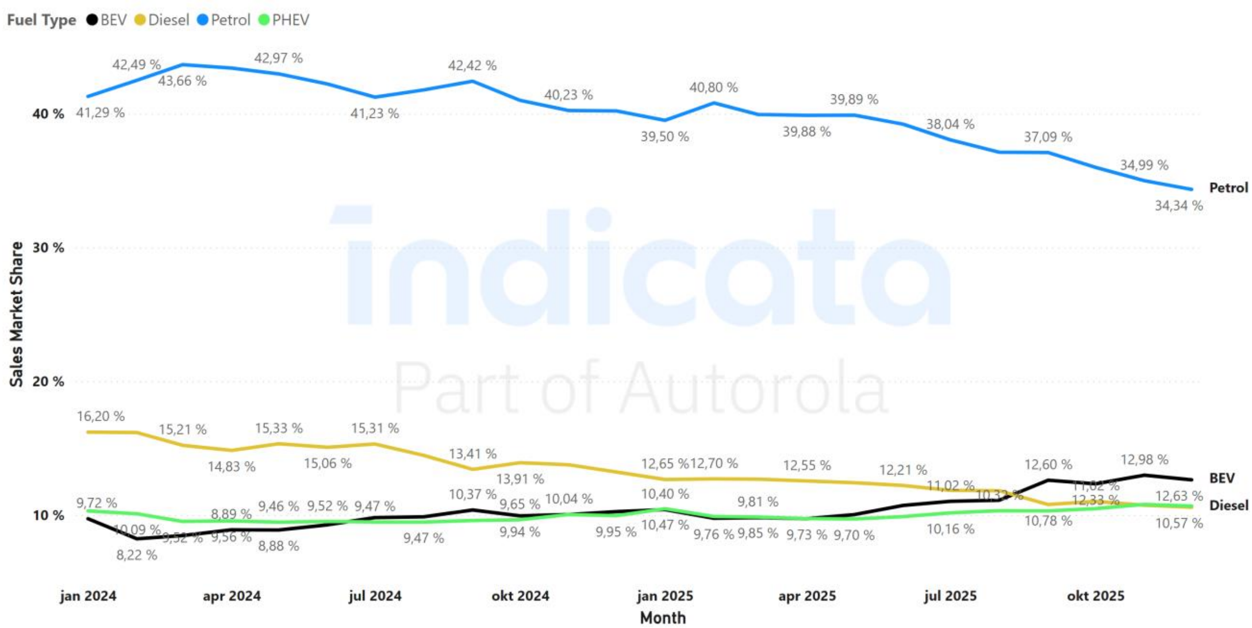

Figure 17: In the younger PV segment below 2 years, the inflow -thanks to subsidies- is creating an effect. Diesel is deprioritized in the PV segment, while diesel remains the dominant powertrain for LCV. Credit of data sourcing to Andrew Shields from Indicata.

The mechanism behind the low adoption rates is explained by the different TCO evaluation. In the *used* market, the TCO gap between professional and retail buyers largely disappears.

Both groups are **budget-constrained** and highly price-sensitive. Utilization rates converge: a used car is typically a secondary vehicle or for short-range use, regardless of ownership type.

- Professional used vehicle buyers (e.g., small businesses) now have **similar affordability barriers** as retail customers, customers as they have a significantly reduced set of mobility service provider options, thus having to address residual value risks directly. The logical difference remains, but Professionals undergo **a compression of TCO differentials towards the private used vehicle buyers population,** due to structural factors.

- The private mass segment purchase decisions are driven primarily by *visible price and perceived reliability, leading to an* **inflated effective TCO**, as compared to their affluent counterparts in the new market that have a deflated effective TCO.

As a result, the **TCO gates become aligned** — both professional and private used buyers face similar economic realities.

The **used-EV market** gets **a fraction of the policy and research attention** compared to the new-car market. Yet the **used market is three times larger** in annual sales volume. When this is combined with the **twelvefold lower EV adoption rate**, the effective **policy leverage gap reaches a factor of thirty-six**—a *multiplier effect* that remains largely **unexploited by current decarbonization strategies**. This imbalance risks slowing the overall transition, as second-hand demand ultimately determines fleet decarbonization at scale.

4.2.3 Between new & used market

A third and often overlooked TCO gap lies in the *numerical dominance and behavioral divergence* of used-vehicle buyers. While around **40% of new cars** in the EU are purchased by private individuals, the **used market is composed of roughly 83% private buyers**. This asymmetry means that vehicles move from a professionally driven new market to a predominantly private second-hand market.

For a young technology such as BEVs—characterized by higher upfront prices, limited model variety, and concentration in premium segments—the gap between first-owner and second-owner profiles is wider than for incumbent ICE vehicles. Consequently, their **TCO logic differs structurally**:

- **New-market buyers** (corporate fleets, leasing companies, high-income households) apply an **objective, discounted, full-lifecycle TCO perspective**, evaluating vehicles as assets with predictable depreciation and fiscal optimization.
- **Used-market buyers**, in contrast, operate with a **subjective, short-horizon, liquidity-based TCO logic**, focusing on affordability, visible running costs, and immediate usability rather than lifecycle economics.

Used/private buyers differ strongly in their sensitivity to the range limitations, charging inconvenience, or residual battery risks, that were relatively more acceptable for the new/professional first buyers.

The *effective* market overlap is simply too narrow, in term of specs wanted by buyer profile. This misalignment has direct market consequences. Corporate and leasing fleets tend to purchase **high-spec BEV models**, which later enter the second-hand market at prices far above the reach of typical private buyers. As a result, vehicles bought under **professionals' economic logic** are resold into a market where buyers **evaluate them under entirely different financial and behavioural criteria**—a structural bottleneck for mass adoption.

4.2.4 Greening of corporate fleets initiative

In July 2025 the Commission launched a Call for Evidence with an indicated Q4 2025 target date for a Proposal for a Regulation. As policy options under review for said initiative, the Commission lists this "will include the setting of national targets, rules on financial incentives for corporate vehicles, and targets for specific entities."

In practice this proposal is likely to result in forcing corporate entities to acquire x percentage of their fleets to be BEV only, with a year-on-year increase of that percentage moving towards 2030. The Commission has indicated that the thresholds should be more ambitious than the CO2 Reg. This principle is generally referred to as a '**BEV mandate'**.

Considering this purely on a TCO basis - without consideration of the new market's dynamics with the used one- the idea of corporate and leasing mandates is with good intentions, as **targeting fleets and lessors *seems* efficient:**

- Corporate fleets and leasing companies buy in bulk, have longer planning horizons, lower discount rates, and manage vehicles professionally. It is also easy to target the big 5 OEM or big 7 lessors on the new market, than to embroil oneself into the complexities of the used market policy design.
- The professionals indeed account very rationally for **full TCO**, not just upfront price, and can capture **fuel and maintenance savings** that make BEVs economically viable **earlier** than for households.
- Mandating BEV quotas for these segments thus *accelerates inflow* of electric vehicles into the market stock, and after 3–5 years, these vehicles enter the **used market**, expanding BEV access to cost-sensitive private buyers.

But through the lens of TCO new/used dynamics, the **downside** is a distorted stock–flow equilibrium (a transient state) for the BEV subpopulation.

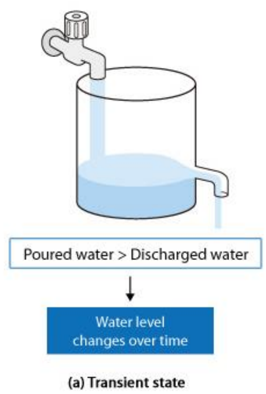

Figure 18: Although the total stock is in a steady state, the low-emission (sub)stock is in strong positive transient state. There is an inherent outflow or absorption constraint: imposed inflow exceeds matching capacity of the used market. This is not classical overproduction. It is temporal misalignment between fast upstream and slow downstream adoption. BEVs enter the stock faster than they can cycle through ownership states. The key metric to improve is resales rate in the used market (foster liquidity).

If policymakers impose strict BEV adoption mandates on corporates and lessors without ensuring downstream used market health, they risk:

1. **Fleet Composition Distortion**
   Mandates push fleets to adopt BEVs even when the operational or regional use case (e.g., long-distance, degree of utilization, pricing) is suboptimal.
2. **Residual Value Compression**
   Reports over all EU countries (e.g., Indicata 2025, Berryls 2025) show that **BEV residual values have underperformed** relative to ICE vehicles, particularly in early years of policy enforcement. Oversupply of de-fleeted BEVs depresses used prices.
3. **New EV's become more expensive**
   Lower residuals mean higher realized depreciation for fleets and lessors, TCO rises and they increase lease prices or reduce BEV procurement later. This weakens the financial TCO case for BEVs, despite lower opex of EV.

Mandates widen the TCO gate gap between professional and retail new buyers, further polarizing the market. The new market becomes increasingly dominated by high-spec corporate BEVs and premium private buyers, creating an artificially narrow demand base. When these vehicles flow into the used market, they don't match the needs or means of the average used-buyer population.

The used BEV stock enters a market with weak demand elasticity. It **creates supply without an obvious demand for it.** Already there is ample evidence to support that the second hand markets are facing an oversupply of BEV vehicles, not undersupply.

It accelerates inflow, but without strengthening downstream absorptive capacity. It aggravates depreciation, which acts as a highly negative multiplier on both used and new market. The necessity of enabling conditions in the used market can simply not be ignored when planning such drastic intervention the automotive ecosystem.

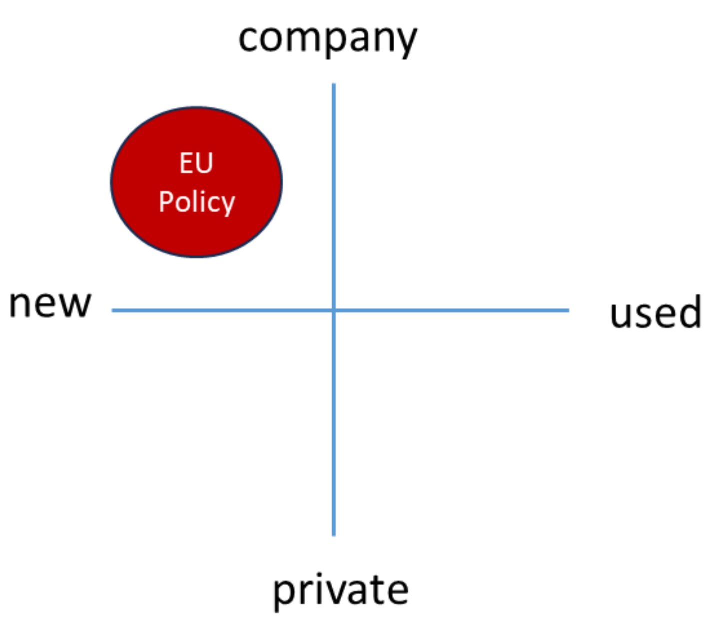

Figure 19: Policies in the upstream new market need to be accompanied by downstream absorption measures in the used market. Likewise, measures imposed on companies need to be accompanied by measures for the dominant private buyer population.

Hard BEV mandates on fleets and lessors will neither increase BEV uptake nor reduce the overall CO2 emissions of Europe's fleet. The system only equilibrates if *used-market demand elasticity* grows in step with *fleet inflows*. To prevent aggravation, policy can for example,

- **Stabilize residual value expectations**, e.g. by:
    - guaranteeing minimum buy-back or trade-in values for BEVs,
    - introducing used-BEV warranty and certification programs.

- **Stimulate used-BEV demand**, e.g. through:
  - subsidies or financing support for older second-hand EVs,
  - improved charging access for apartment dwellers and lower-income buyers.
- **Phase mandates in line with resale market maturation** — aligning fleet turnover rate with used-market absorption capacity.

Mandating BEV adoption for corporate fleets and lessors can have *ambiguous and possibly counterproductive effects* if not balanced carefully with feedback loops with the used market where different and nuanced dynamics are at play. The solution is not to **push harder at the top** (mandates), but to **bridge the bottom**. A healthy used demand side is as important, if not more important, than new demand side.

4.2.5 Policy implications

The market is not one homogenous group. It's a collection of segments defined by their financial constraints and cost-calculation methods (buyer TCO thresholds) interacting with companies that have different cost structures and business models (seller costs/markups).

An effective EV policy framework must be segment-sensitive: it adapts to the specific TCO profile of the four major market segments and acknowledges their mutual interdependence. By strategically enhancing liquidity between these “communicating vessels”, policy can accelerate technology diffusion across the entire market rather than deepening the divide between new and used, or corporate and private, buyers.

There are 3 main gaps to be bridged, visualized in following aggregated figures for the EU-27.

EU-27	**new transaction**			**used transactions**	
	market share	**EV demand**		**market share**	**EV demand**
company	60%	14%		17%	3%
private	40%	15%		83%	2%
company	7.800.000	1.092.000		6.460.000	193.800
private	5.200.000	780.000		31.540.000	630.800
total	**13.000.000**	**1.872.000**		**38.000.000**	**824.600**

Figure 20: A more inclusive and segmented perspective on EV demand. Measures to steer low-emission vehicle adoption require careful design to target both upstream and downstream, both business segments and retail segments, both new and used vehicle segments. Not doing so risks congestion, oversupply, depreciation shocks.

The difference in TCO perception between professional and retail buyers is far more than an accounting nuance. Among professional buyers, TCO awareness is already high — their purchasing decisions systematically optimize lifecycle cost, depreciation, and utilization. In contrast, **private buyers** display a much more *distorted or incomplete* TCO perspective: they focus on upfront price and visible costs while heavily discounting long-term factors such as energy, maintenance, and resale value.

For this reason, EU **policy efforts should rather target the private segment**, not by imposing mandates on the already rational corporate sector (which represents roughly half of the 25% of annual new-vehicle transactions), but by helping households internalize the true cost and benefit structure of BEVs. Otherwise, interventions risk *distorting* an already efficient TCO evaluation framework among professionals, while leaving the real behavioral bottleneck untouched.

Moreover, the **buyer composition between new and used markets** adds another structural layer. The used market — representing roughly **three-quarters of all annual vehicle transactions** — is overwhelmingly retail-driven, characterized by liquidity constraints and short-term decision horizons. If policymakers double down on **corporate BEV mandates**, they widen the TCO and valuation gap between new and used markets. This produces excess BEV supply in the segment *that matters least* (new corporate fleets) and insufficient affordability and appeal in the segment *that matters most* (private used buyers).

Hence, **policy design should rebalance its focus**: shift from pushing BEVs into the new professional fleet channel to supporting their **diffusion into the private retail and used-vehicle market**, where long-term adoption equilibrium is ultimately determined. Mandates can be part of the strategy — but **not the first, not alone**, and never without parallel measures that address the used/private bottleneck.

4.3 Purchase Price Parity Gap

In terms of magnitude, new electrified vehicles in Europe remain significantly more expensive than comparable internal combustion engine (ICE) models. This *BEV **Purchase Price Parity (PPP) gap*** translates into a higher total cost of ownership (TCO) for battery electric vehicles. The introduction of new technology thus comes with a considerable price premium, and a lot of signalling takes place to deliver justification in a logic of cost-conscious accounting.

The deconstruction of BEV prices into their underlying cost components has therefore become a central topic of research. Numerous academic papers, industry reports, news articles and policy analyses attempt to disentangle the drivers of this price deviation, tracing it through the production chain — from raw material extraction and chemical processing to component manufacturing and vehicle assembly.

However, when viewed through the lens of total cost of ownership (TCO) dynamics, a structural disconnect becomes apparent. The production-side logic of cost formation and recovery — grounded in manufacturing economics, scale effects, and R&D amortization — does not seamlessly translate into user-side valuation in the second-hand market. **What manufacturers capitalize as necessary cost-recovery investments are not necessarily recognized by used-car buyers as retained value.** This asymmetry suggests that focusing exclusively on upstream cost and production dynamics overlooks critical **downstream mechanisms** that shape perceived affordability and ultimately determine EV market diffusion.

4.3.1 The gap

It is obvious and well-known that price plays a first and fundamental role in demand for competing products. Studies[16] find consistently that the EV purchase price is the major deterrent to sales.

T&E explicitly states in a briefing that the average price of BEVs increased by **more than €10,000 (up to more than €40,000** between 2021 and early 2024. This increase occurred *despite* falling battery costs.

The IEA 2025 global EV outlook confirms this trend, noting that the EV model range in Europe is **"skewed towards higher-end models with higher prices"** and that fewer than 5% of BEV models were priced below €30,000 in 2024. This is a stark contrast with the norm, T&E: '*Consumers want electric vehicles, but the **median price** Europeans are ready to pay for an EV is **€20,000** (new and second hand sales combined), according to a study from the European Commission*.'

The lack of purchase price equivalence implies an average of today's price *markup* of **circa €15.000** for the latest generation high-end BEV vehicle, for the same ICE make/model.

Electric light commercial vehicles (LCVs) are moving along a trajectory similar to passenger battery-electric vehicles (BEVs). Adoption is growing but still volatile, driven by incentive schemes and low-emission zones. New electric vans typically carry a **price premium of 10–20 % for small vans and 40–60 % for larger models** and continue to be more expensive than diesel counterparts.

Empirically, this is observed in the EUROSTAT car price index (2020–2024): average transaction prices for new vehicles rose circa 20%, despite modest inflation in input costs. The bottom line is that the EV transition is actually equivalent to a systemic 20% inflation rate applied to the population that needs a car, akin to what is normally called an 'affordability crisis'.

The BEV-ICE purchase price gap exists still in 2025, but is **expected to diminish**, reaching purchase price parity (PPP) around 2030.

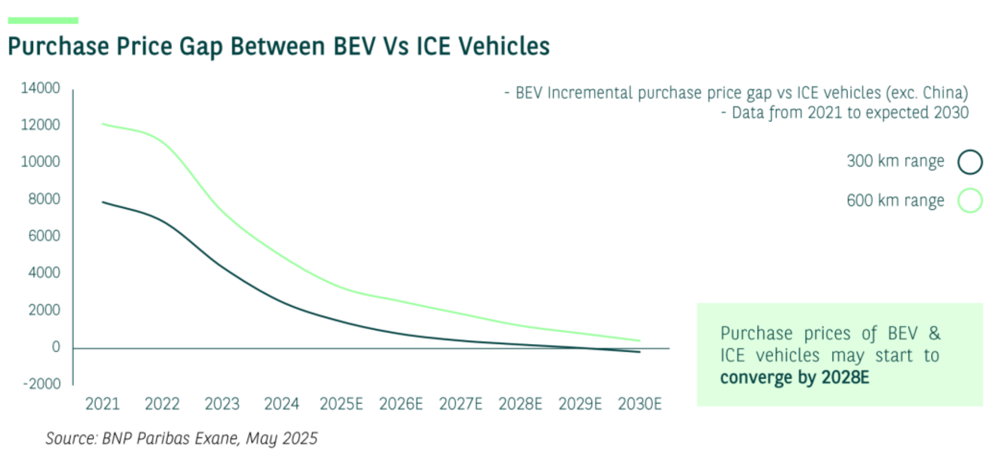

Figure 21: The purchase price parity gap is expected to diminish over time, but it requires to address issues on the used market.

[16] Gómez Vilchez, J.J.; Smyth, A.; Kelleher, L.; Lu, H.; Rohr, C.; Harrison, G.; Thiel, C. Electric Car Purchase Price as a Factor Determining Consumers' Choice and their Views on Incentives in Europe. *Sustainability* **2019**, *11*, 6357.

Including the view of the used market in the price gap components can yield valuable insights for a more complete understanding ***why* the BEV price-parity timeline is facing headwinds**.

4.3.2 Price segment

Because the inflow of new BEVs is concentrated at the top of the price distribution, it also raises the overall median transaction price in the new market and distorts the used market pipeline. As the share of BEVs and PHEVs in the market grows, this compositional shift exerts upward pressure on average prices — not because all models become costlier, but because the market mix tilts toward higher-priced segments. When considering resale or used vehicle prices, it is important to focus on **median prices** as average prices give a distorted view of consumer spending power.

For example, In the Netherlands, the average price of a used car in 2023 was around €25.000 based on BOVAG reporting. However, the distribution of prices was heavily skewed, with the median price being closer to €16.000. As a real-time snapshot of the number of vehicles on offer differentiated by powertrain and price segment as presented on Autoscout24.nl on 19 February 2025 shows the following distribution:

Used vehicle Price Range (€)	Total nr. of ICE vehicles offered	ICE % of total sample by price segment	Total nr. of (P)HEV vehicles offered	(P)HEV % of total sample by price segment	Total nr. of (B)EV vehicles offered	(B)EV% of total sample by price segment
0-5k	27,294	15%	63	0%	79	0%
5k-10k	30,598	17%	483	1%	445	2%
10-15k	26,477	15%	1192	3%	1,244	5%
15-20k	25,373	14%	2429	7%	2,278	10%
20-25k	18,803	10%	4256	12%	2,496	11%
25k-30k	14,722	8%	5538	15%	1,856	8%
30k-100k	38,221	21%	22,846	62%	14,297	63%
	181,488		**36,807**		**22,695**	

61% of the used ICE vehicles on offer can be bought for up to €20.000. For used BEVs, only 17% can be bought within that price bracket. This also clearly indicates that the majority of used BEVs making it to market, even bearing in mind they have significantly worse depreciation, are still out of reach for the average consumer.

A similar story can be told for the Belgian market. The table below shows the distribution of used vehicles prices per price segment and power train, as of 27 February 2025 as available on autoscout24.be (which covers the vast majority of the market).

Used vehicle Price Range (€)	Total nr. of ICE vehicles offered	ICE % of total sample by price segment	Total nr. of (P)HEV vehicles offered	(P)HEV % of total sample by price segment	Total nr. of (B)EV vehicles offered	(B)EV% of total sample by price segment
0-5k	9812	11%	25	0%	19	0%
5k-10k	14651	16%	200	0%	115	2%
10-15k	14823	16%	432	3%	209	5%
15-20k	16163	18%	1155	7%	483	10%
20-25k	11087	12%	1687	11%	614	11%
25k-30k	8135	9%	2120	14%	560	8%
30k-100k	17174	19%	9912	64%	4199	63%
	91845		**15531**		**22,695**	

The table shows that 43% of all used ICE vehicles on offer can be bought up to 15.000 euros, and 60% of all ICE vehicles are offered for less than 20.000. Conversely, in the BEV segment, only 7% can be acquired for less than 15.000 and 17% for less than 20.000.

The vast majority of used BEVs are offered for prices higher than 30.000, despite their disproportionate drop in Residual values. So, whilst BEVs are on average depreciating significantly faster compared to ICE powertrains, the list prices of used BEVs remain substantially higher compared to similar ICE powertrains. It demonstrates the persistence of the PPP gap throughout the BEV vehicle lifetime.

This creates a trickle-down failure: vehicles de-fleeted from corporate use remain unaffordable to mass-market used buyers.

4.3.3 Trim-level bias

While **Premium bias** refers to the inter *segment-level* strategy of OEMs launching BEVs primarily in upper-mid and luxury segments**, Trim-level** bias refers to the *intra-model* strategy where BEVs are typically offered only in highly equipped trims — even when the model itself belongs to a mainstream segment.

It is also called "**feature-content disparity**" or "equipment-content bias" in diffusion literature: a structural bias in the way EVs are positioned and equipped. EVs have h**igher baseline specifications.** BEVs are typically introduced with higher trim levels, including advanced driver assistance systems, infotainment packages, and performance options as standard.

The result is not a like-for-like comparison. Many entry-level ICE models are compared against mid- to high-spec BEVs, creating an **apparent narrowing** of the price gap that does not reflect equal vehicle content or segment equivalence. **Therefore, true equivalence reveals a wider real gap,** when controlling for equipment, performance, and segment size (e.g., comparing a mid-trim ICE with an equivalently specified BEV). Adjusted for true equivalence, the effective BEV price premium is expected to remain significant for longer than predicted.

In the used market, however, buyers do **not** value the premium brand or features proportionally to their new-car price. Instead, they value **functionality** — range, reliability, charging convenience, and total operating cost. Luxury add-ons (brand prestige, high-end interiors, 0–100 km/h acceleration) **lose value disproportionately**. As a result, the “premium brand markup” that inflated new prices **evaporates** quickly in residuals.

The used market discounts the *positional and luxury consumption* component of the new-car price, and retains mainly the *functional consumption* component. This acts as a *natural discounting mechanism* on the non-functional (brand/luxury) cost components of BEVs — further steepening their early depreciation curve.

Hence, while the **new buyer pays full price for the trim**, the **used buyer values it marginally**. Some of these functions may even **require paid software renewals or subscriptions**, further *reducing perceived net value*. The used market implicitly **discounts the non-durable portion of the high trim**.

As a result, used-market prices of BEVs *compress* relative to their inflated new MSRP — not because the vehicles are poor value, but because **the used market refuses to pay twice for early adopters’ optional content**.

The cost component of **trim-level bias** is heavily *under-capitalized* in the used market, because what is “premium content” at first sale often becomes “outdated tech” within a few years. The used buyer values range, battery health, and reliability — not luxury configuration or early-generation software. Thus, the used market discounts high baseline specifications disproportionately, amplifying BEV depreciation and widening the perceived affordability gap.

4.3.4 Policy implications

On the one hand, the purchase price of BEV is built up by several cost components. And it is evident that, one by one, they will shrink, there is no doubt about that. But it is a process that takes time. And when there is no patience to grow organically, due to EU self-imposed decarbonisation goals, new market policies are designed to speed up that process, forcibly. Several policies are setup in the category of **cost-side measures, or “upstream” measures**.

On the other hand, the purchase price components are not only relevant for the new market. The **used market doesn’t just passively receive the single purchase price, but it receives all those components** — and it **amplifies or neutralizes** them -separately- through residual value mechanisms, liquidity effects, and expectations. This is one of the most important but least understood dynamics in EV diffusion models. Policy making overlooks the category of **confidence-side measures**, or “downstream” measures.

Battery costs, economies of scale, and R&D expenditures all determine new-vehicle pricing — yet the transmission of total cost of ownership (TCO) improvements to consumers is not automatic. It does not simply ‘trickle down’. Instead, the price formation mechanism is circular: new-car premiums influence residual values, and residual values in turn reinforce high entry prices. This creates a persistent 'memory effect', delaying normalization even long after real purchase price parity is achieved.

Ultimately, **both** upstream measures (reducing production and battery costs) *and downstream* measures (stabilizing used-market values and lowering perceived risk) are needed to translate technical cost parity into perceived economic parity and accelerate broad BEV adoption.

4.4 Resale price parity gap

In EU, on average, BEVs depreciate approximately **10 percentage points faster per annum compared to ICE vehicles**. To manage the depreciation gap, leasing companies are already increasingly offering used leases and extending rental periods to mitigate financial risks.

Residual value (RV) is not just an accounting outcome; it's an *aggregate signal of future market confidence*. When BEVs exhibit faster depreciation than their similar ICE counterparts, it reveals that **secondary-market buyers discount future worth more steeply.**

We have explained above already that the TCO discounting goes beyond the arithmetic, **consumer perception amplifies the gap**. Private buyers tend to overemphasize resale uncertainty and underweight future operating savings (myopic discounting): they add their perceived premium in the resale value discounting on top (!) of the *already* depressed used price. There is an objective component, and a subjective add-on: both need to be considered.

Depreciation is maybe a more abstract concept. Facing "EV deprecation over the initial years of ownership is the most expensive part of owning a new vehicle". A possible consequence is that as more EV potential buyers are aware of such a fact, the fewer will be interested in acquiring an EV. Yet, it remains one of the most under-discussed topics in EV adoption strategies (a blindspot).

Moreover, there is inversion of price signals: 'Premium' cars nowadays depreciate like economy cars, irrespective of drivetrain. Depreciation deeply distorts valuation norms and it is a reflection of stress. Yet, resale price in used market is a TCO component that gets little attention.

EU Policies focus rather on new market and its players (mandates, ice ban 2035, first owner purchase price subsidy). Tax incentives for *used* car BEV owners, such as vehicle taxes, are often not available, reduced or removed. The used market distress signal is neglected, while it is in fact given by a *threefold* larger population. The question is: how can one disregard the resale price so blatantly?

In this section, we deal with the resale TCO component, tied to the used market.

4.4.1 Savings gap

From an engineering and energy perspective, BEVs possess a **structural cost advantage**:

- Higher drivetrain efficiency leads to **lower energy cost per kilometre**.

- Fewer moving parts reduce **maintenance and repair requirements**.

However, empirical market data show that these savings are **more than offset by depreciation losses** — the difference between purchase price and residual value. Since EU policies already address fuel (via electrification) and partially address purchase price, **depreciation is the remaining dominant cost driver** with zero targeted intervention. Depreciation, not fuel or maintenance, has become the **dominant TCO component** in Europe's used vehicle market.

