



Is the electric car really greener and cheaper? A coupled life cycle and total cost of ownership analysis of a petrol and an electric Volkswagen Golf in the Hungarian context

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Abstract

Electric cars are increasingly popular on the assumption that they have a low environmental impact. Yet, battery production is an exceptionally polluting process, and their higher purchase price calls into question their economic competitiveness. Hence, the electric car is not a perfect alternative to internal combustion engine (ICE) vehicles; it requires context-specific investigation. This study couples a Life Cycle Assessment (LCA) and a Total Cost of Ownership (TCO) analysis of two near-identical vehicles. A petrol Volkswagen Golf 1.5 TSi and an electric e-Golf (both 2019), plus a solar-charged variant of the latter, from production to 200,000 km, using a transparent, openly shared model parameterised for Hungary. The Golf's production emissions are 44% of the e-Golf's, but over 200,000 km, the Golf emits 103% more CO₂-equivalent than the grid-charged e-Golf and 222% more than the solar-charged one, reaching environmental break-even after approximately 38,000 and 30,000 km. Economically, the Golf is 10% and 28% more expensive to own, with financial break-even occurring after approximately 62,000 and 66,000 km, respectively. Only 16.7% of the money spent on petrol, against 70.4% for electricity, is converted into useful motion. Mass adoption of electric cars is thus an environmentally optimal direction,



maximised by renewable charging, but it leaves open questions about public revenue sustainability that deserve further investigation.

Keywords

electric vehicle; life-cycle assessment; total cost of ownership; sustainable mobility; CO₂ emissions; solar charging; Hungary

1. Introduction

Sustainable societal operations and environmental protection are among the most pressing topics of our time, and the burning issue of global warming, driven by the combustion of fossil fuels, is one of its most decisive components (Robinson & Igini, 2025). Road transport is a major contributor: in the European Union in 2022, transport accounted for 31% of all energy use, of which road transport was responsible for the largest share, 73.6%, and within that, petrol/diesel-powered vehicles accounted for 65.4% (Eurostat, 2024). At the global level, transport was responsible for roughly 24% of CO₂ emissions, with the road sector accounting for 74.5%, split between 45.1% private use and 29.4% freight (Richie, 2018). These figures show that road transport plays a decisive role in greenhouse gas (GHG) emissions and that the type of vehicle drivetrain is central to mitigating them.

The electric car family is one of the alternatives developed to address this environmental burden. A battery electric vehicle (BEV) is propelled exclusively by one or more electric motors and has no secondary drivetrain. Its most significant distinguishing feature from Internal Combustion engine (ICE) vehicles is that no pollutants leave the motor as by-products during use (European Commission, n.d.). The momentum behind the technology is considerable: according to the International Energy Agency (IEA), 20% of cars sold globally in 2024 were electric – about 17 million vehicles, compared with only 500,000 in 2016 (IEA, 2025). Electric drivetrains also use energy far more efficiently: an electric motor converts on average about 70% of the stored energy into motion, rising above 90% when regenerative braking is included, whereas an ICE converts only around 30%, the remaining 70% being lost mainly as heat (U.S. Department of Energy, n.d.; Cushman-Roisin and Cremonini, 2021).

Despite these advantages, the electric car is not a perfect, so-called “zero-emission” alternative. Battery production is an outstandingly polluting process: the estimated manufacturing CO₂ emissions of a lithium-ion battery span a wide range, from 55 to 494 kg CO₂-eq per kWh, reflecting big regional differences in mining, processing, and the resources used in assembly (Hall and Lutsey, 2018; Schnell et al., 2025). Moreover, the mining of battery raw materials has impacts that cannot be offset by emissions accounting alone, such as water scarcity caused by intensive lithium production in Chile, Argentina, and Bolivia (Tilly et al., 2024). Two questions therefore arise and motivate this work: would mass electrification genuinely reduce CO₂ emissions, or would additional pollution appear elsewhere in the life cycle of the electric car, and how would such a shift hold its ground economically?

Existing literature has examined these questions separately. Lifecycle comparisons of ICE and electric vehicles exist for various regions (Farzaneh and Jung, 2023; Hall and Lutsey, 2018): Total-cost-of-ownership analyses – including recent work focused on Hungary across affordable, mid-range and premium market segments (Zoldy, 2026a; Zsiborács et al., 2026; Ouyang et al., 2021) – have assessed economic competitiveness. Less common is an integrated, region-specific assessment that couples the environmental and economic accounts for a single, controlled vehicle pair and isolates the effect of the drivetrain rather than vehicle design. The present study addresses this gap.

