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BACK TO THE FUTURE: A LONG-TERM PERSPECTIVE ON GREENHOUSE GAS EMISSIONS IN AUSTRALIAN TRANSPORT

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Abstract

Emissions from fossil-fuelled vehicles are composed mainly of carbon dioxide. Animals produce methane and nitrous oxide; both more potent greenhouse gases than carbon dioxide. Comparison of emission levels in 1900 and 2000 is used to analyse the effect of the internal combustion engine in Australia, including the possibility of an all-electric transport sector.

INTRODUCTION

Transport externalities are not a new phenomenon.

Large cities have always suffered from congestion. Pedestrians in walled, medieval cities with narrow streets competed for road space with animals and carts, and late nineteenth century scenes of cities such as London are replete with depictions of chaotic traffic jams. Young sweepers earned their income clearing paths for pedestrians to cross streets littered with manure and urine from animals.

The stench and bacterium-carrying dust composed of dung have been replaced by noxious emissions such as carbon monoxide and volatile organic compounds. Modern motor vehicles generate noise, congestion and accidents, just as horse-drawn vehicles did. Clearly, some early views of the car as an environmental saviour have not been sustained; only the nature of the problem has changed.

In recent years there has been mounting concern about the contribution of the transport sector to global warming. This concern raises the question of whether the motor vehicle has not only failed to eliminate externalities such as congestion and noxious emissions, but whether it has also exacerbated the greenhouse effect. The commonly held view appears to be that it has.

Emissions from fossil-fuelled motor vehicles, ships and aircraft are composed mainly of carbon dioxide, a direct greenhouse gas. Animals produce methane and nitrous oxide. But methane has a 100-year Global Warming Potential (GWP) 24.5 times that of carbon dioxide, and nitrous oxide has a GWP of 320 relative to an equal mass of carbon dioxide (IPCC 1994, p. 28). Given these large differences in GWPs of emissions, the question is essentially whether the age of the motor vehicle is more, or less "greenhouse-friendly" than the more romantic era that preceded it.

An ideal, controlled experiment between an economy with motor vehicles and its twin without them is obviously not feasible. A second-best option of comparing greenhouse emissions in the year 1900 (the pre-motor vehicle age in Australia) and the year 2000 has been therefore been adopted in this paper.

Inadequate data on the size and scope of the transport task in 1900 precludes comparison with the year 2000 on a standardised basis. Emission levels for the two years are therefore compared by allowing for major demographic and economic changes over the century; providing a rough 'with and without cars' perspective. A counterfactual approach is also used to estimate emissions in the year 2000 if electricity rather than gasoline had achieved dominance over animals and steam in the transport sector.

GREENHOUSE EMISSIONS IN 1900 AND 2000

Greenhouse emissions by major transport mode in the year 1900 are shown in Table 1. These estimates appear to be the only available historical data for Australia.

Because of the paucity of historical information it was necessary to make (often arbitrary) assumptions in Table 1 in areas such as the degree of forest regrowth in the provision of firewood to riverboats, and the numbers of working animals and their specific employment. Coastal shipping is probably the least reliably estimated because of the absence of any official statistics on domestic ship bunkers. Explicit omissions include factors such as rotting animal carcasses, mechanised harvesting of fodder (as part of full fuel cycle estimates of animals), and emissions by ferries. Even the Global Warming Potential (GWP) factors used to convert emissions to CO_2 equivalents in any inventory of greenhouse gases are subject to uncertainties of plus or minus 35 per cent (IPCC 1994, p. 4). It is important therefore to focus analysis more on the order of magnitude of the estimates, rather than the absolute level of individual numbers.

Table 1 Greenhouse gas emissions[a] from Australian transport in 1900

Mode	Energy Consumed GJ	CO_2 Mg	CO Mg	CH_4[b] Mg	No_x Mg	N_2O Mg	CO_2 equivalent[c] Mg
rail	17625576	1525000	3254	476	3828	978	1883500
tram	2521	216	0.468	0.024	0.567	0.142	267
riverboat	361550	24215	69	5	11	1	24815
draught horse[d]	8165415	-	-	19840	-	112	521920
harness horse[d]	7405120	-	-	22022	-	0	539539
saddle horse[d]	9237785	-	-	25251	-	215	687450
camel	193815	-	-	487	-	2	12572
donkey/ mule	16060	-	-	40	-	0.3	1076
bullock	190530	-	-	441	-	3	11765
steamship (dom)	38976894	3332524	7238	790	8760	2388	4193357
international coastal	3101640	265190	576	63	697	190	333686
TOTAL AUSTRALIA	85276906	5122954	11069	69415	13286	3889	8185459
international steamship	267005	2282900	4959	542	6001	1636	2872666

