Research Paper

Assessing Electric Bus Deployment as Adaptive Infrastructure for Extreme Climate Events: A Quasi-Experimental Study of Shenzhen, China

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Abstract

Shenzhen is one of the first megacities in the world to fully electrify its bus fleet. While this transition is often framed as a mitigation success, it can also be interpreted as adaptive infrastructure that reduces fossil-fuel dependence, stabilises energy demand, and improves air quality in a rapidly growing and climate-exposed city. This paper re-evaluates Shenzhen's bus electrification from an adaptation perspective by examining whether transport energy use has begun to decouple from economic growth during the electrification period.

The study adopts an indicator-based, quasi-experimental before–after design using Shenzhen Statistical Yearbook data for 2010 and 2015 (pre-electrification) and 2020 and 2022 (post-electrification). Transport energy use in the storage and transport sector is used as a proxy for transport-related energy demand. A set of indicators is constructed, including transport energy use, energy intensity per unit of GDP, per-capita transport energy use, transport's share in final energy consumption, and passenger vehicle ownership.

The analysis applies index comparison, intensity change analysis, and decoupling elasticity calculations across three periods (2010–2015, 2015–2020, 2020–2022). The results show that GDP and motorisation increase rapidly, while transport energy use grows more slowly. Transport energy intensity declines, and decoupling elasticities indicate a shift from relative towards near-absolute decoupling in the post-electrification period. The trajectory analysis further suggests a transition towards higher motorisation but lower transport energy intensity.

Although causality cannot be isolated, the observed patterns suggest that bus electrification contributes to broader structural changes in urban transport energy demand. The findings highlight the potential of electrified public transport as adaptive infrastructure in rapidly urbanising and climate-vulnerable megacities in the Global South.

Keywords

Electric bus deployment, Transport transport energy intensity, Decoupling analysis, Adaptive infrastructure.,

1. Introduction

1.1 Urban transport, climate risks and resilience

Urban transport is a major source of greenhouse gas emissions and a key channel through which cities experience climate risks. Road-based systems that depend on fossil fuels contribute to CO_2 emissions and local air pollution, while they are also exposed to extreme weather, flooding and heatwaves (Mehrotra et al., 2011; Gössling et al., 2023; IPCC, 2022). The incidence of this type of extremes is likely to rise with climate change and cities will have to decarbonise transport, as well as make mobility networks more resilient (IPCC, 2022; Mehrotra et al., 2011). Such dual pressures are particularly eminent in the rapidly-developing urban centres of the Global South, where income development and the accelerated urbanisation conditions stimulate the growth of motorised transport and consumption of energy-consuming transport.

In recent studies, some efforts have already been made to explore the impacts of extreme weather on transport networks as well as the implications of resilience. Research indicates that flooding and heavy precipitation may interfere with the road systems and slow down traffic and asset damages (Pregnolato et al., 2017), whereas heatwaves and storms can decrease the ridership and reliability of public transport (Miao et al., 2019; Ngo, 2019; Ngo and Bashar, 2024; Liu et al., 2025). The resilience models emphasize the core role of critical infrastructure, such as transport systems, in enabling the city to experience the shock and recover afterwards (Bruneau et al., 2003; IPCC, 2022). More recent studies suggest that analysis should no longer rely on only limited conceptions of risk and robustness but instead the transport systems capable of coping with deep uncertainty and compound stresses (Markolf et al., 2019). But even most of this literature continues to consider mitigation and adaptation as distinct agendas and does not pay much attention to transport sector measures which can help to achieve both objectives concurrently.

1.2 Electric bus transitions in hot-climate megacities

The adoption of electric buses is one of the solutions to decarbonising city transportation. A study on life-cycle and well-to-wheel analysis indicates that battery electric buses have the potential to lower the emission of CO 2 and local air pollutants than the diesel fleet, particularly when electricity mixes are more clean, and operations are optimised (He et al., 2018; Mao et al., 2020). The latest reviews indicate that the socio-economic advantage of electric buses can be extended to additional, yet they are also fraught with challenges associated with costs, technological maturity, institutional capacity and charging network (Alarrouqi et al., 2024; Lobo et al., 2025). Hot climates have left many urban areas suspicious of battery behavior, cooling loads and cooling reliability in hot waves, although early adopters have already shown large coordinations (National Renewable Energy Laboratory, 2024; Alarrouqi et al., 2024). The majority of this literature is devoted to technology, conditions of operations and carbon savings on the level of the route or providing fleet. It does not tell as much how large scale bus electrification would transform the overall energy profile of the transport sector or how it could act as an adaptive infrastructure.