Beyond the technical and economic dimensions, the transition toward electric mobility is also a cognitive one: individuals must reconcile environmental, financial, and practical considerations that are often perceived as conflicting, under conditions of incomplete or asymmetric information. Lerchner and Zoldy (2026a) show that individual car-purchasing decisions rarely align with the environmental preferences that buyers themselves report, pointing to a persistent gap between stated environmental values and realised purchasing behaviour. This gap is amplified by the fact that the cost–emission relationship is not static: Lerchner and Zoldy (2026b) demonstrate, in a yearly total CO₂ emission assessment of passenger-car electrification, that the environmental balance of a fleet shifts non-linearly over time as adoption progresses. This means that a single, static comparison can misrepresent the dynamics a buyer or policymaker actually faces. Zoldy (2026b: 1) frames this problem within the emerging cognitive sustainability paradigm. He argues that the total cost of ownership functions not merely as an economic bottom line but as a “cognitively informed decision interface shaped by perception, trust, and



information asymmetry”, and that the relationship between cost and emissions is dynamic and non-linear over time, particularly during electrification, where short-term increases can precede long-term benefits.

The present study addresses this cognitive dimension in a concrete, quantitative manner. By coupling a transparent LCA and TCO model – openly shared rather than presented only as aggregate results – and by explicitly locating the environmental and financial break-even points rather than reporting only endpoint totals, the analysis is designed to function as a decision-support tool that narrows the information asymmetry identified by Zoldy (2026b) and the preference–behaviour gap identified by Lerchner and Zoldy (2026b). In this sense, the coupled LCA–TCO framework proposed here operationalises, for a controlled Hungarian vehicle pair, the integrated perspective on cost structures, decision-making, and emission dynamics that cognitive sustainability research calls for.

It is not our intention to portray ICE vehicles as an entirely bad option, nor the electric drivetrain as a perfect alternative; rather, we quantify, in the Hungarian context, where the electric car becomes “greener” and “cheaper”, and what conditions maximise its potential.

2. Materials and methods

2.1 Vehicle selection and data

To isolate the effect of the drivetrain, we compare the petrol and electric variants of a single manufacturer’s platform: the 2019 Volkswagen Golf 1.5 TSi (hereafter Golf) and the 2019 Volkswagen e-Golf (hereafter e-Golf), the latter is also analysed under solar charging (hereafter e-Golf(S)). The two cars are built on a fully shared platform and share almost every external feature. The manufacturer differentiates them only in minor details such as a brand logo or specific LED integrations (2019 e-Golf Press Kit, 2019). They also have very similar power, 130 PS (≈ 96 kW) for the Golf and 134 PS (≈ 100 kW) for the e-Golf, and the e-Golf is only about 215 kg heavier. These near-identical body properties make the pair an optimal choice, because differences arising from aerodynamic or design factors do not bias the comparison, allowing more general conclusions about the two technologies (ADAC Autokatalog, 2017, 2018). Key technical data are summarised in *Table 1*.

Throughout, consumption and combined CO₂ values are taken from independent test data (ADAC, 2017), (ADAC, 2018) rather than manufacturer figures to reflect real-world behaviour better.

Table 1 Technical data of the analysed vehicles used as the model framework (manufacturer- and test-data-based).

Source: ADAC Autokatalog (2017, 2018).

Parameter	Golf 1.5 TSi	e-Golf
Consumption	6 L/100 km	15.8 kWh/100 km
Combined CO ₂ emission	135 g/km	0 g/km
Power	130 PS (≈ 96 kW)	134 PS (≈ 100 kW)
Mass	1,400 kg	1,615 kg
Battery capacity	–	35.8 kWh

2.2 Common framework

A custom spreadsheet model was built to automate both LCA and TCO calculations and to enable sensitivity testing with varying input data; the model is openly available (see *Data availability*). Both analyses run from production up to a fixed examined distance of 200,000 km. This distance reflects the Hungarian vehicle-lifetime context: in 2025, the mean age of passenger cars in circulation was 16.2 years (KSH, 2026), which, combined with a European annual mileage of about 12,000 km (ACEA, 2025), yields close to 200,000 km over a full life. A battery replacement is modelled once the car exceeds 150,000 km, conservatively earlier than the manufacturer-guaranteed 160,000 km battery lifetime (Volkswagen, 2026).

2.3 Lifecycle assessment model

The LCA accounts for the direct and indirect environmental impacts of manufacturing, fuel/electricity production, and vehicle use (Method Statement LCA, 2024). All emissions are expressed in kg CO₂-equivalent.