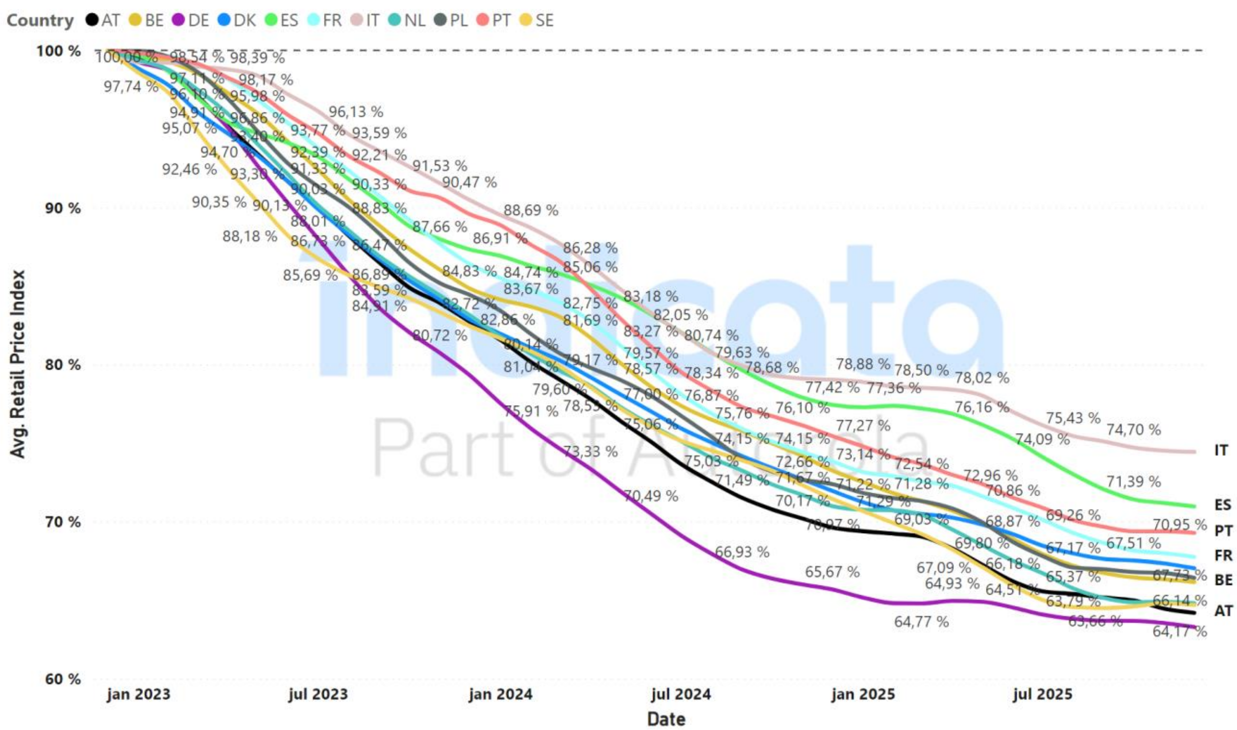

Figure 22: The price index is based on valuations of retail vehicle price for cars aged 36 months with an odometer reading of 60,000 km. Index 100 in 2023 is the start for comparison of the -at that time- 3 year old passenger vehicles. Residual values over a large database of second-hand BEV Passenger vehicles; these reveal strong depreciation of BEV in EU Member States over the last 2 years with values of 25% to 35% loss. Credit of data sourcing to Andrew Shields from Indicata.

Across European markets (2022–2024), average *used* BEV depreciation exceeds that of ICEs by approximately **€2,500 per year**, depending on segment and model (see Indicata figures). In the UK price differences are recorded around -45% for EV, for comparable vehicles.

As a result, even though BEVs may save **€1,000–€1,500/year** on energy and maintenance, a d**epreciation gap of roughly €2,000/year** erases the theoretical benefit, leaving the majority of used buyers with a negative savings gap.

Insurance cost makes the gap even wider. As of 2025, the European motor insurance market remains in a **transitional adjustment phase**. Despite steady growth in battery-electric vehicle (BEV) adoption, **cost parity with internal combustion engine (ICE) vehicles has not yet been achieved**, primarily due to

persistently higher repair and claims costs associated with electric powertrains. These elevated costs stem from **battery-related damage risks**, **limited availability of specialized repair services**, and **incomplete actuarial data** on long-term BEV performance.

Moreover, the price risk is higher, not only because of depreciation being larger in magnitude, but secondly because of higher volatility.

Hence, the ***realized TCO*** remains higher for BEVs in private ownership, despite lower running costs. Leasing companies price this uncertainty directly into higher lease rates to hedge residual risk. Corp fleets with planned short turnover cycles can internalize part of the depreciation risk, but private consumers cannot. Only when utilization rate is very high, the threshold of depreciation can be overcome.

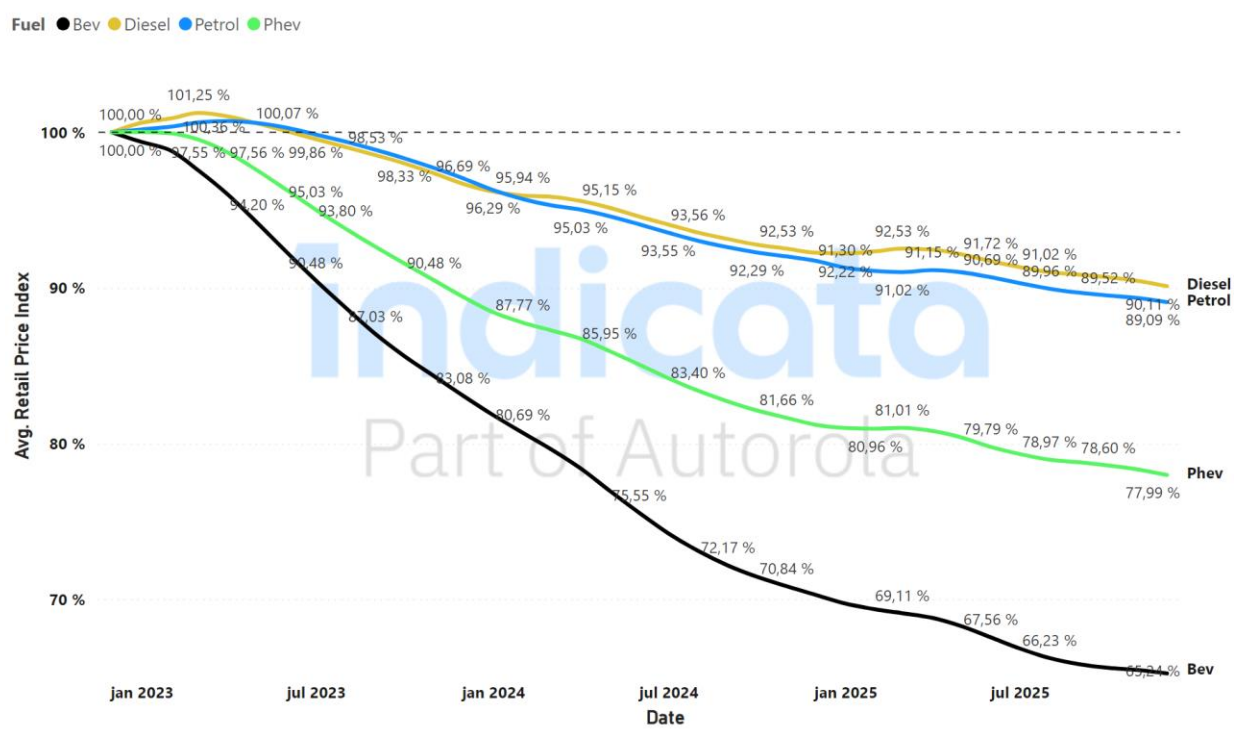

Figure 23: The price index is based on valuations of retail vehicle price for cars aged 36 months with an odometer reading of 60,000 km. Index 100 in 2023 is the start for comparison of the -at that time- 3 year old passenger vehicles in countries (AT, BE, DE, DK, ES, FR, IT, NL, PL, PT, SE). Residual values show that BEV and PHEV loose comparatively most value over time, BEV losing a third of its value over consecutive 2 years' time. Credit of data sourcing to Andrew Shields from Indicata.

Just like Passenger vehicles, also LCV vans suffer under the heavy depreciation of BEV. High BEV depreciation especially increases risk for short-cycle owners or sellers.

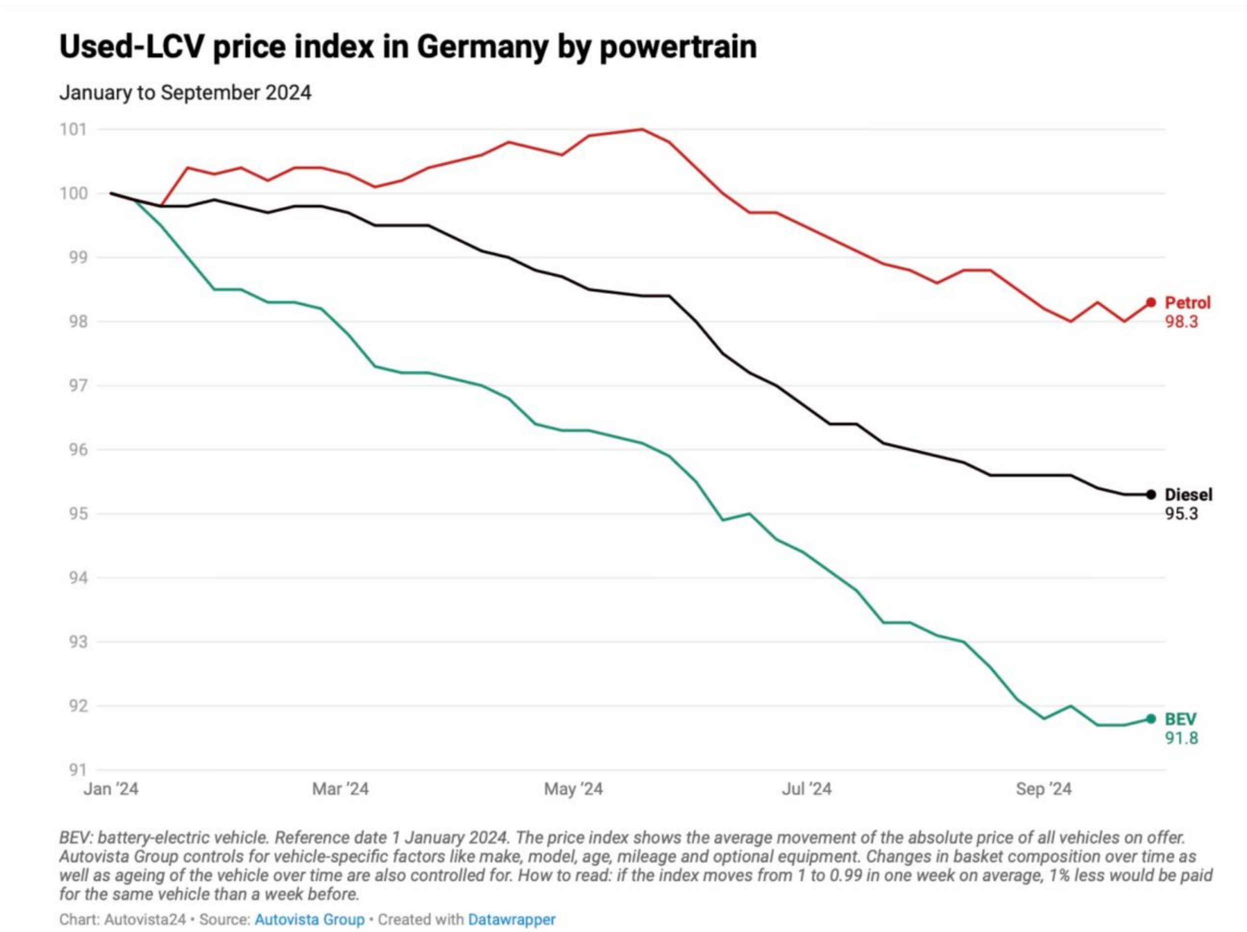

Figure 24: Citation: "BEV LCVs saw the largest decline in prices. In contrast, petrol LCVs showed the smallest drop. For traders, this means that while you can buy BEVs at better deals, petrol LCVs could be a safer bet for maintaining higher resale value." Comment: The 7% steeper depreciation of new BEV LCV price signals problems with value retention, a real-world proof of depreciation deterring BEV adoption. Source: Ecarstrade.com article- European Used LCV Market - What Can We Expect in 2025?

Furthermore, the price difference is not constant, as empirical evidence from an INDICATA l*ongitudinal* sample of Residual Value (RV) at biannual time points shows: the PPP gap overall **gets wider** in the used market over time. The gap gets larger and any Price parity with ICE or PHEV is never reached, apart from one or two brands.

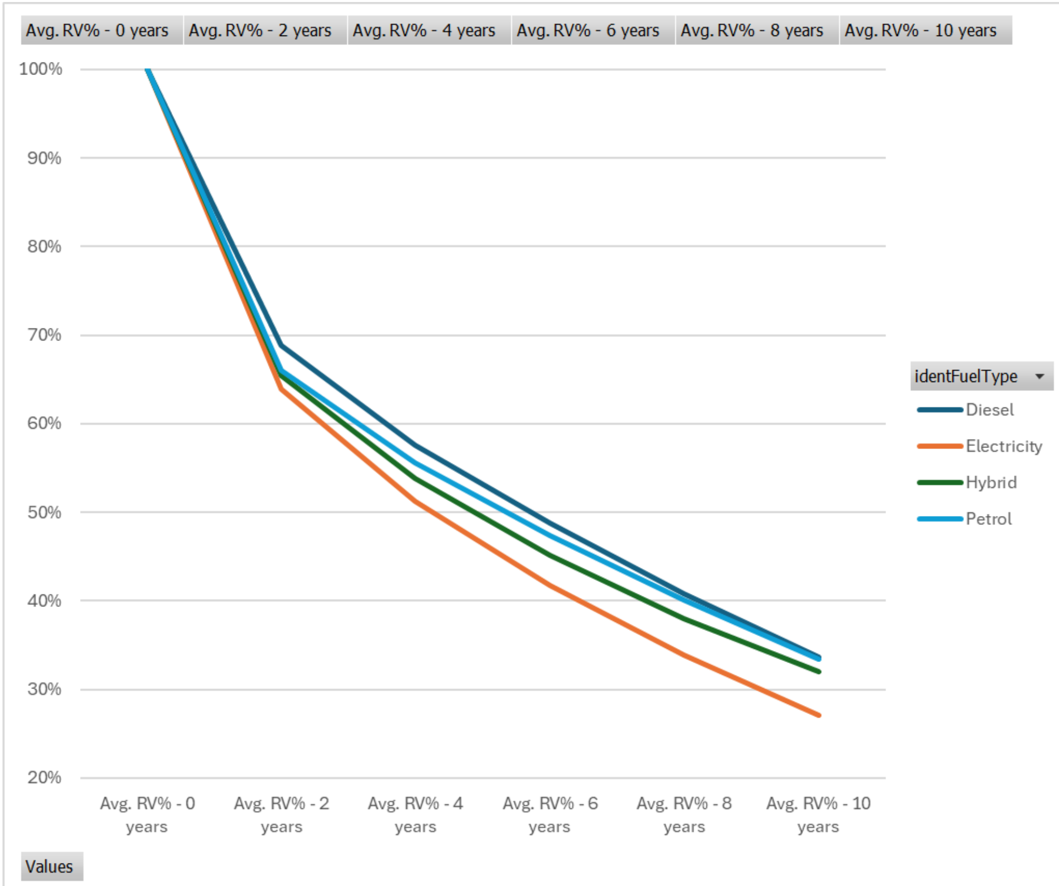

Figure 25: The purchase price gap between BEV with the powertrains is not only persistent but even widens in the used market, which is a stress signal. Credit of data sourcing to Andrew Shields from Indicata.

4.4.2 Sequencing gap

Perhaps a first reason why depreciation tends to be overlooked is the widespread belief that the *purchase price parity (PPP) gap* must be solved first. The reasoning often goes: *"We must close the purchase price gap before worrying about depreciation—if EVs are too expensive upfront, no one buys them, so resale doesn't matter."*

This logic is flawed on several counts. It implicitly assumes that:

- the purchase price is the sole binding constraint;
- depreciation is a secondary issue that only becomes relevant after large-scale adoption; and
- public subsidies should therefore target MSRP reductions first.

All three assumptions are false. **Purchase price and depreciation are jointly determined**—they are two sides of the same market equation. Lower resale values directly feed back into higher effective ownership costs, weakening demand and, in turn, reinforcing the need for higher upfront incentives. Treating depreciation as a downstream symptom rather than a co-determinant of affordability overlooks one of the most powerful levers in improving EV economics and accelerating adoption.

The sequencing error ignores a **self-reinforcing feedback mechanism**:

- Low willingness-to-pay (WTP) for used BEVs depresses residual values.
- Lower residuals increase measured depreciation rates.
- Faster depreciation worsens realized total cost of ownership (TCO), making BEVs *appear l*ess attractive.
- This perception further weakens WTP for both new and used BEVs, entrenching the imbalance.

The result is a **depreciation–perception loop**, where value expectations rather than technological fundamentals drive market outcomes. This circular causality explains why achieving nominal price parity between BEVs and ICEs—whether through mandates or cost declines (T&E, 2023)—is insufficient for sustained market transformation. The perception and *stability* of value retention are equally decisive.

Moreover, even **if price parity is achieved**, **depreciation dynamics can still undermine BEV adoption**, because *parity affects the entry price*, but *depreciation affects confidence and resale expectations*. PPP and depreciation act on **different market mechanisms**.

First, purchase price parity does not equal value parity. When BEV prices reach ICE levels, that solves only the **front-end affordability** problem. But the **back-end value trajectory**—how the vehicle retains worth over time—depends on **market confidence**, not manufacturing cost and efficiency.

If buyers (especially private and used-market ones) **expect rapid depreciation**, they'll still demand risk premiums, lease rates stay high, and the *effective TCO* remains unattractive — *even if the sticker price is fair*.

Second, depreciation is *path-dependent.* BEV depreciation today reflects **past policy volatility** (e.g. sudden subsidy cuts, WLTP shifts), **rapid technology turnover** (newer batteries making older ones obsolete), and **limited secondary-market liquidity**. Those forces don't disappear with parity — in fact, parity can worsen depreciation short-term, because:

- Cheaper new BEVs reduce the value of existing used BEVs.
- Faster model refresh cycles accelerate obsolescence.
- Residual value risk remains unmitigated.

Depreciation is **structural**, not a temporary artifact that is a consequence of initial price difference. We argue that the used market resale dynamics are to be recognized as instrumental in creating a virtuous adoption cycle.

4.4.3 Leverage gap

A second reason why purchase price is of primary concern, is because it is the front-loaded term in TCO, and from a purely financial perspective of TCO, one euro gained in resale value is identical in effect to one euro saved at purchase.

It *seems* to make sense: why would regulators bother with the used market, governments can directly control purchase subsidies but only indirectly influence depreciation (not politically salient). Moreover, used market dynamics are slow (takes years to see effects) hard, depreciation drivers are more complex, these seem not so easily addressed by single policies.

Yet this logic overlooks a crucial fact: **policies that stabilize or improve resale values create far greater leverage** through compounding, system-wide effects. The multiplier economics are straightforward:

- If a €40k BEV depreciates by 60 % over five years, the owner loses €24k.
- If policy interventions reduce that depreciation to 50 %, the owner saves €4k.
- That €4k gain has the *same effect* as a €4k purchase subsidy — but without costing taxpayers a cent.

By contrast, a €4k subsidy on the purchase price still leaves the owner exposed to the same €24k loss in value. In other words, a euro of improved value retention is worth as much as a euro of subsidy — yet it **multiplies** its impact by reinforcing confidence, financing, and liquidity across the entire market

The transmission channels are broad and enduring:

- Improved depreciation benefits not just the first buyer but the **next four or five owners**, spreading value through the **entire ownership chain** of the whole used market.
- Most buyers finance. Higher resale, will lower monthly payment and lower interest (shorter effective loan term). It improves overall funding on **both new and used market** together.
- Lower perceived depreciation risk results in **lower insurance cost** at a lower buyer discount rate.
- Higher resale means more **used EV supply**. Because lower used prices pull new EV demand forward.

Improving resale value deeply influences **leasing rates, fleet renewals, and used-car affordability**. So it has **systemic** rather than one-off effects. Therefore, **€1 spent on stabilizing residual values improves/anchors affordability for more households** and makes the technology more bankable for private buyers, leasing companies, rental fleets, and OEMs.

If the objective is to **maximise EV adoption per euro spent**, strengthening **residual-value confidence** is without question the highest-leverage interventions available at the current stage of EV diffusion. Improvements in expected resale values *simultaneously* lift **new-vehicle demand** and **used-market uptake**, creating a powerful **multiplier effect** across the entire fleet. This mechanism remains widely underestimated: even small upward shifts in resale expectations translate into **large improvements in total cost of ownership**, delivering an exceptional **bang-for-buck** compared to traditional purchase subsidies.

4.4.4 Obsolescence

In the context of sustainable transportation, **technological obsolescence** refers to the process whereby *rapid* advancements in key components, such as battery systems in battery electric vehicles (BEVs), render existing make models less desirable or economically viable over time.

This phenomenon, rooted in Schumpeterian[17] creative destruction, **accelerates depreciation rates** and influences market dynamics in the automotive sector. As battery technologies evolve—enhancing energy density, reducing size and weight, minimizing charging times, and extending range—the residual value of older BEVs diminishes, leading to a cascade of effects including reduced resale appeal and consumer purchase hesitation.

Mechanisms of Value Erosion Through Battery Advancements

Batteries -*which make EVs a practical reality*- play a major role in EV depreciation. Battery technology serves as the cornerstone of BEV performance, and its rapid evolution with every cycle exemplifies how innovation can precipitate obsolescence. Contemporary breakthroughs, such as the transition from lithium-ion to solid-state batteries or enhancements in silicon-anode chemistries, have enabled significant reductions in battery size and weight—often by 20–30% per generation—while simultaneously slashing charging times from hours to minutes and doubling or tripling driving ranges (e.g., from 300 km to over 600 km in premium models).

These improvements not only address consumer pain points like range anxiety but also **elevate baseline expectations for vehicle utility**. Consequently, older BEVs equipped with prior-generation batteries appear suboptimal, suffering from *perceived* inefficiencies such as slower charging (e.g., 30–60 minutes vs. 10–15 minutes for new models) and diminished range due to natural degradation (typically 1–2% capacity loss annually).

This obsolescence is exacerbated by the modular nature of BEV architecture, where battery packs constitute 30–50% of vehicle cost, making **retrofits economically unfeasible** for most owners.

Empirical analyses quantify this devaluation: three-year-old BEVs often depreciate by 52% of their original price, compared to 30–40% for internal combustion engine (ICE) vehicles, primarily attributable to battery-related obsolescence. For instance, models from 2020–2022, with ranges below 400 km, now command 20–30% lower resale values than anticipated, as newer entrants like those with 800V architectures offer superior **fast-charging** capabilities.

This dynamic is further intensified by economies of scale in battery production, with average prices projected to fall toward €80/kWh by 2026—a nearly 50% drop from 2023—flooding the market with more advanced, affordable alternatives that undercut the appeal of legacy systems. As a result, **older BEV vehicles become "unwanted" assets**, languishing in secondary markets and contributing to inventory gluts, as evidenced by a 50% year-over-year increase in excess used BEV stock in 2025.

[17] Creative destruction, popularised by Joseph Schumpeter, explains the mechanism by which innovations disrupt existing markets, which in turn leads to economic development and transformation.

Consumer Hesitation and the Role of Media Amplification

The psychological and behavioral ramifications of these advancements manifest in consumer hesitation, akin to the **Osborne effect**[18], wherein announcements of forthcoming innovations deter purchases of current models. Potential buyers, bombarded by media coverage of breakthroughs—such as solid-state batteries promising 1,000 km ranges or ultra-fast charging via graphene composites—often delay acquisitions in anticipation of "better versions" or market stabilization.

This **"wait-and-see" attitude** is particularly pronounced in the used BEV segment, where buyers weigh the risks of investing in potentially outdated technology against the promise of superior alternatives on the horizon. Surveys indicate that 22% of prospective EV adopters cite high upfront costs and technological uncertainty as barriers, with rapid evolution fostering perceptions of instability.

Media amplification, through outlets highlighting annual CES or IAA announcements, reinforces this cycle, as **consumers internalize narratives of perpetual improvement**, leading to deferred demand and further price erosion in secondary markets.

Quantitative evidence supports this **behavioral inertia**: in markets like Norway and the U.S., where EV adoption is advanced, resale values for pre-2022 models have plummeted due to buyer wariness of obsolescence, with some vehicles losing over 70% of value in five years. This hesitation not only depresses immediate sales but also **perpetuates a feedback loop**, as lower resale values inflate TCO calculations, further dissuading risk-averse consumers.

4.4.5 BEV Purchase subsidy

Purchase subsidies (like grants or tax deductions) are *effective* at lowering the **initial cost barrier** and boosting **first-hand adoption**. They help overcome the “sticker shock” that deters new buyers — especially when the EV-ICE price gap is still large. So, the *intent* is good: they make new EVs affordable enough to sell in volume.

But they distort price signalling in the used market. Here’s where the problem starts. Subsidies **artificially compress the new vs. used price difference**.

- Suppose a new EV costs €45,000 and gets a €7,000 subsidy → effective new price = €38,000.
- A used version of the same car (1 year old) might sell for €35,000.
- The buyer sees: “Why buy used if I can get a new one for only €3,000 more — with warranty and latest tech?”

[18] Osborne Computer Corporation's premature announcement of a next-generation product in the early 1980s led to the 'Osborne Effect,' decimating its sales and leading to bankruptcy. This phenomenon still influences tech giants like Apple and Samsung to maintain extreme secrecy about future products to avoid a sales slump of current models.

This creates **downward pressure on used prices**, because sellers must discount more to make their cars attractive. The result is a**ccelerated depreciation**. It *seems* to close the depreciation gap, as new price and resale price get closer, but in reality, *purchase subsidies push down the resale price*.

When subsidies **end**, the new EV price jumps up again. Besides the expected sharp drop[19] in demand, suddenly the used EV suddenly looks *cheap* in comparison. This should, in theory, **stabilize or slow depreciation**, because the relative price gap widens again. However, if the market has already internalized high depreciation as *expected*, it may take years for confidence to rebuild — this known as the *"memory effect"* of volatility.

It's not the subsidy itself that imbalances resale price — it's the **inconsistency, concentration** and **short-term design** of subsidies: it is **policy volatility**, not **policy generosity**, that destroys the resale component of TCO.

4.4.6 Policy implications

Policy and marketing focus on **flow costs** (fuel, maintenance per year) to offset **stock costs** (purchase price premium), while ignoring that the real killer is the **exit cost** (depreciation), which needs actually 'an insurance policy' (pun intended).

We argue that **depreciation is the primary factor to consider** - it's not just another cost component, it's the one that completely invalidates the operational savings narrative, yet it's systematically underweighted in policy design.

The interplay between technological advancements and **obsolescence** poses challenges for the sustainable diffusion of BEVs, potentially threatening adoption rates if not mitigated. Policymakers and manufacturers could address this through strategies like **battery leasing models** or **standardized upgrade paths** to decouple vehicle value from battery lifecycle, thereby stabilizing resale markets.

The EU overemphasizes *entry affordability* (purchase price) while neglecting *exit affordability* (resale value). To ensure sustained adoption, policymakers must stabilize expected future value, through design of subsidies that are:

- Predictable and gradually phased out (so depreciation can adjust smoothly)
- Complemented by used-EV incentives (e.g., VAT exemptions, battery warranties, certified pre-owned programs)

This aligns new and used market dynamics — stimulating *diffusion* rather than *volatility*.

In mature markets, where the fleet's average age and replacement cycle drive emissions, **policies that stabilize used values yield greater leverage per euro** (of order three) than those that only cut upfront prices:

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[19] Autorai, 3/25, '60% van EV-rijders wil bij wegvallen belastingvoordeel weer benzineauto': A study covering the Dutch market assessed that one in three EV drivers would choose to revert back to an ICE engine as their next car, citing an increase in circulation taxes as key concern.

- **Macro-efficiency:** A stable residual value reduces financing costs, leasing rates, and ultimately the public subsidy need for new BEVs.
- **Social equity:** The used-car market is how 70–80% of households actually access mobility; improving depreciation directly expands BEV adoption to lower-income groups.
- **Market stability:** Predictable depreciation attracts corporate buyers (fleets, leasing) that dominate new registrations.
- **Environmental durability:** A higher resale value delays premature scrapping, optimizing lifecycle emissions.

Hence, one euro spent to reduce depreciation (via residual value insurance, battery certification, or secondary-market transparency) is more cost-effective and equitable than one euro given as a front-end purchase rebate, because it **compound**s across many owners and time, maximizing taxpayer ROI.

Subsidizing new sales cannot be done alone, it must be accompanied with protecting resale worth.

4.5 Funding gap

Looking at the EV–ICE purchase price gap and resale depression in isolation, overlooks its powerful **financial transmission effects** on both retail and professional buyers (secondary effects). The higher upfront cost of BEVs does not only affect affordability — it reshapes **credit access, balance sheet structure, and vehicle turnover dynamics** across the market.

4.5.1 Debt-to-income gap

For the **retail segment**, it results in a **Financing Barrier Intensification**. The higher absolute purchase price of BEVs amplifies pre-existing financing constraints for households and small businesses:

- **Affordable access to credit becomes a binding constraint[20].** A typical €30k ICE vehicle remains within the affordability range of most households, given established credit scoring models and predictable resale values. However, a €45k BEV — with uncertain residual value and faster depreciation, reduces the pool of financeable customers. Lenders apply stricter collateral haircuts and higher risk margins to cover potential value volatility, which effectively excludes marginal or lower-income buyers through debt-to-income (DTI) or loan-to-value (LTV) limits.

- **Demand substitution and delay effects.** Buyers excluded from the new market either **shift to the used segment** (increasing pressure on second-hand supply) or **extend their ownership cycles**, delaying replacement. This leads to a '**retention effect'** in the stock — slowing fleet turnover and thus delaying the decarbonisation effect of new BEV inflows. Recent studies (e.g., BNEF 2024, ECB

[20] Under the existing Consumer Credit Directive (CCD) [DIRECTIVE 2008/48/EC] and relevant Loan Origination Guidelines of the European Banking Authority [EBA/GL/2020/06], and further restricted creditworthiness assessment foreseen under the revised CCD2[Directive (EU) 2023/2225].

Financial Stability Review 2023) confirm that rising vehicle prices are now the dominant factor behind declining private registrations in the EU.

In the EU, BEVs' higher upfront price (e.g. €42,000 vs. €30,000 for ICE) and highly uncertain residual values trigger stricter lending terms, **reducing annual private-sector auto-loan funding** by roughly €10 billion.

Across 12 million new-vehicle and 38 million used-vehicle transactions, approximately 2.5 million BEV purchases are financed. Lenders apply lower loan-to-value ratios (75 % for BEVs vs. 85 % for ICE) and exclude 10–15 % of marginal buyers due to debt-to-income and collateral-risk constraints, cutting average loan principal by €4,500 on new BEVs and €3,000 on used ones. This yields roughly a €6 billion shortfall in the new-car segment and €3 billion in the used-car segment.