Electrification of buses in Shenzhen is also one of the most high profile cases in the world. The city has created an all-electric fleet of buses, and has also deployed much of the charging infrastructure as part of a wider plan to support the adoption of electric vehicles and clean energy (Ng, 2003; World Resources Institute, 2018; Wang, 2021). The transition case studies of Shenzhen approximate energy consumption and emissions of electric buses in real operating conditions and compare them with diesel buses and implications on the electrification of a fleet (He et al., 2018; Mao et al., 2020). On a broader level than the vehicle and route scale, recent studies have also begun to model the electrification transition and carbon

emission reductions of the whole urban passenger transport system (Hou et al., 2023) and to study planning of charging networks in an “electric bus city” (Lin et al., 2019). These donations demonstrate that bus electrification in Shenzhen is institutionally and technically possible and that it results into significant emission cuts. Nevertheless, they put less emphasis on the interactions between the transition and climate risks and spill over on alterations in energy consumption practices in the transport sector.

1.3 Research gap, aim and contribution

It is already observed that in most cities, extreme heat and heavy rainfall already influence the functioning of the public transport system and can increase in frequency in the future (Gössling et al., 2023; IPCC, 2022; Miao et al., 2019; Ngo and Bashar, 2024). Arguably, the cities could counter this risks through electrified public transport. Reduction of oil price shocks through low consumption of fossil fuels and cleaner buses lead to improved air quality in the area, especially in cases of health risk in times of heatwaves (He et al., 2018; Mao et al., 2020; Alarrouqi et al., 2024). Regarding resilience, electrified bus networks can be regarded as an element of the adaptability of a city, following the suggestion to develop transport infrastructure that is resilient to a modified climate instead of merely being resilient to historical extremes (Markolf et al., 2019). However, such an interpretation has not been evaluated very frequently through quantitative indicators at the city level.

Simultaneously, in assessments of the global climate and national investigations, the concept of economic growth and decoupling of energy-related emissions (IPCC, 2022) have been discussed. Relative decoupling which happens when energy consumption continues without lessening but at a lower rate than GDP and absolute decoupling which happens when GDP remains increasing and energy consumption becomes constant or declines again. On the case of city transport, decoupling refers to the fact that a city provides increased mobility and economic productivity using less fossil fuel. Available quantitative studies of electric buses in Shenzhen have primarily looked at how the electric buses at the fleet/system level have contributed to the emission savings (He et al., 2018; Mao et al., 2020; Hou et al., 2023; Lin et al., 2019), whereas there is minimal literature on whether transport energy demand in the city itself has begun to decouple with the growth of the economy in the period of electrification, or whether this decoupling can be understood as an indicator of adaptive infrastructure.

Such gaps are inspirational to this paper. The article redefines the bus electrification in Shenzhen as adaptive infrastructure and posits whether the energy need in transport in the city has already started to decouple with economic growth and motorisation. Instead of employing detailed emission inventories, or even spatial microdata, it employs sectoral energy statistics in the Shenzhen Statistical Yearbook to develop a set of simple indicators. These are index trends of GDP, energy use and passenger vehicles of transport, intensity energy use in transport per unit of GDP and per capita, the portion of transport in final energy consumption and decoupling elasticity of transport energy use and GDP.

The article contrasts the years before the electrification (2010 and 2015) with the years already post-electrification (2020 and 2022) and explains the obtained patterns in the context of the concepts of resilience and adaptive infrastructure (Bruneau et al., 2003; IPCC, 2022; Markolf et al., 2019; Wang, 2021). Theoretically, it relates the literatures that deal with bus electrification, climate effects on transport and urban resilience. Empirically, it gives a city scale evaluation of transport energy portrait transformation of Shenzhen throughout the bus electrification. Theoretically, it demonstrates that downstream indicators provided by statistical yearbooks can provide a low-cost means in a data-constrained city to assess the electrified public transport as an adaptive infrastructure in hot-climate settings of the Global South.

