





## TRANSPORT FINDINGS

# Impact of Charging Rates on Electric Vehicle Battery Life

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## Findings

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This article synthesizes the sparse empirical literature on the impact of different charging rates on electric vehicle battery life with a focus on popular electric car models. The findings show that rapid and ultra-rapid charging cause more degradation of the most common electric vehicle batteries than fast charging, although this degradation is limited to an extent by battery management systems. The information in this article can aid in planning the expansion of different types of charging infrastructure and be used to inform drivers who are switching to battery electric vehicles.

## Questions

The transition to electric vehicles (EVs) is seen as an important means to reduce global carbon emissions from the transport sector, but a number of barriers to mass adoption of EVs have been identified. Technical concerns such as battery range, charging time, and battery life are prominent among these, particularly for battery-only EVs as compared to hybrids (Biresselioglu, Kaplan, and Yilmaz 2018). Increased battery sizes increase the range of EVs and the provision of rapid charging infrastructure reduces charging time, but we ask what effect these have on the third concern of EV battery life?

We aim to answer this question, whilst considering the impact of charging speeds on battery life more generally. We also have identified a lack of clear guidance for prospective EV purchasers and for charging infrastructure providers on the interactions between battery types, range, charging times, rate of charge, and battery life. Therefore, we aim to fill this gap with a simple table providing this information for ten of the most common private electric cars on the market today.

## Methods

We define battery life and the processes causing battery degradation, then review the sparse literature empirically testing battery degradation. As degradation and the impact of charging speeds are dependent on the size and type of battery, we use web searches to synthesize information on how choosing different charging options affect battery life for common EV models in the UK.

All batteries degrade with time and use. Most EVs have a warranty for eight years or 100,000 miles, whichever is earlier. An EV battery is considered at end of its life if it no longer maintains 80% of total usable capacity and has more than 5% self-discharge rate over a 24-hour period (Engel et al. 2019).

Table 1: Literature on the influence of charging rate on battery degradation

Reference	Type of battery	Number of batteries tested	Charging rate of tests	Conclusion
Gao et al. (2017)	18650-type NMC	21	0.5C, 0.8C, 1C, 1.2C, 1.5C	NMC battery degrades significantly on C-rates higher than 1. Battery degrades by 10% and 23% at 1.2C and 1.5C respectively at the end of 300 cycles as against degradation by 7% at 1C.
Somerville et al. (2016)	18650-type NMC	12	0.7C, 2C, 4C, 6C	Increased charging rates negatively affect the lifetime. Charging at rates higher than 4C alters the chemical composition resulting in significant damage and reduction of life.
Anseán et al. (2016)	LFP	3	1C, 4C	Capacity degradation is 15% at 1C and 17% at 4C after 4,000 cycles. Up to 1000 cycles, the degradation from both charging rates are similar.
Wang et al. (2011)	LFP	200	0.5C, 2C, 6C, 10C	Experimental results indicated that the capacity loss was strongly affected by time and temperature, but minimally by charging rates.

Accelerated battery degradation can be caused by charging and discharging patterns, such as repeatedly using the entire capacity of a battery, or repeated rapid charging (IEA 2020).

Charging (and discharging) patterns are measured via ‘C-rates’ per hour, so that 1C-rate means that the battery will be completely charged or discharged in 1 hour at that level of current. Ignoring the conversion efficiencies, the C-rate can be calculated by dividing the charger’s power level by the battery capacity or size. For a given charging power, the larger the battery capacity, the lower the C-rate for charging.

Battery life is also dependent upon the type or chemistry of the battery used in the EV, which can be Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Nickel Cobalt Aluminum Oxide (NCA), or Lithium Iron Phosphate (LFP).

## Findings

A review of literature on the impact of charging speeds on battery life was conducted using keywords of ‘Lithium battery degradation’ and ‘Lithium battery life’ on Google Scholar. Although there is considerable work on the different degradation mechanisms, few studies quantify degradation through empirical experiments on batteries suitable for EVs. Even less research maintains uniformity across discharge rates to enable a direct comparison of the impact of charging rates. The remaining literature is summarized in [Table 1](#) and shows that for NMC batteries, charging rates above 1C rate adversely affects the battery life whereas, for LFP batteries, the battery life is not significantly affected by charging rates up to 4C.

Thus, rapid chargers can hasten the degradation of batteries in vehicles with NMC battery chemistry. However, the battery management systems in vehicles are set to limit the level of power received to prevent accelerated degradation.