Manufacturing. Manufacturing carbon footprints of specific vehicles are generally undisclosed by manufacturers, so estimates are required. We use the figures reported by Buchal, Karl and Sinn (2019), in which a petrol Golf has a manufacturing footprint of 26 g CO₂-eq/km and an e-Golf of 57 g CO₂-eq/km over a 200,000 km lifetime. Converted to absolute terms (Eq. 1):

$$Emission_{manuf} = (g \text{ CO}_2\text{-eq/km}) \times km / 1000 \quad (1)$$



$$Emission_{manuf,Golf} = 26 \times 200,000 / 1000 = 5,200 \text{ kg CO}_2\text{-eq}$$

$$Emission_{manuf,e-Golf} = 57 \times 200,000 / 1000 = 11,400 \text{ kg CO}_2\text{-eq}$$

These values assume primary-production materials only. According to Volkswagen's 2024 reporting, ICE cars contain, on average, 21.3% reused or secondary-recycled parts. Meanwhile, the same value for electric cars is 18.7% (Volkswagen Group, 2024), which are produced with lower energy input. To avoid a logical error of subtracting recycling credit twice – once at end of life and once at manufacturing – the model corrects the manufacturing estimate by the recycled-content share, since the cars are already assembled with a portion of recycled content (Eq. 2):

$$Emission_{corr,manuf} = Emission_{manuf} \times (1 - \text{recycled share}) \quad (2)$$

$$Emission_{corr,manuf,Golf} = 5,200 \times (1 - 0.213) \approx 4,092 \text{ kg CO}_2\text{-eq}$$

$$Emission_{corr,manuf,e-Golf} = 11,400 \times (1 - 0.187) \approx 9,268 \text{ kg CO}_2\text{-eq}$$

The excess of the e-Golf is attributable to battery manufacturing. For its 35.8 kWh battery, we apply a unit footprint of 71 kg CO₂-eq/kWh, the globally weighted average reported by Green NCAP (2024) across Chinese (77 kg CO₂-eq/kWh), U.S. (57 kg CO₂-eq/kWh) and European (50 kg CO₂-eq/kWh) production, giving $35.8 \times 71 \approx 2,542$ kg CO₂-eq for one battery.

Use phase. Use-phase emissions combine direct (tailpipe) and indirect (well-to-tank, WTT) contributions (Eq. 3):

$$E_{use} = (\text{combined CO}_2 \times \text{distance}) + (\text{distance} \times \text{consumption}/100 \times \text{upstream factor}) \quad (3)$$

For petrol, a WTT factor of 17.5 g CO₂-eq/MJ (Prussi et al., 2020) with an energy content of 33.03 MJ/L (SEAI, 2024) gives 0.578 kg CO₂-eq per litre of petrol produced. For electricity, we use the Hungarian grid factor of 0.2194 kg CO₂-eq/kWh, derived from the 2023 national generation of 35,545 GWh and 7.8 Mt CO₂-eq (IEA, 2025); this is below the European average of 0.2559 kg CO₂-eq/kWh (IEA, 2026). For the solar-charged e-Golf(S), use-phase emissions are taken as 0 kg CO₂-eq, assuming the photovoltaic system fully covers the car's electricity demand. Over 200,000 km, these yields use-phase emissions of 33,936 kg (Golf), 6,935 kg (e-Golf, grid), and 0 kg (e-Golf(S)); for both electric variants, a single battery replacement adds 2,542 kg.

Total and break-even. Total lifecycle emissions are the sum of corrected manufacturing, use, and (where applicable) battery-replacement emissions. To locate the environmental break-even – the distance at which the cumulative emissions of two cars become equal – the model expresses each car's emissions as a linear function of distance (Eq. 4), and solves pairwise for the intersection.

$$F = ((Emission_{total} - Emission_{manuf})/\text{km}) \times x + Emission_{manuf} \quad (4)$$

Because every realistic break-even occurs before the 150,000 km battery-replacement step, the battery-free linear functions are used for this calculation, avoiding the discontinuity.

2.4 Total-cost-of-ownership model

The TCO is the comprehensive aggregation of all expenses associated with owning and operating an asset, including the initial purchase cost, use costs, and depreciation (Toyota, n.d.). Methodologically, it mirrors the LCA; costs are computed as a function of distance, but with phase-specific complexity. All purchase costs are expressed in 2019 Hungarian forint (HUF), converted from the cars' euro list prices at the 2019 exchange rate (≈ 325 HUF/EUR), to capture what the buyer actually spent "then and there". Purchase prices were 8,878,048 HUF (€27,285) for the Golf and 10,379,686 HUF (€31,900) for the e-Golf, the latter being about 17% more expensive (Exchange Rates UK, n.d.). A second examined distance basis of 200,000 km over an assumed 12,000 km/year (≈ 17 years) is used for time-dependent costs.