As such, in the EU today a total of **€10 billion friction in lending** is taking place, shrinking the pool of financeable households and **slowing EV adoption**.

As it stands, the rules and standards for the creditworthiness assessment (CWA) provide for conservative and restrictive limitations, which can fundamentally limit the extent to which predictable, asset-linked cost characteristics can be reflected in the CWA decision. Greater methodological clarity on permissible forward-looking inputs could therefore support access to sustainable mobility finance while remaining consistent with responsible lending objectives and a high-level of consumer protection.

4.5.2 Credit rating gap

For the **professional** segment, it results in **balance sheet pressure**. For leasing companies, fleet operators, and mobility providers, the higher capital intensity of BEVs produces a **balance-sheet amplification effect**:

- **Capital cost and regulatory capital exposure.** A more expensive BEV asset inflates the company's total exposure on its balance sheet. To maintain credit ratings and comply with **CET1 ratio** or **risk-weighted asset (RWA)** constraints, financial intermediaries must either raise more capital or limit portfolio growth. This creates a **"capital requirement gap"**, especially when residual value uncertainty inflates risk weights under prudential regulation (e.g., CRR/CRD IV).
- **Profitability erosion from rapid depreciation.** Faster-than-expected BEV depreciation leads to unrecovered residual losses at lease maturity, eroding profitability and in some cases turning standard operating margins into losses. The mismatch between projected and realized residuals becomes a key source of volatility in financial performance.
- **Reduced leverage and higher lease pricing.** To compensate for higher asset costs and residual risks, lessors increase monthly lease rates or shorten contract durations — further raising the effective TCO for end-users. The feedback effect is circular: higher capital requirements lead to higher financing costs, which further reduce affordability and demand.

The professional fleet's absorption capacity of these funding costs is maximal at the current adoption rate in the current market environment (a balanced TCO gate). Mandating much higher rates without addressing the underlying technological and infrastructure constraints, or activating enabling conditions, simply forces the system out of balance, creating a **capital requirement gap** for lessors.

For example, under a 2027–2030 BEV-only mandate, EU leasing and rental companies would face a **capital cost** from a €15,000 higher acquisition price of circa 20 million BEVs, requiring an extra €8 billion in annual CET1 equity (at 11% ratio) to maintain prudential compliance—partially offset by securitization, netting €5 billion/year. This results over 4y into a **€20 billion capital gap.**

Simultaneously, a €3,000 per-vehicle profit-to-loss swing (from +€1k ICE to –€2k BEV due to €3k residual shortfalls) on circa 12 million maturing leases would generate a €9 billion annual P&L hit, reduced to €2.5 billion/year after hedging, tax shields, and re-marketing—cumulating to a circa **€10 billion net income gap** over four years.

In essence, the transition from ICE to BEV assets imposes a dual financial burden: **a surge in capital intensity** and **a compression of profitability**, both of which naturally constrain the sector's ability to scale electrification. Policymakers should exercise caution with demand-side interventions that amplify these pressures without careful design, as they potentially result in falling below regulatory thresholds.

4.5.3 Policy implications

The purchase price and resale gap as combined mechanisms create a **systemic financing bottleneck**. Current policy instruments largely target the **purchase price** of BEVs, yet they **overlook the financing layer** — the decisive factor determining who can actually acquire a vehicle. This omission has significant ripple effects: financing frictions propagate through the market as **slower fleet turnover, higher leasing rates, and tighter credit supply**, all of which **dampen the intended impact** of EV purchase incentives.

For the **retail segment**, the funding gap can be mitigated through **Financing-Neutral Policy Tools** that de-risk lending and improve affordability without direct subsidies:

- **Public residual value backstop:**
    - BEV depreciation risk triggers €3k lower loan principals per vehicle, creating an €10B annual private lending gap and €20B capital lockup for leasing firms (over 2027–2030). Policies could e.g. setup a €2B public backstop fund for residual value insurance, that would unlock €6–8B in private capital — it implies a 3–4 times leverage, no new debt. It could be an EIB-managed guarantee fund covering up to 50 % of residual value shortfalls, reducing risk premiums for lessors and banks, or state-backed residual-value guarantees or public–private depreciation pools.
- **Standardized battery health scoring:** A transparent "battery passport" (as pioneered in Norway) to reduce lender uncertainty and improve used-BEV valuations.
- **Tax credits for used BEV purchases:** A credit for age- and mileage-restricted vehicles to stimulate demand and liquidity in the second-hand market.

- **Low-interest green loans:** Offered via national promotional banks (e.g., KfW, CDP) to align consumer EV financing costs with the climate transition.

For the **leasing industry and corporate fleets**, these twin pressures — **high asset costs and regulatory capital burdens** — under BEV mandates result in major **balance-sheet distress and reduced fleet investment capacity**. Without lessors and corporate buyers taking protective measures, a BEV-only mandate could trigger a **cascade of adverse effects**: regulatory actions, shrinking business opportunities, rising unemployment, capital outflows, higher user fees, and declining consumer appeal for electric vehicles.

At the **regulatory level**, **prudential rules remain misaligned with climate goals**. Under CRR/CRD IV, BEV leases could be classified as **high-RWA assets** due to price volatility, despite evidence of lower lifetime default and performance risk. This creates a **policy contradiction.**

4.6 Market Depth gap

An often-overlooked aspect which must be factored into the TCO calculus, especially for fleet and used-car buyers, is market depth.

Compared with internal combustion engine (ICE) vehicles, the **battery electric vehicle (BEV) market** remains **less diverse in makes and models** (=concentrated) and has **fewer total units in** circulation (500 EV vs 1500 ICE).

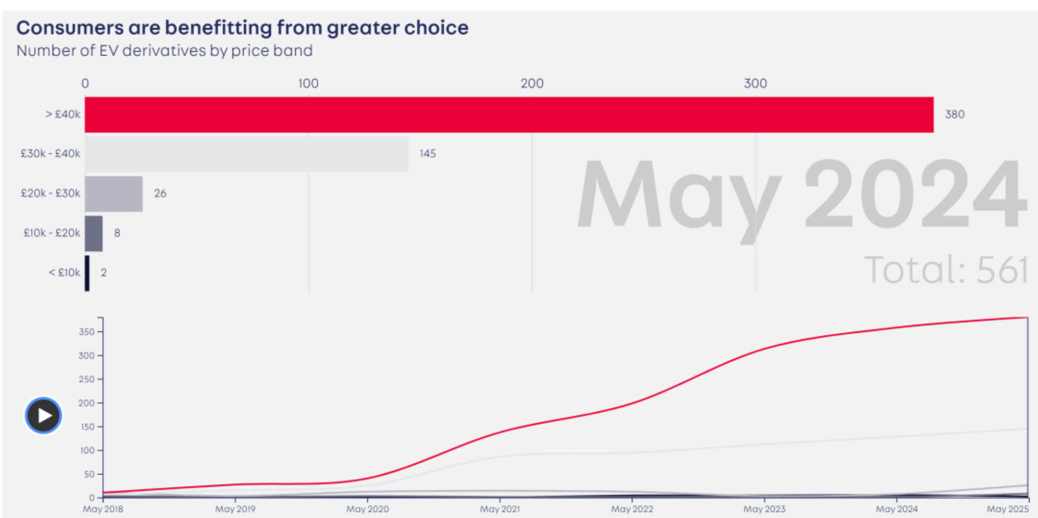

Figure 26: For example, In UK in 2019 there were about 50 models, while in 2025 about 500, so there is growth, but it remains concentrated in the +40k price bin.

This dual limitation—**low diversity and low volume**—creates limited substitutability ("not many, and all the same."), increasing TCO by inflating costs and introducing significant financial uncertainty.

4.6.1 Definition

Market depth refers to a market's **capacity** to absorb large buy or sell volumes **without causing disproportionate price fluctuations**.

- **Deep/thick market:** Large volumes can be traded without destabilizing prices.
- **Shallow/thin market:** Even small volumes trigger pronounced price changes.

Market depth is a more **structural** perspective on used market dynamics, it captures the "thickness" of supply and demand—how many buyers, sellers, units, and substitutes exist. Deep markets create the *conditions* for liquidity, as you have:

- More participants (buyers/sellers), yielding higher probability of matching
- More inventory diversity, implies better substitutability, and reduced search costs
- Greater volume is a more continuous price discovery, resulting in tighter bid-ask spreads

Besides **limited diversity and low volume**, the EV market 'thinness' is also evidenced by high sensitivity to discrete events (e.g., new BEV model launches, manufacturer recalls, subsidy changes); they result in amplified and persistent price effects in shallow markets. An example is the the car rental company Hertz: Large cohorts of same Tesla model entering used market at once (due to coordinated fleet lease maturities) depressing heavily the residuals in the local market.

4.6.2 Supply/demand dynamics

Regarding market depth, the EV technology creates a schism in the automotive market:

- The **incumbent** ICE market is deep or '**thick**'. It has diverse buyer segments that absorb volume: retail consumers, secondary dealers, export markets, fleet refurbishers. The number of substitutes, in any segmentation dimension, are plentiful—if one model floods the market, buyers can easily shift to alternatives. Any price impact is diffused across broader inventory.

- The **nascent** EV market is shallow or **'thin'**—characterized by limited inventory, fewer participants, and trading frictions. Thinness manifests in **higher price volatility, steeper slope of depreciation, and reduced transaction liquidity**, even as the broader EV market expands. Participants internalize this volatility as a **risk premium**—a behavioral adjustment that raises the **perceived TCO** and dampens market confidence, which in turn raises perceived TCO and suppresses demand.

The available data (MDS, supply > demand) strongly support the thesis that the used-EV market is thin/scarce relative to ICE. A 2025 report by Indicata across EU: used-BEV supply in Europe is **exceeding demand**, with "Market Days' Supply" (MDS) for BEVs being between 80 to over 100 days (versus circa 50 for petrol). The **objectively determinable oversupply of used BEVs** is causing a massive depression of EV prices in the used market.

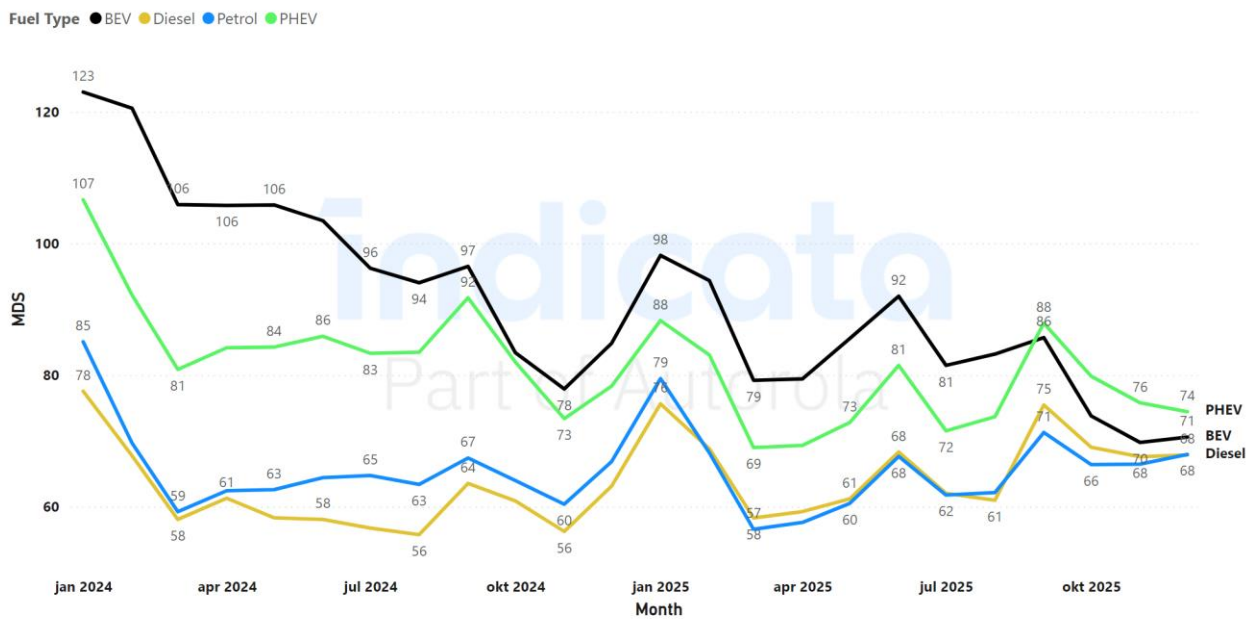

Figure 27: Passenger vehicles MDS over the main EU countries- lower is better. Credit of data sourcing to Andrew Shields from Indicata.

Market Day's Supply (MDS) indicators show fast rotation for young petrol and hybrid vehicles, and slower movement for older diesels and electrics.

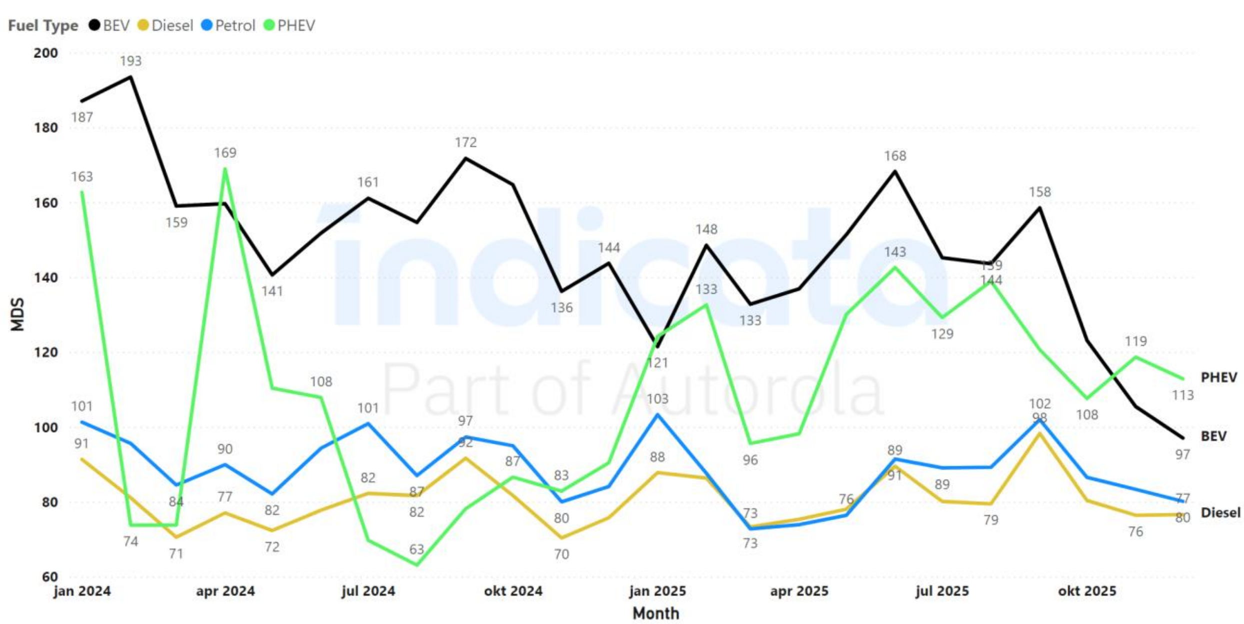

Figure 28: Light Commercial Vehicles MDS (dataset is smaller, more volatile) - lower is better. Credit of data sourcing to Andrew Shields from Indicata.

It is paradoxical that there is an oversupply, and yet the market is qualified as thin. But this apparent contradiction is resolved, once we distinguish ***quantity*** from ***liquidity***. Thinness reflects weak matching efficiency and high transaction frictions, not physical scarcity in number of units available.

In the used-BEV segment, asymmetric information (unlike ICE cars, BEVs carry unobservable attributes like battery degradation, charging speed, thermal management history), heterogeneous preferences, and institutional risk aversion suppress trading volumes…even amid ample nominal supply. Thus, the market's problem is not insufficient vehicles but insufficient *confidence and alignment* between supply and demand. This lack of EV market depth is shaped by conditions on **both the supply and demand sides**, in both the new and used vehicle markets:

- **New Vehicle Market**
  - **Supply:** The BEV segment remains **thin,** fewer models, fewer brands, and limited availability across price brackets.
  - **Demand:** Dealer networks face **reduced discount margins** compared with ICE vehicles, constraining their incentive structure and flexibility for price negotiation.

The combined effect in the new market is a **convergence toward a narrow, mid-range equilibrium**: transactions concentrate in a small set of models at relatively stable (but rigid) price levels, limiting dynamic market expansion. There is abundant evidence of this effect.

- **Used Vehicle Market**
  - **Supply:** The **inflow of used BEVs** remains limited due to their shorter historical production cycles and lower past sales volumes, but also dealers face depreciation of BEV and become reluctant to sell BEV over ICE, as it eats their margin.
  - **Demand:** The private dominated **buyer pool is restricted** by factors such as charging accessibility, range anxiety, and technological uncertainty.

As both sides of the used market are simultaneously thin, **trade tends to converge on a narrow segment of nearly new, low-mileage BEVs**—vehicles young enough to retain warranty and battery confidence, yet discounted enough to attract risk-averse buyers.

A recent 2025 paper[21] evidences this effect through the following observation in USA: *"BEVs enter the used market having been driven significantly less than similarly aged vehicles featuring other powertrain technologies".* Thus BEV have faster turnaround, which is also an effect observed in the used market in the EU according to recent Indicata data, or likewise, as T&E states it: BEVs depreciate more with usage compared to other powertrains with the largest effect in Italy and Spain.

This **"low-mileage equilibrium"** represents the **tradable core** of the used BEV market (=concentration). Most transactions cluster around "nearly new" BEVs — this reduces comparables and volume depth for depreciation modeling. Lessors cannot rely on robust historical price data, which leads to conservative (i.e., high-cost) pricing. And that directly feeds into TCO pricing logic of professionals.

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[21] *Charged and almost ready – stylized facts about the emerging market for used BEVs Levi Bognar, Scott Brave, Thomas Klier, Leslie McGranahan,* 2025, publication, Federal Reserve Bank of Chicago.

With a whole series of consequences that trickle down. The exit market for lessors becomes illiquid, they simply must price this illiquidity risk into contracts as a premium-not doing so would crystallize losses on their residual-value books. On top of that, frequent changes in subsidies or taxation (as in Germany in 2024) alter used BEV prices abruptly, worsening forecasting confidence. Leasing firms must at such moments hedge against such shocks, again inflating lease rates.

Often, stakeholders fail to recognize the structural lack of market depth as a major bottleneck: it constrains volume, limits liquidity, and delays the maturation of the broader electric vehicle ecosystem. The frustration that EV adoption is so low, does not necessarily mean that people or businesses are “unwilling” (which is an often heard conclusion). The true constraint on electrification is *not* willingness, but **thinness.**

4.6.3 Policy implications

Conventional EV policy focuses on *marginal incentives*—subsidies, tax credits, or mandates that move individual buyers or sellers. These instruments treat the market as atomistic, while a more systemic approach is needed, that addresses underlying dynamics.

Small, well-targeted interventions that change expectations or **reduce search/friction costs** can produce multiplicative effects on turnover and adoption because they convert a thin, fragile market into a self-sustaining one. This is the “Copernican shift”: move from marginal price subsidies to structural market-architecture interventions that increase the marginal impact of every euro spent.

Examples of policy levers to build market depth:

- **Strengthen inter-segment linkages** (new-used-export): Encourage mechanisms that make the used EV market predictable and liquid—such as guaranteed buyback schemes, certified second-life programs, and cross-border used-EV trade harmonization. This allows the first buyer’s decision to cascade more smoothly through the ownership chain, deepening effective demand and EV adoption in a natural and *sustainable* way.

- **Expand model and price diversity**: Support local assembly or modular manufacturing to bring a broader range of models and price points. Depth grows when variety grows—especially in lower-income segments that currently have no substitutes.

- **Reduce transaction frictions and information asymmetry**: Create trusted data infrastructures—battery health certificates, standard depreciation indices, transparent warranty tracking. This reduces perceived risk, lowers volatility, and increases willingness to trade.

- **De-risk residual values for financiers and fleets**: Introduce residual value insurance or public co-insurance pools to stabilize expected resale prices. This increases leasing uptake and keeps professional buyers active even as technology evolves.

- **Enable horizontal network effects** (infrastructure–vehicle co-evolution): Synchronize charging rollout with regional fleet concentrations, so perceived utility and liquidity rise together.

And last but not least, supporting the **used car market network** is essential because it fundamentally **enhances market depth**. A healthy used market is one where professional dealer and digital platforms dominate transactions, and high-quality, young cars flow quickly from leasing contracts into the market.

Yet currently the maturity of the used car market is typically split between **Western/Northern Europe (EU14)** and **Central/Eastern Europe (EU13)**. The differences come down to the balance between the **Organized Channel** (franchised dealers, OEM certified pre-owned, large digital platforms) and the **Unorganized Channel** (small independent dealers, private-to-private sales).

The transition to **used EVs** will further amplify this disparity: mature markets are better positioned to handle the complexity of battery health certificates, residual value calculations, and specialized servicing, while fragmented markets will struggle with the technical demands of used EV sales. Moreover, transient EV growth concentrates in Western EU, while Eastern markets absorb fewer, widening decarbonization gaps.

Rather than treating adoption as a sequence of isolated purchases, policymakers should **treat market depth (liquidity, diversity, and information friction) as an explicit policy objective**—in the same way central banks treat liquidity in financial markets. EV policy must evolve from *price correction* to *market architecture-design*.

4.7 Conclusion

The second link between the new and used vehicle markets is governed by **depreciation**, the central mechanism linking the value of vehicles across their lifecycle and, by extension, the total cost of ownership (TCO).

A new vehicle effectively becomes a used vehicle the moment it leaves the dealership, initiating a continuous process of **value decline over time**. The **rate of depreciation**—that is, the slope of the vehicle's price trajectory—determines its **residual value (RV)**, which serves as the key connector between the two markets. This intertemporal linkage may be conceptualized as the **"Depreciation Bridge."**

From a TCO perspective, depreciation is the dominant cost component for most vehicle owners, typically exceeding energy, maintenance, and tax costs combined. Consequently, **residual value expectations directly shape the perceived and actual affordability** of vehicles:

- **High residual values** reduce the effective cost of ownership by lowering depreciation expenses. They improve financing and leasing conditions through stronger collateral values, facilitate trade-ins, and thereby **stimulate new vehicle demand**.
- **Low residual values**, by contrast, diminish collateral quality, increase leasing and lending costs, and extend ownership durations, ultimately **suppressing turnover and new sales**.

Through these mechanisms, **residual value expectations create a “price feedback loop”** that binds the new and used markets into a unified economic system. Price adjustments in the secondary market influence the affordability and attractiveness of new vehicles, while changes in new vehicle pricing and technology feed back into used vehicle valuations.

At its most fundamental level, the **used vehicle market functions as a large-scale exchange mechanism**, where prices are continuously **discovered and equilibrated** through the interaction of supply and demand. This ongoing price discovery process not only clears the used market but also **anchors the valuation framework** upon which the new vehicle market depends.

5 Utility dynamics

In the previous section we argued that TCO expands the vehicle value beyond the cost of just sticker price and how it impacts the view on effectiveness of decarbonization policies.

The sensitive reader will recognize that while TCO provides a strong foundation for understanding vehicle adoption economics, it still remains an incomplete representation of real-world decision-making.

TCO relies on **market prices**—both purchase and resale—as inputs, yet it can only indirectly reflect several **systemic feedbacks** that determine those very prices. It captures only the **cost dimension** of adoption, whereas buyers' **subjective valuations** reshape each component according to their preferences, expectations, and context.

Beyond costs, **non-monetary factors** such as convenience, pride, range confidence, comfort, and social signalling often offset, discount, or even dominate monetary differences. This recognition motivates a conceptual extension of TCO into a broader framework that includes both cost and non-cost elements:

$$Utility = TCO + NonCost$$

People approximately, but not strictly, minimize costs — they **maximize perceived utility**. This lens provides higher resolution and explanatory power: for example, **high-income or early adopters** may select BEVs with higher TCO because they derive additional utility from innovation, environmental commitment, or brand identity.

For Fleet Managers and Corporate Buyers, the decision is **much closer to a pure TCO calculation**. But private individuals make the final choice based on the "utility premium"—the emotional, aesthetic, and performance benefits—that they are willing to pay for on top of the base TCO.

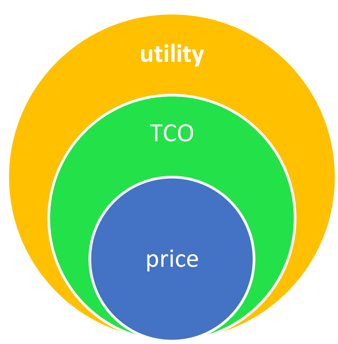


Figure 29: a vehicle's resale PRICE capitalizes not only its immediate purchase cost but also all future expected costs (TCO), …plus risks, and benefits of ownership (utility)—understanding new tech adoption, requires understanding decision dynamics.

Conceptually, **utility** operates at the **microeconomic level** of individual optimization, shaping the **demand side**, while **price** emerges as the **macroeconomic equilibrium outcome**—the aggregate intersection of all buyers' utilities (demand) with all sellers' costs (supply). P**rice** encapsulates the market's consensus on total costs and total benefits, while **TCO**—and, by extension, **utility**—dissects it, deconstructs that consensus.

The utility framework is useful because it structures decision factors even more coherently than TCO, which is crucial for effective decarbonisation policy:

- TCO captures only part of the real decision space, it works well for steering the corporate segment, but consumers are more driven by the non-cost component.

- Utility-based insights reveal why subsidies underperform, as policies that only reduce TCO (e.g. tax incentives) **shift the curve less** than expected, because the real bottleneck is in **non-cost utility dimensions**. Utility makes explicit the underlying drivers, frictions, and policy levers that shape adoption dynamics.

- Utility analysis expands the policy toolbox. Once policymakers understand the nuance of utility, they can target **high-leverage, low-cost policy levers** beyond subsidies. Benefit per euro subsidy increases: A pure TCO policy tries to make green technologies cheaper. A **utility-informed policy** can instead make *green options feel better* or make *polluting options feel worse* (access restrictions, nuisance). This shifts choice probability more efficiently per € spent.

A critical **caveat** in current BEV adoption debates is the **assumption that purchase price parity will automatically unlock mass-market adoption**. This notion—often presented by advocacy groups such as **Transport & Environment (T&E)**—treats price parity as a decisive **tipping point**. In reality, this assumption is **misleading**: **purchase price parity is not equivalent to total cost of ownership (TCO) parity**, and it is fair to say that even TCO parity itself does not guarantee adoption. Therefore, in this section, we bring forward the importance of a shift from a *"cost-based"* to a *"utility-based"* policy paradigm.

5.1 Decision dynamics

Classical economists have traditionally focused on the paradox of value, whilst paying less attention to the perception of value and demand. Utility and the diminishing marginal utility solved the paradox.

Essentially, utility theory provides a formal mathematical framework for understanding and predicting **human choice**. Utility theory provides the micro-foundation that explains WHY demand curves slope downward, WHY elasticities differ across products and consumers, and HOW policy interventions translate into market outcomes. In this section, we cover the most basic elements for practical use.

5.1.1 Utility

In general**, utility** (or "fitness") is a number (call it a score) that represents how much a particular buyer likes (or values) a product. It indicates a level of satisfaction or attractiveness. The higher the utility, the more people will **want** that option.

Utility is a function of several drivers (attributes), that results in a 'score', for example for an individual:

$$\boldsymbol{Utility\ U = w_1.price + w_2.energy_{cost} + w_3.income + w_4.gender + w_5.brand\ loyalty + \cdots + w_n.x_n}$$

It is fair to say that utility is a weighted combination of many drivers. Each of the drivers (attributes x) have a different **weight (coefficients w)**, depending on the preferences of the individual. **Utility weights** measure the marginal utility per unit change in a driver.

When people choose between options, they don't look at utility in isolation — they **compare** it to the utility of other alternatives. People are considered as agents that compare their utility of competing products and pick the one with the highest utility.

Customers find a shortlist of vehicles that meet their basic functional needs and have an acceptable TCO.

They then make the final choice based on the "***utility premium***"—the emotional, aesthetic, and performance benefits—that they are willing to pay for on top of the base TCO. As such, the decision by an individual for a specific powertrain comes into realization.

5.1.2 Demand

All these individual valuations over the population lead to aggregate outcomes by which the market moves in certain directions, expressed on a higher level through complex network effects, cascades and clustering pathways. The result at the market level (as aggregate) is the relative **market share** of each alternative, representing the relative demand. In other words, market share reflects how often an option "wins" in people's comparisons (counting frequencies). Simply multiplying that share by the total number of vehicles, yields the *absolute* **demand** for that powertrain.

Specifically, the demand for the powertrain type is expressed in volume, the quantity of vehicles sold over a reference period. Formally we are interested in the relative amount, % sales, or relative market shares in powertrain (ICE, PHEV, BEV).

To understand **demand**, it is vital to recognize **what are the relevant components of utility** — because utility is the sum over many attributes. If you know **how utility changes** with attributes like price, range, incentives, charging ease, or fuel cost, you can predict how people will shift their choices when those factors change.

5.1.3 Marginal utility

Although there is huge variation in weights from person to person, there is over a large group (e.g. country) an **average** typical value of the weight for each driver observable, the marginal utilities.

$$\widehat{w_1}, \widehat{w_2}, \widehat{w_3}, \ldots$$

Of specific interest to the case at hand, is aggregation of utility over each of the 3 powertrain subpopulations separately, to arrive at the *particular* set of **average weights,** specific for ICE, BEV and PHEV.

Knowing these specific average driver weights, allows to understand:

- **Importance**: what compels the average customer in 1st place, 2nd place (ranking). The relative size of the average weights shows which attributes drive choice most strongly.
- **Variance**: what is the stretch on an attribute (unanimity among individuals). The more people's preferences cluster around similar satisfaction levels, the more influence a small increase in utility can make, which is of great interest if one wants to influence decision-making.