2. Methodology

2.1 Research approach

This is an indicator-based, quasi experimental before and after study that is at the city. It is expected to examine whether the trend in the transport energy consumption in Shenzhen has been altered in the years when this city has electrified its buses (Mao et al., 2020; Wang, 2021; World Resources Institute, 2018). The pre-electrification phase happens between 2010 and 2015 when internal combustion buses were predominant and the post-electrification phase between 2020 and 2022 when the fully electrified bus fleet was acknowledged in the city (World Resources Institute, 2018).

Electrification of buses, as well as transport and energy aspects are considered as a treatment policy measure that has the potential to have treatment effects on aggregate transport energy demand, although many other variables, including restructuring of the economy, and travel behaviour, matter (Gössling et al., 2023; IPCC, 2022). The question is rather to understand whether or not there is evidence that transport energy consumption has started to lose its dependence on economic growth and motorisation at an aggregate level, as opposed to trying to estimate one causal effect of the bus programme. The indicators are built on the city level, and this is the same level equivalent to reporting the official statistics and brings a conservative presentation of the overall change within a fast developed megacity (Ng, 2003).

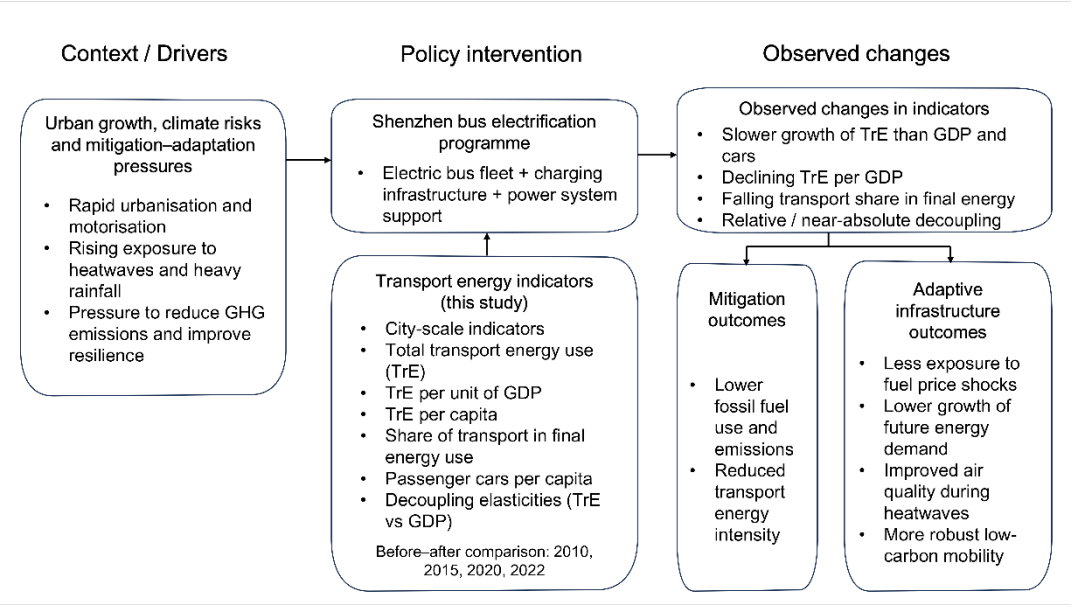
2.2 Theoretical framework used

Two concepts are connected that serve as the background of the study: the adaptive infrastructure, and the decoupling of energy usage and economic growth. Resilience and critical infrastructure are also addressed as genres of work, and these areas are a part of the ability of the city to withstand the effects of climate crises and to restart functioning following disruptions (Bruneau et al., 2003; IPCC, 2022). Infrastructure determinants of exposure to extreme weather, fuel crisis and peak energy demand in the event of heatwaves (Gössling et al., 2023; Pregnolato et al., 2017; Liu et al., 2025). According to empirical research, there is already an impact of weather and climate extremes on the people using public transport regarding their ridership and reliability, particularly bus-based public transport (Miao et al., 2019; Ngo, 2019; Ngo and Bashar, 2024). Electrified public transport can hence be construed as adaptive infrastructure as it makes the energy demand predictable and the low carbon mobility more reliable under hot climates. (Alarrouqi et al., 2024; National Renewable Energy Laboratory, 2024).