Fuel and electricity. Petrol cost is computed based on distance, consumption, and an inflation-adjusted average price. Because petrol prices over 2019–2025 showed no stable trend in real terms, a nominal increase of 55.3% corresponded to a



1.85% decrease in real value once inflation was removed. The model does not estimate past prices, but starting from the 2019 average, it applies a conservative constant 4% annual inflation (below the measured 7% historical geometric mean and consistent with the Hungarian National Bank (MNB, 2025) 3–4% forecast), yielding an average price of 532.73 HUF/L over the examined period. For the grid-charged e-Golf, the model applies Hungary’s two-tier household electricity tariff: a reduced price of 36 HUF/kWh up to an annual consumption ceiling and a “market” price of 70 HUF/kWh above it (MVM Csoport, n.d. a; n.d. b), allocated by the shares 0.17 (subsidised) and 0.83 (market) implied by an average household’s prior consumption. For the solar-charged e-Golf(S), the electricity cost is zero by construction.

Vehicle tax, battery replacement, solar system and resale. The model includes the Hungarian vehicle tax, which depends only on power and age and so can be standardised (unlike insurance or service costs, which are owner-dependent and therefore excluded). Over the modelled life, this amounts to 457,920 HUF for the Golf, whereas the electric variants are exempt, as battery-electric vehicles paid no Hungarian vehicle tax in the modelled period. Battery replacement is priced at 50,000 HUF/kWh – derived from a market battery price of ~139 USD/kWh and an insurer rule-of-thumb of 50,000–100,000 HUF/kWh including labour costs (Allianz, 2026) – giving $35.8 \times 50,000 = 1,790,000$ HUF ($\approx$ €5,500).

The solar option is sized based on the annual energy demand, with a Photovoltaic Geographical Information System (PVGIS)-based result of 1,150 kWh/kWp/year for optimally placed Hungarian installations (European Commission, 2025). Based on the examined yearly driven distance and energy consumption, the e-Golf’s demand requires a 1.7 kWp system, priced at an inflation-adjusted 440,000 HUF/kWp (from a 2022 market quotation), totalling 748,000 HUF ($\approx$ €2,300).

Resale value is treated as a negative cost (an amount the owner can recover) and estimated by logarithmic regression on listed prices of 2019 vehicles $p = a + b \cdot \ln(\text{km})$, with $R^2 = 0.796$ (Golf) and 0.967 (e-Golf). At 200,000 km, this gives 5,408,003 HUF (Golf) and 4,862,410 HUF (e-Golf/e-Golf(S)). The total end cost is the aggregate cost minus the resale value. The same intersection logic obtains financial break-even points as in the LCA.

2.5 Economic-utility model

To assess how much of the money spent on energy actually moves the car, the model computes the useful-energy fraction of fuel and electricity expenditure, removing per-unit taxes and contributions, dividing by VAT, multiplying by drivetrain efficiency, and dividing by the gross price. For petrol (gross 580 HUF/L; excise 158.8; energy-efficiency contributions 8.25 and 3 HUF/L; VAT 27%; engine efficiency 30%) and for electricity (gross 70 HUF/kWh; excise 0.415; VAT 27%; drivetrain efficiency 90%), the model returns the useful share of each forint spent (NAV, 2025; 2026a; 2026b).

2.6 Sensitivity analysis

Robustness to driving style and climate was tested by varying consumption. A uniform +10% increase was applied to both cars. As a uniform increase is unrealistic given the greater weather sensitivity of electric drivetrains (extreme temperatures can raise BEV energy use by 50–60%; Parker et al., 2025), an asymmetric scenario (Golf +2%, e-Golf +10%) was also examined, for both the emission and the cost outputs.

3. Results

3.1 Lifecycle emissions

Over 200,000 km, total lifecycle emissions were 38,029 kg CO₂-eq for the Golf, 18,744 kg for the grid-charged e-Golf, and 11,810 kg for the solar-charged e-Golf(S). Although the Golf’s corrected manufacturing footprint (4,092 kg CO₂-eq) is only 44% of the e-Golf’s (9,268 kg CO₂-eq) due to its manufacturing “backpack” driven by its battery, its far higher use-phase emissions dominate the full life cycle. The Golf therefore emits 103% more CO₂-equivalent than the grid-charged e-Golf and 222% more than the solar-charged variant over the examined distance (*Figure 1*). Notably, even the solar-charged e-Golf is not “zero-emission”: its 11,810 kg arises from manufacturing and battery replacement, a reminder that indirect and embodied emissions remain even when use-phase emissions vanish.