Marginal utilities capture heterogeneity and intensity of population preferences: how strongly different groups or individuals respond to the same drivers. Manufacturers invest primarily in improving the high-utility attributes, and to policy makers they reveal which attributes are preventing or enabling adoption.

5.1.4 Willingness-to-pay

By comparing the difference in coefficient on common attributes, e.g. between weight of price of BEV against weight of price of ICE, one can infer the **marginal utility gap** of price. If this gap is significantly positive, it implies that on that attribute there is a significant relative preference intensity (higher marginal utility) for one powertrain over the other, or vice versa.

For example, if *w_price(BEV) < w_price(ICE),* the difference is large negative, meaning BEV buyers (or potential BEV adopters) are more price-sensitive than ICE buyers:

- A small price increase reduces the perceived utility of BEVs *more strongly* than it would reduce the utility of ICEs. Or stated conversely, a price reduction (e.g., subsidy) increases BEV utility *more strongly* — they react more to price.
- Economically, this suggests that **price remains a key barrier** for BEV adoption: consumers weigh price more heavily when evaluating BEVs than ICEs.

Pairwise comparison of estimated marginal utilities across powertrains highlights *where* BEVs outperform or underperform on specific attributes (utility parity analysis), but the magnitude is difficult to interpret raw coefficients are expressed in latent utility units and are not directly comparable across attributes.

To enable meaningful comparison, coefficients are typically normalized by the marginal utility of income (the negative price coefficient) to produce attribute-specific **marginal willingness-to-pay (MWTP)** measures:

$$MWTP_{energycost,BEV} = \frac{\widehat{w}_{energycost,BEV}}{-\widehat{w}_{price,BEV}}$$

MWTP translates heterogeneous attributes into monetary values, making it less abstract. It asks: "How much must the price change, *to keep the consumer's utility constant*, given a one-unit change in the attribute?"

The example of a BEV's driving range (an attribute) is an excellent application of MWTP:

- Initial Range: A consumer is willing to pay P1 for a car with a 300 km range.
- Incremental Range: They are willing to pay P2 > P1 for a car with a 350 km range.
- MWTP for Range: P2−P1 is their WTP for the extra 50 km. Dividing this difference by 50 km gives the MWTP per km.

The MWTP for an extra km of BEV range is the ratio of the utility gained from that extra km, divided by the utility lost from spending one euro. It gives a more relatable currency **valuation**: How much money are consumers in this segment willing to trade for a one-unit improvement in range?

MWTP facilitates interpretation of utility, and allows policymakers or firms to quantify:

- How much price reduction would offset a disadvantage (e.g., range anxiety).
- How large an incentive would equalize perceived value between powertrains.
- Which attributes deliver the greatest perceived benefit per € for each group.

It is incorrect to assume that some or even all disadvantages can be compensated by going proportionally lower in purchase price, as this would ignore the **Law of Diminishing Marginal Utility**: as standard range on BEV gets longer, the MWTP for each additional km decreases. The MWTP for offsetting a disadvantage is not constant. The first unit of disadvantage might be easily offset, but subsequent units become increasingly intolerable. The relationship is not linear. In some cases, consumers even don't make trade-offs at all.

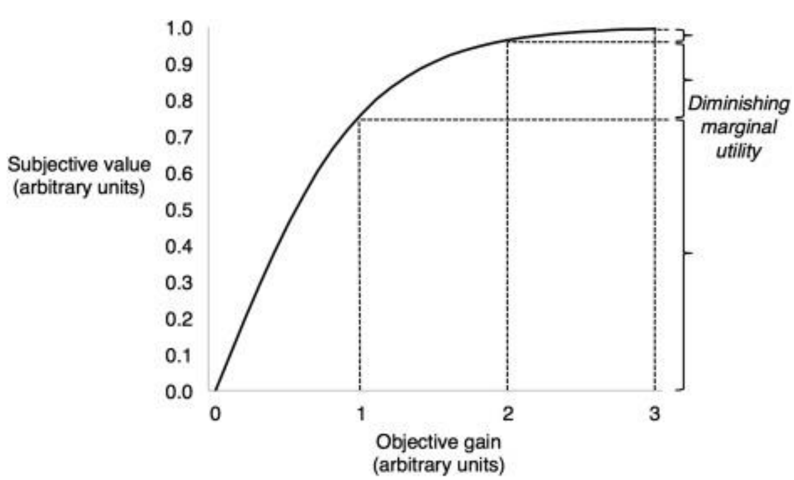


Figure 30: One can say that we are for BEV range at the early start of the curve, where each extra km brings a lot of utility.

Bearing this in mind, it is important to identify deal-breakers first: before calculating MWTP offsets, research must identify which attributes are hygiene factors or fundamental requirements. **No amount of price reduction will work if some core needs aren't met**.

To conclude, understanding marginal utilities (and variations) is paramount in understanding powertrain market share and the dynamics at play. For Manufacturers it is critical in pricing, but also optimize planning of future design and cost-benefit analysis. Policy Makers require knowing where diminishing returns of their incentive program sets in.

5.1.5 Elasticities

When car manufacturers, car dealers or fuel companies set prices, or when policymakers are to determine the tax level, they have an interest in knowing **how much** the demand for the product(s) in question responds to price changes. With the advent of new powertrains, there is now a policy forcing to incentivize electrification, which requires deep understanding how demand between powertrains behaves, in response to changes in purchase price, energy price, co2 level, charger density, etc.

Such insights in behavioral response are obtained by the study of **elasticities**: measures of responsiveness that indicate how much one economic variable changes in response to a change in another (assuming the other competing alternatives remain constant).

$$elasticity = \frac{\%\ change\ in\ demand}{\%\ change\ in\ driver\ of\ demand}$$

This dimensionless number comes directly from how **utility** of that powertrain reacts to that driver. For example, if utility drops sharply when price rises, and market share falls steeply in response, then elasticity is large (people are very responsive). But if the utility hardly changes (people don't care much about price), then elasticity is small (people are insensitive). Elasticity is fundamentally determined by the availability and quality of substitutes. The *ease of substitution* creates *sensitivity* (high elasticity).

For example, in **powertrain choice:**

- High price elasticity = A 5% price increase in BEV and I'll switch to ICE.
- Low range elasticity = Even doubling range won't change my decision—I'm committed to ICE.

Remark that utility weights (coefficients) and elasticities are intimately related, but represent different perspectives on consumer preferences. Utility gaps of driver weights are indispensable diagnostic tools to identify **where** to intervene. Elasticity is about **how much** to intervene (level of intensity), bearing a predictive aspect.

Elasticity on the **micro level** of a consumer is itself linked to three factors:

- Utility Weights
  - Larger utility weights produce larger elasticities. If consumers place high importance on fuel costs (large w), then fuel cost elasticity will be high—small price changes significantly affect choices.
- Level Dependency
  - Unlike utility weights, elasticities depend on attribute levels. A vehicle with higher initial price will have higher price elasticity than a cheaper vehicle, even with identical utility weights across consumers.
- Market Share Effects
  - Elasticities vary with market position. Dominant powertrains exhibit lower (own) elasticities, niche powertrains show higher elasticities.

Elasticity on the **macro level** (aggregate) emerges from their **distribution, interaction, and aggregation** within the broader market system. Many studies overlook the detail of the distribution of these factors. Recognizing and modeling this distributional information is therefore essential to understand *true aggregate elasticity* and to design effective policy or pricing strategy by manufacturers.

Here it is possible to discern two types of elasticity. Elasticity describing how demand for a product responds to changes in its *own* attributes, such as e.g. its price, is called **own-price elasticity.** It reflects: How easily can consumers substitute to *anything else*?

It can also capture how changes in one powertrain affect the demand for *other* powertrains, which can qualify as intra-group (same powertrain, but different brand) or inter-group (different powertrain) substitution. This relationship is known as **cross-elasticity:** How easily can consumers substitute to *this specific alternative*?

For example, if BEV prices fall, some consumers may shift from ICE vehicles to BEVs — indicating a positive (inter-group) cross-elasticity between the two. The magnitude and sign of cross-elasticity reveal the **degree of substitutability or complementarity** between alternatives: strong positive values imply close competition (strong substitutes), while weak or negative values indicate limited substitution or complementary relations.

In conclusion, elasticity of powertrain demand with its drivers is critical for understanding competitive dynamics, such as how BEV price drops can draw more sales away from ICE or PHEV in a finite market like the EU. Elasticities enable advanced manufacturers to price strategically, while policymakers require these quantitative predictions for their Cost-benefit analysis, Budget allocation and Target setting.

5.2 Driver dynamics

A critical initial step in comprehending vehicle demand involves systematically **identifying its key drivers**: discerning the factors that significantly influence powertrain choice: what steers powertrain choice and which not?

5.2.1 Horizontal scope

Identification of drivers requires recognizing the *scope* of the analysis in a broad, horizontal sense. This means ensuring that the set of explanatory variables captures a **sufficient range and diversity of structural factors** that systematically influence utility and, consequently, observed choices.

Ideally, utility must root in all of five structural spheres:

- **Socio-economic environment** – income levels, demographics, urbanization, and cultural context that shape mobility needs and purchasing power.
- **Policy and regulation** – taxes, subsidies, emission standards, and other government interventions that directly influence cost and choice.
- **Vehicle characteristics** – price, total cost of ownership, performance, technology, range, safety, and design features that affect consumer valuation.
- **Infrastructure and ecosystem** – availability of fuel or charging networks, maintenance services, and broader system compatibility that enable or constrain usage.
- **Customer context** – habits, tastes, risk perception, beliefs, preferences, brand loyalty, and behavioral barriers that slow or redirect adoption.

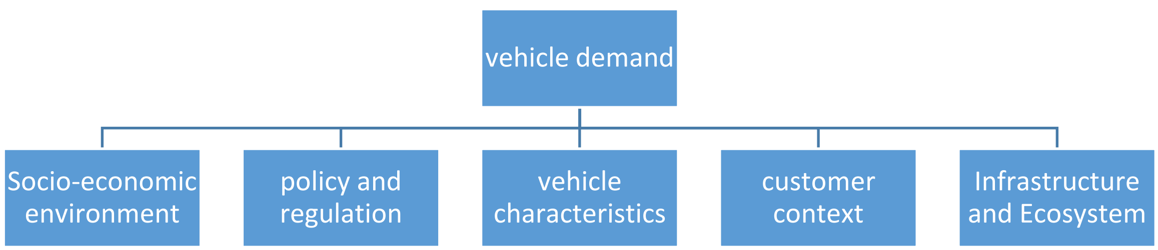


Figure 31: the five fundamental domains that govern vehicle demand

Thus, identifying drivers in a "horizontal" sense is about recognizing the **completeness and representativeness** of the factors shaping utility, not only their individual weights. It is important to acknowledge that **each** of these domains influence demand, and some domains are often overlooked in models presented in literature. One is consequently often presented with a biased view, and a great deal of caution is recommended when policy making is based on such narrow or incomplete views.

5.2.2 Vertical scope

Identification of drivers also requires recognizing the scope in a *vertical* sense — that is, the **depth of observation** across individuals or subpopulations.

Obviously, there is the class of **objective** factors, which go from macro to micro level:

- **Observable**: they can be quantified and measured on various levels from public to more
  - Global factors: Affect all markets, e.g. Battery technology costs (reduces BEV "barrier"), Oil price levels (affects ICE "burden"),
  - Country factors: are tied to a jurisdiction influence, e.g. National incentive subsidies, Fuel taxation regime, Grid carbon intensity, etc
  - Industry/Segment factors: OEM and aftermarket players, Vehicle class (PV, LCV, etc), like Model availability in segment, TCO dynamics, Fleet vs private economics,
  - Idiosyncratic factors: Household-specific factuals, like Individual charging access, urban/rural location, family size, etc

Besides the objective factors, there are the subjective factors[22], which are accessible to varying degree:

- **Semi-Observable**: Deeply personal, but can be measured via surveys/stated preferences/interview, e.g.
  - Psychological Factors: like peer effects, Word-of-mouth bias, Social Status seeking, professional identity, political signaling, group membership etc.
  - Contextual, geographical and Situational Factors: like towing needs (boat, trailer, camper), child care logistics, housing type, parking space, Health status, climate, electricity installation details…
- **Unobservable**: Operate unconsciously, almost impossible to measure objectively, create noise as idiosyncratic variations, e.g.
  - Emotional and Aesthetic Preferences: like visceral reactions, Nostalgia for "real" cars, attachment, pride in ownership, sensory preferences…etc.

[22] Empirical evidence supports this: Rezvani et al. (2015, Renewable and Sustainable Energy Reviews) show that psychological and contextual factors significantly moderate EV choice.

- Cognitive Biases and Heuristics: Decision-Making Shortcuts of people like Hyperbolic discounting of future fuel costs, Mental Accounting that subsidies are free money, Decision Simplification like brand solves everything, or only tech I understand, etc.

- Unobservable Idiosyncrasies: Personal and family History and experience shape tastes or habits or thinking patterns (I am a Mercedes man), Personality Traits, like Risk tolerance, moral values (utilitarian or environmental), even Spiritual/Philosophical views on progress and modernity, etc.

Perhaps it is possible to list and even rank many of the subjective factors, but catching the dynamics is the hard part, as consumer preferences are emergent, contextual, and evolving.

Modellers often underestimate the importance of hidden factors that shape the observable economic drivers, with a complex -often overwhelming- subconscious train of thoughts associated or unexpected interdependencies. For example,

- it is not just "price" but there is influence of upfront price, perception of monthly payment, a difficult negotiation, a past previous car depreciation experience, ...

- It is not just "range" but there are several rated ranges according to different untransparent standards, real-world range is just a fraction of that, winter range is very volatile, plan careful for highway range, city range is better, counting in degraded range, etc.

- Not just "charging time" but: are we surely home overnight, is there a charging place today at my workplace, stress of how much time do i loose on a road trip versus fast charge damage to battery, what if i need suddenly an emergency top-up in a traffic jam, etc

When observed behavior deviates from model-based policy predictions due to such unaccounted behavioral inertia (e.g., status quo bias, risk aversion), it does not necessarily mean that consumers are “irrational”, rather it means the **model’s representation of bounded rationality was incomplete**. It requires (i) expanding its **horizontal/vertical scope and** (ii) better implementation of marginal utility modulation of explanatory attributes by contextual attributes, as we will explain in the next sections.

5.2.3 Explanatory drivers

A first distinction to make is **explanatory drivers**: these are *choice-defining attributes* that affect directly the utility of each alternative and help explain *why* a certain option is chosen, these are **causal,** vary **across alternatives** (e.g., BEV vs ICE) and often drive substitution effects when their values change.

- Common to all powertrains
  - Total Cost of Ownership (TCO)
    - financing
    - energy cost
    - Repair and Maintenance

            - Insurance
            - taxes
        - Powertrain (ICE, PHEV, BEV)
        - subsidy (euro - penalty if negative)
        - power (kW)
        - range (km)
        - CO2 (grams/km WLTP)
        - ...etc

- EV specific
    - Charging time
    - battery health
    - …etc

5.2.4 Context drivers

The other distinction to make is **contextual drivers**: in contrast, these describe the *environment or characteristics of the decision-maker* — These don't directly compete across alternatives but rather influence **how much weight** a person gives to each explanatory variable. Examples are:

- Related to the vehicle (characteristics)
    - car type (PV, LCV)
    - size (A/B, C/D, LUXury)
    - Make (e.g. Volkswagen)
    - Model (GOLf)
    - Vehicle Age (or production year)
    - Country of registration
    - mileage (km)
    - lifecycle point (between new and facelift)
    - Other Objective factors
        - Cargo space
        - Seating capacity
        - Safety rating
        - Warranty coverage
        - ...etc

- Related to the customer (socio-demographic)
    - Buyer type (retail, corp, lessor)
    - Income level or business' financial health
    - Age
    - Gender

        - educational level
        - household size
        - Urban/rural
        - Average Annual mileage
        - Short/long commute
        - EV literacy
        - Other Subjective factors
            - Environmental concern
            - Risk averse
            - Design vs practical
            - Tech savvy or not
            - …etc

    - Related to the environment (geo/economic)
        - Regional climate
        - Infrastructure/Service/repair ecosystem
        - Interest rate
        - Consumer trust index
        - ...etc

It is worth to expand on "context attributes" via analogy:

- **Cooking analogy**
    - explanatory variables are the ingredients of utility for each powertrain, while contextual variables are the conditions that alter the recipe.
    - Context variables are e.g. the altitude, humidity, oven quality, available equipment, time pressure, and who you're cooking for. You're using the same ingredients, but cooking at 10,000 feet elevation versus sea level produces completely different results. Baking for someone with a nut allergy changes everything. Having only a microwave versus a professional kitchen transforms -dramatically- what's possible.
    - Contexts "seasons" the utility dish differently, it can make or break it.
- **Waves analogy**
    - Context creates interference patterns that amplify, cancel, or complexly modulate all attribute utilities: it changes the medium, changes how waves propagate.
    - Many-to-many: All variables are basic waves that *all* affect one another (even context impacting context), like income context interferes with price signal, geographic context interferes with range signal, infrastructure context interferes with charging signal.
    - Resonance: Rural context doesn't create utility alone (no range-no effect), yet range doesn't get such a utility boost without rural context in the model.
    - Anti-resonance: Charging time creates a disutility wave (annoying to wait), but home charging creates an opposite-phase wave (charging while sleeping = no waiting experienced). So some waves nearly cancel out, like noise-canceling headphones.

  - Pattern formation: Rural + Cold amplify significantly, but HomeCharging + Public Charging partially cancel, while net result may still be amplified, but less than rural+cold alone would suggest. Like beating patterns in acoustics, the sum is more than the parts.

In the next section we unpack how context impacts marginal utilities and make the case that "**Context Is Central, Not Peripheral".**

5.2.5 Utility Modulation

Contextual variables frame the decision-making environment - they modify, condition, or moderate the effects of explanatory variables. In other words, these do not themselves define the intrinsic attractiveness of a powertrain, but **shape how explanatory drivers are valued.** For example,

- Country inclusion reflects that different countries have different policies, taxation, infrastructure: e.g. country A strongly shifts utility of price by tax credits to EV buyers, while country B does that marginally.
- Buyer type inclusion reflects that different types of users have different preferences and weigh the attributes differently: e.g. corporates are more lifecycle-focused, while retail is more upfront price sensitive; or rural drivers attach more utility from refueling convenience to charging infrastructure than urban city dwellers.

Some context attributes will "modulate" weights of other (explanatory) attributes positively, adding to its weight, while some will risk-adjust by decreasing the weights.

For example, without context variable, the automotive utility model thinks: "People generally value range moderately"

$$\boldsymbol{U = \cdots + w_5 . range + \cdots}$$

But, we know that people that live in a cold climate are more sensitive to range, than those in warmer. This identifies a to-be-added interaction term (in green) that captures that range utility depends on context:

$$\boldsymbol{U = \cdots + w_5 . range + w_6 . (cold . range) + \cdots}$$

A simple rearrangement of terms, demonstrates that the effective marginal utility of range is modified:

$$\boldsymbol{U = \cdots + (w_5 + w_6 . cold) . range + \cdots}$$

This model now suddenly reflects that cold climate customers demand longer-range. If the automotive model ignores temperature context, one estimates a single weight across all consumers, which is a seriously biased view (omitted variable effect). One would conflate two distinct groups: those experiencing 200 km as "200 km" vs. those experiencing it as "140 km". Estimated range weight appears lower because you average over contexts where range is effectively differently valued. It demonstrates that omitting context variables, can lead to biased values for the sensitivity of attributes, ergo the choice in powertrain.

In reality, each attribute weight is influenced by **multiple** contextual modifiers:

$$many \rightarrow one$$

For example, rurality, climate conditions, or charging infrastructure density—that refine and segment the **marginal utility of range**. Consequently, the range coefficient itself becomes a **context-dependent function**, effectively forming a **submodel** of its own:

$$\boldsymbol{w_5 = f(cold, rural, cold, charging, \ldots)}$$

Conversely, a **single dominant contextual variable** can simultaneously alter **multiple weight estimates**

$$one \rightarrow many$$

This happens through underlying **correlation structures**, producing **cascading effects** across the utility model. In some cases, such interdependencies can even **reorder the relative ranking of utilities**—a phenomenon referred to here as the **rank effect**.

Furthermore, the **enhancement of context variables, or weights, beyond a linear specification** enables the model to capture the realistic presence of **positive feedback loops**—where infrastructure availability and adoption reinforce each other over time.

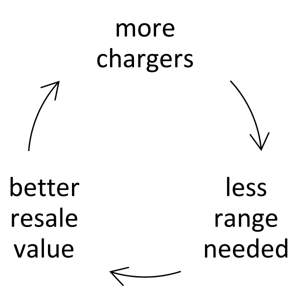


Figure 32: Models and policies underestimate that some enabling conditions are powerful multipliers with great network effects.

For example, the weight function can include the number of charging points N:

$$\boldsymbol{U = \cdots + w_5 . range + w_6 . (N . charging . range) + \cdots}$$

As such, utility INCREASES as adoption increases, so that charging utility grows as adoption grows (**multiplier effect**). A rigorous modeller must explicitly account for this **self-reinforcing dynamic**, as it is central to understanding diffusion processes in emerging technologies.

Developing smart submodels that capture feedback mechanisms and **nonlinearities** provides *critical value* for policymakers: it reveals how and where exponential growth can result from linear investments in contextual enablers, thereby identifying points of **high policy leverage** — where each euro spent yields disproportionately large benefits. Such "*policy benefit pockets*" in the automotive sector remain largely unexplored today.

A **context-sensitive model specification**—particularly along the *vertical dimension as outlaid above*—is crucial because it embeds the **interdependencies and externalities** that shape how technologies diffuse. When such interrelations are modelled explicitly, **network effects**—for instance, between vehicle uptake, charging availability, and resale value—**emerge endogenously** rather than being imposed as exogenous assumptions.

Capturing these feedbacks is vital for **effective drivetrain transition policy**, as they govern not only the **speed** of adoption (how fast markets grow once critical thresholds are reached) but also the **resilience** of those pathways (how stable adoption remains when incentives are withdrawn or shocks occur).

In other words, policy designs that recognize these vertical interdependencies can accelerate transitions more efficiently and ensure that once adoption takes off, it becomes self-sustaining.

5.2.6 Benefits

The power of context integration lies in revealing the deeper mechanisms and pressure points that shape automotive micro–decision-making. It allows analysts and policymakers to move beyond aggregate metrics and understand how real-world factors—such as charging conditions, usage patterns, and behavioural context—interact to drive or hinder the transition to low-emission vehicles.

*Firstly, c*ontextual variables capture heterogeneity in marginal utility, they reveal **distributional impacts** that remain hidden in explanatory attribute-only models, and are as such *diagnostic*, e.g.

- **Without context**: "BEVs aren't competitive yet; we need better batteries"
- **With context**: "BEVs are highly competitive for wealthy suburban homeowners with garages, but less accessible for low-income urban apartment dwellers"

Secondly, modulators are enablers: contextual variables enable to influence *multiple* objective attributes of a vehicle *simultaneously*. A real-world example of *aligning contexts to create resonance* is Norway:

- **With context**: Norway
  - High purchase subsidies (attribute)
  - Free parking/tolls (urban context advantage)
  - Dense charging network (infrastructure context)
  - Bus lane access (daily commute context)
  - Result: 80%+ BEV market share

- **Without context**: United States
    - Tax credits (attribute-only)
    - Minimal infrastructure coordination
    - No context-specific targeting
    - Result: 7% market share (slowly growing)

Thirdly, a focus on context attributes would reduce to need to focus on many other attributes (read: lower financial footprint), yet can create ultimately a stronger effect (exponential returns from a linear investment), more durable effect (e.g. invest in infrastructure assets vs one-time tax break), and overcome thresholds (trigger critical mass) since they exert *a multiplier effect* of cascading across many utilities in second order, third order, etc.. For example, in R&D innovation prioritization:

- **Without context**: "Direct billions towards subsidy into 800-km range and 5-minute charging"
- **With context**: "90% of buyers never need 500 miles; prioritize infrastructure R&D, which solves the 10% use case, and for many billions less"

The multiplier effect of context-inclusive policies speeds up electrification, as energy economics research[23] demonstrates: *"The cost-effectiveness can be improved by twofold by targeting incentives by income, vehicle disposal, geography, and/or vehicle miles traveled*."

And last, but not least, policies working on many contexts builds broader support, e.g. across political coalitions or diverse automotive stakeholders, as it implies leveling the playing field: no winner/loser picking. Each context attracts different supporters, cross-cutting benefits dissolve opposition, and are more durable.

Attribute-only models show average effects across everyone; they show only an overall demand response and lead to development of generic policy measures. They hide that the *same policy helps some people much more than others.* **Context-inclusive models** show how effects vary by circumstances, they reveal:

- Who benefits and how much (heterogeneity in marginal utility)
- Who is excluded and why (binding constraints by context)
- Hidden inequalities (regressive vs. progressive impacts)
- Structural barriers (infrastructure, liquidity, geography)
- Where to target interventions (context-specific bottlenecks)
- Guideline in redesign toward justice/welfare (remove deadweight loss)

Context variables don't just improve model fit—context modifies the entire utility landscape and create shared utility that benefits everyone. They amplify policy effectiveness, and create positive feedback loops (network effects), resulting in a self-sustaining adoption, avoiding automotive policy shock waves. They **fundamentally expand what policymakers can do**.

[23] Sheldon, Tamara L. & Dua, Rubal, 2019. "Measuring the cost-effectiveness of electric vehicle subsidies," Energy Economics, Elsevier, vol. 84(C).

5.3 Illustrations

In this section we provide several examples of how EV attributes are considered.

5.3.1 Affordability

Over the last decade, there is abundant evidence in EU countries, that **purchase subsidies work**. It takes many forms, like a direct upfront reduction (rebates, grants or credits), or fiscal exemption on VAT, registration tax, annual road tax, insurance tax, tolls, fees. In Norway, Sweden, France, and, to a lesser extent, in the UK, EV policies are based on a **carrot-and-stick** approach: A lower tax or even a cash bonus for EV purchases in combination with a higher tax (malus) for vehicle purchases with higher CO2 emission levels, following a **polluter-pays** principle.

On a per capita basis, there is a clear impact on EV adoption when comparing several EU countries, as shown in following graph.

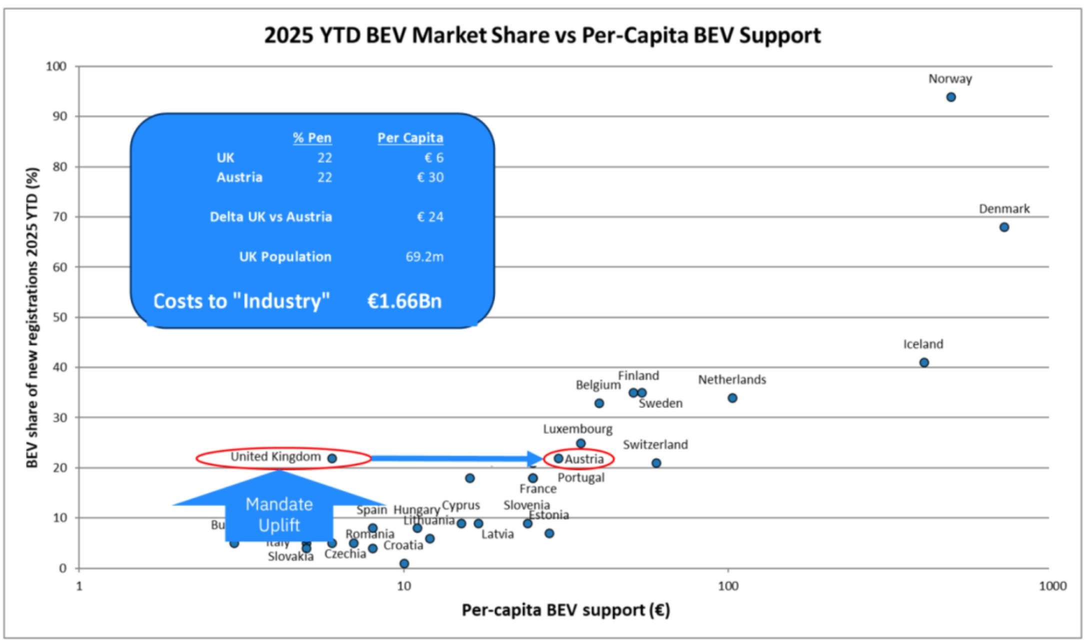


Figure 33:Illustration of the dependency of BEV share on per-capita subsidy level. Source: Indicata 2025.

Pearson (linear) correlation indicates a moderately strong relationship:

$$correlation(incentive\ per\ capita, BEV\ market\ share) \approx 70\%$$

where R^2 =50%, meaning half of the cross-country variation in BEV market shares can be explained by differences in **total support levels**. This suggests that comprehensive support schemes effectively translate into **real-world affordability**, with leading countries achieving **20–50% effective price reductions** and, correspondingly, **5–10× higher adoption rates** than the EU average.

A laggard Member State like Italy, having BEV adoption of only 5% of new registrations, has understood this analysis and decided in June 2025 that it will ramp up incentives to €11,000 per vehicle, **coupled to scrappage of old ICE** (!), enhancing efficiency by retiring ~1–2 tCO_2e extra per vehicle via immediate fleet cleanup.

Norway is a bit of an outlier, most notably for its **charging-network density** (e.g. Norway operates at nearly **20× the EU average**) and having max generosity incentives of €40k. The EU median is around €7k, with standard deviation around €10k. Top 6 countries account for circa 70% of EU BEV sales, but these nations also have disproportionately **high GDP** shares (circa 68% of EU total), highlighting how wealthier markets amplify adoption. In the context-aware setting GDP is a structural enabler for the subsidy attribute, that on its turn influences price.

$$GDP \rightarrow Subsidy \rightarrow price \rightarrow TCO \rightarrow Utility$$

With 50% explanatory power, it is an unescapable statistical fact that the context of **'affordability' remains the single most fundamental determinant of EV demand**. The price gap between BEVs and ICE vehicles directly limits the pool of potential buyers, both in the new and used markets. Simply put, **higher vehicle prices require higher disposable incomes**—a condition that only a fraction of households can meet.

