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Observations on electric vehicle's first hurrah - horse, steam and electric tram technology adoption rates in the UK 1860s to 1960s

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Abstract

The momentum for the adoption of electric vehicles is currently the strongest it has been for over 100 year. This paper provides data and observations on electric vehicle's first major success – the largely forgotten rise and fall of the electric tram. Using a data set from 1860s to 1960s for the progressive adoption and abandonment of horse, steam and electric traction technologies in towns in the United Kingdom, graphs show the rollercoaster path of tram technologies and the strong similarities in their take-up rates consistent with a simple S-curve innovation path.

However, observations from the history of the period and the path of electric trams adoption suggests the efficiency benefits that came with the rapid rise of the tram and that transformed intraurban mass transport could only happen once. Although technology transitions and the take-up rates for new technologies involve a range of issues, care needs to be taken in expecting similarly efficiency benefits to support a simple S-curve innovation path for the current resurgence of electric vehicles, even with their positive climate change and air pollution reductions impacts.

1.Introduction

"The electric vehicle is coming!
It is an integral part of man's future and survival on this planet.
Today we are observing the stepping stones that will bring technology and imagination together to create truly efficient vehicles and energy systems worthy of the 21st century….
The threshold of a new age is upon us. It is ours to behold"
The Complete Book of Electric Vehicles, 2nd edition 1981

"In 1900, 4,192 cars were manufactured in the United States. Of them, 1681 were steam, 1,575 electric, and only 936 gasoline. ……Unfortunately, it is much easier to document the triumph of the internal combustion engine than to explain its success. In 1905 each of the power plants had advantages and disadvantages; none had a clear-cut technological superiority. The electric car appeared to have all of the good points of the horse and buggy with none of its drawbacks." Basalla, The Evolution of Technology, 1988

"Australia is on the cusp of a new era in lower-cost, longer-range electric vehicles, across a range of vehicle types" Institute for Sensible Transport, email received July 2021

With hindsight the dominance of internal combustion engines (ICE) in cars, trucks and buses through the 20th and into the 21st century seems natural and inevitable. It wasn't always so. The technical limitations of new technologies and the barriers that need to be overcome to replace incumbent technologies can be quickly forgotten. Also missed is the success and persistence of older and intermediary technologies,[1] the interplay between old and new technologies and the mulitple factors that need to be in place to support a new technology transition.[2] A dominant new technology can make an old technology invisable.

In the popular imagination cars replaced horses[3] whereas: firstly only the very rich could afford horses until horse buses and then horse trams replaced walking for the better off; steam trams were briefly trialed; then finally electric trams made intraurban transport affordable for all.

A detailed look at all the factors behind shifts to new technologies and the pace of their adoption is beyond the scope of this paper but data and observations from the history of electric trams in the UK around the turn of the 20th century may help inform the current reemergence of electric vehicles.

2. Tram traction technologies in the UK – 1860s to 1960s

There is an active heritage community interested in the history, technical details, aesthetic and preservation of early trams and tram memorabilia, however data on the economics and statistical details of the rise and fall of electric trams is not as readily available. The economic history of trams also appears to be less comprehensively researched and documented than that of railways.[4]

The narrative around the rise and fall of electric trams has been covered elsewhere[5] but has been so largely forgotten that British Trams have been called "history's orphans". [6] The graphs in this paper seeks to illustrate this story. McKay's "*Tramways and Trolleys; the rise of urban mass transport in Europe*" published 45 years ago remains the most comprehensive source of data on the topic but has gaps (if better data sets exist they were not apparent at the time of writing). As Spearritt notes:

> *"There is a vast enthusiast's literature on former tramway systems in most parts of the world. The books tend to be reliable on the opening and closing dates of routes, and go into great detail about the rolling stock, but as with railway history, are usually less interested in the public policy and political issues around public transport versus private car use."*

Three waves of tramway adoption in UK towns are shown in Figure 1 based on opening and closing dates of new lines. The uptake of newer technology is mainly due to the progressive replacement of old technologies but the pattern is was not always a progression from horse to steam and then electric tram. Delayed adoption of trams in a town could see it move straight to electric trams while some towns continued to use horse trams well after mechanised technologies were economically viable elsewhere. Horse and steam tram numbers are combined in Figure 1 to better show the major focus of this paper, the shift to electric trams.

The eventual up-take of ICE buses, starting in London with Frank Searle's B type motor bus around 1912, as they became reliable and economically viable substitutes and replaced trams, is not examined here. This is partly because cities often ran combined and complementary

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[1] See Basalla, Mokyr, Bird, McKay, Cannon but particularly Edgerton's *Shock of the Old* and *Geels*

[2] Horse numbers increased with the expansion of railways with trams doing short feeder and connecting trips. Edgerton, and particularly McKay

[3] Forbes and Brasch for the romanticised view of horses' role of Australia.

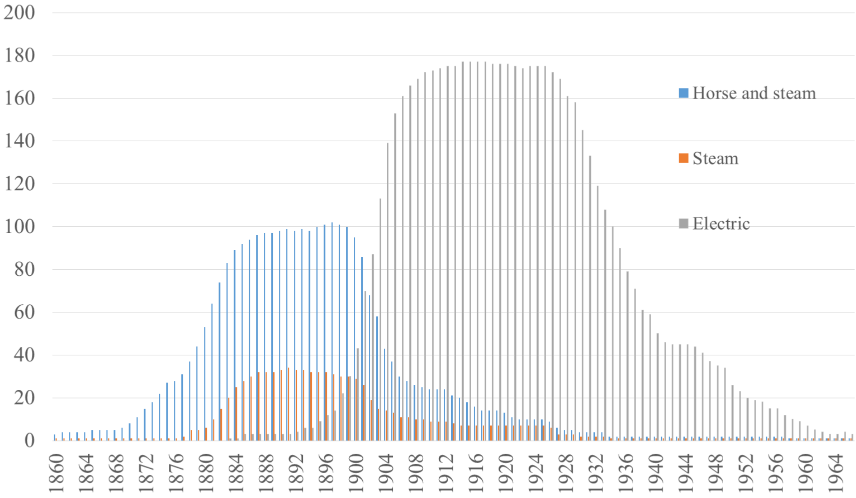
[4] As Mokyr states "*Railroads were the invention that par excellence defined modernity, both to contemporaries and to economic historians"* and railways were, though Robert Fogel, a pioneering area for cliometrics.