Notes:

a. - means that there were no emissions, or that Global Warming Potentials (GWP) were unavailable. Zero (0) means that emissions were too small to record. Rounding errors may mean that totals do not always match sums of rows or columns. GJ = Giga joules = 10^9 joules. Mg = Megagram = 10^6 grams.

b. includes estimated fugitive CH_4 emissions from coal seams during mining for rail, tram, and steamships

c. 100-year horizon GWPs used per Mg of gas were 1.0 (CO_2, carbon dioxide); 1.0 (CO, carbon monoxide); 24.5 (CH_4, methane); 8 (NO_x, oxides of nitrogen other than N_2O); 320 (N_2O, nitrous oxide); based on IPCC (1990, pp. 11-13; 1992, pp. 19-21; 1994, p. 28). IPCC (1994, p. 27) points out that GWPs are 'calculated on the assumption that present background atmospheric composition remains constant indefinitely. An assumption of increasing CO_2 concentrations, which lowers the additional forcing of incremental CO_2 emissions, would increase the GWP of other gases relative to CO_2'. From this perspective, it is possible that GWPs for gases such as CH_4 are overstated for 1900 when atmospheric concentrations of CO_2 were lower than the present.

d. includes an allowance for horses used to produce fodder for transport animals (based on proportion of fodder grown to total acreage of crops).

Source: Dobes (1995), various tables.

Coal-burning railways and steamships accounted for three quarters of CO_2-equivalent emissions from domestic transport in 1900. Emissions from animals accounted for only about a quarter of total greenhouse emissions; on a par with steam locomotives. Emissions from wood-burning riverboats were comparatively low, but the transport task that they performed was limited to the Murray-Darling river system. Coastal shipping was itself the source of over half of all greenhouse emissions in 1900. Although the figure for steamships is high, it is not inconceivable because of the importance of shipping in connecting coastal towns and cities.

Table 2 provides a comparison of greenhouse emissions from the transport sector in the year 1900 with emissions in 1988 and 2000. Emissions for each of the three years are expressed as far as possible on a full fuel cycle basis. That is, emissions from the fuel consumed during the actual activity of transportation, as well as from energy used to extract, process and distribute the fuel to end users.

IPCC/OECD (1994, p. 1.11) recommends that, for informational purposes, international bunker fuels should be subtotalled separately in national inventories of greenhouse emissions. Emissions due to air and maritime fuel uplifted in Australia have therefore been recorded separately at the end of Table 2, rather than being attributed to domestic Australian emissions. It is interesting to note that emissions per head from international ship and air bunkers combined were roughly 50 per cent greater in 1900 than in 2000. In terms of real GDP, however, greenhouse emissions from international bunkers have decreased almost seven-fold.

Table 2 Greenhouse gas emissions from the Australian domestic civil transport sector in the twentieth century

Mode	1900	1988	2000
rail and tram	1,884	3,886	4,421
riverboat	25	0	0
animal	1,774	0	0
coastal ship (excluding ferries)	4,527	3,405	2,011
motor vehicles (cars, commercial vehicles, buses, motorcycles)	0	68,051	75,164
aircraft	0	4,565	5,990
Total emissions	**8,210**	**79,907**	**87,586**
population (millions)	3.8	16.5	19.0
Total emissions per capita	2,161	4,843	4,610
real GDP ($Abill., 1989-90=100)	21.0	342.6	481.1
Total emissions/real GDP	**391**	**233**	**181**
urban density factor (capital city average, weighted by population)	144	55	55
Total emissions/urban density	**8,210**	**51,405**	**57,354**
International			
ship	2,873	2,192	2,571
air	0	3,527	7,004
international total per capita	756	347	504
international total/real GDP	137	17	20

(10^9 grams of CO_2 equivalent on full fuel cycle basis)

Sources: BTCE (1995); Dobes (1995); *Official Year Book of the Commonwealth of Australia 1901-1907*, (1908, p. 171); ABS (1994a); ABS (1994b); Maddock & McLean (1987, pp. 359-361); ABS (1994c, Table 58); ABS (1991) and CBCS (1917).