The second element is the idea of relative and absolute decoupling between economic growth and energy-related emissions, widely discussed in global climate assessments (IPCC, 2022). Relative decoupling occurs when energy use still increases but more slowly than GDP, while absolute decoupling occurs when GDP continues to grow as energy use stabilises or falls. For a fast-growing city such as Shenzhen, decoupling in the transport sector would indicate that more mobility and output are being delivered with less fossil energy (He et al., 2018; Mao et al., 2020). By combining these two ideas, the study examines whether bus electrification contributes to transport energy decoupling and can be understood as adaptive infrastructure in a Global South megacity (Wang, 2021; World Resources Institute, 2018).

2.3 Analytical framework

The overall analytical framework is summarised in Figure 1.



igure 1. Analytical framework linking bus electrification, transport energy indicators and mitigation–adaptation outcomes in Shenzhen. Source: Author's elaboration based on Bruneau et al. (2003), IPCC (2022), He et al. (2018), Mao et al. (2020) and Wang (2021).

2.4 Data collection

All quantitative data are taken from the Shenzhen Statistical Yearbook, which reports sectoral energy use, economic indicators and vehicle ownership at the city scale (Shenzhen Municipal Bureau of Statistics, various years). Sectoral energy statistics come from tables on total and sectoral energy use and on energy consumption by the transport, storage and postal sector, reported in 10,000 tons of standard coal equivalent. These tables also provide total final energy consumption for the whole city.

Economic and demographic data are drawn from tables on regional gross domestic product (GDP) and resident population. GDP at current prices and the year-end resident population are used to match the timing of the energy statistics. Data on civil and passenger vehicle ownership come from the transport and motor vehicle sections of the yearbook. The analysis uses passenger vehicles as a proxy for motorisation and private mobility demand. Four benchmark years – 2010, 2015, 2020 and 2022 – are selected because a consistent set of energy, economic and vehicle data is available and because these years bracket the bus electrification programme documented in previous studies (Mao et al., 2020; Wang, 2021; World Resources Institute, 2018).

2.5 Data analysis methods

The analysis proceeds in several steps. First, total transport energy use is measured as the energy consumption of the transport, storage and postal sector and used as a proxy for transport-related greenhouse gas emissions at the city scale (He et al., 2018; Mao et al., 2020). Transport transport energy intensity per unit of GDP is calculated as total transport energy divided by GDP, and transport energy per capita as total transport energy divided by resident population. The share of transport energy in final energy consumption is calculated as transport energy divided by total final energy consumption, indicating

the structural weight of the transport sector in city-wide energy demand. Per-capita passenger vehicles are calculated as passenger vehicles divided by population and provide a simple measure of motorisation.

Second, index values are computed for GDP, transport energy and passenger vehicles, with 2010 set equal to 100. Plotting these three index series on a single graph allows a visual comparison of how quickly transport energy use grows relative to economic output and vehicle ownership.

Third, transport transport energy intensity in the pre-electrification period (2010–2015) is compared with that in the post-electrification period (2020–2022). For each indicator, average values are calculated for the two periods and percentage changes are computed, summarising how strongly transport energy per unit of GDP and per capita has fallen or risen.

Fourth, simple decoupling elasticities are calculated for three intervals: 2010–2015, 2015–2020 and 2020–2022. For each interval, the percentage change in transport energy use is divided by the percentage change in GDP. Elasticity values between zero and one indicate relative decoupling, while negative values indicate absolute decoupling (IPCC, 2022). Finally, a trajectory diagram is drawn with per-capita passenger vehicles on the horizontal axis and transport transport energy intensity per unit of GDP on the vertical axis. Points for 2010, 2015, 2020 and 2022 are connected in chronological order. Movement towards the bottom-right of the diagram indicates higher motorisation but lower transport energy intensity, a pattern consistent with efficiency gains and the impact of bus electrification as part of a wider package of transport and energy measures (He et al., 2018; Mao et al., 2020; Wang, 2021).

3. Main findings and their significance

3.1. Indicator results: trends in GDP, transport energy and decoupling

Figure 2 plots index trends for GDP, transport energy use and passenger vehicles in Shenzhen between 2010 and 2022 (2010 = 100). The figure shows that GDP and passenger vehicle ownership increase very rapidly over the period, while total energy use in the transport, storage and postal sector grows much more slowly. In other words, economic output and motorisation expand much faster than aggregate transport energy demand. This divergence is the first indication that transport energy use is no longer rising in proportion to income and vehicle numbers (IPCC, 2022; Gössling et al., 2023).