[5] Good tram tracts include McKay, Bond, and Green Oakley for the UK, McShane and Tarr for the USA

[6] Bond

horse then ICE buses with tram systems but primarily due to the lack of a comparable data set for buses. A fuller data set would be useful to understand the change in technologies over time and also allow for a matching of towns to the number of horses, number and length of tramlines, number of passengers and numbers of buses and bus routes.[7]

Figure 1: Number of towns in the United Kingdom operating electric, steam and horse tramlines 1860-1970



The total number of UK towns with tramways, shown in Figure 2, displays a two tiered curve with initial up-take leveling off in the years surrounding 1890 and peaking in around 1911, followed by stable numbers into the late 1920's then decline. While to modern eyes this seems natural it is worth noting that overall horse numbers as "living machines" in the UK, as elsewhere, remained high well after 1911. Horses continued to be significant in short trip haulage because trucks took longer than trains, trams and the passenger ICE automobiles to become economically viable. For example horses for transport and haulage outnumbered other vehicles in the British army throughout World War I, with over 0.8 million horses and mules in service by 1917. Horses even continued as an essential part of the German army's logistics throughout World War II.[8]

Figure 2: Total number of towns in the United Kingdom operating horse, steam, or electric tramlines 1860s-1960s

[7] Selected other graphs of tram statistics have been included as attachments, and further sources welcomed.
[8] Edgerton, in the USA from 1870 to1900 city populations doubled while horse numbers quadrupled (Standage).

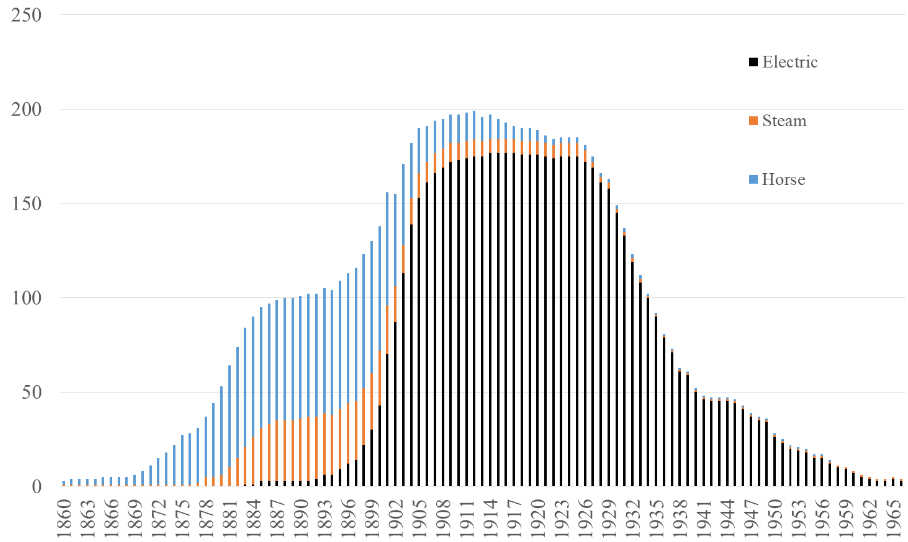
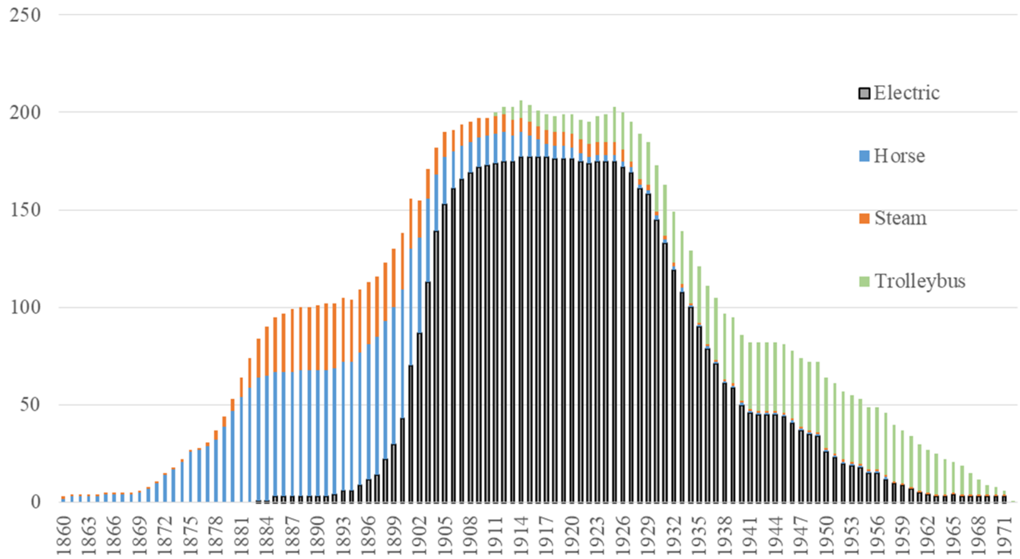


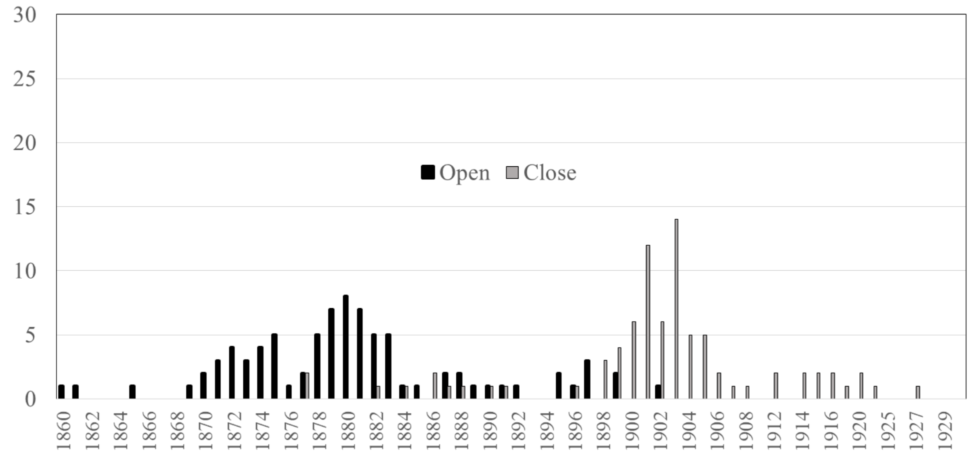
Figure 3: Towns in the United Kingdom operating horse, steam, electric tramlines or trolleybus routes 1860s-1970s



In Figure 3 trolley buses are added to the data graphed in Figure 2 and show an extended and slower decline in the number of towns with electric vehicles on their streets, particularly during and immediately after World War II. Trolleybus adoption started later, lasted longer and eventually towns with trolley buses outnumber those with electric trams but trolleybuses never had the transformative impact of trams.