As might be expected, total domestic emissions in the year 2000 are an order of magnitude greater than those in 1900. The dominance of the motor vehicle is also of little surprise. Emissions from coastal shipping, however, show an absolute decline. This is probably partly due to improved thermal efficiencies of engines, but the main effect is the switch of domestic freight transport to rail and road, as well as to air travel by passengers.

Because it is the anthropogenic Greenhouse effect that is relevant, differences in the (human) population need to be taken into account in any historical comparison. Adjustment for population levels results in a per capita level of emissions in 2000 that is only just over two times that of 1900; whereas the unadjusted level is more than 10 times that of 1900. Clearly, population growth is an important factor in explaining increased greenhouse emissions in the Australian transport sector over the last 100 years or so.

The amount of freight and the distance that it was transported will have changed significantly because of increased specialisation in the Australian economy. The processing of goods at more than one location and their ultimate transport to distant markets, encouraged partly by lower freight rates, will have increased with economic growth. Pizza deliveries, couriers, and other services requiring transport have also grown. Increased national income thus reflects the greater range and volume of commodities and services transported, particularly in the latter half of the twentieth century.

The long-term increase in real GDP has also permitted the rise of discretionary or recreational travel and increased levels of ownership of personal transport means such as motor vehicles. Discretionary travel, already on the rise early in the century, was referred to quaintly as the 'travelling habit' in the *Report of the Board Appointed to Investigate the Problem of Relieving Congestion of Traffic in Melbourne* (1919: 3):

> The principal causes of the congestion of street traffic in portions of the City proper are the growth of population, the increase of what has been termed the 'travelling habit' of the people, and the greater volume of vehicular traffic induced by the expansion of the City's commercial and industrial activities.

On the other hand, increased national income has fostered the use of telecommunications in Australia. In 1900, riverboats relied on telegraphed information of wool clips and river levels. Steamships and railways also coordinated freight and passenger movements using electrical energy. Modern telecommunications have permitted better coordination of freight (goods deliveries to retail outlets or customers are made only when required), but just-in-time production methods may have increased the overall number of trips. However, the almost universal availability of telecommunications in recent years has enabled it to become a significant substitute for passenger transport.

The effect of allowing for changes in economic activity is illustrated in Table 2 where emission levels have been adjusted for differences in real GDP. Even taking into account the usual problems of such long-term comparisons, the result is still remarkable. Per unit of GDP in real terms, domestic transport emissions will have declined in 2000 to almost half their level in 1900.

While domestic transport emissions will have grown about 10 times since 1900, living standards (real GDP per capita) will have increased only 4.6 times by 2000. Transport emissions have thus grown about twice as fast during the twentieth century as living standards. On an admittedly simplified interpretation of this figure, it is nevertheless arguable that even a substantially lower historical level in living standards would not itself have reduced significantly the level of transport-related emissions of greenhouse gases in the year 2000. The corollary of this proposition is that reductions in living standards alone would not be a particularly effective means of reducing emissions in the transport sector.

Some of the decrease in transport sector emissions relative to real GDP is probably due to the growing share over the century of that part of the service sector that does not utilise transport inputs intensively. Fuel intensities (fuel used for distance travelled) of motorised transport will have decreased substantially due to technical progress, but no adjustment has been made because of fundamental differences in technologies: horses and camels cannot be treated simply as the technological counterparts of motor vehicles. It is likely, however, that trip distribution patterns will have changed over 100 years, particularly with the growth of lower density suburbs around cities.

Adjustment for relative urban densities is fraught with difficulty because of historical inconsistencies in the statistical specification of urban areas. A single-figure measure of urban density is also only an approximate representation of a whole city. No forecast of urban density appears to be available for the year 2000, and the same value (based on the 1991 Census) has been used in Table 2 for both 1988 and 2000. Nevertheless, the urban component of transport emissions for 1988 and 2000 has been adjusted in Table 2 to reflect the fact that Australian metropolitan densities in 1900 were more than double those of today.

While increased population density alone is not a sufficient condition for reduced urban travel, it is arguable that a significant change in density is likely to affect modes of transport and travel patterns. For example, walking and bicycling were common modes of passenger transport in 1900, and freight would not have needed to move as far within the more compact cities of the time. Whether the same would be true in equally compact but motorised cities is debatable, but the figures in Table 2 have been adjusted on the basis that increased urban densities are reflected directly in decreased emissions. The adjusted figures therefore represent the best possible outcome from increased densities.