As a result, the **effective addressable market for BEVs is structurally smaller**, not due to lack of awareness or interest, but due to **income-based affordability barriers**. This straightforward economic reality explains much of the observed demand gap from a demographic perspective: where affordability is low, uptake remains low—no technological or behavioral complexity is needed to explain it.

Affordability is an umbrella concept that extends far beyond household income. It encompasses multiple structural and financial contexts — including borrowers' debt capacity, lenders' risk tolerance, and corporate balance-sheet liquidity. One critical yet overlooked dimension is **funding**: how vehicles are financed, and how credit dynamics influence market accessibility.

A growing number of consumers are now **"upside-down"** or **"underwater"** on their car loans — owing more than their vehicle is worth. According to a 2025 *Edmunds* article, the average negative equity in the U.S. reached a record **$6,905**. This situation often arises when consumers trade in vehicles too quickly or hold loans issued during the pandemic price surge, when car values were inflated. As prices normalized, many borrowers were left with residual debts exceeding their vehicle's resale value, making it increasingly difficult to purchase another car without accumulating additional debt.

This **trade-in trap** creates a debt spiral: owners cannot sell or refinance without incurring losses, and trading in deepens their debt burden through larger loan rollovers. In effect, it immobilizes a portion of the car fleet and suppresses replacement demand. Used-vehicle loans represented 55% of the European car loan market size in 2024.

The electrification transition amplifies this structural vulnerability. BEV adoption depends heavily on financial liquidity, and several mechanisms reinforce this constraint:

- **Funding exclusion in the mass market:** Roughly **one-quarter of used car buyers** in EU face credit or equity shortfalls. Negative equity thus acts as a systemic brake on new car demand, especially for BEVs that remain newer, higher-priced, and often positioned in premium segments.
- **Underwater borrowers are excluded from the more expensive BEV market**, effectively shrinking the addressable base of potential buyers.
- **Rapid depreciation risks push financed BEV buyers underwater**, particularly those using car loans or financial leases. Only operational leases shift this risk to the lessor — otherwise, consumers become “locked in,” unable to sell or upgrade, which constrains the natural trickle-down of BEVs into the used market.
- **Extended loan terms** — now stretching to **7–9 years** — are being used to mask affordability pressures and maintain low monthly payments. This creates a *false sense of accessibility*: subsidies may boost new BEV sales temporarily, but they ignore the rollover-debt effect and rising loan-to-value (LTV) ratios that now exceed **110–120%** in some cases.

In short, **vehicle electrification and consumer debt dynamics are tightly intertwined**. Without addressing the funding side — credit structure, residual value stability, and lender confidence — affordability policies risk amplifying financial fragility rather than broadening access.

5.3.2 Price elasticity

Context inclusion transforms elasticity from a descriptive metric into a strategic policy compass. It allows governments to shift from “one-size-fits-all” incentives toward **adaptive, evidence-based calibration**, where each euro spent aligns with local responsiveness, financial constraints, and behavioral realities.

Different powertrains have different elasticities against price change, both their own or the other’s. Clearly, the elasticities break down in two types:

- **Own-Price Elasticity of Demand (OPE)**: This measures how the quantity demanded of a specific good (e.g., BEVs) changes in response to a change in its own price. E.g., a 10% rise in BEV prices might decrease BEV sales by 9.9% if OPE(BEV, BEV) = -0.99.
- **Cross-Price Elasticity of Demand (CPE)**: This assesses how the quantity demanded of one good changes when the price of a competing good (e.g., ICE vehicles) changes, also called substitution elasticity. There are two types of substitution possible: same-kind or different-kind. It is typically positive, because a price increase in one type, increases demand for the alternatives. E.g., a 10% increase in BEV price increases Diesel demand by 4.8% if CPE(Diesel, BEV) = 0.48.

In a research publication[24] on Norway 2002–2016 data, a nested logit model on ~1.8 million transactions yielded following results:

demand (sales)	Price (purchase) Gasoline	Diesel	BEV	PHEV	HEV
Gasoline	−1.08	0.64	0.19	0.20	0.15
Diesel	0.51	−1.27	0.48	0.34	0.10
BEV	0.36	0.09	−0.99	0.20	0.14
PHEV	0.43	0.71	0.18	−1.72	0.17
HEV	0.38	0.32	0.13	0.43	−0.97

Figure 34: column powertrain (e.g., DP(i,j) is the elasticity of demand for i with respect to price of j). DP(1,1): the own-price elasticity of gasoline driven cars is estimated at −1.08. That is, if all gasoline cars in the market had their prices increased by 10%, while the prices of all other cars remained unchanged, the number of gasoline cars sold would drop by 10.8%. Results from Fridstroem et al, 2021.

All diagonal (OPE) elements are negative, confirming the observation that a price increase of a powertrain type reduces its own demand. For example, it is observed that when BEV become 1% less expensive, they gain 1% market share.

Likewise, all off-diagonal (CPE) values in the matrix are positive, confirming that all powertrains act as substitutes. The matrix contains no negative CPEs, indicating no complementary relationships (e.g., no powertrain's demand rises with another's price decrease, which would be unusual for vehicle types). Low CPE values, close to zero (<0.01), would indicate independence.

It is worth noting how the relative magnitude of CPE between cross-pairs reveals **substitution intensity**: for example,

- The higher CPE(PHEV, Diesel)=0.71 versus CPE(BEV, Diesel)=0.09 highlights that Diesel price changes impact PHEV demand 7 times more than BEV demand, reflecting PHEV's role as a closer substitute to Diesel due to its dual-fuel flexibility.
- The matrix supports the idea that BEV competes double as intensely with diesel than with other types, as evidenced by higher CPE of 0.48 with diesel, as compared to 0.19, 0.18 and 0.13.

Taking note of the **asymmetry** in CPE values is also informative: for example,

- CPE(BEV,Diesel)=0.09 means that a 10% increase in Diesel price increases BEV demand by 0.9%.
- CPE(Diesel,BEV)=0.48 means a 10% increase in BEV price increases Diesel demand by 4.8%.
- Side-by-side, it says that ICE (Diesel) was a stronger fallback than BEV was a substitute in Norway in 2016.

[24] Fridstrøm, L., Østli, V. Direct and cross price elasticities of demand for gasoline, diesel, hybrid and battery electric cars: the case of Norway. European Transport Research Review, **13**, 3 (2021).

Understanding differential elasticities across powertrains is extremely informative for both policy design and market analysis of manufacturers for competitive pricing, as they

- **Reveal substitution patterns:** e.g. cross-price elasticities show which powertrains consumers view as close substitutes. High cross-elasticity between ICE and BEVs in compact cars indicates that price signals strongly affect switching behavior in that segment, while low cross-elasticity for luxury BEVs shows non-price preferences dominate.

- **Identify heterogeneous responsiveness:** it helps predict which segments will respond to subsidies, tax breaks, or maluses, improving targeting (especially when subsidies taper off).

- **Quantify "leverage points" for policy:** Policies like subsidies or registration taxes can be tailored to segments with high elasticity, maximizing adoption per euro spent. For low-elasticity groups, non-price measures (charging infrastructure, convenience, education) may be more effective.

- **Facilitate budget planning:** e.g. a study[25] on German data derived that for a one percent increase in the purchase subsidy, BEV registrations increase by about 3.16%.

- **Reveal hidden constraints:** Low elasticity may indicate budget constraints, lack of infrastructure, or behavioral barriers. Cross-price responses can reveal whether adoption is limited by relative cost, or by other unobserved factors (range anxiety, brand preference, dealer availability).

Powertrain-specific own- and cross-price elasticities reveal how consumers **trade off cost, convenience, and preference across vehicle types**. Elasticity patterns offer more than academic insight—they provide a *map of behavioral leverage points* for policymakers. By interpreting how strongly (or weakly) consumers react to price shifts between powertrains, regulators can design differentiated and cost-effective interventions.

5.3.3 Energy cost

After price, energy cost is the second most important factor mentioned in many stated preference studies[26] over countries.

A simple example can already illustrate how infrastructure access modulates the energy cost component:

- **Home charging available:** BEV operation is highly cost-competitive.
- **No home charging:** Drivers rely on public charging, typically priced at €0.50–0.70/kWh.

[25] Haan, P., Santonja, A. & Zaklan, A. Effectiveness and Heterogeneous Effects of Purchase Grants for Electric Vehicles. Environ Resource Econ 88, 185–223 (2025).

[26] Gómez Vilchez, J.J.; Smyth, A.; Kelleher, L.; Lu, H.; Rohr, C.; Harrison, G.; Thiel, C. Electric Car Purchase Price as a Factor Determining Consumers' Choice and their Views on Incentives in Europe. *Sustainability* 2019, *11*, 6357.

  - This corresponds to roughly **€7.50 per 100 km**, compared with **~€3/100 km** for home charging and **€10–12/100 km** for petrol.
- **Implication:** The **total cost of ownership (TCO)** for a BEV can vary by **up to 150% in its energy cost component** purely due to charging access.

This illustrates how **contextual variables**, such as **infrastructure availability**, can **modulate the perceived and actual competitiveness** of low-emission technologies. Even when intrinsic attributes (efficiency, price, emissions) are identical, **the decision environment**—in this case, charging accessibility—can fundamentally **reshape consumer valuation and adoption potential**.

A more advanced illustration is to look into research on elasticities to quantify how sensitive demand is to the rise in energy price. In a research publication[27] on Norway 2002–2016 data, a nested logit model on ~1.8 million transactions yielded following results:

		Price (energy)			
		Electricity Price	Liquid Fuel Price (General)	Diesel Price	Gasoline Price
demand (sales)	BEVs	−0.18	0.62	0.23	0.38
	PHEVs	−0.09	0.41	0.31	0.08
	HEVs	−0.04	0.15	0.20	0.38
	Diesel	−0.10	0.06	−0.60	0.52
	Gasoline	0.06	−0.41	0.31	−0.71

Figure 35: Elasticities of demand in powertrain vs energy price. The real price of grid electricity sold to private households (annual average) is used for cost calculation. Norway data 2002-2016, Source: Fridstroem et al 2021.

The table contains a lot of information to unpack, let us do that systematically per powertrain:

- BEV
  - BEVs' own elasticity for increasing electricity price is negative as expected, but very low in magnitude at −0.18, while those of fossil fuels is higher around -0.60. It implies BEV demand is 3x less sensitive to energy cost.
  - BEV demand undergoes particularly large cross effect from **liquid fuel price (0.62)** — implies strong **substitutability** between BEVs and fossil-based powertrains in the face of rising fuel prices.
- PHEV
  - Own elasticity for electricity is just −0.09: very low, so PHEVs are even less sensitive to electricity costs than BEV, as they are dual.

[27] Fridstrøm, L., Østli, V. Direct and cross price elasticities of demand for gasoline, diesel, hybrid and battery electric cars: the case of Norway. European Transport Research Review, 13, 3 (2021).

  - Cross elasticities: High positive with diesel (0.31) and liquid fuel (0.41), means PHEVs compete most with conventional combustion vehicles, although less with gasoline (0.08), so weaker substitution in that segment, consistent with evidence that PHEVs occupy a bridge position, with stronger ties to ICE consumers than to BEV adopters.

- HEVs
  - Own elasticity (electricity = −0.04): negligible — as expected, they don't rely on grid energy.
  - Cross elasticities: Moderate positive with fuel prices (0.15–0.38), especially gasoline.This indicates that HEVs benefit from rising fuel costs but less than BEVs or PHEVs. HEVs' substitution potential is limited but positive; they attract some cost-sensitive drivers but lack the structural shift magnitude of BEVs.

- Diesel vehicles
  - Own elasticity (diesel = −0.60): large and negative — strong sensitivity to diesel price increases.
  - Cross elasticity with gasoline (0.52): strong, implies diesel and gasoline vehicles are close substitutes. Small positive with electricity (−0.10) means weak interaction with BEVs. Diesel and gasoline compete directly within the fossil segment; diesel users will switch to gasoline more than to electrified powertrains when fossil prices change.

- Gasoline Vehicles
  - Own elasticity (gasoline = −0.71): largest in table — highly price-sensitive, because diesel drivers choose often for this powertrain as they are long distance oriented.
  - Cross elasticity with diesel (0.31): indicates fuel substitution symmetry with diesel. Negative with liquid fuel price (−0.41), likely because diesel cars are more energy efficient, they are less hardly hit than gasoline cars by a uniform fuel price surge.

From this Norwegian, study, the following conclusions can be drawn:

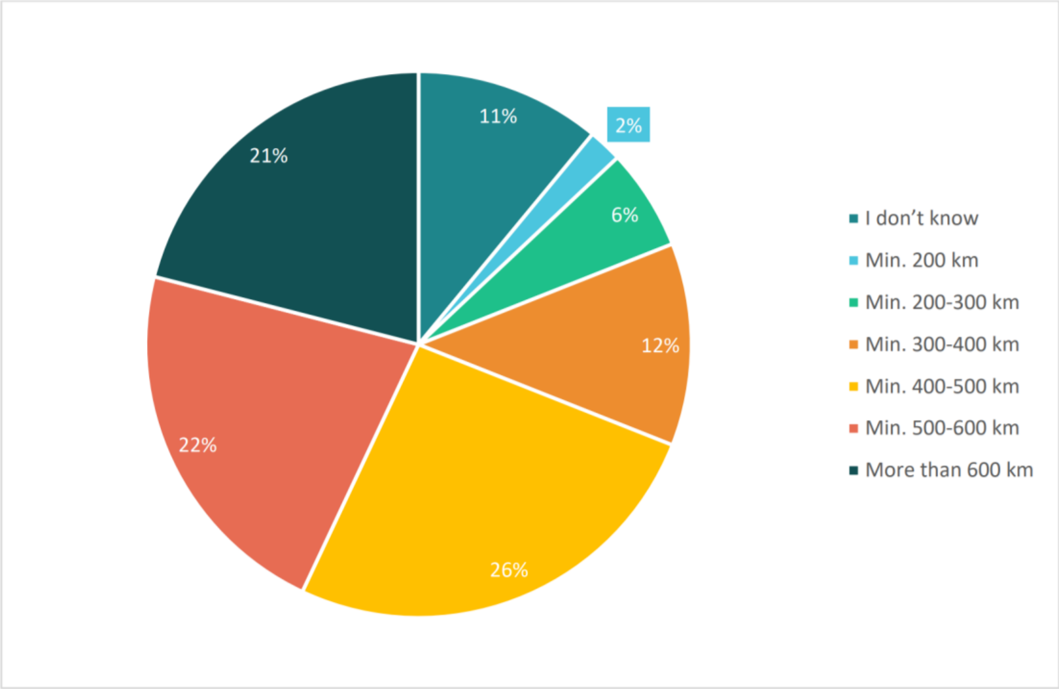
- **Energy price has strong asymmetry:** BEVs are far more affected by *liquid fuel* prices than by electricity prices, which signifies that substitution is driven by **relative cost advantage**, not energy dependence.
- Energy operating costs are a smaller part of BEV buyer calculus. **Energy is a small share of vehicle lifecycle value** for BEVs compared with purchase price and range/infrastructure concerns — so marginal changes in €/kWh move utility less than changes in upfront cost or range.
- It reveals **substitution pathways**: Elasticities show a chain of substitution: from diesel to gasoline, to hybrids, then to BEVs. Change is gradual, not binary. Effective policy recognises this progression instead of assuming immediate full electrification.
- **Diversion implication**: BEV adoption primarily draws from ICE segments, confirming that the transition follows a true substitution effect rather than internal cannibalization among electric powertrains.

The analysis shows that energy costs influence vehicle choice in ways that depend strongly on context. In other words, price incentives only work if the surrounding infrastructure **allows** people to benefit from them. The insights shifts policies to **target behaviour, not products**: policies are more effective when they align with actual usage patterns (=context), not only with *vehicle labels* or specifications.

5.3.4 Range

In the EAFO consumer monitor survey[28], desired BEV **driving range** was described as the number of km that can be driven with a full battery without recharging. A minimum desired range between 300 km to 500 km was the choice of 38% of all Dutch drivers surveyed.

5. Figure: Dutch drivers' desired driving range of a battery electric vehicle.



Source: EAFO Consumer Monitor and Survey 2023.

Figure 36: Result from a survey, indicating that driving range is an important context variable. We show how such variable can be strongly modulated by the fact of having a EV driving experience or not. Context matters in order to draw the right conclusions and design the right policies.

[28] Lieselot Vanhaverbeke, Dennis Verbist, Gabriela Barrera, VUB-MOBI Electromobility Research Centre, Máté Csukas, FIER, Rein Jüriado, EC-DG MOVE, Consumer Monitor, 2023, European alternative fuels observatory country report: the Netherlands.

Despite rapid technological progress, **battery-electric vehicles (BEVs) still fall short of internal combustion engine (ICE) vehicles in driving range**, a limitation that continues to discourage potential buyers. This concern is especially relevant in the **light commercial vehicle (LCV)** segment, where range, payload, and charging cycles directly affect operational utility. Depending on the market, LCVs represent up to one-third of corporate fleets, making range performance a critical determinant of adoption in professional use cases.

Environmental conditions further accentuate these limitations. BEV range can **drop by 20–40% in cold temperatures** due to increased battery resistance and cabin heating demand—an acute disadvantage in Nordic and other cold climates. Similarly, sustained exposure to high temperatures accelerates battery degradation, reducing both efficiency and lifespan.

Beyond purchase price, **driving range remains one of the strongest psychological and practical barriers** to BEV adoption. Studies[29] consistently show that consumers tend to **overestimate their actual range requirements**, often projecting expectations based on habitual ICE experience. For instance, Franke and Krems (2013) found that **consumers' preferred range significantly exceeds their real mobility needs**, reflecting the influence of *range anxiety*—the fear of running out of charge before reaching a destination. However, their longitudinal study also showed that **range preference declines after several months of EV use**, as drivers gain experience and confidence in daily operations.

In a 2022 discrete choice survey[30]of 2500 respondents conducted in Belgium focusing on electric vehicles, for which willingness to pay had been derived for different attributes, with following results:

Table 24 Willingness to pay for EV and V2G attributes of private car owners

	median	mean	std dev	conf interval
Driving range	25.74	26.56	6.75	13.3 – 39.8
Recharging time	-5.08	-5.25	1.36	-2.6 - -7.9
GMR	26.05	27.01	7.38	12.5 - 41.5
Yearly savings	5.89	6.29	2.33	1.7 – 10.9
Single upfront payment	5.84	6.06	1.70	2.7 - 9.4

Statistically insignificant values are shown in light grey.

Figure 37: Care must be taken with discrete choice survey results, as 'revealed' preferences may be very different, which underscores that not taking into account context has major consequences.

As expected, driving range is an influential attribute in the valuation of BEVs by consumers. The average marginal WTP for increased driving range is found to be on average €26/km. This means that the accepted

[29] Zhi-Ang Ooi et al., Estimating the Choices of Electric Vehicles: A Random Utility Model, Global Business and Management Research: An International Journal Vol. 13, No. 1 (2021)

[30] Rosanne Vanpée, Inge Mayeres, The market potential for V2G in Belgium, Report in the context of the Energy technology modelling framework for POlicy support towards a Cost-effective and Sustainable society in 2030 and 2050 – EPOC 2030-2050, Transport & Mobility Leuven, june 2022.

price difference between EVs with a range of for example 300 km and 400 km is somewhere between €1300 and €4000.

The authors note their result is on the lower end of other surveys that arrive at estimates between 50 to 150 €/km. We bring forward that it is not just a matter of heterogeneity. No, there are two fundamental reasons at play:

- On the one hand, there is the known ***hypothetical bias*** problem of surveys that leads to overestimation. In the study of WTP literature, one must be careful about the difference between **Stated** vs. **Revealed** Preferences. For example, Rodemeier[31] (2024) shows, in a supermarket setting, that hypothetical WTP (surveys) overstates revealed WTP (actual purchase decisions) by 1,388%. How much bias, is another debate of course, the multiplier depends on the context.

- On the other hand, there is the -much less known- ***context bias*** problem that leads to underestimation. The Belgian study is not controlling for "true EV experience" in the sample[32]. The power of this missing attribute in analysis, was discovered in an excellent two-wave 2013 Danish study's estimate[33] of WTP for driving range. It revealed that WTP, **after** they experienced BEV driving (an average €134/km for a single-car household), doubled as compared to their WTP **before experiencing an EV** (€65/km). Real-life practical experienced range anxiety **increased** WTP, while it was rather a theoretical thing before.

Stated-preference surveys tend to overstate WTP (hypothetical bias). Conversely, samples lacking experienced EV drivers can understate ex-post WTP because real-world experience modifies valuations (context bias). Together these biases can pull CE estimates in opposite directions; the net effect depends on survey design and sample composition.

The fact that customers have a higher WTP after experience for many attributes, explains perhaps why so many BEV users would still consider other powertrains in the future. In a recent global BCG survey of 9000 respondents, there are 15 BEV entrants vs 14 leavers to ICE, indicating very slow inflow from ICE owners. This in contrast to (P)HEV that have strong inflow to BEV (PHEV 28 in vs 10 out of BEV; HEV 20 in vs 5 out of BEV), suggesting that (plug-in) hybrids indeed deserve their nickname of *'a gateway drug'* to BEV.

[31] Matthias Rodemeier, Willingness to Pay for Carbon Mitigation: Field Evidence from the Market for Carbon Offsets, *The Review of Financial Studies*, 2025.

[32] It is likely not the only one missing, but an important one that illustrates the point. For example, another missing context could be 'climate': possibly there is in the Nordics a 20–50% premium on range due to long commutes/cold weather, as compared to more southern Europe.

[33] Jensen AF, Cherchi E, Mabit SL. On the stability of preferences and attitudes before and after experiencing an electric vehicle. Transp Res Part Transp Environ. 2013 Dec 25:24–32.

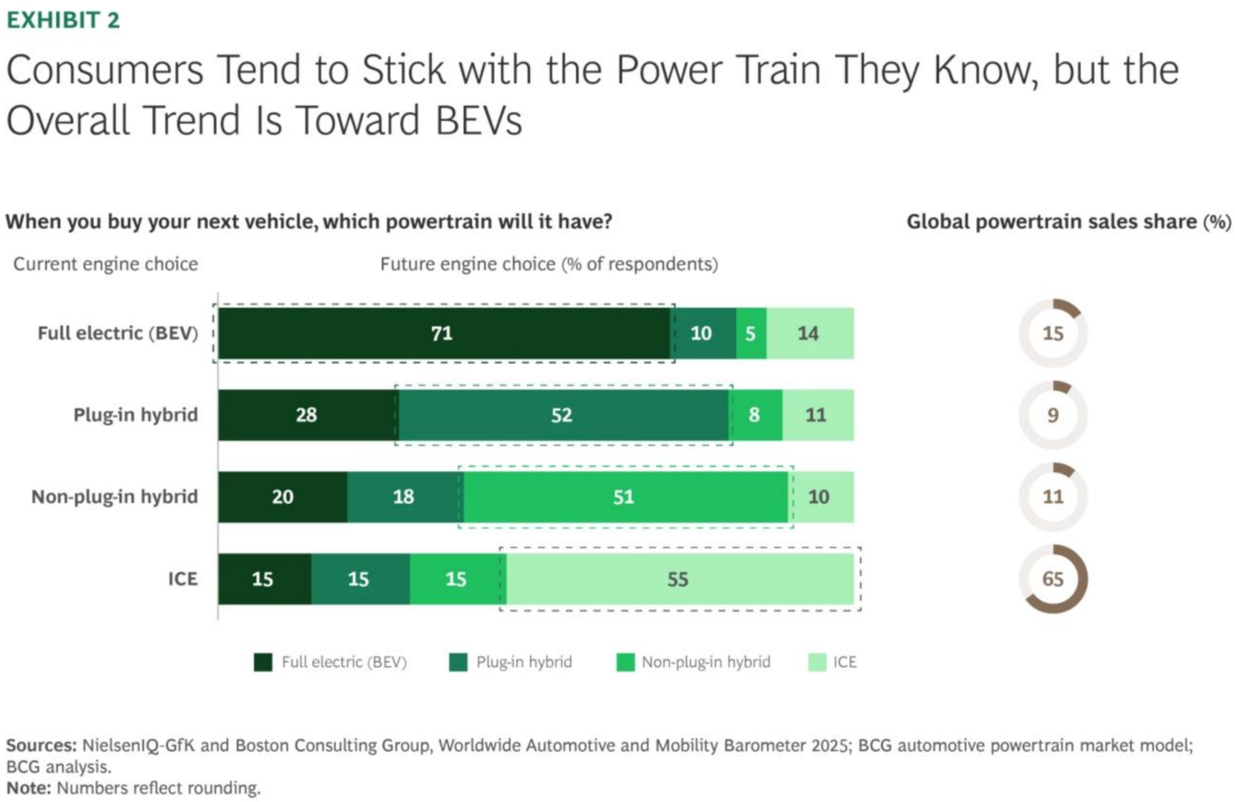


Figure 38: An interesting transition preference survey that does take into account the context, although follow-up with the revealed choice would be of most value (longitudinal studies). Credit to BCG.

In short, **willingness-to-pay for driving range or other EV attributes is very context-dependent.** We illustrated that the purchase price is affected by both range and recharging time, but also the often overlooked attribute of “experience with BEV” appears to be of vast importance, as it changes the values of the range attribute itself. Understanding the need for context and how these factors interact, is essential for designing cost-effective battery sizes, solid pricing strategies, and supportive policy measures.

5.3.5 Charging

Regarding **recharging time**, a 2024 survey[34] measured a WTP of $0.29 per minute ($17.40/hour) to reduce charging time (in a 100-mile recharge range, average income setting). The Belgian 2022 study indicated between €100 to €500. It is literally research into the principle of “time is money”.

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[34] Dong, L., Hardman, S., Bunch, D., Mabit, S., & Chakraborty, D. (2024). Cost Sensitivity and Charging Choices of Plug-in Electric Vehicle Drivers – A Stated Preference Study. UC Davis: National Center for Sustainable Transportation.

Battery-electric vehicle (BEV) policies have largely focused on **price-based incentives** and the **new-car market**, assuming that lowering purchase cost would be sufficient to drive adoption. Yet, real-world adoption patterns show that **contextual variables—particularly infrastructure access, charging cost, and housing type—profoundly modulate the effectiveness** of these incentives.

The speed of BEV adoption is also capped by the pace of upstream network capacity and connection permits. Electrification is seen as a "transport" issue, whereas it is equally an *electricity market integration* challenge. The result is policy asymmetry: generous support for car buyers, but underinvestment in the physical grid and regulatory enablers that make charging reliable, affordable, and resilient.

In many regions, distribution grids are already operating near capacity, leading to multi-year delays in connecting new fast-chargers or depot fleets. Infrastructure improvement is a precondition, and still to be recognized as a high-leverage intervention: e.g. a study[35] on Norway data concluded that a €1,000 price reduction increased BEV sales by 3.09% on average, while the same amount spent on charging station subsidies increased sales by 8.42%—making infrastructure subsidies more than twice as effective per euro. It is a textbook example of context not being picked up.

The result is that charging infrastructure expansion consistently lags behind BEV sales by a **factor of three**, creating a persistent *chicken-and-egg* dilemma: a critical mass of BEVs is needed to justify infrastructure investment, yet infrastructure coverage is a prerequisite for widespread BEV adoption. This imbalance amplifies consumer concerns over charging convenience and reliability.

Urban environments illustrate this challenge most clearly. City dwellers often lack access to private parking or home photovoltaic (PV) systems, leaving them dependent on public charging networks. Public charging is not only **costly (€0.60–0.80/kWh)** but also involves **search and waiting time**, making BEV ownership less practical than in suburban or rural contexts where home charging is feasible.

Charging is not merely a technical variable, —it is **a multidimensional cost factor** encompassing *time*, *place*, and *price*.

- At home, BEVs can operate at around **€3/100 km**, while public charging can exceed **€7–8/100 km**, narrowing or even reversing the operating-cost advantage over petrol.
- Installing a private charging point adds further cost and administrative burden, often exacerbated by **unfavorable fiscal treatment** or landlord restrictions.
- As a result, **total cost of ownership (TCO)** varies dramatically depending on access to home charging—sometimes by **150% on the energy-cost component alone**.

These context effects create a distinct **"homeowner premium"** and **"apartment discount"** in the used EV market—an asymmetry that does not exist for internal combustion engine (ICE) vehicles. BEVs owned by households with home-charging access retain higher value and deliver greater lifetime savings, while those in urban or rental contexts face accelerated depreciation due to higher operating costs and inconvenience.

[35] Katalin Springel, 2021. "Network Externality and Subsidy Structure in Two-Sided Markets: Evidence from Electric Vehicle Incentives," American Economic Journal: Economic Policy, American Economic Association, vol. 13(4), pages 393-432, November.

Furthermore, unlike conventional refueling, which is nearly instantaneous and transparent in price, **EV charging is plagued by fragmentation**. Users face a patchwork of incompatible payment systems, proprietary networks, and vendor-specific apps or RFID cards. Access to the lowest tariffs often requires **subscription-based "memberships" or prepayment schemes**, creating a de facto **vendor lock-in**. This undermines the principle of universal service that consumers are accustomed to in fuel retail.

In addition, **dynamic pricing and poor price visibility**—for instance, variable tariffs depending on time of day, location, or grid load—further obscure cost expectations. While dynamic pricing could in theory improve system efficiency, in practice the absence of clear **price signalling at the point of use** (as one sees with fuel station displays) makes consumers feel manipulated or even deceived. Many charging operators quote prices in €/kWh, others in €/min or per session; some only give an upper bound; roaming fees and idling penalties add further confusion.

The result is **a perceived loss of control over operating costs**, which is particularly detrimental in high-involvement purchases like cars, where transparency and predictability are key to consumer trust. Context-aware policy is about creating conditions: e.g. harmonized billing standards, mandatory display of real-time prices, and open roaming agreements could yield large welfare gains by restoring the intuitive, competitive price signalling that has long underpinned the conventional fuel market.