The movement of towns into and out of horse, steam and electric tram traction technology is shown in Figures 4, 5 and 6.

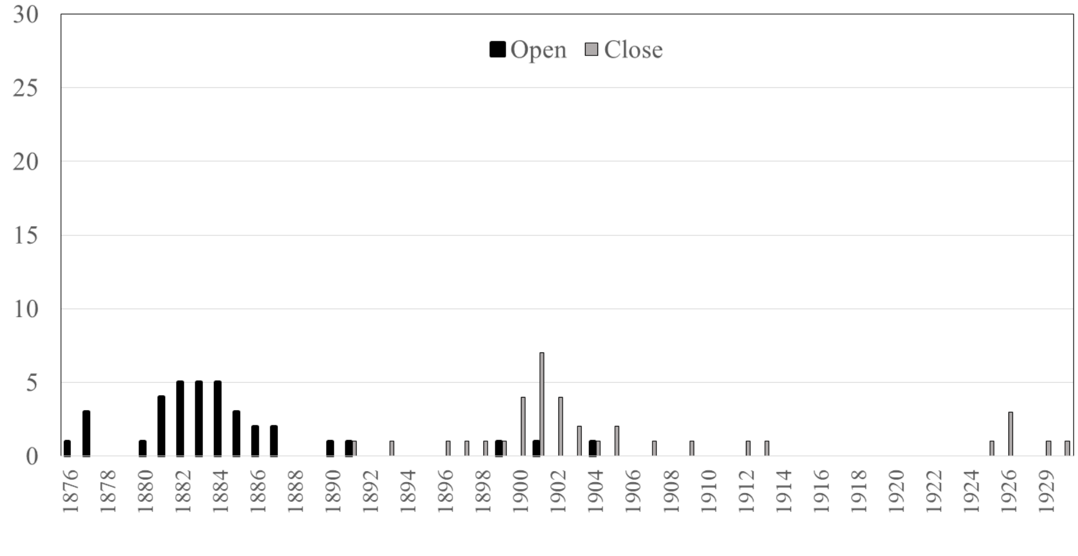
Figure 4: Towns in the United Kingdom opening and closing horse tramlines 1860 to 1930



Even at its peak around 1880 fewer than ten cities a year opened new horse tramlines despite activity recovering from a dip through the Long Depression post 1873. The equine flu that crippled the North American streetcar industry in 1872 is also likely to have increased the desire for mechanised replacements (as in 1816, "The year without a summer", horse starvation and death assisted the bicycle's development).

While in the early 1880's fewer towns adopted horse trams, steam trams only opened in as many as five towns per year for a brief period and were quickly supplanted in popularity by electric tram technology. Smoke, weight, noise, long start-up times, boiler explosions and particularly risk of fire were major limitations on the acceptance of steam trams with governments facing vocal opposition from local populations.[9]

Figure 5: Towns in the United Kingdom opening and closing steam tramlines 1876 to 1930



The data for both horse and steam trams show that, despite early replacement and closures, new towns continued to adopt horse and steam trams even after electric trams were on the ascendency. Cable, diesel, petrol, soda, gas and battery trams were also tried in the UK and elsewhere in Europe but in smaller numbers and generally (with some exceptions) disappeared fairly quickly and have not been covered in this review.

The movement of towns into and out of trolleybus operation technology, shown in Figure 6 has a different pattern than for trams, starting later and with a longer flatter spread of openings

[9] McKay covers steam's challenges in detail.

and closing. Not needing the high upfront cost of putting rail in the road gives trolleybuses a different operational profile than trams and suggests they may be closer substitutes to ICE buses.

The rest of this paper will concentrate on horse, steam and particularly electric tram technologies.

Figure 6: Towns in the United Kingdom opening and closing Trolleybus lines 1911 to 1972

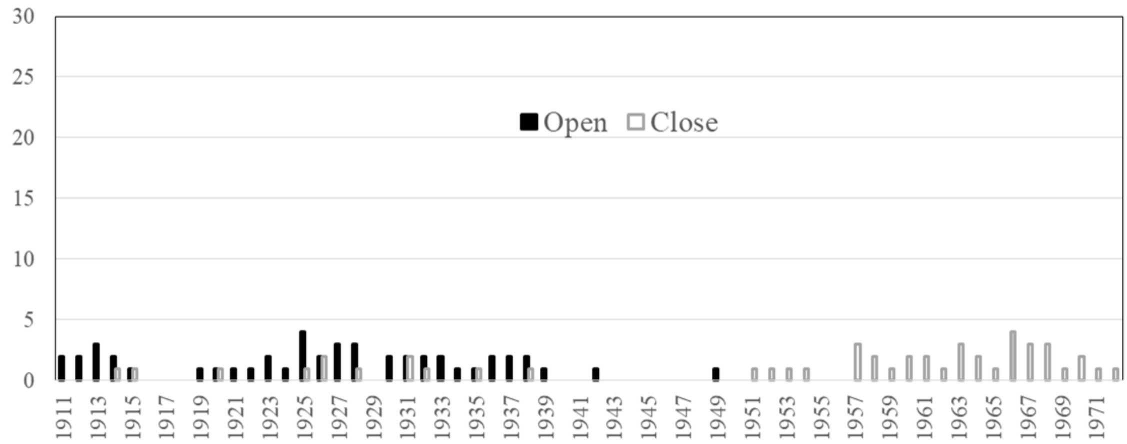
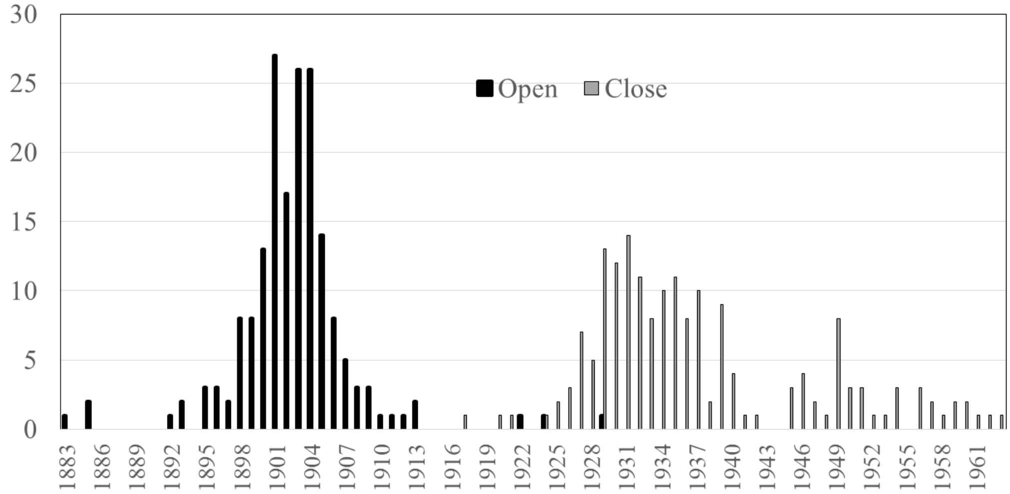


Figure 7: Towns in the United Kingdom opening and closing electric tramlines 1883 to 1963



The pattern of electric tram adoption in the UK is shown in Figure 7 with rapid take-up by new towns around the turn of the century which dwindled by 1910 and had stopped by the advent of World War I.[10] Closures start in the late 1920s, peak through the Great Depression years of the 1930s, are paused in World War II while petrol supplies for buses and cars were rationed, then continue with at long tail that extends into the 1960s.