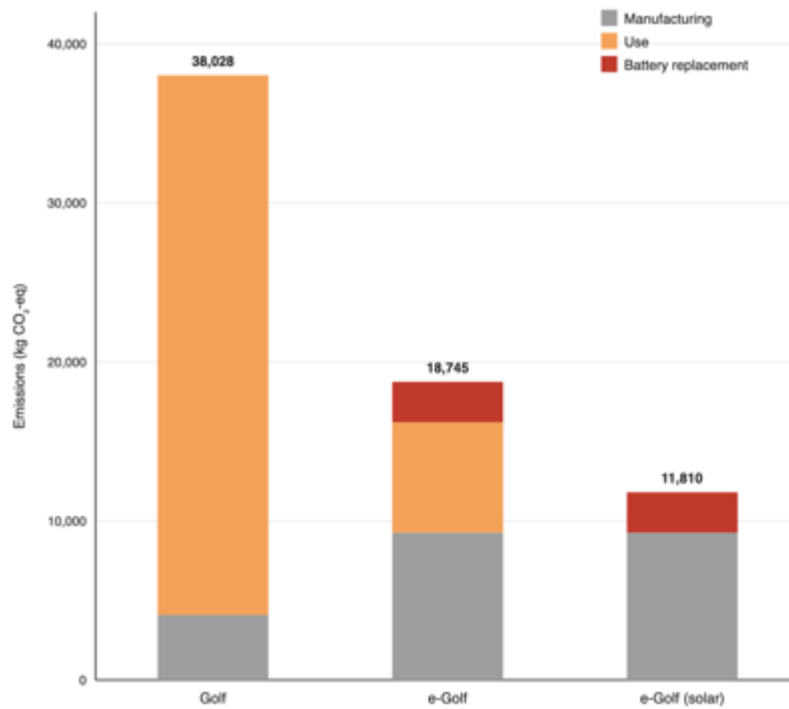


Figure 1. Total lifecycle carbon footprint of the three vehicles over 200,000 km, decomposed into manufacturing, use, and battery-replacement emissions.

Source: own calculation.

The cumulative-emission curves intersect well before the battery-replacement step. So the environmental break-even points (*Table 2*) were computed on the battery-free linear functions (*Figure 2*). The e-Golf overtakes the Golf in cumulative emissions at 38,336 km when grid-charged and at 30,305 km when solar-charged. Beyond these distances, each additional kilometre widens the electric car's environmental advantage.

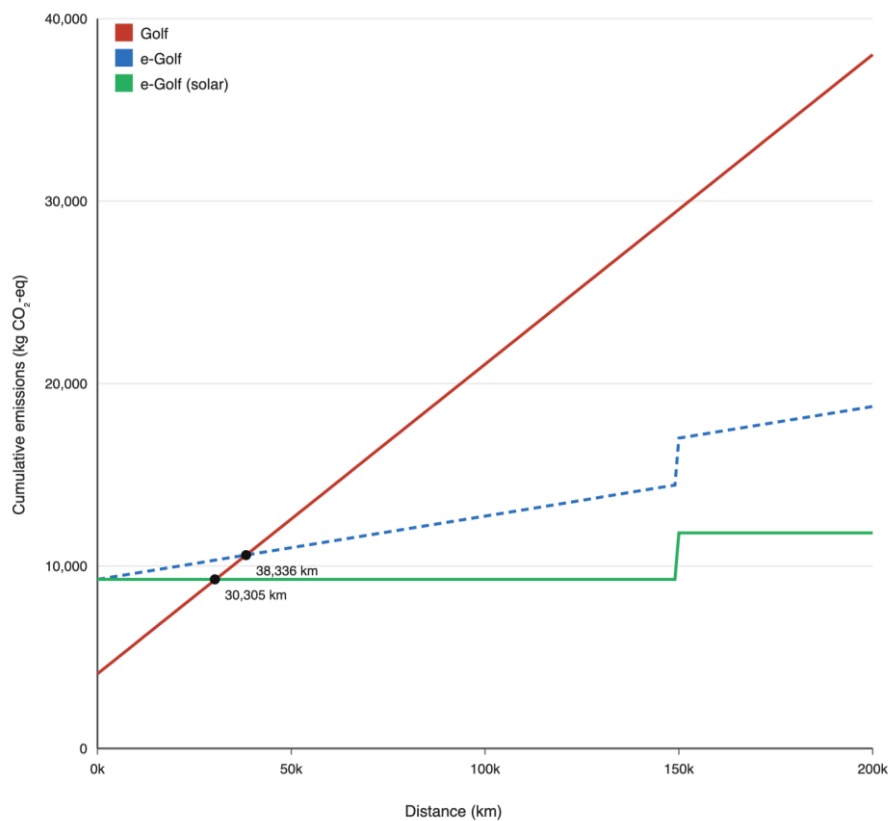


Figure 2. Cumulative lifecycle emissions as a function of distance, with the environmental break-even points marked; the step at 150,000 km reflects battery replacement in the electric variants. *Source: own calculation.*