Such institutional and informational complexities amplify *range and cost anxiety*, especially for new adopters. It reduces the attractiveness of BEVs relative to ICE vehicles, not because of technological shortcomings, but because of **coordination failure in the charging market**.

All of above aspects represent utility context variables that heavily influence charging experience:

1. **Location context:** rural vs. urban setting
2. **Infrastructure type:** home, workplace, or public charging
3. **Energy source:** access to PV/self-generation vs. grid-only
4. **Charging speed:** time required to reach full charge
5. **Interoperability:** universality of charging ecosystem (cross-network access)
6. **Pricing factors:** transparency, predictability, and perceived fairness of tariffs
7. **etc**

While charger density is a visible indicator of infrastructure rollout, it captures only *capacity*, not *utility*. The decision to adopt or use an EV depends on whether charging is **convenient, reliable, affordable, and predictable** in each driver's specific context. A high number of chargers may still deliver *low perceived utility* if they are poorly located, slow, incompatible, overly complex, or expensive.

In this sense, **context variables shape the effective accessibility** of charging in the same way that **physical density shapes nominal accessibility**. Both dimensions jointly determine real-world usability:

- *Without enough chargers*, access is constrained.
- *Without supportive context*, access remains inconvenient or unattractive.

Neglecting context thus undermines behavioural change, because consumers evaluate **the experience**, *not the count*. Therefore, *utility context is not secondary—it is co-determinant* of adoption, as it defines the *quality* of access while infrastructure density defines its *quantity*.

Failing to recognize this dual playfield, reinforces a **lock-in effect** favouring ICE vehicles, whose ecosystem benefits from over a century of dense infrastructure—ubiquitous refuelling stations, repair networks, and spare parts availability.

Hybrid (HEV) and plug-in hybrid (PHEV) vehicles, by contrast, leverage this existing network. PHEVs, in particular, function as **"training wheels" for electrification**: they mitigate range anxiety, infrastructure dependence and many other wide BEV utility gaps.

5.4 Policy implications

The presented foundations of decision and driver dynamics, together with the illustrations in this chapter, underscore that BEV policy cannot rely on price instruments alone. It calls for a profound **shift in policy** thinking **— from a *price-centric* to a *utility-centric* paradigm**.

- A context-aware policy portfolio integrates non-price levers, making sustainable options *feel* better and conventional ones *less convenient* achieves larger behavioural shifts per euro spent than uniform purchase subsidies. It deploys *context-differentiated measures to* target heterogeneity, transforming subsidies from blunt instruments into precision tools.

- Once contextual enablers are in place, adoption accelerates non-linearly and becomes self-sustaining. Recognizing "**policy benefit pockets**" — points where modest, well-targeted interventions trigger cascading behavioural change — is key to maximizing impact under budget constraints. Contextual differentiation enhances both efficiency and equity, avoids free-riding and builds broader political and social legitimacy for the electrification agenda.

In automotive, context variables are exactly what is otherwise referred to as the "**enabling conditions**" that OEM point at. These are in past policies and academic models often overlooked or only regarded as secondary. Which is surprising, as overlooking contextual drivers runs the risk of producing biased weights. The traditional view too often treats context as refinement, as nice-to-haves.

Not adequately taking into account this context leads to weights being incorrectly attributed, resulting in mis-specified models, and ultimately policymaking suffers from:

- **Misidentified Barriers**: biased estimation suggests e.g. Range is the primary barrier. While in reality Range matters much more in specific contexts (rural, no home charging). It would be a policy mistake to invest billions only to EV with a long-range battery. A cheaper and more optimal solution would be to targeted infrastructure for underserved contexts.

- **Inefficient Subsidy Design**: biased estimation suggests high Price sensitivity uniform across population. But in reality, price elasticity varies by income, urban/rural, home charging access. A flat €7,500 subsidy for all buyers would be a policy mistake. The context-inclusive model could refine the policy to means-tested subsidies (higher for low-income) and infrastructure subsidies (for apartment dwellers).

- **Incorrect Forecasts:** biased weights give biased elasticities and therefore wrong adoption predictions. E.g. weight estimation without income context predicts that: "5,000 subsidy yields 15% adoption increase. In reality the effect is 25% for low-income (high weight), 8% for high-income (low weight). It explains why targeted adoption rates are not achieved in the EU.

- **Misunderstood Market Dynamics: w**ithout context one might conclude "EVs are competitive in urban areas because of superior performance", but *with context* one discovers: - "EVs are competitive in urban areas because infrastructure + short trips + parking incentives create favorable context" The implication for policymaking: replicating urban success in rural areas requires different interventions, not just better or more supply of vehicles.

Conventional monetary approaches that rely on narrow subsidies, taxes, or price parity assumptions misrepresent the broad actual **decision calculus** of consumers and fleets. Real-world adoption hinges on *perceived* utility, which is co-determined by contextual, infrastructural, and behavioural factors. Therefore, a **utility-based** framework enables policymakers to understand and act upon the true determinants of consumer choice - delivering faster, fairer, and more resilient decarbonization outcomes.

5.5 Conclusion

The third link between the new and used vehicle markets operates through the **behavioral and contextual dimensions** that shape individual and collective **utility perceptions**. Whereas the *Flux Bridge* connects markets through the **quantity flow** of vehicles and the *Depreciation Bridge* through **price and value transmission**, the **Utility Bridge** encompasses the **enabling conditions, institutional frameworks, and consumer contexts** that modulate both.

This bridge reflects how **policies, infrastructure, incentives, and information** shape the perceived **utility and risk** associated with different vehicle technologies. These contextual factors — including **charging availability, taxation, income distribution, regulatory certainty, and cultural acceptance** — alter the **weights** consumers assign to cost and non-cost attributes within their decision-making processes. In economic terms, they **reshape the utility function** that underlies market behavior, thereby modifying both the speed and direction of technological diffusion.

It is important to note that these behavioral and institutional parameters affect **both markets simultaneously**. Policies that target only new vehicle supply (e.g., CO_2 standards or purchase incentives) may **distort adoption dynamics** if not accompanied by **complementary measures** in the used market, such as warranty regulation, secondary financing instruments, or trade facilitation. Similarly, the **absence of enabling infrastructure or resale confidence** can attenuate consumer willingness to adopt even when TCO or purchase price parity is achieved.

The **Utility Bridge**, therefore, represents the **systemic layer** that integrates economic, behavioral, and institutional feedbacks across both markets. It is through this bridge that **contextual variables propagate**—reshaping the entire **utility landscape** of the mobility ecosystem. Only by addressing these enabling conditions holistically can policy interventions achieve durable, equitable, and self-sustaining progress toward **transport decarbonization and fleet renewal**.

6 Appendix – Vehicle stock flow statistics

In this section, we offer a broad aggregated view on the components of the used market in the EU bloc. The attention here is predominantly focused on the role of BEV and PHEV powertrains.

6.1 Components

The vehicle stock interacts with inflow and outflow, and in case of vehicles, possesses another internal of subflow through the process of resales, giving vehicles several usage cycles under different owners.

Keeping track of the absolute numbers happens with varying degrees in real life:

- Inflows are well-recorded[36] in official national databases. New vehicle **registrations** are the official recording of a civilian vehicle with the competent authorities to permit legal road use.

- Outflows are much less followed up. Vehicle **deregistration** is the process of formally removing a vehicle from the national vehicle register, but the final destiny is rarely known.

- Internal flows are least transparent, as domestic resale or transfer of used vehicles do **not** generate a new registration, and there is free movement of vehicles with international trading companies.

In summary, the stock of vehicles, be it at the global, national, local or company level, is the result of several flows over time. This is visually depicted in the figure below.

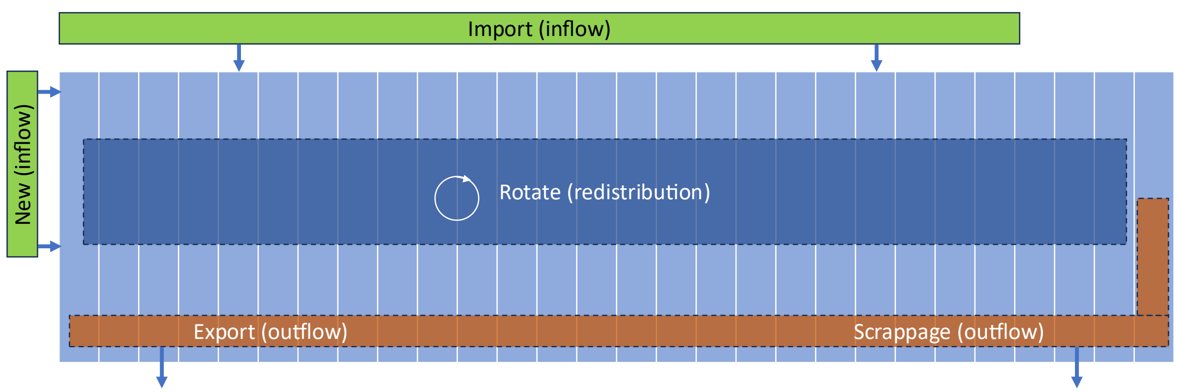

Figure 39: Vehicle stock in all age bands is undergoing inflows (new and import) and outflows (export and scrappage).

Let us have a closer look at a breakdown of the flows of the used vehicle stock into its components.

[36] It is estimated that about 2% of vehicles in the EU are driven uninsured/unregistered, but this peculiar stock population is commonly neglected.

6.2 Inflow

Two categories constitute **inflows** to the national vehicle stock:

1. **New vehicles:** never previously registered or driven on public roads. This includes vehicles manufactured domestically and vehicles imported as new.
2. **Used imported vehicles:** have been previously registered in a foreign country and driven. Imported used vehicles receive a (new) registration when they enter the country.

6.2.1 New

According to ACEA 2024 figures, total new inflow is the sum of the flow of:

- new vehicles manufactured domestically (~60%) and
- new vehicles imported from non-EU (~40%).

In the EU-24 in 2024, New Passenger Vehicles (PV) comprise circa **10.5 million** registrations per annum, while new Light Commercial Vehicles (LCV, up to 3.5 tonnes) comprise circa **1.6 million** registrations per annum. The ratio of new LCV to new PV is circa 1 to 6.

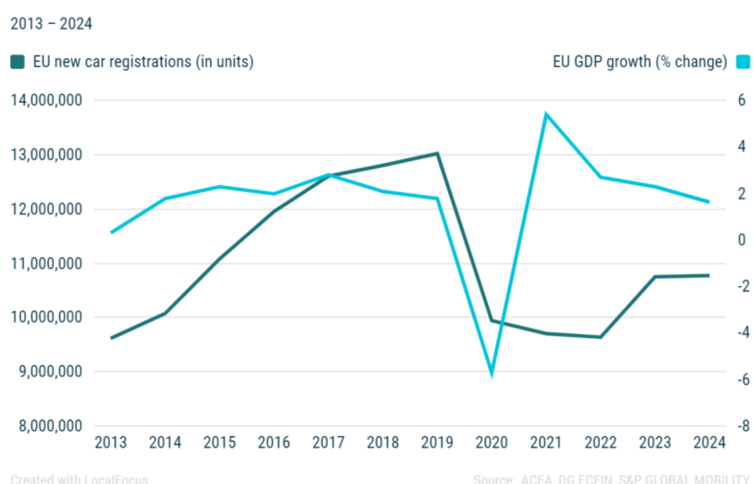

Figure 40: The Covid period was disruptive, but this has stabilized, yet no recovery in new market.

The average annual number of new passenger vehicle (PV) registrations in the EU-24 over the past three years has been around 10.5 (based on Eurostat) million, reflecting a market that continues to recover after the post-pandemic supply disruptions.

The structure of these new registrations by powertrain type shows that electrified vehicles are gradually gaining market share. As illustrated in the chart below, hybrid vehicles now account for a similar number of new registrations as conventional petrol cars, while fully electric vehicles (BEV) represent around 13% of all new passenger cars in 2024.

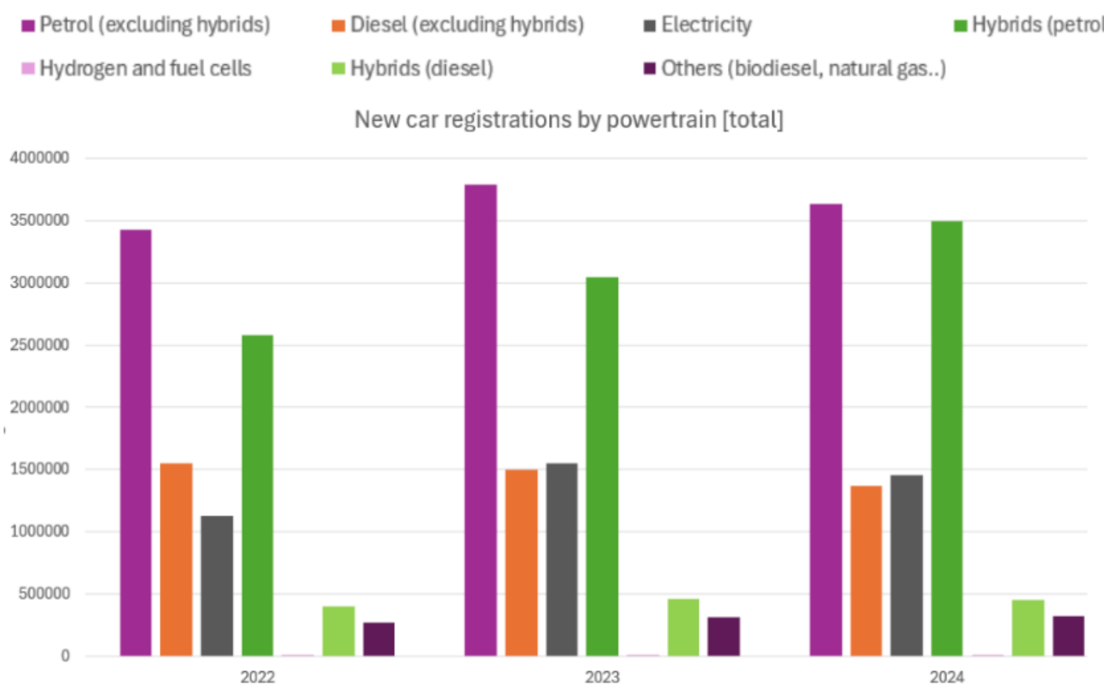

Figure 41: The distribution of newly registered passenger cars by powertrain type, highlighting the growing share of hybrid and electric vehicles.

This reflects the continued diversification of the European new car market and the progressive shift in inflow composition from internal combustion engines to low- and zero-emission technologies.

6.2.2 Used import

Used imported vehicles have been previously registered in a foreign country and driven.

Import of **used cars** from abroad into EU is *marginal (as compared to the import of new cars)*: around **250k units** per annum[37]. This is due to the strong industrial automotive production base of the EU. The new vehicle market is thus relatively about **50 times** larger than used import.

[37] Zacharof, N., Nur, J., Kourtesis, D., Krause, J. and Fontaras, G., A review of the used car market in the European Union, Publications Office of the European Union, Luxembourg, 2025, JRC140203.

Trade flows of used passenger vehicles involving the EU (2010 – 2022)

The Figure below summarizes the international trade flows of used passenger vehicles related to the EU. While intra-EU exchanges and exports outside the Union have grown steadily, imports from non-EU countries remain marginal and relatively stable over the past decade.

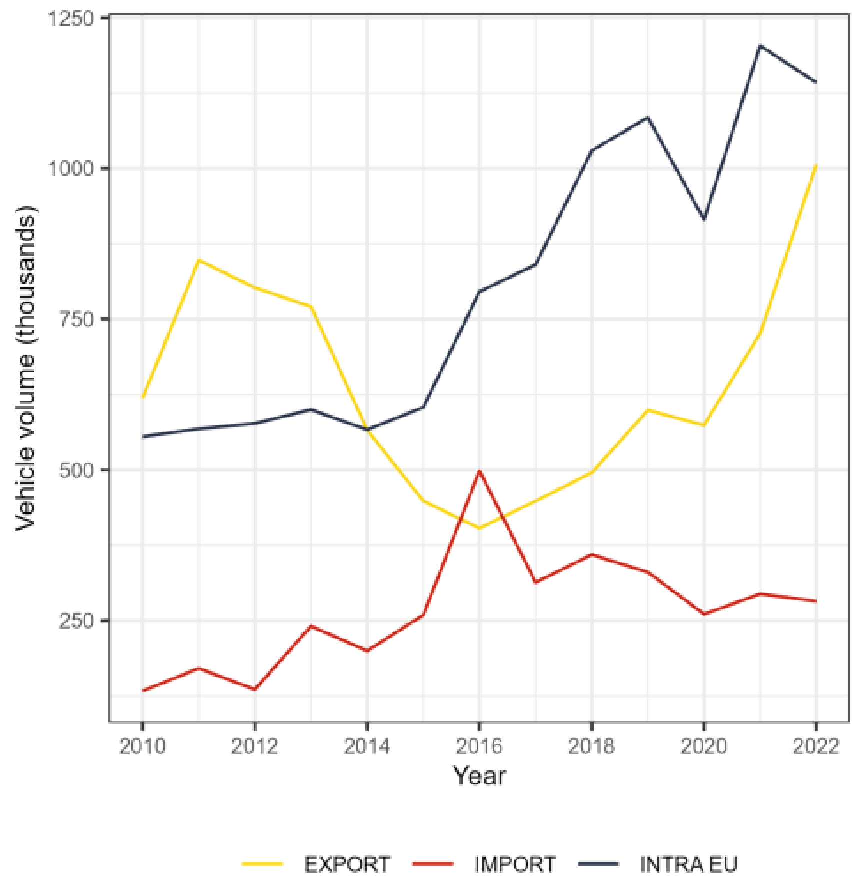

Figure 42: A breakdown of the vehicle flows within EU.

The chart illustrates the volume of used passenger vehicles traded within the EU (intra-EU), exported outside the Union, and imported from non-EU countries.

The data clearly show that the European Union acts primarily as an exporter of used vehicles, with intra-EU exchanges exceeding one million units per year, while imports remain below 300 000 units annually. This confirms the self-sufficiency of the EU used-car market and the limited significance of extra-EU imports compared to domestic and intra-EU flows.

Used passenger car trade trends by Member State in the EU-27

The structure of trade flows differs across Member States, as illustrated in figure below, showing varying levels of intra-EU exchange intensity and export orientation.

Figure 43:breakdown of vehicle flows per country.

The figure shows the development of used passenger car trade flows by country, distinguishing between intra-EU exchanges, extra-EU exports, and imports from non-EU countries.

Intra-EU trade dominates in almost all Member States, particularly in Germany, France, and the Netherlands, which act as major hubs for cross-border vehicle exchange within the Union. Imports from non-EU markets remain marginal in volume, typically below 100 000 units per year per country, whereas extra-EU exports (yellow) have been increasing steadily, especially from Western European countries.

6.3 Outflow

Two categories constitute an **outflow** from the stock:

- **Export:** the owner decides to sell it on foreign markets

- **Scrapping**: the process of dismantling and recycling an old, damaged, or unwanted vehicle that is beyond economical repair.

Notice that the total scrappage outflow is a **sum** over the outflows of:

- **Mechanical/technical failure** → scrappage due to wear-out or prohibitive repair cost.
- **Accidents** → scrappage after total write-off events.
- **Policy-driven retirement** → incentivised scrappage programs, emissions bans.

Mechanical failure is the **largest and most persistent driver of outflow**[38], because vehicles, like any other technical product, have inherently a limited lifespan. Their components simply wear out over time under normal use. It requires a great deal of regular investment to keep it roadworthy: about the same amount as the purchase cost of the vehicle is spent on regular maintenance and repair, in prolonging its lifespan.

6.3.1 Scrappage

In total around **11 million vehicles** reach end-of life **and** leave European roads[39] due to total loss after an accident, economic write-off, non-compliance with new safety or emissions standards or a change in design preferences. After deregistration, the final destiny is uncertain:

- **Legally scrapped** **(~40%)**: processed within the EU at authorized recycling facilities. The vehicle is typically dismantled for (partial) recycling against circa 0.2 eu/kg.

- **Unknown (~60%):** mostly illegal scrapping, dumping, including circa 1 million units that are illegally exported as "used" vehicles to non-EU countries.

Mechanical outflow stands out as it is purely a *vehicle-level* property, while all other outflows are shaped by the economic, regulatory and social context of the stock considered.

The dynamics of the stock are governed by the simple law that vehicles leave the stock at a rate dependent on their age.

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[38] The category of administrative removals (e.g. seasonal, theft, abandonment, long-term storage (speculation, or display), etc.) can be considered negligible in outflow.

[39] European Mobility Atlas, Heinrich-Böll-Stiftung European Union, Brussels, Belgium, publication, 2021

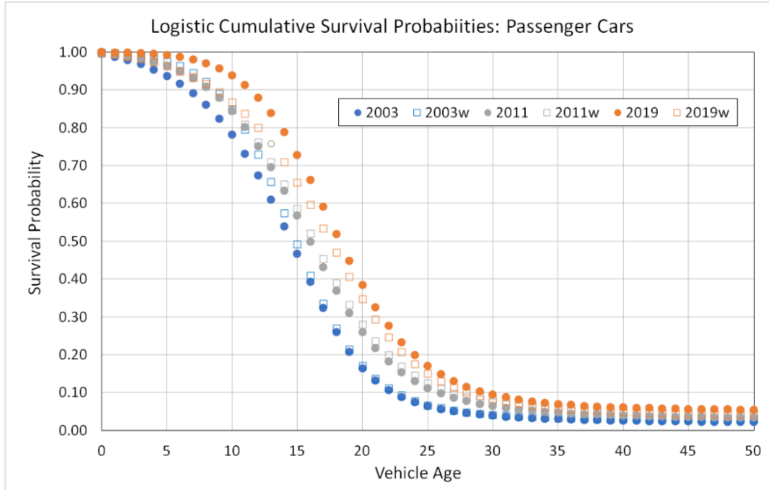


Figure 44: Improved quality, safety and standardized maintenance led to increased longevity.

On the one hand, wear-and-tear, which is an intrinsic effect belonging to the vehicle itself, dominates the form of the survival curve. On the other hand, different countries exhibit very different curves, despite having the same vehicle composition, due to the extrinsic influence from (i) export, and (ii) import. Thus outflow depends additionally on the local economic and social context of the country.

More specifically, a study[40] demonstrates the separate impact of the cross-border balance on the outflow rate, which is relevant to understand powertrain diffusion dynamics. Some countries have strong export markets: their car owners prefer selling their used cars to foreign markets, long before their "natural" retirement age in the national market. Conversely, some countries have strong import markets: instead of buying brand new cars from local distributors, buyers prefer imported used cars from foreign markets.

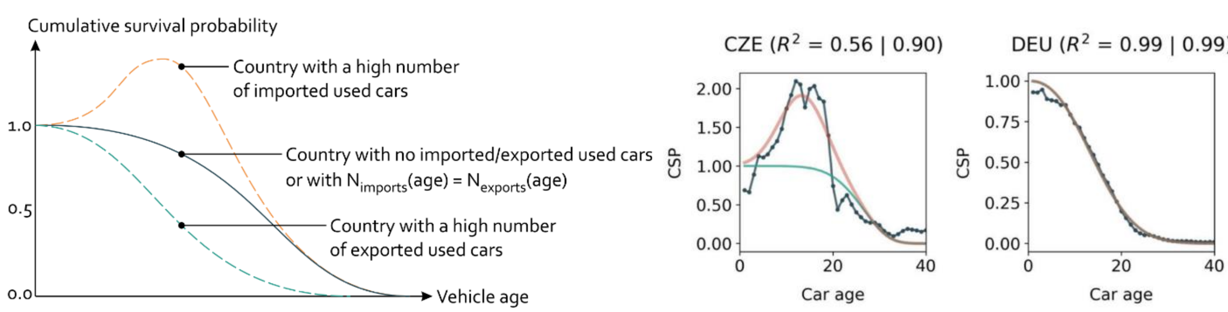


Figure 45: Left: impact of import or export on the normal stock outflow; (right) examples of Czech outflow profile with strong used vehicle import effect, and German profile with effect of young used car export. Credit of figures to Held et al. 2021.

[40] Held, M., Rosat, N., Georges, G. *et al.* Lifespans of passenger cars in Europe: empirical modelling of fleet turnover dynamics. *Eur. Transp. Res. Rev.* 13, 9 (2021).

Ratio of newly registered and decommissioned passenger cars (2007–2023)

The balance between new vehicle registrations (inflow) and decommissioning or scrappage (outflow) determines whether the overall passenger car stock is expanding or contracting.

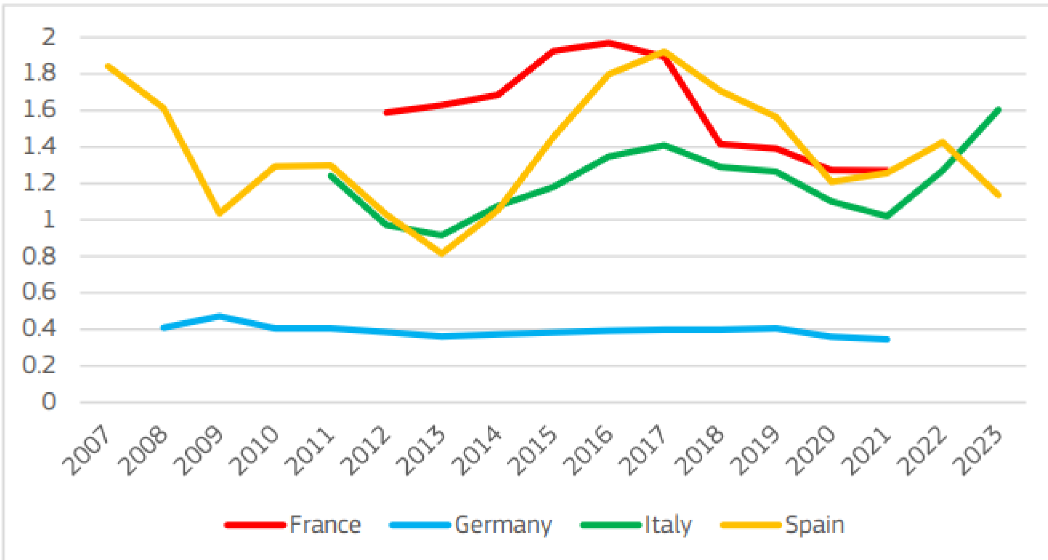


Figure 46: The dynamics of the passenger car stock are determined by the interaction between new registrations and vehicle decommissioning. The curves represent the ratio between these two flows, indicating whether national fleets are expanding or contracting.

This is illustrated as a ratio for several major EU markets. A ratio above 1.0 indicates fleet expansion, as more new cars are registered than decommissioned, whereas a ratio below 1.0 suggests a shrinking or ageing fleet.

France and Spain show stronger fluctuations over time, reflecting both market cycles and incentive-driven scrappage programmes. Germany maintains a nearly balanced pattern, consistent with its stable new-car market, while Italy displays a moderate post-pandemic recovery.

These trends reveal structural differences in fleet renewal rates across Member States, which directly influence both the size and the average age of the European passenger car stock.

Annual volumes of newly registered and decommissioned passenger cars (2008–2023)

The chart illustrates the absolute number of new registrations (solid lines) and vehicle decommissioning (dotted lines) in four major EU markets.

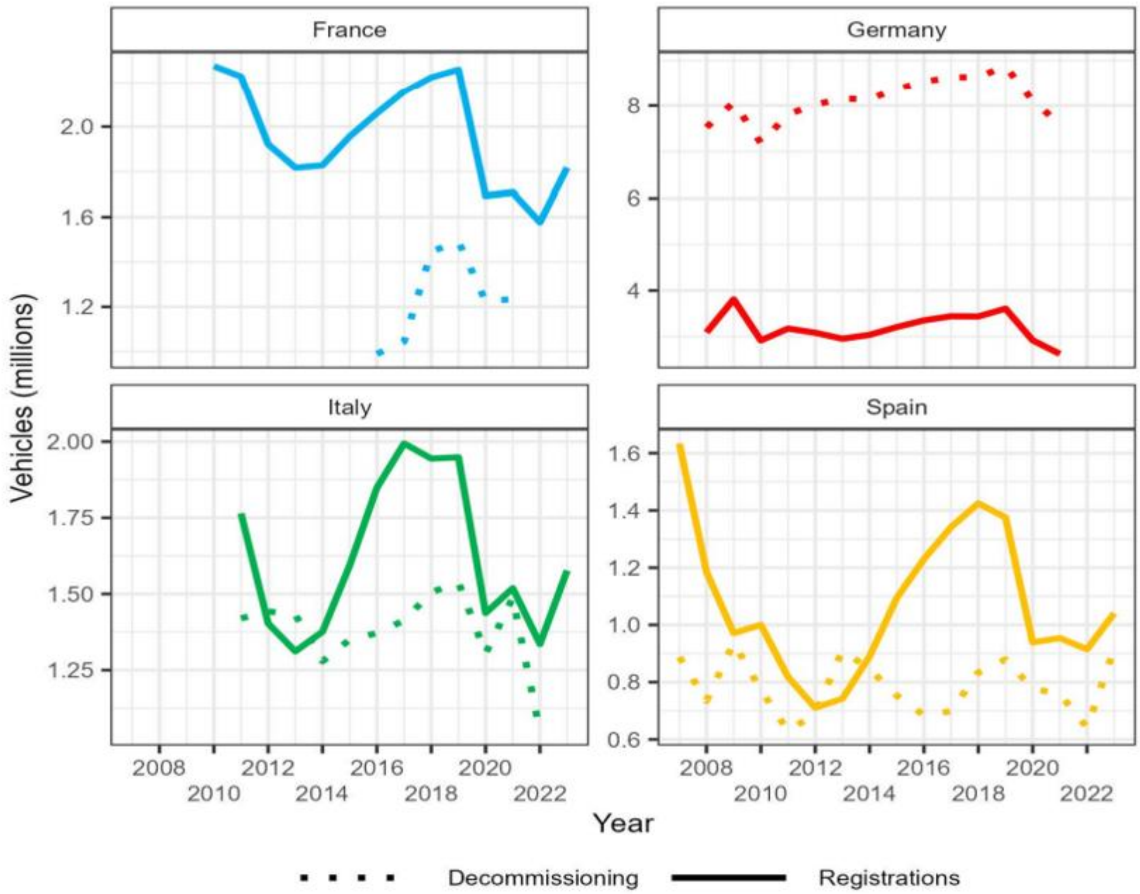


Figure 47: The dynamics of the passenger car stock are determined by the interaction between new registrations and vehicle decommissioning. The Curves show the absolute annual volumes of newly registered and decommissioned vehicles in major EU markets, providing a more detailed view of the underlying balance that drives fleet renewal.