The result indicates that total greenhouse emissions in 2000 could be reduced to two-thirds of their currently projected level if Australians lived in cities populated about two and a half times more densely than today. However, this is likely to be an upper bound estimate of potential reductions in emissions. It assumes availability of transport altematives to the motor car (including walking), as well as corresponding changes in the 'travelling habit' of the population.

Taking into account lower urban densities and higher levels of economic activity and population, it is arguable that transplanting today's transport system to the year 1900 would have improved greenhouse emissions, despite the replacement of animals by the internal combustion engine. It needs to be recognised, however, that no allowance has been made for broader structural change in the economy or for increases over time in the technical efficiency of fuel consumption. A more cautious conclusion might therefore be that transport-related greenhouse emissions would not have been significantly better today even if the motor car had not been invented.

ELECTRIC VEHICLES IN THE YEAR 2000: BACK TO THE FUTURE

An alternative perspective can be gained by applying a counterfactual: what would domestic greenhouse emissions have been without the internal combustion engine?

A three-wheeled 4.8 km/hr steam-powered cannon wagon was produced in 1769 in France and a steam-powered carriage in England in 1801. Electric cars and locomotives were made in England in the 1830s. In 1900 the French B.G.S. Electric Car held an electric vehicle distance record of almost 290 km per charge, and a Belgian vehicle attained a world speed record for automobiles of 105 km/hr in 1899. Of the cars manufactured in the United States in 1900, 1575 units were electric, 1684 were steam-driven and only 936 units were gasoline powered. (IEA 1993, ch. 1; Shacket 1979, ch. 1).

Lack of electricity in rural areas, and the limited range of electric and steam (which required ten minutes to start) vehicles, coupled with development of electric starter motors for gasoline cars and the low priced Model T Ford, ensured the dominance of the internal combustion engine from the mid 1920s. Arthur (1989, p. 127) quotes a contemporary assessment from 1904 predicting that steam would win out over the inconvenience of gasoline vehicles, but points out that 'a series of trivial circumstances pushed several key developers into petrol just before the turn of the century and by 1920 had acted to shut steam out'.

Probable developments over the course of the century require some speculation. However, detailed speculation may not be necessary if we accept the thesis of a high degree of similarity in logistic development noted in a wide range of social phenomena by Marchetti (1986). Using the same approach as Marchetti, Nakicenovic (1987, p. 317) identifies two separate exponential 'pulses' in the growth of motor-vehicle fleets: 'the first characterises the substitution of horse-drawn road vehicles and the second the actual growth of road transport at large'.

If the thesis proposed by Marchetti and Nakicenovic is correct, then it is likely that the growth in usage of motor vehicles over the twentieth century could have been substituted by a similar pattem of growth by electric or steam vehicles or some other mode determined by historical circumstances. It can simply be assumed that the replacement of one transport mode or technology follows the same growth pattern as the replacement of a different mode at a different time in history.

It is arguable that there were significant potential cost advantages to be reaped from economies of scope in supplying electricity at street outlets because of shared infrastructure and a more even base load demand. Capital cities and country towns such as Tamworth in NSW had already begun in the 1880s to provide a supply grid for street lighting, electric tramways, and delivery to homes and factories. In Victoria, regional centres like Ballarat and Bendigo had electric trams by 1905. Lincolne (1954, p. 29), writing about the Melbourne Electric Light and Traction Co. in about 1905 states that 'about this time the electric motor car was introduced and, as another source of revenue a scheme was prepared for the installation of charging stations using Nodon valves in rectifiers. [But] this scheme did not advance very far'.

It is not unrealistic to assume that relatively rapid reductions in unit costs would have produced conditions sufficient to foster 'take-off' and then 'lock-in', at least in urban areas or their vicinity in the first half of the century. Further economies of scope might have been gained later in the century from the supply of electricity along inter-urban routes where electrified railroads were close to roads. Technical development after the Second World War in lightweight materials for car bodies, rare earth magnets, solar assisted charging, low drag tires, etc, all hold the potential to have permitted rapid expansion in personal electric vehicle ownership in the same way that motor car numbers grew.

Even if technological development had not solved the problem of the low operating range for electric vehicles by 2000, it is reasonable to assume that other means would have been found to overcome technical limitations. For example, commercial street outlets for quick battery exchanges akin to filling up with petrol might have developed. Given such options it is even reasonable to assume that urban densities may not have differed significantly from those of today. To the extent that the rest of the world would also have been using electric vehicles, demand for Australian coal and materials such as aluminium can be assumed to have maintained GDP at historical levels.