Table 2. Environmental break-even distances (km). *Source: own calculation.*

Golf / e-Golf	Golf / e-Golf(S)	e-Golf / e-Golf(S)
38,336	30,305	0

3.2 Total cost of ownership

Over 200,000 km, the total end cost was 10,320,717 HUF ($\approx$ €31,700) for the Golf, 9,336,628 HUF ($\approx$ €28,700) for the grid-charged e-Golf, and 8,055,276 HUF ($\approx$ €24,750) for the solar-charged e-Golf(S). Despite its higher purchase price, the e-Golf developed far lower operating costs. 2,029,352 HUF of electricity against 6,392,752 HUF of petrol. So even after a costly battery replacement, the Golf is still 10% more expensive to own than the grid-charged e-Golf, and it is 28% more expensive than the solar-charged variant (Table 3, Figure 3). If the owner does not replace the battery, the gap widens to 37% and 65%, respectively.

Table 3. Total cost of ownership summary over 200,000 km (HUF), including a battery replacement for the electric variants.

End cost = aggregate cost – resale value. *Source: own calculation.*

Vehicle	Purchase	Energy	Tax/battery	Resale	End cost
Golf	8,878,048	6,392,752	457,920	5,408,003	10,320,717
e-Golf	10,379,686	2,029,352	1,790,000	4,862,410	9,336,628
e-Golf(S)	11,127,686	0	1,790,000	4,862,410	8,055,276

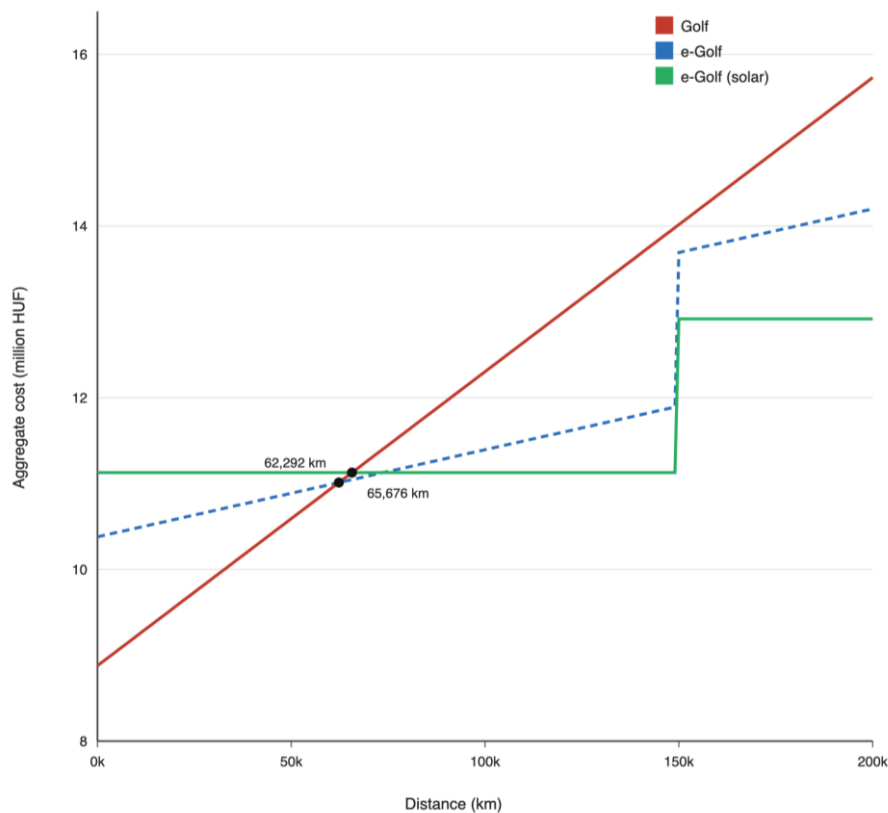


Figure 3. Cumulative ownership cost as a function of distance, with the financial break-even points marked; the step at 150,000 km reflects battery replacement. *Source: own calculation.*

The cost curves cross before the battery-replacement step: financial break-even occurs at 62,292 km (5.19 years) for the Golf/e-Golf comparison, 65,676 km (5.47 years) for Golf/e-Golf(S), and 73,718 km (6.14 years) for e-Golf/e-Golf(S) (Table 4). The owner of an electric car must therefore be patient – the higher initial outlay is recovered over the longer term. But over a full ownership cycle, the electric variant carries the lower cost burden. Moreover, charging it from a solar system makes it the outright cheapest option.