Changes in numbers in individual years may reflect random factors or faults in the data but the overall pattern is clear. In each town particular economic, geographic, social and political factors, including nationalisation and privatisation, could influence both the opening and closing of tramlines and the choice of traction technology at any particular time. However, the data in Figure 7 and Figure 1 shows the clear roller coaster pattern of repeated growth and decay for new tram technologies within towns.

[10] A similar graph just of openings is found in Bond, 1981

3. Tram Traction Technology adoption

Table 1 provides a broad overview of the progress in tram technologies but the pattern is more clearly shown by a series of line graphs of the progressive uptake rates over time.

Table 1: Average start and end dates, mean life and mode life for Tram technologies in UK towns

Tram type	Start date mean	End date mean	Start date mode	End date mode	Life mean	Life mode	Town numbers
Horse	1880	1903	1880	1903	23	23	85
Steam	1884	1908	1882	1901	24	22	37
Electric	1903	1938	1901	1931	36	31	180
Trolleybus	1926	1954	1925	1966	27	41	48

Note the total town numbers are not additive as towns can move between technologies and progress from horse to steam then electric traction or horse to electric or trolleybus over time. Less common technologies in cable, gas, battery petrol and diesel are not included but can create gaps in the numbers.

Figure 8 shows the same data as in Figures 1 and 2 but as a line rather than a bar graph and scaled. Numbers of towns with pre-electric technology are graphed on the right hand scale and towns with electric trams graphed on the left hand scale. The switching of towns with tramways from horse and steam to electric traction is shown clearly. Interestingly in each case some towns persist with older technologies when the majority have moved on.

Figure 8: Towns in the UK with tramlines by number and type a scaled comparison 1860s to 1960s

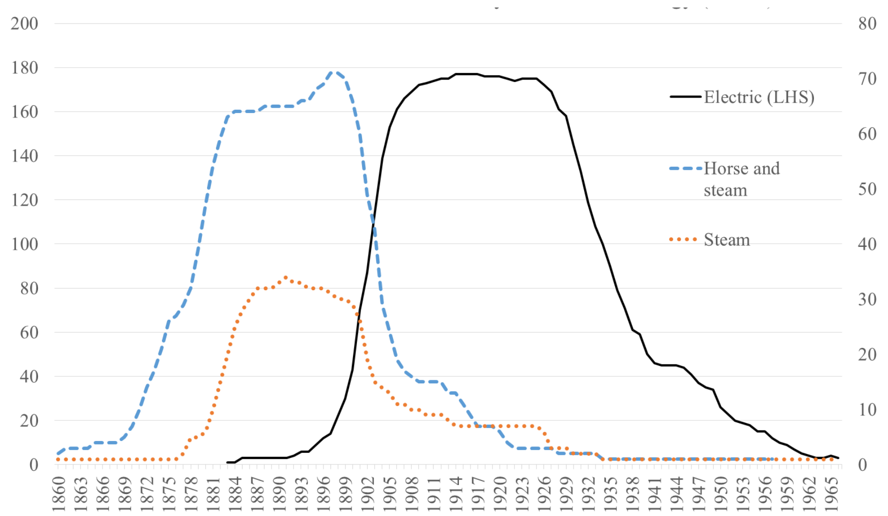


Figure 9 takes the data in Figure 1 and shifts the starting dates for steam and electric trams back in time to align the earlier take-up of horse trams. This shows the three technologies on a common timeline and reflects the average lives shown in Table 1.

Figure 9: Towns in the UK with tramlines by type, time shifted to earliest tram adoption

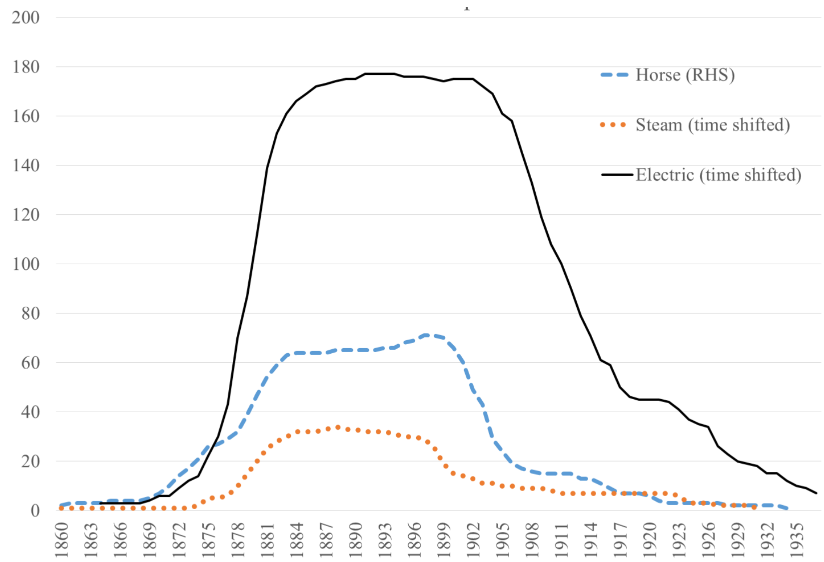
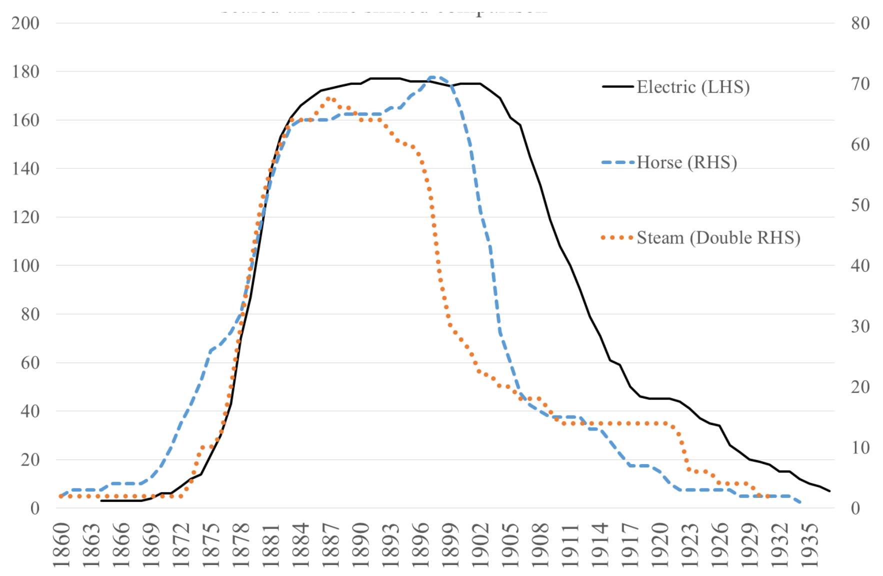