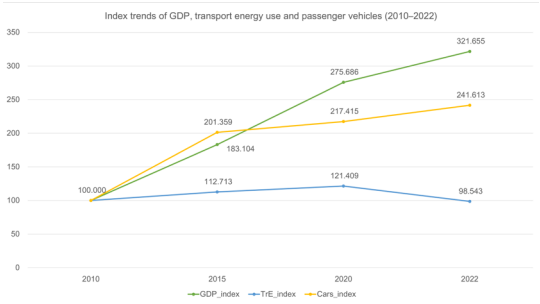


Figure 2. Index trends of GDP, transport energy use and passenger vehicles (2010–2022). Source: Shenzhen Municipal Bureau of Statistics (various years); author's calculations.

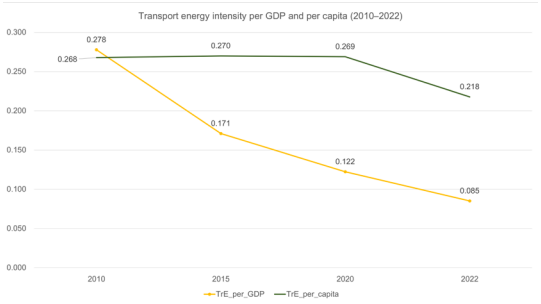


Figure 3. Transport transport energy intensity per GDP and per capita (2010–2022). Source: Shenzhen Municipal Bureau of Statistics (various years); author's calculations.

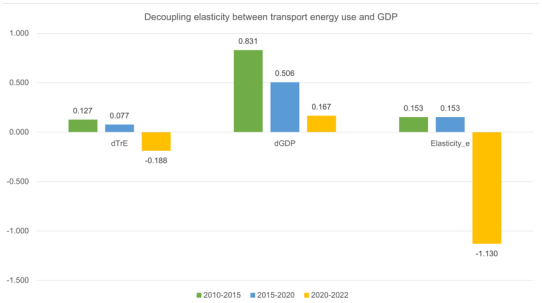


Figure 4. Decoupling elasticity between transport energy use and GDP. Source: Shenzhen Municipal Bureau of Statistics (various years); author's calculations.

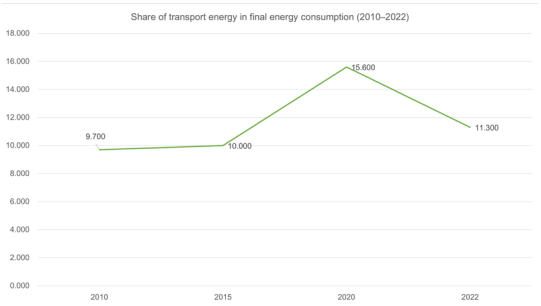


Figure 5. Editing the Headline. Source: Shenzhen Municipal Bureau of Statistics (various years); author's calculations.

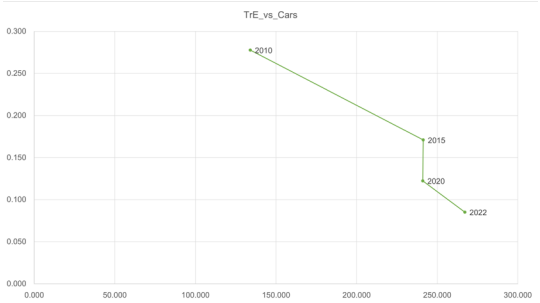


Figure 6. Trajectory of per-capita passenger vehicles and transport transport energy intensity in Shenzhen, 2010–2022. Source: Shenzhen Municipal Bureau of Statistics (various years); author's calculations.

Figure 3 shows the intensity of transport energy divided by unit of GDP and capita. The energy consumption per unit of GDP in transport in pre-electrification years (2010 and 2015) decreases, whereas the changes in the per-capita transport energy consumption are during the post-electrification years (2020 and 2022) not as significant. This implies that the transport sector has become economically less energy-intensive though the average energy load per capita might also be quite similar. The decrease in the energy-to-GDP ratio is one of the indicators of a city with a high rate of growth that more energy is being produced with less fossil energy in the transport industry (He et al., 2018; Mao et al., 2020).