Table 4. Financial break-even distances (km) and the corresponding ownership time at 12,000 km/year. *Source: own calculation.*

	Golf / e-Golf	Golf / e-Golf(S)	e-Golf / e-Golf(S)
Break-even (km)	62,292	65,676	73,718
After (years)	5.19	5.47	6.14

3.3. Economic utility of the energy spent

The fraction of energy expenditure that was useful energy differed sharply between the two technologies. Only 16.7% of the money spent on petrol is converted into useful motion, the remainder being lost to excise (27.4%), VAT (15.0%) and mechanical/thermal losses (39.0%). For electricity, 70.4% of the money spent is converted into useful motion, with much smaller shares lost to VAT (21.1%), mechanical losses (7.8%), and a negligible excise (Figure 4). This difference is driven mainly by the higher drivetrain efficiency of the electric car and by the much lower excise burden on electricity. These percentages (16.7% useful + 27.4% excise + 15.0% VAT + 39.0% mechanical/thermal = 98.1%) don't sum to 100%. The missing ~1.9 percentage points corresponds closely to the 'energy-efficiency contributions' ($8.25 + 3 \text{ HUF/L} \approx 1.9\%$ of the 580 HUF/L gross price) that are included in the Methods 2.5 calculation but not listed here as a separate loss category, unlike the electricity breakdown in the next sentence, which explicitly notes 'a negligible excise' for its own small residual.

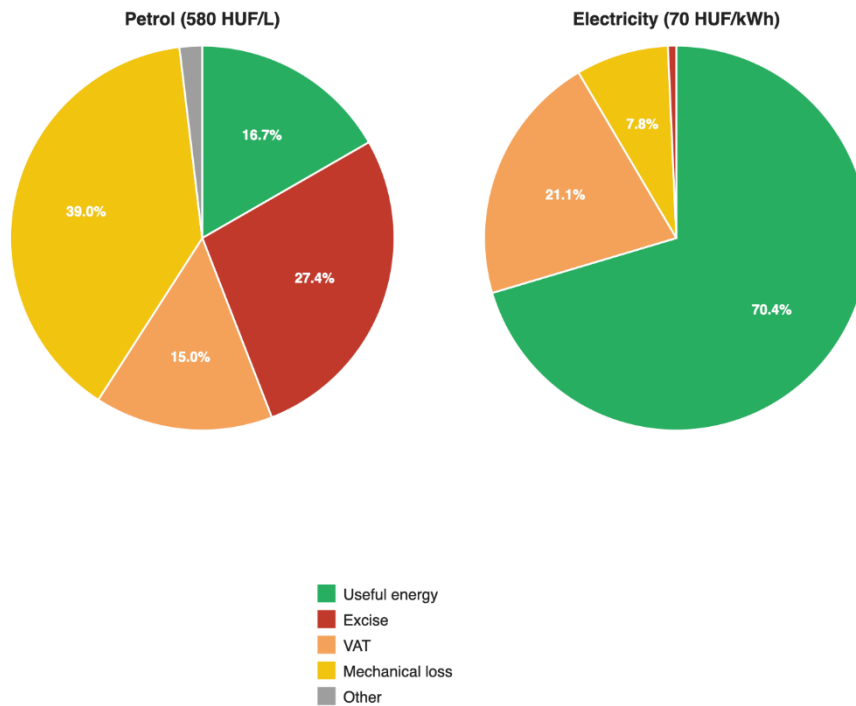


Figure 4. Share of money spent on petrol versus electricity that is converted into useful motion, with the remainder lost to taxes and mechanical/thermal losses. *Source: own calculation.*

3.4 Sensitivity analysis

Emissions and costs scaled predictably with consumption but did not alter the ranking. Under a uniform +10% increase in consumption, the Golf's larger absolute and partly direct emissions caused its total lifecycle footprint to rise more than the e-Golf's, shifting both environmental break-even points slightly "earlier" (in the electric car's favour). Crucially, the e-Golf would have to increase its consumption roughly fivefold to match the additional CO₂ generated by a 10% increase for the Golf; even modelling the e-Golf's consumption growth at five times the Golf's moved its environmental break-even point by only about 21 km, negligible over 200,000 km. On the cost side, a 10% increase in consumption raised the Golf's end cost by 6.19%, but the e-Golf's by only 2.69%, leaving the economic ranking unchanged. The electric car's advantage is thus robust to driving style and colder climates.