Figure 10 combines elements of the approaches taken in Figures 8 and 9 to show the adoption curve by towns of horse, steam and eclectic tramways when both scaled and time shifted. To compare the three technologies the starting dates for steam and electric trams are shifted back, the number of towns with horse trams scaling by 2.5 to 1 (shown on the right hand scale) and of steam trams by double this to 5 to 1 (or twice the right hand scale) compared to the number of towns with electric trams (shown on the left hand scale).

Represented in this fashion a different picture emerges than that shown in the summary statistic in Table 1. The take-up rates of all three tram technologies look to be strikingly similar, and almost identical for adoption of mechanised steam and electric trams. The period of operation by towns is clearly shortest for steam trams, longer for the horse trams that preceded them but longest for electric trams. The decline in particular tram technologies looks quickest for horse trams (reflecting switching rather than closing lines), slightly slower for steam trams and slowest for electric trams. It could be argued that trolley buses formed a bridge between electric trams and ICE buses (as for example they did from 1930 to 1957 in Pontypridd in Wales) or that they are more closely aligned to bus systems than trams. The comparative longevity and slower closure by towns of electric tramlines is partly the effect of World War II but also represents the replacement of the entire tramway system by trolleybuses, ICE buses or passenger cars rather than just changing the energy source for moving people along dedicated tramways.

Figure 10: Towns in the UK with tramlines by type, scaled and time shifted to earliest adoption



The adoption rates for trams fits the standard “S-curve” map for forecasting new technologies. On closer scrutiny the S-curve, that in retrospect looks like a reliable pattern useful for prediction, is really more of narrative than a roadmap. Things that eventually succeed start growing slow, pick up speed, become widespread, reach an asymptotic saturation acceptance level, where subside. The exact scale, timing and end of the narrative is not predictable. But when compared to other technology adoption trend curves trams were clearly in the fast lane of adoption rates, and similar S-curve growth is expected for today’s EVs.[11]

“Time and again, industry leaders, policy makers, and experts have been surprised by the pace at which new technologies transform markets and societies. From horses to cars, landlines to mobile phones, or videos to streaming. Technological innovation tends to follow the ‘S-curve”[12]

4. Glimpses at the historic economics and efficiencies of tram lines and roads

Sitting behind these graphs is the seismic shifts that the rise and fall of the tram technologies created at the turn of the 20th century in intraurban mass transport, urban populations and economies both in the UK and worldwide. Schaeffer and Scalar characterised this as a transition of urban centers from the “Walking City” to the “Tracked City” to the “Rubber City”. Before horse trams only the richest rode, after electric trams everyone could. The reduced travel time, longer journeys, lower costs and increased passenger volumes tramways allowed lifted effective employment density, created a dramatic effect on urban form and the organisation of industry within cities and delivered productivity improvements from agglomeration economies.

Trams, when first introduced and again when improved through electric traction, clearly created the sort of Wider Economic Benefits that are currently controversial inclusions in cost benefit analysis of transport infrastructure.[13]

[11] McKinsey, as shown in Figure 16, and Grubb for the current EV S-curve as Figure 17 in the Appendix
[12] Grubb on predicting EV adoption
[13] Warner on Boston is a classic study and Jackson for US suburbanisation

How big the Wider Economic Benefits and other benefits from trams were when they were introduced is difficult to measure. Ideally there would be data, in addition to the uptake of tram technologies by towns that would support ex post and ex ante comparisons of the cost and benefits of walking, horses and horse buses, then steam, cable and electric trams followed by trolley buses and ultimately petrol driven pneumatically tired cars, trucks and motor buses. This is difficult to reconstruct. Both the technologies and the conditions they operated changed rapidly at the dawn of the 20th century and hindsight is liable to be biased when the eventual winners are now clear.

The full reason for the growth of rails in roads rather than alternative options, and their eventual removal, involves a complicated range of social, political and technological issues.[14] Not just the impact of individual things but also of a network of things interacting together. A proper analysis of the issues is beyond the scope of this paper but observations by several historians are instructive.

Before trams the very poor quality of early roads made travel difficult and costly. Just as this had earlier stimulated the rise of canals and railways it advantaged trams within cities over other road users. [15] A key area where trams were initially technically and economically superior is at the point where the rubber hits the road – the inefficiency of solid rim wheels before the development of cheap and long lasting pneumatic tires.

"It is difficult for modern motorists to visualise the magnitude of the tyre problem at the beginning of the century"[16]

"*Mounting a bus (horse-drawn omnibus) on rails was the first improvement in an attempt to find a transit system capable for expanding the city…the much lower friction between wheel and rail, compared to wheel and road , meant the same load could be pulled by less power. …Horse-drawn trams could carry 18-20 people like horse buses but drawn by one horse not three*."[17]

"*the cost of horsepower for a tram was half that for a bus of comparable capacity, and if allowance is made for the cost of laying and maintaining track the tramway still showed an advantage of about one–third*"[18]

The shift from horse to electric trams then created a second wave of technological and economic efficiency benefits:

"*the electric tram was about twice as fast as the horse tram (12 mph vs 6 mph) and it eliminated the problem of horse manure. Operational cost were lower, reducing from 8-11 cents for horsepower to 1.5 cents for electric power"*[19]

Compared to horsepower electric trams could travel further, go faster, had larger capacity, ran cheaper, did to need to be fed, watered, groomed, rested, leave manure or drop dead in city streets. The mechanisation of electric trams made intraurban transport accessible for all, whereas the cost of horsepower immediately before and private ICE passenger vehicles immediately after meant they were only accessible to the rich and middle classes.

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[14] For example Gordon, Basalla, Mokyr, Jackson-Stevens, Bird, Cannon and Spearritt but particularly Geels.