Figure 4 summarises the changes in terms of decoupling elasticities involving transport energy consumption and GDP represent three periods; 2010–2015, 20152022. During the former period, the elasticity is above zero, but below one which is a sign of relative decoupling where the use of energy increases in a slower pace compared to GDP. During the later periods, the value of elasticity decreases further and goes either near or below zero. This trend is in line with the change of relative to near-absolutes decoupling: the growth of the economic output remains, whereas the transport energy demand levels off or even decreases (IPCC, 2022). A combination of Figures 2 13 evidences that Shenzhen is departing a more growth, more transport fuel nexus and shifting to a lower-intensity direction.

3.2. Structural change and motorisation

Figure 5 shows a graph of per-capita passenger vehicles versus transport energy density per unit of GDP on the vertical axis and horizontal axis respectively. The 2010, 2015, 2020 and 2022 points are on a track. The curve tends with the shift to the bottom-right of the diagram: the per-capita passenger vehicles tend to grow, whereas the intensity of energy tends to decrease. Increased consumption and emission of transport fuel and emissions have been linked to increased personal vehicle ownership in most cities (Gössling et al., 2023). The trend to escalate motorisation and decrease transport energy intensity in Shenzhen implies that a rise in demand in the mobility sector has at least partially been taken up by efficiency-gaining benefits, electric-based buses and other admonitory strategies (He et al., 2018; Mao et al., 2020). Combinations of Figures 5 and 6 show that not only Shenzhen is decreasing the amount of energy needed by a unit of output, but also in the place of transport in the system as a whole (Mao et al., 2020; Wang, 2021).

In Figure 6, the per-capita passenger vehicles are plotted on the horizontal axis and the intensity of transport energy divided by a unit of GDP is plotted on the vertical axis. There is a trajectory between the points of 2010, 2015, 2020 and 2022. It moves to the bottom-right of the chart: per-capita passenger vehicles grow, however, the energy-intensities decrease. The growth in the transport fuel consumption and emissions have been linked to increasing the ownership of personal vehicles in most cities (Gössling et al., 2023). In Shenzhen, the shift towards more motorisation and lower transport energy intensity indicates that the growing pressure on mobility has at least been partially compensated by the improvement of efficiency, electric buses and other ways of mitigating these effects (He et al., 2018; Mao et al., 2020). A combination of Figure 5 and Figure 6 shows that Shenzhen is not merely decreasing the amount of energy that each unit of output uses but is simultaneously altering the place of transport in the total energy system.

3.3. Bus electrification as adaptive infrastructure

The adaptive infrastructure can be applied to these results of indicator. The resilience frameworks state that critical infrastructure is the key to successfully shock-absorb and climb back on the feet after a disruption caused by climate issues (Bruneau et al., 2003; IPCC, 2022). Technology decision-making and network layout are associated with exposure to extreme weather, sensitivity to fuel prices and peak demand of energy in the transport sector (Gössling et al., 2023; Pregnolato et al., 2017; Liu et al., 2025). The observed disconnection of GDP and transport energy consumption, as well as the reduced transport cost in the final energy consumption, indicate that Shenzhen is slowly decreasing the fossil-fuel intensity of its mobility system.

In that sense, mass electrification of buses may be regarded as an adaptive and mitigation policy. Reduced transport energy intensity of transport means that they are no longer at the mercy of oil markets and that when oil prices shoot up. Peak electricity demand can also be controlled by efficient, electrified bus network provided that charging approaches and improvements of power-grids are aligned (National Renewable Energy Laboratory, 2024). By substituting diesel buses with electric buses, the local air pollution emissions decrease and this helps to alleviate the health effects that are usually exacerbated during heatwaves and stagnant air events (He et al., 2018; Mao et al., 2020; Alarrouqi et al., 2024).

The research of extreme weather and public transport demonstrates that the presence of heat, heavy rain, and other extremes already affects the work of buses and their attendance (Miao et al., 2019; Ngo, 2019; Ngo and Bashar, 2024). Though Figures 2-6 in this paper is not started by direct observation of reliability in service, the overall energy patterns in these figures are consistent with a transport system that provides

increased mobility using less fossil energy and reduced emission of emissions. The latter helps to argue in favor of viewing the electric bus fleet in Shenzhen as an extension of a more general adaptive infrastructure policy in a hot-climate megacity, and not merely as a greenhouse gas reduction initiative.