4. Discussion

The coupled analysis gives a consistent answer to the two motivating questions for the Hungarian context. Over a realistic 200,000 km life, the electric car is both substantially "greener" and modestly "cheaper" than its petrol twin, and both advantages are maximised by charging from renewable energy. The environmental result is decisive: a 103% to 222% more reduction in emissions, and the economic result, though smaller, is real and favours the user, primarily because of low (partly subsidised) electricity prices and the high efficiency of the electric drivetrain. These findings are consistent with prior lifecycle work (Farzaneh & Jung, 2023; Hall & Lutsey, 2018) and with recent Hungarian total-cost-of-ownership analyses reporting EV competitiveness under domestic energy prices and incentives (Zoldy, 2026a; Zsiborács et al., 2026), while adding a controlled, single-platform, environmentally and economically integrated perspective.

Two caveats temper the optimism. First, the electric car cannot be labelled "zero-emission": even when use-phase emissions are eliminated by solar charging, manufacturing and battery replacement leave a substantial embodied footprint. The result depends on manufacturing estimates – the Buchal, Karl and Sinn (2019) figures have been criticised for, among other things, not crediting expected grid decarbonisation over a vehicle's life. Second, the mining of battery raw materials has impacts that CO₂ accounting does not capture and may be irreversible, such as water depletion linked to lithium extraction in South America (Tilly et al., 2024). The greatest potential, therefore, lies in stronger regulation of raw-material extraction and in charging from renewable sources, which together would shrink both the manufacturing hump and the use-phase footprint.

The economic findings raise a distinct, policy-relevant concern specific to public finance. The same features that make electricity cheap and efficient for the driver – namely low excise and low public contributions –, mean that an electric-car



owner contributes far less to public goods than the owner of an ICE vehicle, whose fuel price is heavily taxed. Because household electricity cannot be separated by end use, it is difficult to tax the electricity used for charging without also taxing, say, a washing machine. If an increasing share of drivers switches from ICE to electric vehicles under non-repayable state subsidies, the revenue available for road maintenance is likely to fall. Sustaining mass adoption, in countries and regions where governments have an environmental interest in promoting through incentives, requires a mature charging infrastructure in which users can place their trust (Guo et al., 2018; Gupta et al., 2021; Sierzechula et al., 2014). It will therefore require a new mechanism through which electric-car owners also contribute to public goods.

Several limitations should be kept in mind. The analysis rests on a single, near-identical model pair; while this design isolates the drivetrain, the emission and cost ratios are broadly representative. The absolute values are specific to these vehicles and to Hungary. The manufacturing emissions rely on a single, debated source, and the recycled-content correction is a transparent but non-standard simplification. Solar charging is idealised as fully covering demand and as carrying zero use-phase emissions, excluding the embodied emissions of the photovoltaic system. The cost model assumes a stable 4% inflation rate with no economic turbulence, excludes owner-dependent insurance and service costs, and assumes the same driver and route for both cars. These constraints narrow the number of exactly modelled cases but do not overturn the relative results, whose ratios reasonably represent the relationship between electric and ICE passenger cars.

5. Conclusions

Coupling a lifecycle and a total-cost-of-ownership analysis on a controlled petrol/electric vehicle pair shows, for the Hungarian context, that mass adoption of electric cars is an environmentally optimal direction. Over 200,000 km, the petrol Golf emits 103% more CO₂-equivalent than a grid-charged e-Golf and 222% more than a solar-charged one, reaching environmental break-even after only about 38,000 and 30,000 km. The electric car is also the lower-cost choice over a full ownership cycle, 10% to 28% cheaper than its petrol twin, with the solar-charged variant the cheapest of all, and with 70.4% of energy expenditure converted into useful motion versus 16.7%. The greatest potential is unlocked by charging from renewable energy, which simultaneously minimises emissions and operating costs. However, the same low energy taxation that benefits the driver implies that electric-car owners contribute little to public goods. So the central open question raised by these results is whether, and through what mechanism, the government can sustain public-revenue contributions as the fleet electrifies. Future work should generalise the analysis beyond a single model pair and quantify the fiscal instruments that can resolve this tension.

Data availability

The full LCA and TCO spreadsheet model, with all input parameters and equations, is openly available at: <https://docs.google.com/spreadsheets/d/1DRdjkeZzqt0dpeKhH2rSj8XbvILozpGs37Zg1Jh55as/edit?gid=1566974654#gid=1566974654>

Declaration of generative AI use

Generative AI was used to speed up translation from the Hungarian thesis.

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