[15] Mokyr "*a cause celebre in the economic history of the industrial revolution*"

[16] Bird

[17] Schaeffer and Scalar who also estimate 10 horses were needed to support each tram.

[18] Bird & Rolt

[19] Gordon on the United States, also Standage's introduction for a brief summary of manure in UK.

"*horse drawn vehicles were dominant in 1905 but had largely disappeared by 1917. The short period of transition from urban streets is one of the most rapid in the history of invention*"[20]

Both in foresight and in hindsight the issue of how much better a new technology is than an older or another alternative is difficult to gauge due to the uncertainties and interdependencies involved. Electric trams were not a standalone product but developed along with electricity power plants and grids with the demand from electric traction, trams and railways, providing a large and dependable daytime base load for early electricity networks, supplementing and counterbalancing their otherwise heavy dependency on nighttime lighting loads. Public option and regulation are hard to reflect in the data, such as the UK's 1870 Tramways Act with its 21 year municipal acquisition clause which possibly delayed electric trams in the UK by 10 years compared to the USA and Germany. Circumstances differed between private and municipal companies, buses could be excused from taxes that were levied on trams and tram fares could be regulated and fixed. Tramlines could also be developed not as business in their own right but to drive short term profits in suburban real estate developments.[21]

Looked at in hindsight the graphs can be seen as representing the rapid and inevitable replacement of one tram technology with a technically superior alternative until eventually giving way worldwide (with a few notable exceptions like Melbourne) to the superiority of ICE cars and buses. Viewed in real time history is more complex and varied. Henry Ford supported and encouraged the building of a municipal electric streetcar line to his Deerborn Model–T factory. Mrs. Clara Jane Ford, Henry's wife, chose to drive a competitor's Detroit electric vehicle.[22] Henry, with Thomas Edison, also extensively trialed an electric car around 1910 based on Edison's belief:

"I don't think nature would be so unkind as to withhold the secret of a good storage battery if a real earnest hunt was made for it"[23]

Yet finding a good battery remained the major constraint for electric vehicles for over 100 years. When affordable reliable pneumatic tires allowed ICE vehicles to break free from the efficiency of rails, the unkind century-long "real earnest hunt" for good batteries kept mass transport electric powered vehicles tethered to overhead lines, as trams or trolley buses, until they eventually ceased to be accepted or economic.[24]

The point when electric tramlines ceased to be economic and how viable they were at the point when they were closed remains a controversial topic. Suspicions of nefarious corporate behavior in the United States continues to feed disputes about the historic economics and efficiencies of streetcars and has become known as the "General Motors streetcar conspiracy" or the "Great American Streetcar Scandal". This is ironic given the previously suspicion and distrust of private tram companies which led to their poor public image in the US, delayed their adoption in Europe and lead to the popularity and success of the Glasgow model of municipal ownership. Like the recent reemergence of trams worldwide, including in major Australian cities, this topic is beyond the scope of this paper.

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[20] Ibid.

[21] Xie and Levinson

[22] An expensive, luxurious and popular car model in the period when electricity cars were seen as suitable as town cars and for ladies and which remained the highest selling electric vehicle from the 1910s till the 2010s.

[23] DeGraaf, also see Barber

[24] This paper has omitted discussing possibly the most invisible, ubiquitous, transformative and widely used form of electric transport in cities, one that hides in plain sight every day, the electric lift or elevator. Lifts made skyscrapers viable, high density possible and, in partnership with the similarly grid connected electric tram, shaped cities in the years after hope for battery powered electric vehicles faded and before the internal combustion engine private car became ubiquitous.

5. Data Sources and interpretation

This paper was started after discovering "*British Electric Tramways"* (Jackson-Stevens 1971) at Berkelouw Books Sydney in June 2021 and its appendix listing open and close dates, ownership and rail gauges of electric trams. This was then supplemented with data on horse and steam trams available from Wikipedia (originally sourced from Turner's *Directory of British Tramways. Volume 1 and. Volume 2*) and further supplemented with trolleybus data also from Wikipedia (sourced from Murray's, *World Trolleybus Encyclopaedia*).

Due to their small numbers cable, battery, petrol and gas trams were not included in the data analysed. Also largely excluded were early, experimental and non-commercial attempts at tramways as well as predominantly tourist and historic tram lines which continued once major service has halted. The data on company versus municipal ownership was not examined and might be best understood through case by case stories of individual towns, individual companies and individual tramlines.[25] Similarly the wide divergence in rail gauges evident in the data showed no strong pattern and was not analysed further, and is less relevant for intraurban trips on city based trams than the "rail gauge" issue for intercity and national railways where major rail lines interconnected (see Blayney, Dobes).

The data is only intended to be indicative of adoption and decline trends as the definition of town can vary and one instance is recorded per town even when the number of companies operating in a town, the numbers of lines, line length, number of vehicles, numbers of passengers and freight, and kilometers of freight and passengers carried can all vary. A large city for example counts as one data point as does Pontypridd in Wales. Importantly the scale of tram usage is also not covered although by 1905 patronage was such that "*tramways carry the whole population of the United Kingdom four times every month*."[26]

5.1. Note on Australia and other nation's tram data

This paper does not attempt to explore issues around Australian tram technologies, their adoption and decline. Similar data for trams in Australia (21 towns) and New Zealand (14 towns) is available in Wikipedia and other sources. These smaller numbers are more conducive to individual narratives, like the scale of trams in Sydney, safety, early cable tramlines, closure elsewhere[27] and the persistence of trams in Melbourne.[28]

With the excellent work in graphing historic transport use by Cosgrove, Lahoorpoor and the evolution maps developed by Levinson and Lahoorpoor as notable exceptions, long data series on trams in Australia are not readily assessable.[29]

The recent revival of trams in several Australian cities is not covered and the issues around their reemergence has not been considered.

Consideration was given to adding European and North American towns where electric trams were adopted earlier than in the UK to the data set but the source material is much larger, is not as consistent or as easily compiled from a single source. However some graphed data is included as attachment Figures 11, 12, 13 14 and 15 and the author would welcome information on other sources.