Table 2: Battery chemistry, capacity, charging power limits, and C-rates

EV model (market share of BEVs <sup>1</sup> )	Battery chemistry <sup>2</sup>	Battery capacity or size <sup>3</sup> (kWh)	Charging power limit <sup>3</sup>		C-rate in per hour by charger type (charger power limit kW)			
			AC <sup>4</sup> (kW)	DC (kW)	AC <sup>4</sup> Home charging (7 kW)	AC <sup>4</sup> Fast charging (22 kW)	DC rapid (50 kW)	DC ultra- rapid (150kW)
Nissan Leaf (22%)	NMC	40 or 62	6.6	49	0.11C	0.11C	0.79C	NA <sup>5</sup>
Tesla Model 3 (17%)	NCA	55	11	170	0.13C	0.20C	0.91C	2.7C
BMW i3 (6%)	NMC	42	11	49	0.17C	0.26C	1.17C	NA <sup>5</sup>
Volkswagon e-Golf (5%)	NMC	35.8	7.2	40	0.20C	0.20C	1.12C	NA <sup>5</sup>
Renault ZOE (9%)	NMC	55	22	46	0.13C	0.40C	0.84C	NA <sup>5</sup>
Tesla Model S (7%)	NCA	100	16.5	250	0.07C	0.17C	0.5C	1.5C
Kia e-Niro (3%)	NMC	42 or 67	7.2	50	0.10C	0.11C	0.75C	NA <sup>5</sup>
Jaguar I-Pace (6%)	NMC	90	11	104	0.08C	0.12C	0.56C	1.2C
Tesla Model X (4%)	NCA	100	16.5	250	0.07C	0.17C	0.5C	1.5C
Hyundai IONIQ (2%)	NMC	40	7.2	44	0.18C	0.18C	1.10C	NA <sup>5</sup>

<sup>1</sup> Department for Transport 2020.

<sup>2</sup> <https://pushevs.com/2020/04/04/comparison-of-different-ev-batteries-in-2020/> Accessed January 2021.

<sup>3</sup> <https://ev-database.uk/> Accessed January 2021.

<sup>4</sup> The electricity that comes into our households from the grid is Alternating Current (AC). Most modern electronics, including EVs, use Direct Current (DC) for their operation. During AC charging of EVs, current from the grid is converted into DC using the on-board inverter, whereas in DC charging, the rapid or ultra-rapid charger converts AC into DC.

<sup>5</sup> Many models do not currently support the use of ultra-rapid chargers.

Therefore, the impact of rapid charging also depends upon these limits, which can be used as the numerator instead of the charger's power level in calculating C-rate. [Table 2](#) shows the battery chemistry, size and any power limits of the top ten battery-only EV models sold in the UK (Department for Transport 2020). The vehicle power limit or the maximum power capacity of the charger, whichever is lower, is then used to calculate the respective C-rate.

[Table 2](#) shows that EV models with NMC batteries have DC charging power limits that prevent the C-rate from going much above 1C. Even without power limits set by battery management systems, none of these EVs come close to exceeding 1C whilst using fast chargers. For rapid and ultra-rapid charging, the exceedance is minimal due to the power limits. Consider the Jaguar I-Pace: the additional degradation is limited to around 3% in 300 cycles when using ultra-rapid chargers. Such charging rates can reduce the NMC battery life by up to 10% as against home, fast or rapid charging in 300 cycles. Thus, regular rapid and ultra-rapid charging does reduce battery life, but this is minimal due to battery management systems.

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## REFERENCES

- Anseán, D., M. Dubarry, A. Devie, B.Y. Liaw, V.M. García, J.C. Viera, and M. González. 2016. “Fast Charging Technique for High Power LiFePO<sub>4</sub> Batteries: A Mechanistic Analysis of Aging.” *Journal of Power Sources* 321 (July): 201–9. <https://doi.org/10.1016/j.jpowsour.2016.04.140>.
- Biresselioglu, Mehmet Efe, Melike Demirbag Kaplan, and Barbara Katharina Yilmaz. 2018. “Electric Mobility in Europe: A Comprehensive Review of Motivators and Barriers in Decision Making Processes.” *Transportation Research Part A: Policy and Practice* 109 (March): 1–13. <https://doi.org/10.1016/j.tra.2018.01.017>.
- Department for Transport. 2020. “VEH0133: Licensed Ultra Low Emission Vehicles by Body Type and Propulsion or Fuel Type: United Kingdom.” *Ultra Low Emissions Vehicles (ULEVs)*. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/942249/veh0133.ods](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/942249/veh0133.ods).
- Engel et al. 2019. “Second-Life EV Batteries: The Newest Value Pool in Energy Storage.” *Our Insights*. <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage#>.
- Gao, Yang, Jiuchun Jiang, Caiping Zhang, Weige Zhang, Zeyu Ma, and Yan Jiang. 2017. “Lithium-Ion Battery Aging Mechanisms and Life Model under Different Charging Stresses.” *Journal of Power Sources* 356 (July): 103–14. <https://doi.org/10.1016/j.jpowsour.2017.04.084>.
- IEA. 2020. “Global EV Outlook 2020.” Paris: IEA. <https://www.iea.org/reports/global-ev-outlook-2020>.
- Somerville, L., J. Bareño, S. Trask, P. Jennings, A. McGordon, C. Lyness, and I. Bloom. 2016. “The Effect of Charging Rate on the Graphite Electrode of Commercial Lithium-Ion Cells: A Post-Mortem Study.” *Journal of Power Sources* 335 (December): 189–96. <https://doi.org/10.1016/j.jpowsour.2016.10.002>.
- Wang, John, Ping Liu, Jocelyn Hicks-Garner, Elena Sherman, Souren Soukiazian, Mark Verbrugge, Harshad Tataria, James Musser, and Peter Finamore. 2011. “Cycle-Life Model for Graphite-LiFePO<sub>4</sub> Cells.” *Journal of Power Sources* 196 (8): 3942–48. <https://doi.org/10.1016/j.jpowsour.2010.11.134>.