Germany maintains the largest overall volumes, with relatively stable trends.France and Italy show sharper cyclical fluctuations driven by economic conditions and policy incentives, while Spain displays the strongest volatility, particularly during post-crisis recovery periods.

These differences highlight the varying intensity of vehicle replacement and stock growth across Member States.

6.3.2 Export

Export of **used cars** from the EU bloc to foreign countries is *marginal (as compared to the scrapping of used):* circa **1 million units** annually[41].

The total trade in cars between the European Union and non-EU countries slightly decreased in volume between 2019 and 2024 but increased significantly in value. The number of exported vehicles fell by 13%, and imports declined by 3%, reflecting the impact of supply shortages and changing demand patterns.

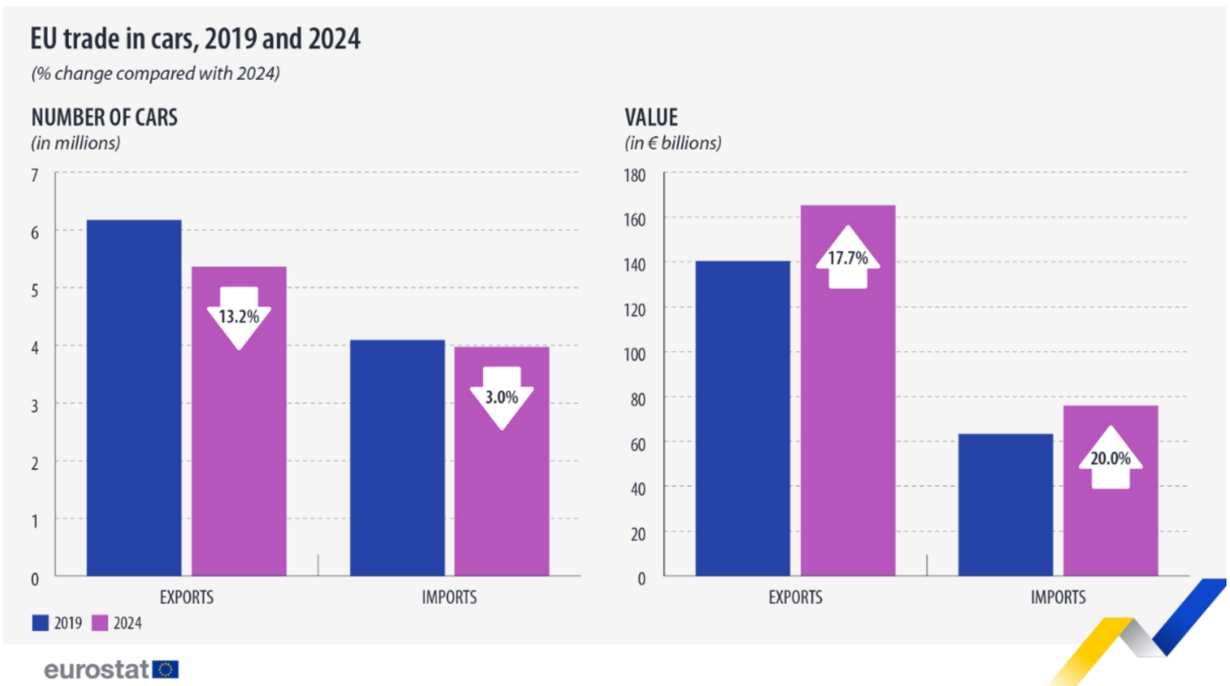


Figure 48: A view on EU bloc vehicle flows outwardly and inwardly.

However, in value terms, exports rose by 17.7% and imports by 20%, driven by higher average vehicle prices, electrification, and the growing share of premium and technologically advanced models. This trend underlines the structural shift of the EU car trade towards higher-value vehicles despite stagnating volumes.

[41] Zacharof, N., Nur, J., Kourtesis, D., Krause, J. and Fontaras, G., A review of the used car market in the European Union, Publications Office of the European Union, Luxembourg, 2025, JRC140203.

6.3.3 Cross-border EU

Main export flows of used passenger vehicles from EU Member States (2023)

The export dimension of the European used-vehicle market is illustrated in figure below, showing how Member States channel used cars either to other EU countries or to destinations outside the Union.

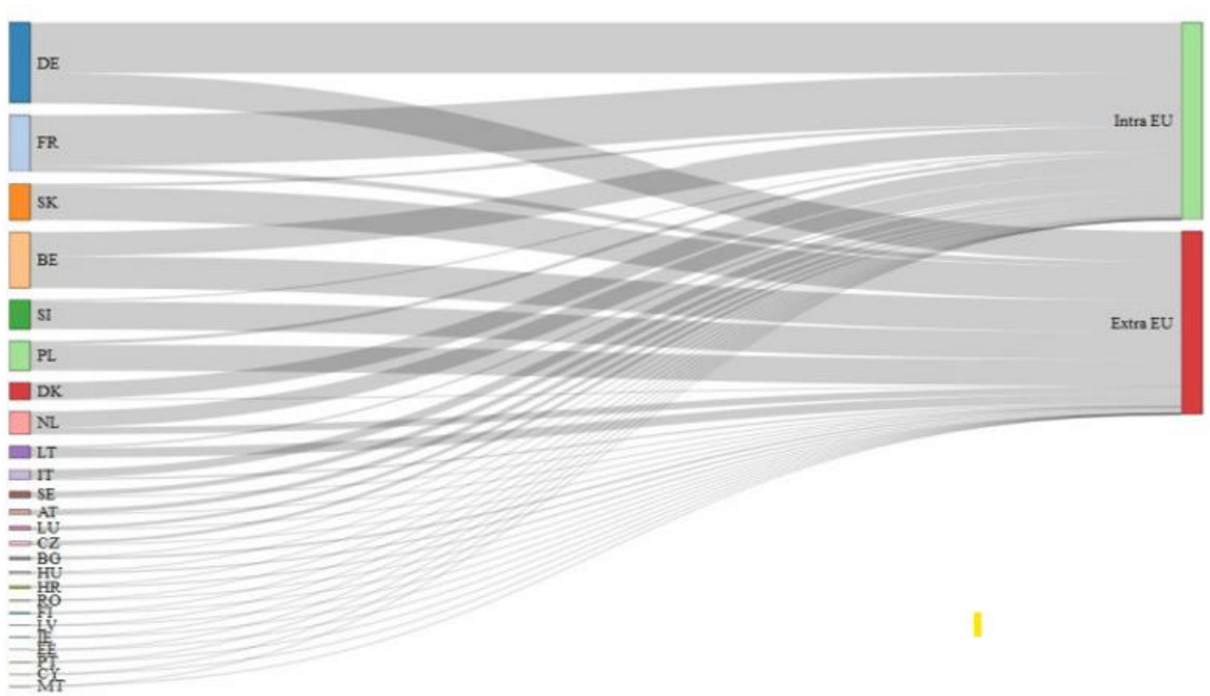


Figure 49: A visual of the cross bloc export flows in EU 2023.

The figure visualises the principal export flows of used passenger vehicles from EU Member States, distinguishing between intra-EU exports (to other EU countries) and extra-EU exports (to non-EU destinations).

The data highlight that Germany and France are by far the largest exporters of used cars within the EU, followed by Slovakia, Belgium, and Slovenia, which also act as major re-export hubs.

A substantial share of vehicles exported outside the EU originates from Western and Central European countries, while smaller Member States show more balanced flows between intra- and extra-EU trade. Overall, the analysis confirms that the European used-car market is highly interconnected internally, yet remains a net exporter globally, with a consistent surplus of vehicles leaving the Union compared to imports.

Intra-EU trade flows of used passenger vehicles, 2015–2020

The figure illustrates the main trade flows of used passenger vehicles between EU Member States. Germany, France, the Netherlands and Belgium appear as the principal exporting countries, while Poland, Romania, and Bulgaria are the leading importers of used vehicles.

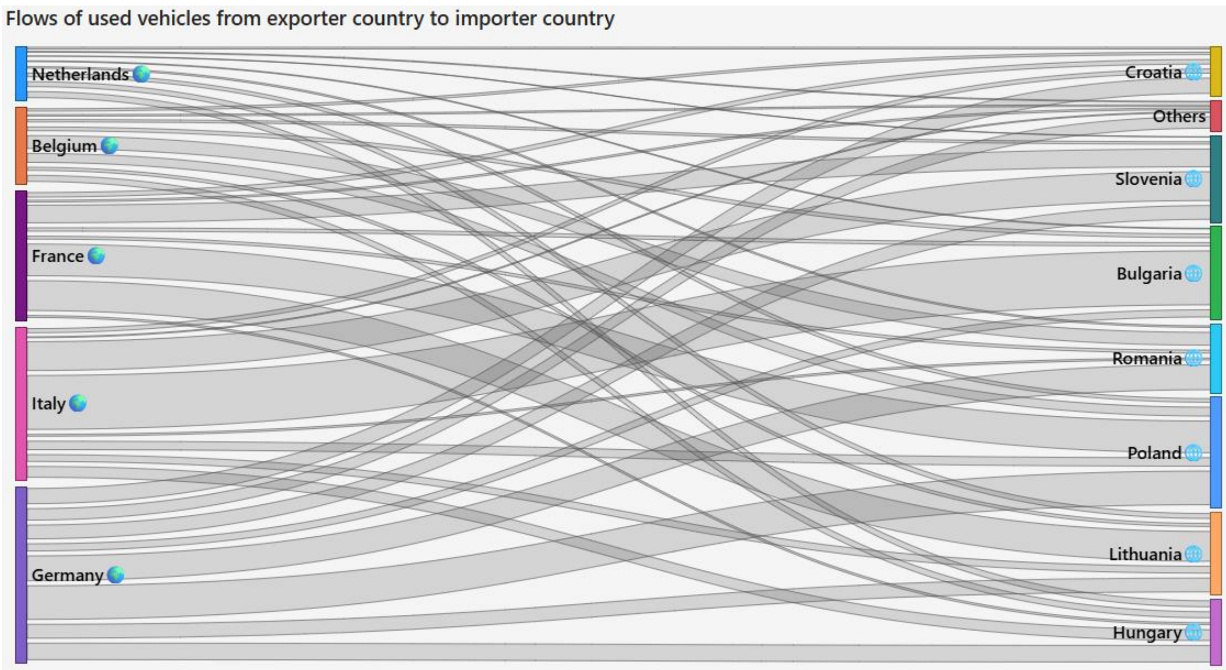


Figure 50: A visual of the intra-bloc flows

Germany is the largest exporter, with significant volumes directed towards Central and Eastern Europe. Poland alone absorbs a substantial share of EU-wide imports, while Lithuania acts as a transit and re-export hub, serving markets outside the Union.

These flows highlight a clear eastward movement of older vehicles within the EU, driven by differences in purchasing power, emission standards, and vehicle taxation. The pattern confirms the structural segmentation of the European used-car market between western supply and eastern demand.

6.4 Stock

The used vehicle stock of a region is defined as the total inventory of second-hand vehicles available for sale or transfer.

Over EU-27 in 2024, the total stock of Passenger Vehicles (PV) comprises circa **253 million** units, while total stock of Light Commercial Vehicles (LCV) comprises circa **32 million.**

As a rule of thumb, there is about 1 LCV for every 8 PV in use on the road.

The **non-EU** stock within Europe, is in size about one third of the **EU stock**.

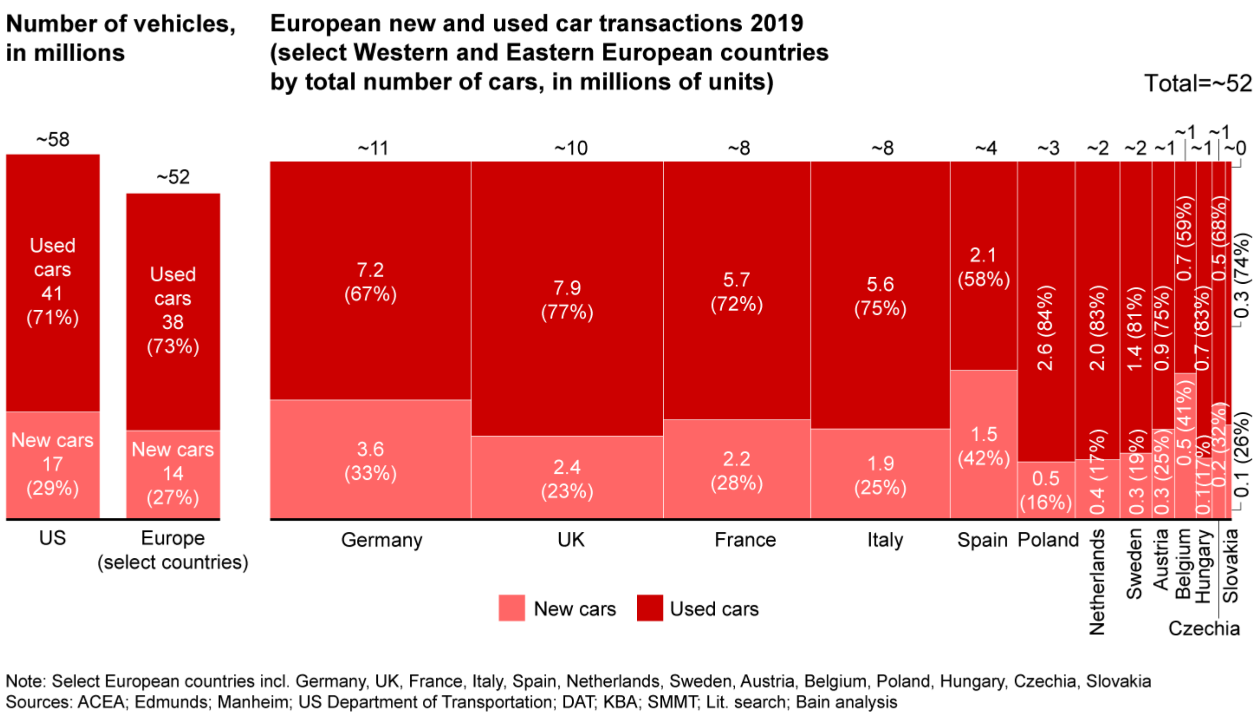
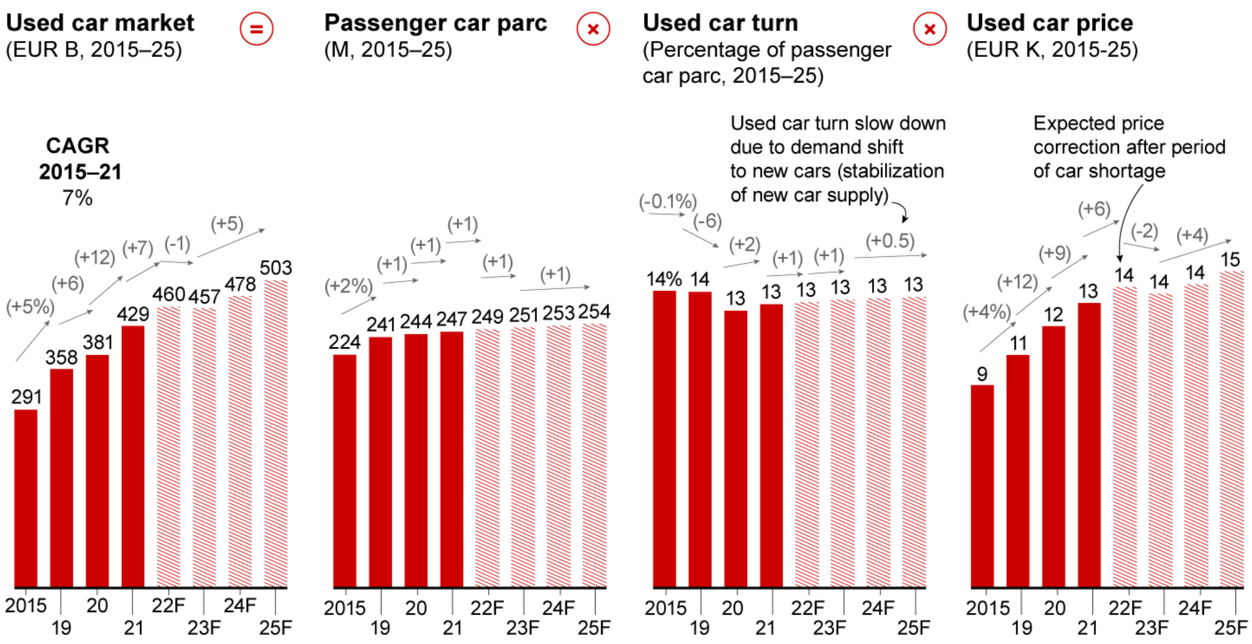


Figure 51: An overview of the new and used car units and transactions. Credit to Bain.



Source: Bain Market Model

Figure 52: Key metrics of the used car market. Credit to Bain.

6.4.1 Motorization rate

If the **inflow rates** are greater than the **outflow rates**, the total number of vehicles will increase, causing the motorization rate to rise. Conversely, if outflows exceed inflows, the fleet will shrink, and the motorization rate will fall.

$$Motorization\ Rate(t) = \frac{Stock(t)}{Population(t)} \times 1000$$

Rising motorization rates (cars per 1,000 inhabitants), which reached an EU average of 576 in 2024, are due to

- improving living standards lead to Multi-Car Households
- better access to affordable used cars
- Vehicles are lasting longer due to improved durability
- better maintenance
- economic incentives to repair rather than replace
- fuel efficiency, and alternative fuels (e.g., diesel-gas shifts) have made cars more appealing and longer-lasting
- no more scrappage incentives
- Urban and suburban expansion

- Shifts in work patterns (e.g., remote/hybrid work post-COVID) have also encouraged secondary car ownership for flexibility.
- Trade imbalances: While exports of used cars have increased, net retention within the EU (intra-EU flows) contributes to stock buildup.
- Favorable policies for EVs indirectly support stock growth by diversifying options

Currently outflow (circa 3%) is lower than inflow (circa 5%), leading to net accumulation (circa +1%). This "legacy effect" means fewer vehicles are decommissioned annually. Eastern EU countries show the fastest increases due to catch-up growth, while Western Europe faces saturation but still adds vehicles through multi-ownership.

That means there are **more cars in circulation overall**, which weakens used-car prices in general. However EVs, being the more expensive and fastest-growing segment, feel the brunt of this oversupply.

This trend poses challenges for decarbonization, as older ICE fleets hinder emission reductions. Future policies like scrappage incentives could mitigate this, but without intervention, stock may reach 270 million by 2030 for eu-27, at the current constant rate.

EV market growth adds to stock without proportional scrappage of ICE vehicles. In other words, EV sales today **add to the global car stock**, because scrappage of ICE vehicles does not rise proportionally with EV uptake. Since BEV started uptake around 2015, it will take up till about 2035 before the scrappage of BEV is starting.

Instead of incentives on the inflow side, the EU could also achieve its goals by incentives on the **outflow side** (e.g. scrappage subsidies, export controls, or boost car recycle ng programs, faster turnover in leasing fleets). Focusing only on EV sales growth risks overstating climate progress if scrappage and total fleet size are ignored.

In short: EV growth alone doesn't guarantee emissions decline, because the *stock* of ICE cars is 'sticky'. Unless policies target the existing fleet, we'll have a "layering effect": EVs adding on top of ICE cars rather than replacing them.

6.5 Resales

The (unit) resale rate is a sum of subflow or turnaround rates consisting of

- Intra-Member State unique vehicle transfers (97%)
- Inter-Member State (or cross-border[42]) vehicle transfers (3%).

[42] Cross-border intra-EU dealer relationships enable redistribution that bypasses traditional import/export statistics, making actual redistribution volumes significantly (10% to 20%) higher than recorded trade flows. Without specific dealer transactions, the extent remains speculative.

In 2024, the number of used passenger car resales in the EU bloc is estimated[43] at **38 million** annually. It is noteworthy that depending on the country, 75%-90% of consumers buy only used vehicles.

The "trade-in rate" for new vehicle purchases refers to the percentage of new car buyers who trade in their old vehicle. Recent data indicates the rate is around 40%, though this can fluctuate. In 2022, this rate was 45.2%. Trade-ins are a significant part of the market, with about half of all dealer sales involving a customer trade-in, and roughly 65.6% of the used vehicle inventory comes from these transactions.

6.5.1 Cycles

Each new-car sale generates approximately 3 to 4 used-car sales over the vehicle's lifetime (across multiple ownerships), although the level of change of ownership varies substantially between countries.

Arthur D. Little summarizes an interesting metric: "*The ratio of new car transactions to used car transactions varies by country. Pre-pandemic, it ranged from fewer than one UC transaction for every new one in Saudi Arabia to three to four used car transactions per new car transaction in the UK (see Figure below). In Europe, the long-term average is between two-and-a-half and three, with vehicles typically changing hands at two to five years, five to 10 years, and 10 years of age or older*."

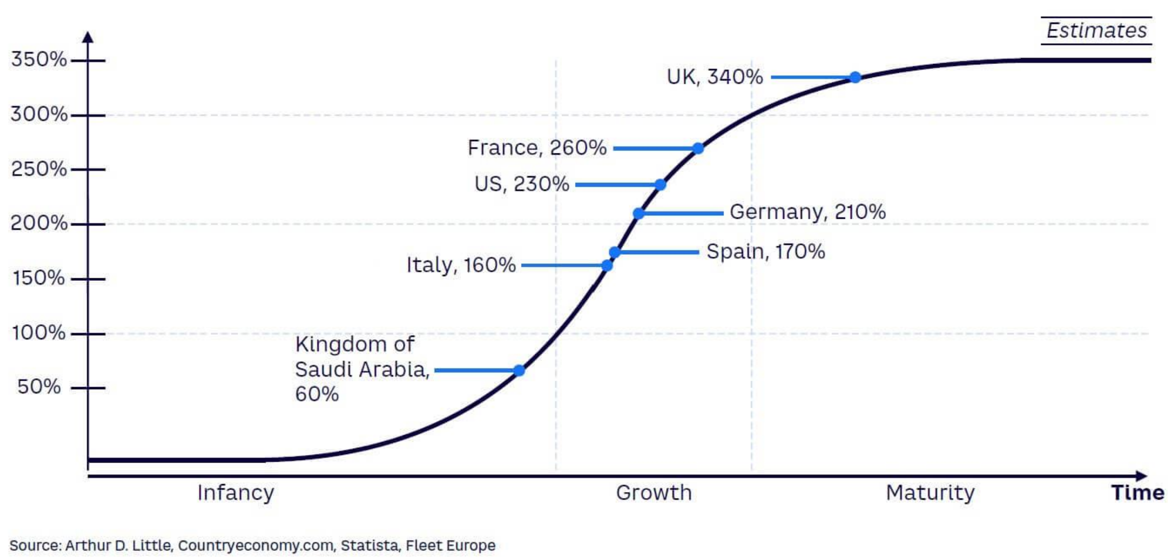


Figure 53: The used car market is not always larger than the

[43] Zacharof, N., Nur, J., Kourtesis, D., Krause, J. and Fontaras, G., A review of the used car market in the European Union, Publications Office of the European Union, Luxembourg, 2025, JRC140203.

According to [Bain and company](), over Europe, 44% were sold privately in consumer-to-consumer (C2C) transactions, while 56% were sold by professional retailers (B2C), which tend to focus on higher-class, younger cars.

So far, Europe's car retailers are still highly fragmented, and most firms operate only in very confined local markets: Together, Europe's top 20 car dealerships trade only around 6% of all used cars.

6.5.2 Turnover

The level of turnover within the passenger car fleet reflects the activity of the second-hand market and the overall liquidity of used vehicles. The Figure below shows the number of annual ownership transfers in the four largest EU-27 markets.

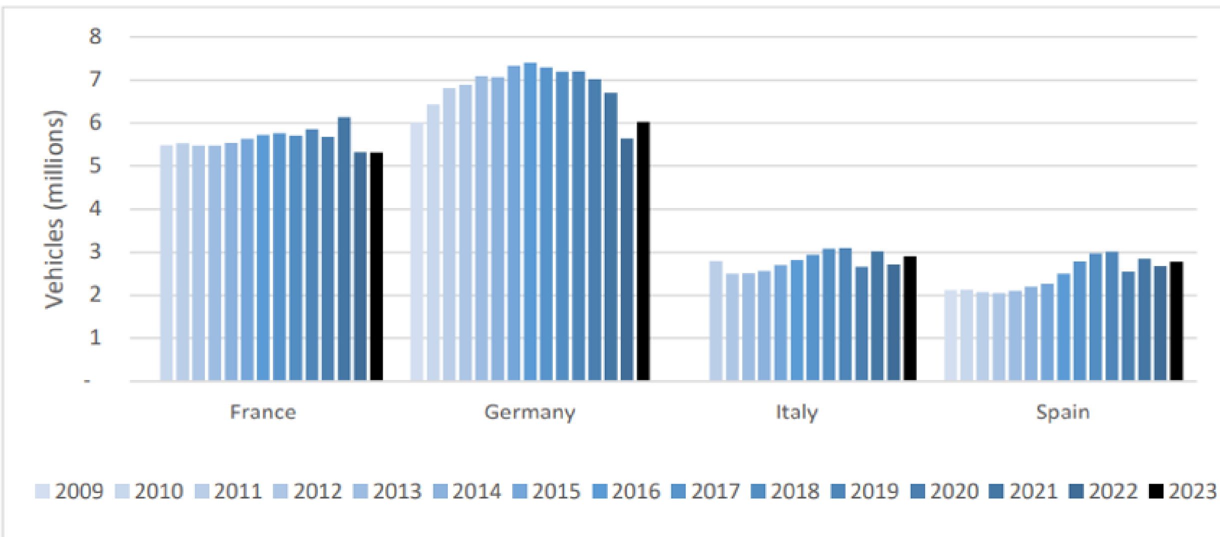


Figure 54: Illustration of turnover variation in some EU countries.

France and Germany display relatively high and stable turnover volumes, exceeding five to seven million ownership changes per year, indicating mature and liquid used-vehicle markets. In contrast, Italy and Spain have significantly smaller secondary markets, each accounting for less than half the volume of France or Germany, although their activity has gradually increased in recent years.

These differences demonstrate how national market structures and consumer behaviour influence the speed of vehicle circulation and the average age of cars in use.

Ratio of turnover and newly registered passenger cars (2010–2023)

Beyond absolute volumes of ownership transfers, the ratio between used-car turnover and new-car registrations provides insight into the relative maturity and dynamics of national second-hand markets.

As shown in the figure below, the turnover-to-registration ratio is consistently above one in all major EU markets, confirming that used-car sales significantly exceed new registrations.

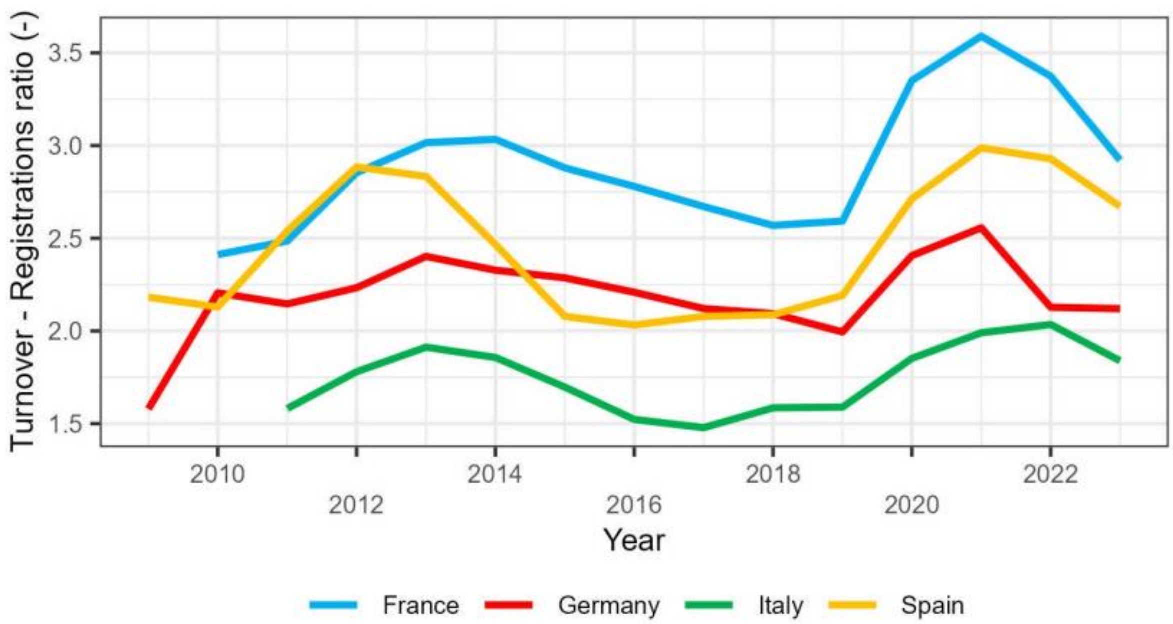


Figure 55: The used car market is large compared to the new market. Credit to JRC.

France and Germany exhibit the highest ratios, with used-car transactions reaching up to three times the number of new registrations, particularly after 2020, when new-vehicle supply constraints intensified demand for used cars. Italy and Spain maintain lower ratios, around two to 2.5, yet both show a gradual upward trend as the used market gains relevance.

These patterns illustrate the structural importance of the second-hand market in Europe, where the turnover of existing vehicles largely exceeds the inflow of new ones.