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[25] Again the best coverage is McKay for Europe and McShane and Tarr for the USA.
[26] Garcke (1906)
[27] Howard
[28] Spearritt also see Cosgrove for post 1900 patterns in public transport use, Edmonds and Tuffrey on safety.
[29] Network Design Lab

6. Observations and conclusions

"There have been passenger tramways in Britain for more than 150 years, but trams have had a roller coaster ride for most of this period. They have been characterised at various times both as a progressive transport success and a long term failure in shaping our urban lifestyle. Their history could be represented on a graph showing early growth under horse and steam power in the late Victorian period, a striking Edwardian electric boom in the early 1900s, a peak in use and development in the 1920s, then a steady decline to virtual extinction in the 1960s.[30]

Despite its limitations, the data on UK town adoption rates shows the roller coaster ride of tram traction technologies. A picture that has largely been forgotten**.** It also shows a surprising consistency in the take-up rate but different eventual life span**s** of horse, steam and electric technologies. This could give confidence to the promoters of electric vehicles that what has happened once can happen again. However, a quick inspection of the historical detail suggests that the dramatic century old change in transport that included the rise and fall of the electric tram, could only happen once.[31]

The benefits from electric trams came in improvement compared to walking and significantly less efficient horse drawn and steam powered vehicles and supported a rapid S-curve style adoption. The necessary shift to support Greenhouse gas reductions from ICE to battery electric vehicles, including electric buses and trucks, will be harder having less scope for the rapid efficiency gains and wider economic benefits than electric trams could achieve over 100 years ago.

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[30] Oliver
[31] As Gordon emphasises for 1879-1940.

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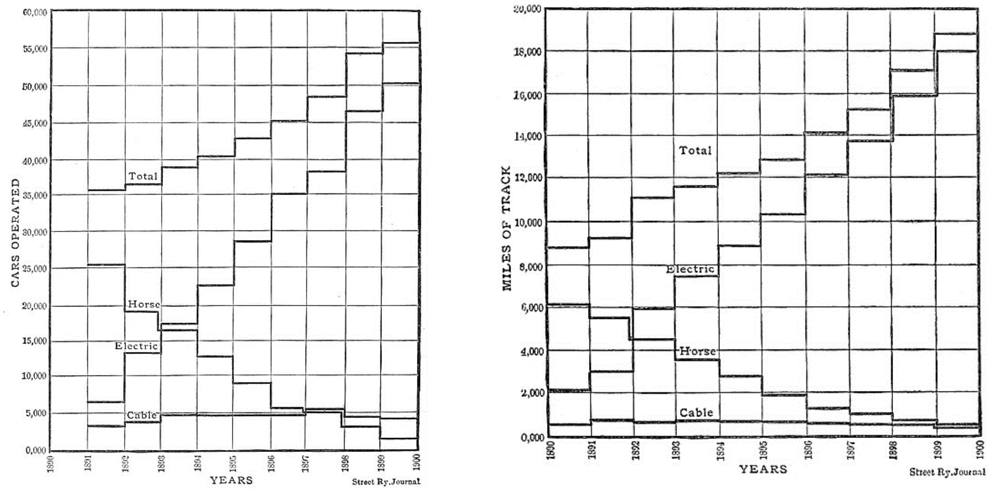
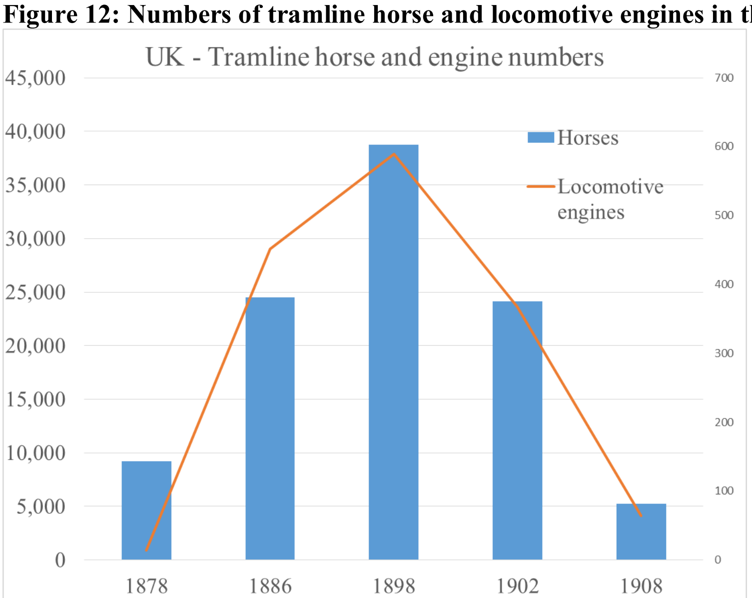
Appendix – Supplementary graphs

Figure 11: Horse, Cable and Electric Streetcars in the United States 1880 to 1900



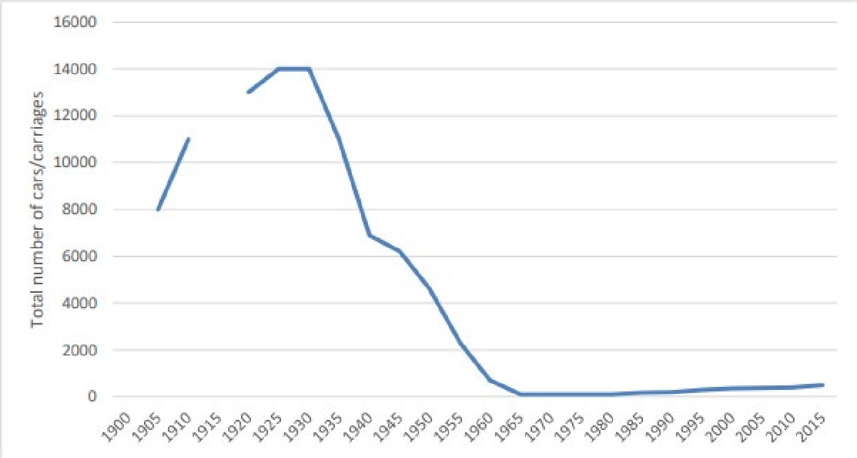
"In respect to street railway transportation generally the most notable facts are the enormous growth of street railways in mileage and capital invested, and the predominant position held by electric traction for street railway operation...... A similar course of development has been recorded in the tramway systems of England and Continental Europe, although the totals do not reach the aggregates recorded for the United States"
Extract from the "*The New International Encyclopædia; Street Railway (1901)*"

Figure 12: Numbers of tramline horse and locomotive engines in the United Kingdom 1878 to 1908