It has therefore been assumed in this paper that electric vehicles would have eventually outcompeted steam in a two-way contest, and that they would have grown in number in an almost identical manner to motor cars during the twentieth century. It is acknowledged that uncertainty in invention and innovation make other outcomes (path-dependencies) equally possible. The assumption of eventual domination by electric vehicles is a working hypothesis made purely for the purpose of the thought experiment essayed here.

The intensity of competition at the turn of the century to develop a flying machine suggests that air travel may not have been significantly different today even in the absence of the internal combustion engine. Steam-powered propeller-driven flight was demonstrated to varying degrees from the 1870s onwards; with Ader achieving the first take-off under an aircraft's own power in 1890, using steam (Angelucci 1984, p. 40). More importantly, modern aircraft are mainly propelled by jet turbines which are likely to have been developed at the same time (or even earlier) even without internal combustion engines. (Aviation gasoline—used in piston driven aircraft engines—forms only about 10 per cent of domestic aviation fuel use in Australia today.)

Ships are still largely driven by steam engines, and some modern Australian coastal vessels are coal-fired. As with air transport, greenhouse emissions from shipping are unlikely to have changed significantly in the absence of the internal combustion engine. It is possible, however, that more freight would have been transported by ship than is the case today if shipping offered cheaper freight rates.

In estimating emissions from electric vehicles, one approach would have been to use fuel intensities from modern vehicles such as the General Motors *Impact,* and compared them with those from the petrol-powered *Ultralite.* However actual transport emissions are based on average fleet fuel efficiencies which are far higher than those of the *Ultralite*. The more realistic approach adopted has been to assume that the level of primary energy usage and the level of technology available for electricity generation would not have differed substantially from today's. On this basis, the main difference between the internal combustion engine and electric vehicles lies in the lower level of non-carbon dioxide greenhouse gases emitted during electricity generation.

Table 3 summarises the likely differences in greenhouse emissions if electric vehicles only had been used in the road and rail sectors. Overall, emissions would have been about 10 per cent lower in 2000 than currently projected for a transport sector that relies on the internal combustion engine. Table 3 also compares emissions from air transport and an alternative assumption that something like a Very Fast Train performed the air transport task. Had this assumption been made, total greenhouse emissions from transport would have been about 13 per cent lower than currently projected.

CONCLUSIONS

A lot of attention has been given during the twentieth century to the negative aspects of motor car usage. While the negative externalities generated by the motor vehicle are significant, it is also true that non-motorised transport systems created comparable externalities thousands of years before the advent of the internal combustion engine.

Table 3 Electric-equivalent domestic transport system in 2000

Mode	Current Projections[a]	Electric Vehicles	Savings	%
road passenger	44,810	40,329	4,481	10
road freight	27,493	24,469	3,024	11
bus	1,564	1,408	156	10
urban rail	1,107	1,050	57	5
non-urban rail	3,314	3,120	194	6
Very Fast Train[c]	[5,990]	2,261	3,116	60

(10^9 grams of CO_2 equivalent emissions)

Note: a. Current projections figure for Very Fast Train (VFT) refers to domestic air transport.

Sources: BTCE (1995); SSCTCI (1991)

Greenhouse emission levels in 1900 and 2000 are compared to provide an insight into the relative effect on global warming of the internal combustion engine. Animal emissions in 1900 included methane and nitrous oxide, both of which have Global Warming Potential factors many times those of carbon dioxide, the major emission from modern motor vehicles.

There was a more than ten-fold increase in total greenhouse emissions between 1900 and 2000. Over the same period, however, population has increased five-fold, real GDP has increased 23 times, and urban densities are about one third of those of 1900.

Within the limits of long-term historical comparisons, it may therefore be concluded that the internal combustion engine itself has not contributed disproportionately to greenhouse emissions in the transport sector. Had electric vehicles rather than gasoline-powered ones come to dominate the transport sector early in the twentieth century, greenhouse emissions in the year 2000 would be about 10 per cent lower than current projections.

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Abbreviations

ABS	Australian Bureau of Statistics
AGPS	Australian Government Publishing Service
BTCE	Bureau of Transport and Communications Economics
CBCS	Commonwealth Bureau of Census and Statistics
DEST	Department of Environment, Sport and Territories
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
NGGIC	National Greenhouse Gas Inventory Committee
OECD	Organisation for Economic Cooperation and Development
SSCTCI	Senate Standing Committee on Transport, Communications and Infrastructure

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