Newly registered passenger cars and turnover (ownership transfers), 2010–2023

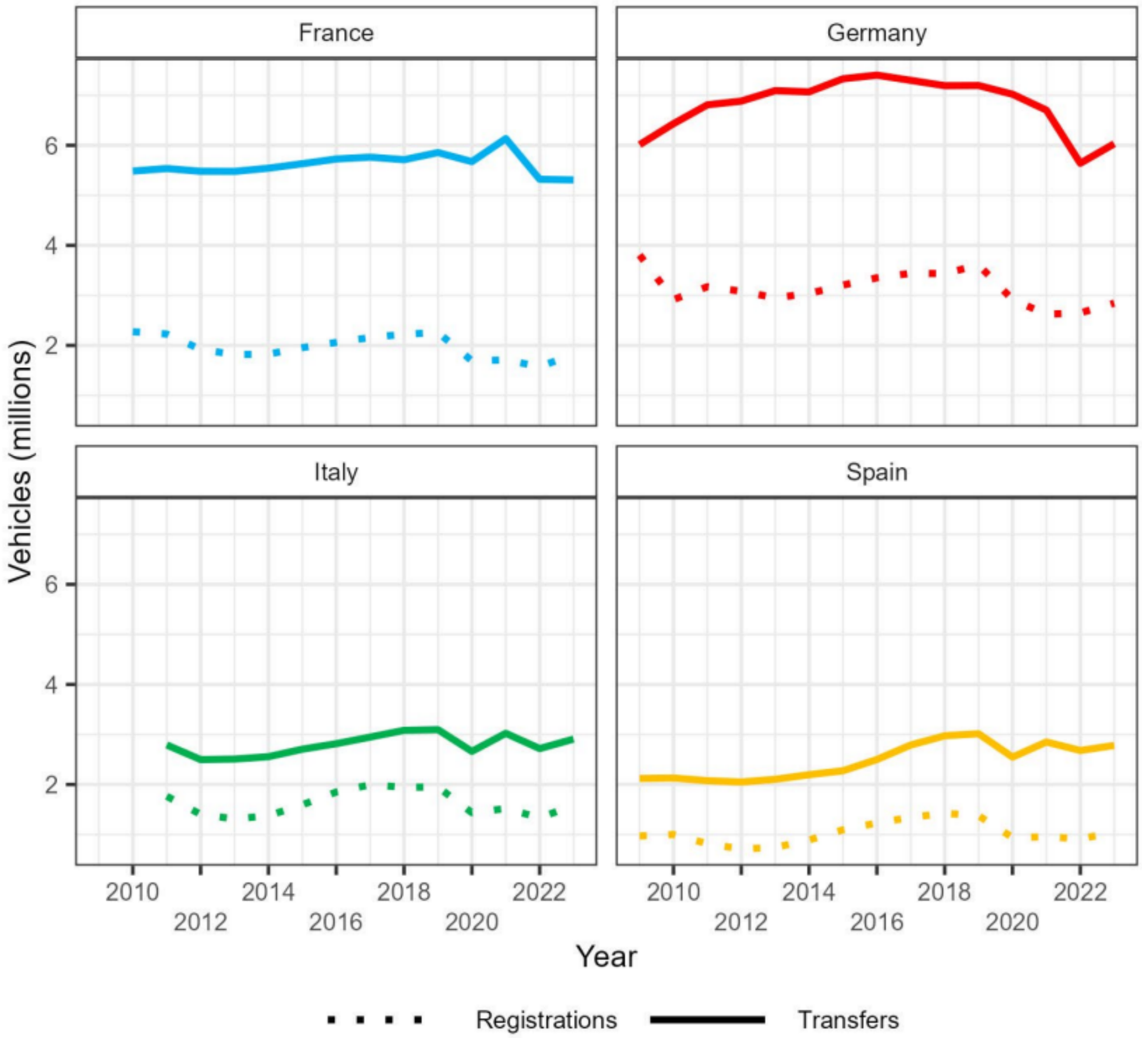


Figure 56: Another take on relative size of sales. Credit to JRC.

The chart compares the annual number of new registrations (dotted lines) with ownership transfers (solid lines) across the four largest EU markets.

The data confirm that in France and Germany, ownership transfers consistently exceed new registrations by a factor of two to three, illustrating the maturity and liquidity of their used-car markets. In Italy and Spain, the gap between new and used transactions is smaller but has widened gradually in recent years as second-hand demand increased.

These differences underline the structural importance of the used-vehicle market in maintaining mobility and fleet renewal even during periods of reduced new-vehicle supply.

6.6 Summary of flows

The European Union (EU) vehicle market, particularly for passenger cars, is a prime example of a **finite market space**—a mature, saturated ecosystem where overall demand grows slowly or stagnates, constrained by high ownership penetration, demographic shifts, and structural limits on household mobility needs.

Unlike emerging markets with rapid fleet expansion, the EU's vehicle parc (total stock in use) has reached near-equilibrium, with annual new sales primarily replacing aging vehicles rather than adding net new units. This zero-sum dynamic intensifies competition among powertrains (ICE, PHEV, BEV), as gains for one (e.g., BEVs via policy-driven electrification) come at the direct expense of others, without expanding the overall "pie."

In 2025, with the EU facing economic headwinds and regulatory pressures, this finitude underscores challenges for the used BEV segment, where low market depth amplifies supply-demand mismatches.

Finally, we can summarize the various flow metrics in following table:

EU 27	flow type	vehicles	rate		years	
total stock		284.000.000				
inflow (growth rate)	new	12.500.000	4,4%	4,5%	23	22,3
	used import	250.000	0,1%		1.136	
internal flow (unit resale)	intra-border	37.000.000	13,0%	13,4%	8	7,5
	cross-border	1.000.000	0,4%		284	
outflow (turnover)	scrappage	11.000.000	3,9%	4,2%	26	23,7
	used export	1.000.000	0,4%		284	

Figure 57: Summary of main figures used throughout the report. Annual flow rates and replacement time in years.

Regarding new vs stock, we can observe that the annual inflow of new vehicles is a rather small contribution to the total stock:

- in terms of units, the used car stock is **25 times larger** than the new car stock inflow.
- In terms of sales, for every single new vehicle sale, there are 3 used resale transactions.

Comparatively, against usa or within eu:

- US: higher churn than EU, due to higher scrappage and faster replacement cycles.

- EU: lower churn, aging fleet, weaker scrappage incentives, strong cross-border used car trade (export of older units eastward).
- Developing markets: churn patterns strongly affected by imports of used vehicles, with domestic outflow often **suppressed by weak enforcement of scrappage.**

The *speed* at which a new powertrain enters the fleet (e.g. EVs replacing ICE) depends on churn:

- For fast substitution, one needs BOTH **High inflow + high outflow**
- even if EV sales are high relative to new registrations, substitution can be slow when one has BOTH **Low inflow + low outflow**

Regarding inflow vs outflow, we can observe that:

- Scrappage rate is the most fundamental driver of stock flow, and new inflow the second
- demand for new vehicles (Growth rate) is fundamentally paired with (or depends on) the scrappage rate- a clear indication of a "replacement-driven" market
- Although from a trade balance perspective, the EU exports 4 used vehicles for every single used vehicle imported, both are relatively negligible flows on the level of the EU bloc, which indicates a stagnant vehicle market (or a steady state).

Regarding the flow *within* the stock, one may observe that:

- On average, vehicles change hands every 7 years.

6.7 Car park age

Due to Covid supply chain problems in 2021, stricter EU regulations and reluctance for electrification, the car park has continued to show a linear ageing progress and the average age of a passenger car stands at almost 13 years in 2025.

Each new-car sale generates approximately 3 to 4 used-car sales over the vehicle's lifetime (across multiple ownerships), although the level of change of ownership varies substantially between countries.

As leasing and subscription models accelerate, the first-cycle cascade is **shortening**—meaning newer vehicles move into the used market faster, especially EVs.

A direct way to understand turnover is to track the mean or median age of the vehicle fleet.

- Faster turnover (high inflow of new vehicles) will decrease the average age of the fleet.
- Slower turnover (low inflow, low scrappage) will increase the average age of the fleet.

Mean Age of the Fleet is a very common metric used by government agencies to track the modernization of the fleet. For example, a "cash-for-clunkers" program's success is often measured by the reduction in the average fleet age.

Car fleet by vehicle age in the EU, 2015–2023

The chart shows the composition of the European passenger car fleet by vehicle age and its development between 2015 and 2023. The figures represent an aggregated total for the EU based on available data from 24 Member States.

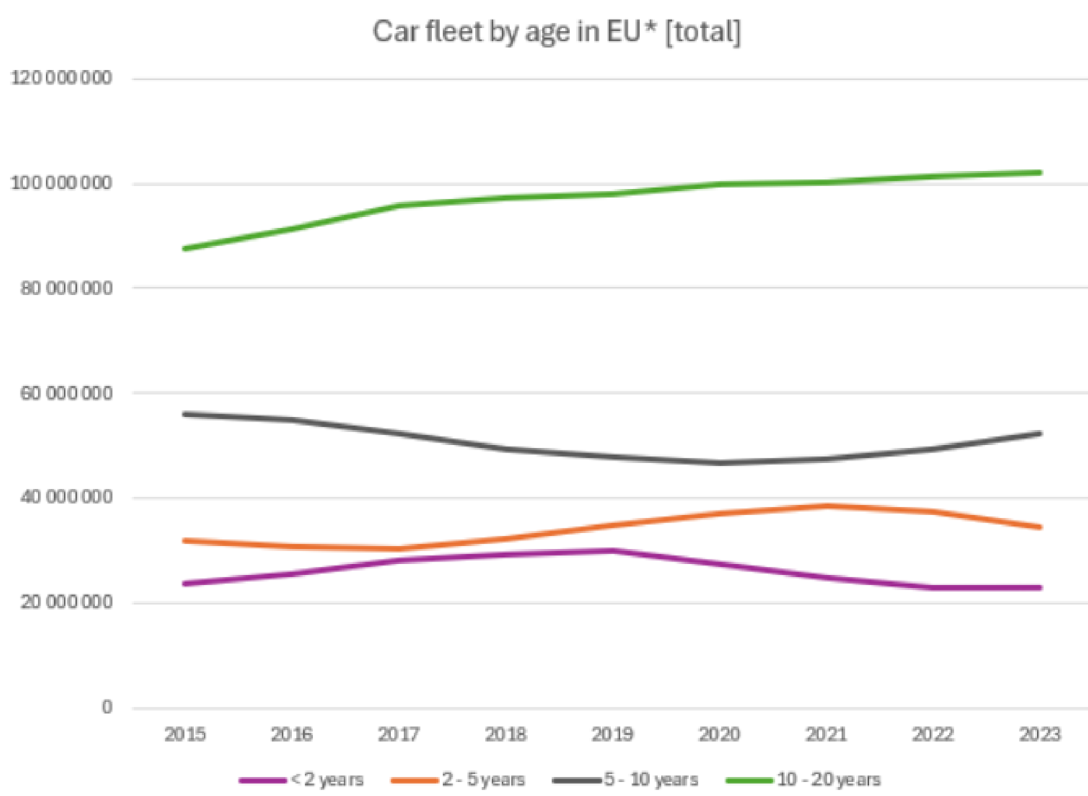


Figure 58: Car fleet age bands. Credit to JRC.

The share of older vehicles (10–20 years) has steadily increased, now exceeding 100 million units, while the number of young vehicles (< 2 years) has declined since 2019 as a result of lower new registrations. Vehicles aged 5–10 years also show a decreasing trend, indicating slower fleet renewal and extended vehicle lifetimes.

These trends confirm the ageing of the EU car park, driven by supply disruptions in the new-car market, high prices of new vehicles, and longer retention periods by private owners.

Average passenger car fleet age evolution from 2007 to 2023

The average age of passenger car fleets has increased significantly across all major EU markets over the past 15 years.

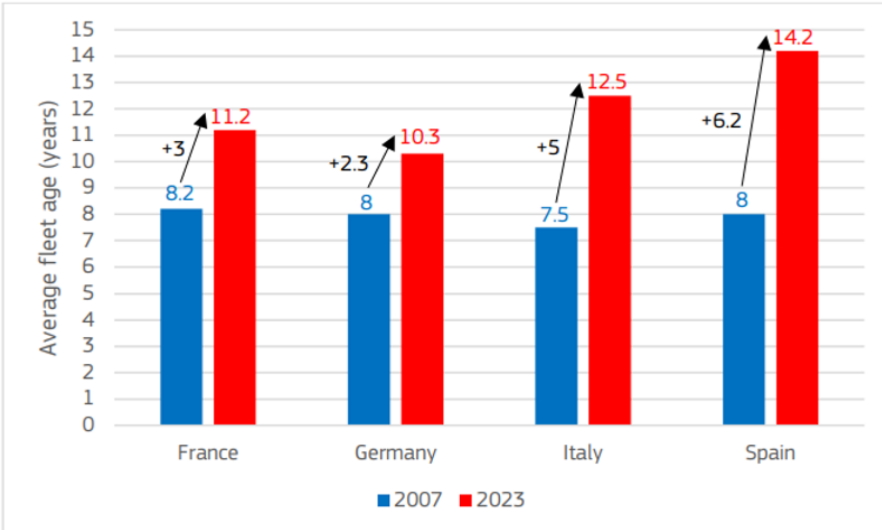


Figure 59: Trends in car fleet age for some EU countries.

Spain and Italy show the highest ageing, with average fleet ages rising by more than 5 years since 2007, reaching 14.2 years and 12.5 years respectively in 2023. France and Germany maintain comparatively younger fleets, though both still exhibit a noticeable increase – by 3 years in France and 2.3 years in Germany.

The continued ageing of the European car park reflects slower fleet renewal rates, the economic effects of the 2008 and 2020 crises, and the persistent expansion of the used-car market. These factors underline the challenge of accelerating turnover and decarbonisation within Europe's ageing vehicle fleet.

6.8 Car park value

According to Bain and company, t*he used car market is generally quite stable, even in downturns: Many* people rely on their cars to reach work and see family, and they would rather sacrifice other purchases than give up their cars.

In addition, new car buyers may switch to used cars when their older cars cannot be maintained economically and they can no longer afford new cars—so there will always be turnover in the used car market. Therefore, even though the economic environment is expected to become more difficult in the coming years, Bain expects the used car market to be more stable than other markets.

6.8.1 Germany

The value of exported used cars from Germany (2000–2022)

Germany is by far the largest exporter of used vehicles in the European Union. The total export value increased steadily from 2000 to 2022, exceeding €25 billion in 2022.The average value per exported car rose to nearly €20 000, reflecting the predominance of newer and higher-value vehicles in Germany's export portfolio.

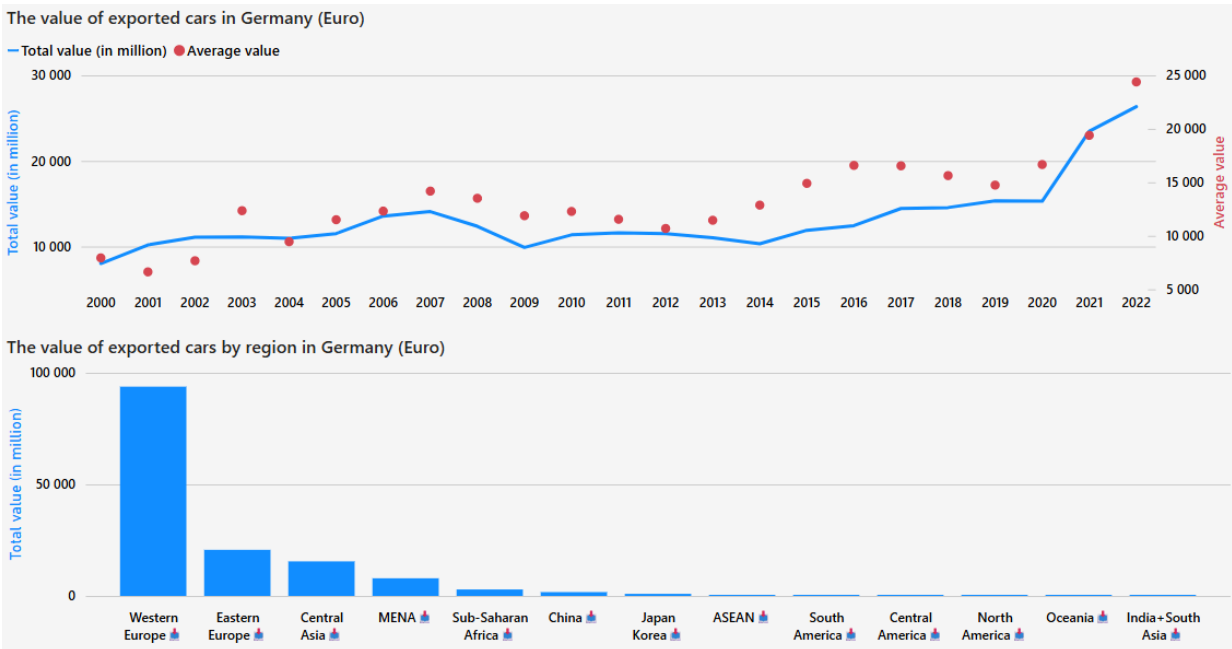


Figure 60: Breakdown of the automotive export.

As illustrated above, Western Europe remains the primary destination for German used-car exports, followed by Eastern Europe, Central Asia, and the MENA region. This confirms Germany's role as both a source and transit hub for vehicles redistributed within the EU and exported to neighbouring regions outside the Union.

The value of imported cars in Germany (2000–2022)

While Germany is the EU's largest exporter of used vehicles, it also records a substantial level of imports, primarily from neighbouring Western European countries.

The total import value increased from €1 billion in 2000 to around €6 billion in 2022, with the average unit value nearly doubling to over €18 000 per vehicle.

As shown in the lower chart, Western Europe dominates Germany's import structure, accounting for the vast majority of inbound trade. Imports from other regions remain limited, confirming that Germany's used-car market operates largely within the internal European circulation of vehicles.

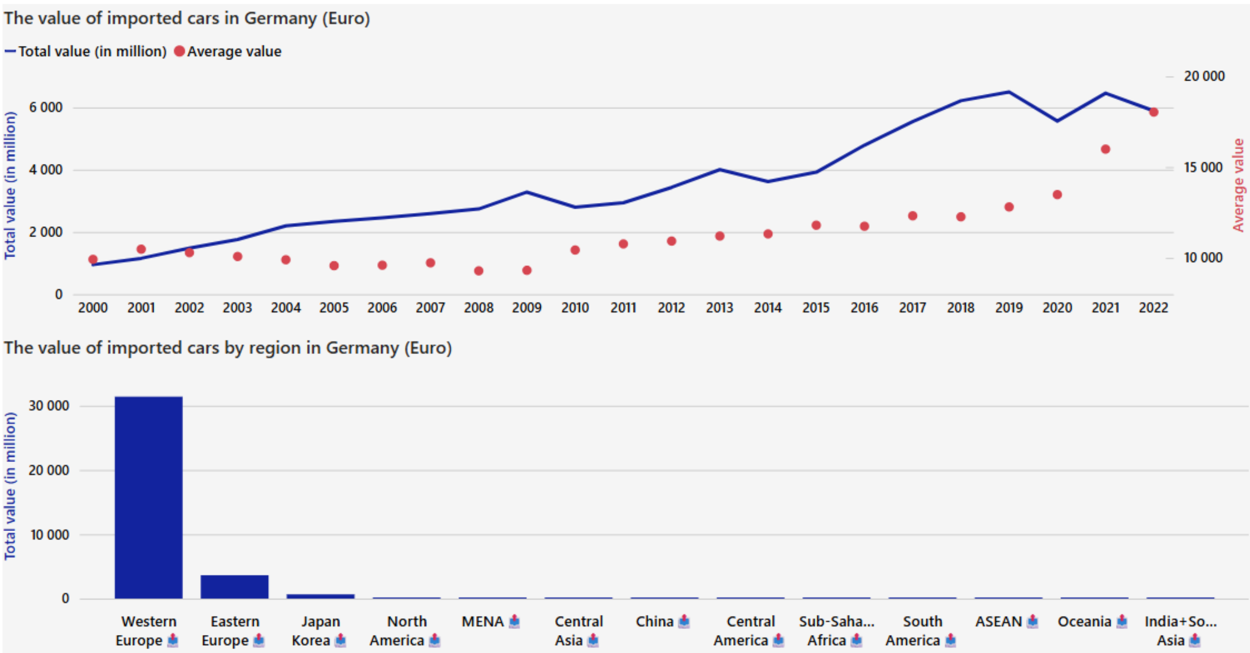


Figure 61: Breakdown of the automotive import.

6.8.2 Italy

The value of exported cars in Italy (2012–2020)

Italy's exports of used passenger vehicles display a moderate and regionally focused profile. The total export value declined from over €1.2 billion in 2012 to €0.8 billion in 2016, before gradually recovering to €1.1 billion in 2019.

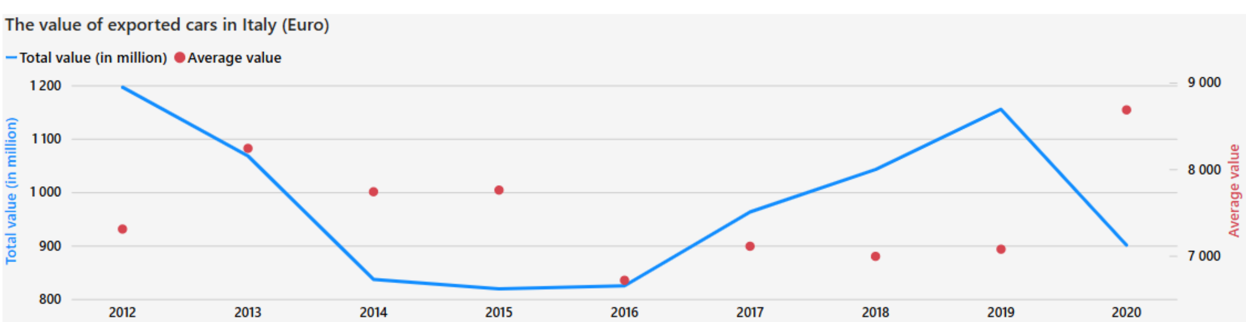


Figure 62:Breakdown of the automotive export.

The average export value per vehicle remained relatively stable, between €7 000 and €9 000, reflecting a market dominated by older and lower-priced vehicles compared with Western European exporters.

Most Italian exports are directed to neighbouring EU countries, such as Slovenia, Croatia and Romania, while trade beyond the EU remains limited but slowly expanding. This highlights the structural role of Italy as a regional rather than global exporter within Europe's used-car market.

The value of imported cars in Italy (2012–2020)

Italy's imports of used passenger vehicles have shown a steady upward trend over the past decade. The total import value rose from around €250 million in 2012 to more than €800 million in 2019, before slightly declining during the COVID-19 pandemic in 2020.

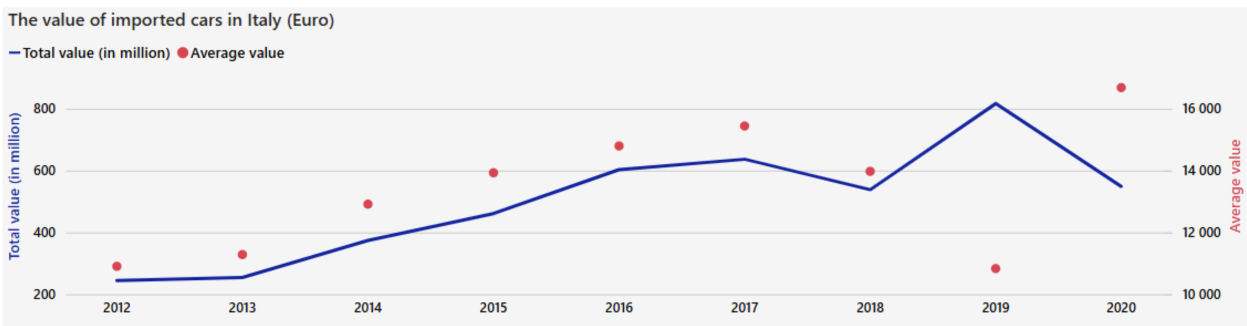


Figure 63: Breakdown of the automotive import.

The average value per imported car increased gradually from €12 000 to €16 000, reflecting higher-quality and younger vehicles entering the Italian market. Most imports originate from Western European countries, mainly Germany, France and the Netherlands, confirming Italy's integration within the intra-EU used-vehicle trade network.

This pattern highlights Italy's dual role: a regional exporter of older vehicles and a net importer of newer used cars from other EU markets.

The graphs can alternatively be replaced with a version showing the **quantity trend** instead of the monetary value, which can be generated or modelled directly in the ITF-OECD **Used Vehicles Dashboard.**

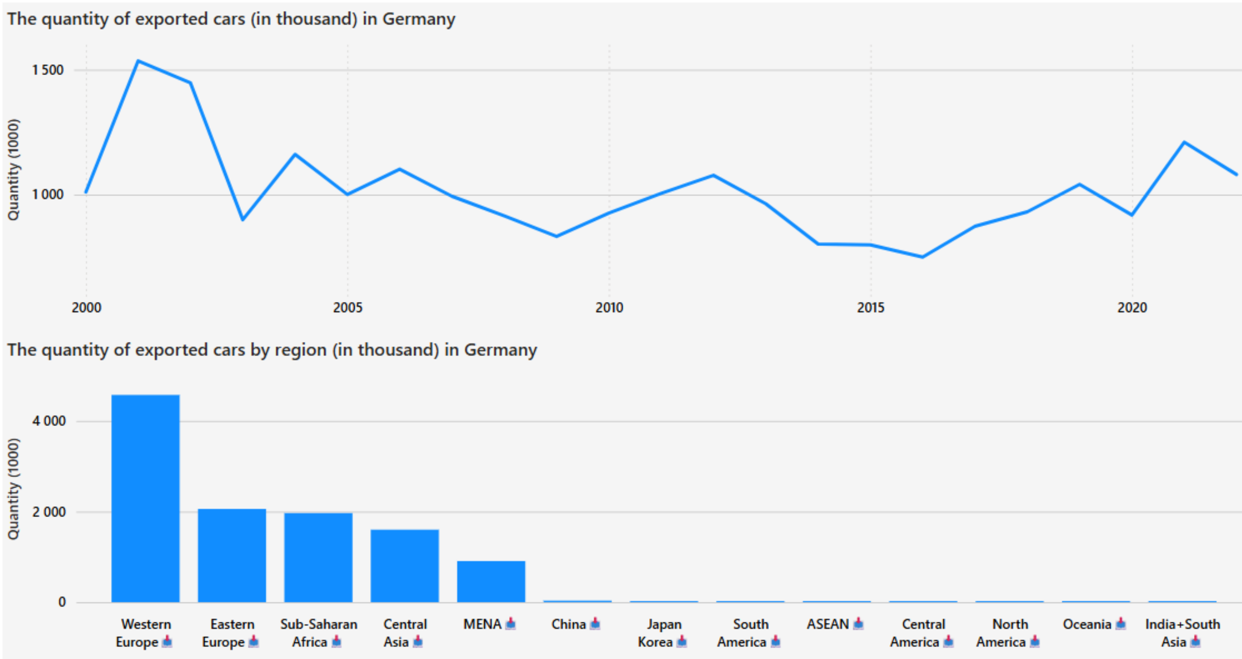


Figure 64: Quantity view of export.

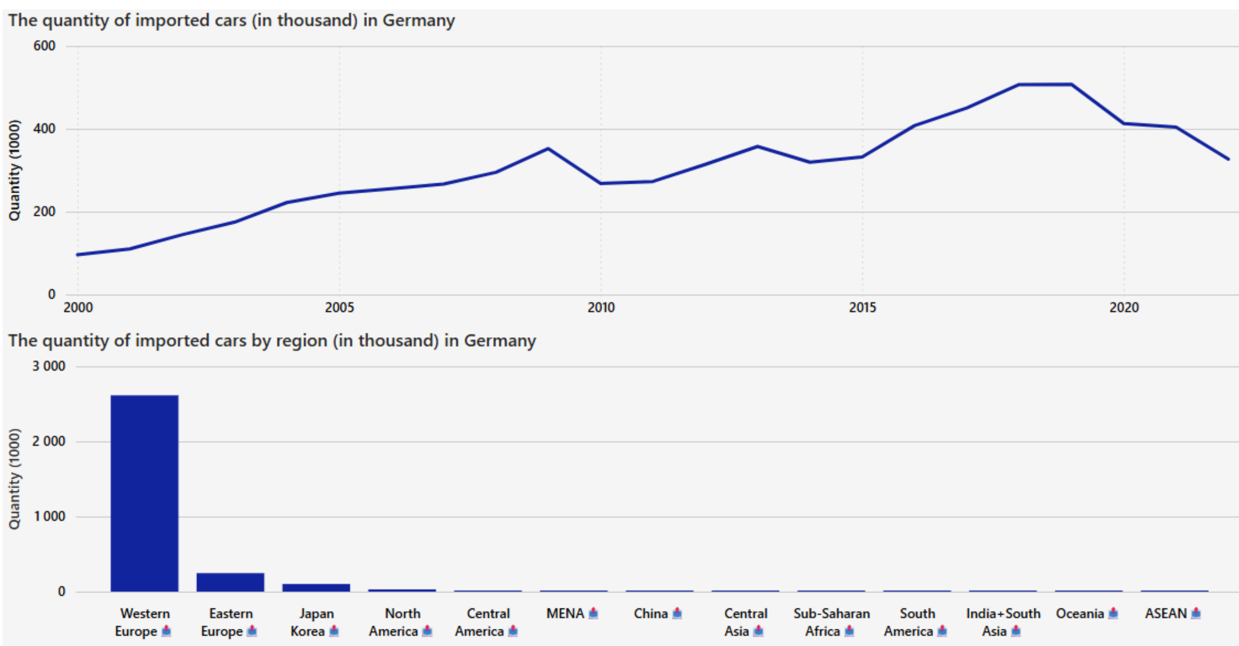


Figure 65: Quantity view of import.

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