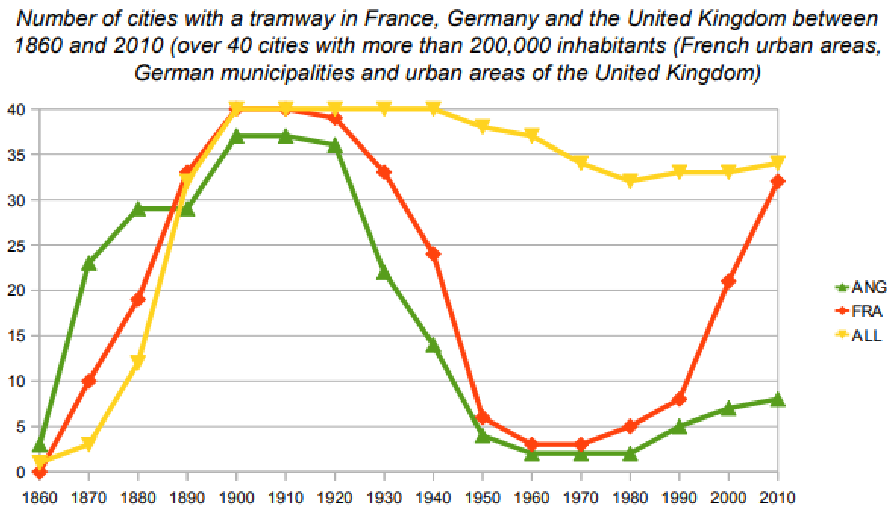
Data from Garcke 1911

Figure 13: Tramcars and light rail carriages in England, 1905 to 2015



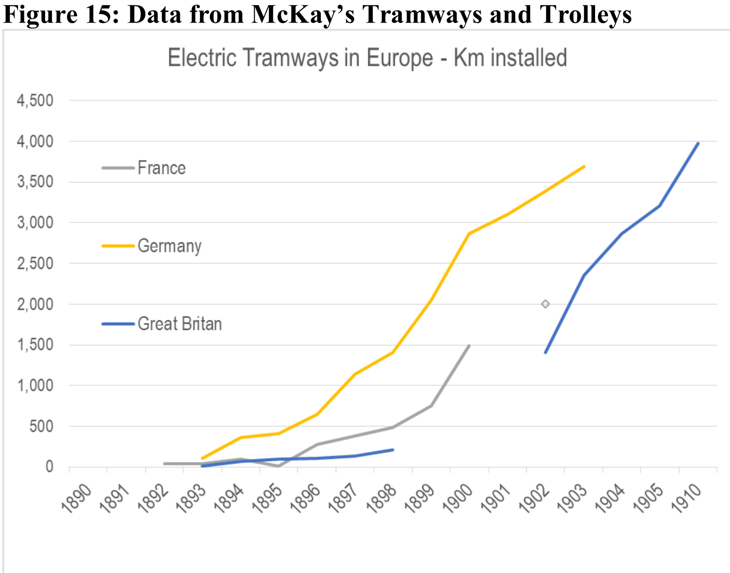
Data from Gunn 2018

Figure 14: Large towns with tramways in France, Germany and England, 1860 to 2010



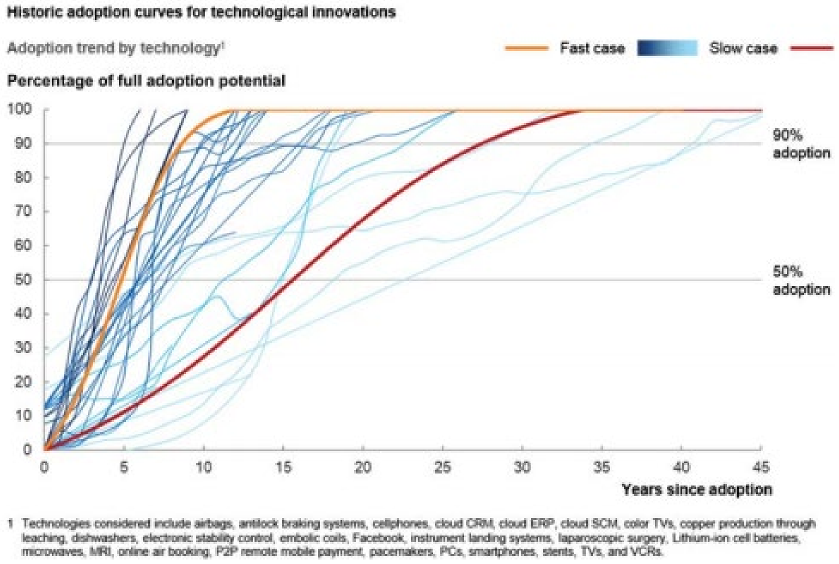
Note the source data for Figure 14 is still untraced it shows UK (ANG) in green, France (FRA) in red and Germany (ALL) in yellow.

Figure 15: Data from McKay's Tramways and Trolleys



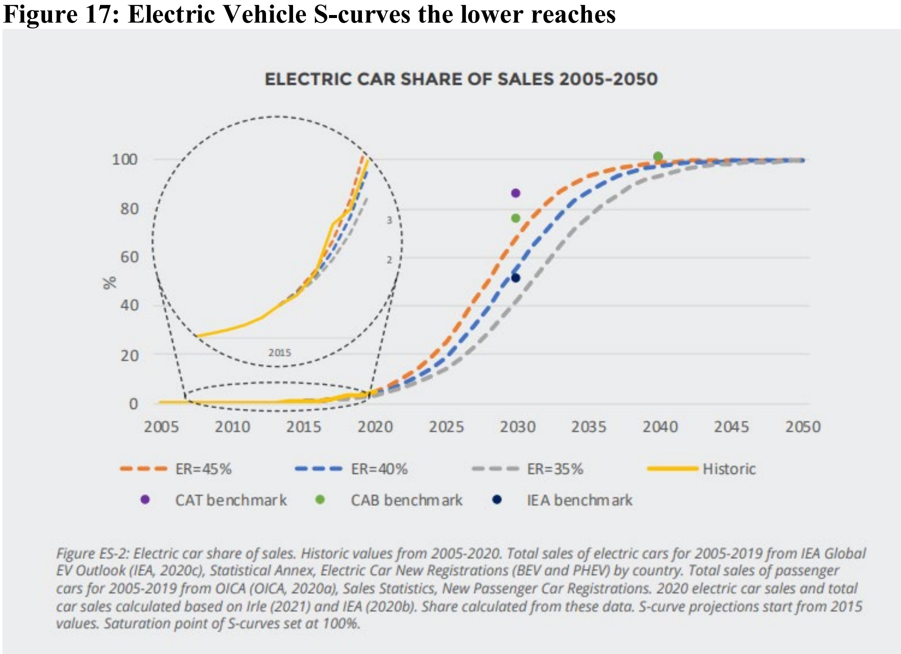
From McKay

Figure 16: McKinsey S-curves fast and slow



Source: McKinsey

Figure 17: Electric Vehicle S-curves the lower reaches



Source: Grubb et al. "*Historic examples of such S-curve dynamics include mobile communication technologies, jet engines, successive steel-making technologies, and the displacement of the horse and cart by motor vehicles*"