3.4 Implications, limitations and future research

3.4.1 Implications

The findings suggest that Shenzhen's experience offers relevant implications for other rapidly urbanising and hot-climate cities in the Global South. First, the results indicate that transport energy intensity can be reduced while GDP and motorisation continue to grow, provided that supportive policies and large-scale infrastructure investment are in place (Ng, 2003; Gössling et al., 2023). Shenzhen demonstrates that the combination of electric bus deployment, industrial policy and power grid upgrades can help bend the growth trajectory of transport energy demand and generate co-benefits for both mitigation and adaptation (Wang, 2021; World Resources Institute, 2018; Alarrouqi et al., 2024).

Second, the indicators used in this study provide a low-cost analytical tool that can be applied in cities where detailed emission inventories are not available. This makes the approach particularly relevant for data-constrained contexts in the Global South.

3.4.2 Limitations

Despite these contributions, the study has three main limitations.

First, it relies on aggregate city-level data from statistical yearbooks, which limits the ability to capture spatial inequalities in the distribution of benefits and risks associated with bus electrification (Shenzhen Municipal Bureau of Statistics, various years). As a result, neighbourhoods with limited access to electrified bus routes or higher exposure to flooding and heat may not experience the same benefits reflected in city-level indicators (Liu et al., 2025; Pregnolato et al., 2017).

Second, the indicator-based before–after design does not allow for causal identification of the effects of bus electrification. Changes in transport energy use may also be driven by concurrent structural processes, including industrial restructuring, improvements in building energy efficiency, and shifts in travel behaviour (IPCC, 2022; Gössling et al., 2023).

Third, the study does not explicitly capture system-level interactions between electrified bus operations, charging infrastructure, urban heat conditions, and electricity grid stability. In particular, charging patterns may influence peak electricity demand and interact with heat island effects during extreme temperature events. These dynamics are not represented in the current indicator framework (National Renewable Energy Laboratory, 2024; Miao et al., 2019; Ngo and Bashar, 2024).

3.4.3 Future research

Future research should address these limitations by integrating sectoral energy data with GIS-based mapping of bus networks, land use, and climate exposure to better capture spatial distributional effects. More rigorous causal approaches, such as panel data across multiple cities or operator-level operational datasets, would help isolate the contribution of electric buses from other policy changes. In addition, incorporating indicators of service reliability, power system stress, and health outcomes during extreme weather events would provide a more complete assessment of electrified buses as adaptive infrastructure.

Overall, despite these limitations, the results show that even simple energy indicators can reveal meaningful shifts in the relationship between economic growth and transport energy demand, providing a

useful entry point for evaluating the co-benefits of mitigation and adaptation in rapidly growing, climate-exposed cities.

4. Conclusion

This paper aimed at evaluating the bus electrification of Shenzhen as adaptive infrastructure, but not as a mitigation project. It posed the question of whether the energy demand of the transport in the city has already started to decouple with economy growth and motorisation in the years of Shenzhen transitioning to an all-electric bus fleet. Based on sectoral energy statistics of Shenzhen Statistical Yearbook and a collection of simplistic indicators, an analysis of pre-electrification (2010 and 2015) and post-electrification (2020 and 2022) in the city scale was performed.

The actual results of the indicator demonstrate that there is a definite alteration in the correlation existing between economic growth and the use of transport energy. The growth in the GDP and passenger vehicle ownership between 2010 and 2022 was very sharp, whereas the rise in energy consumption in the transport, postal and storage sector was significantly lower. It was found that transport energy divided by a unit of GDP reduced, and that the proportion of transport in the total final energy usage decreased in comparison between the period before and after electrification. Simple decoupling elasticities indicate that there has been a relative to near-absolute decoupling that occurred in the latest period. Shenzhen has been trended on a trajectory chart to imply that the city is orienting towards a higher per-capita vehicle ownership and a lower transport energy intensity. These results, combined, point to the fact that the city is achieving increased mobility and economic performance using less fossil energy in the transport sector.

These trends are significant to climate risk in the context of adaptive infrastructure. Reduced transport transport energy intensity and a reduced transport part in the final energy consumption make one less reliant on oil markets and serve to assure future growth in energy demand. With a city of hot climatic characteristics, which is already exposed to excessive heat and downpours, an electrified and more efficient bus service can help meet the mitigation and adaptation objectives. It delivers a cleaner air locally, offers more predictable low-carbon movement and can alleviate pressure on power infrastructure in case of charging and grid planning coordination. The experience of Shenzhen indicates that the investment in electric buses coupled with broader transport and energy policy would allow in re-shaping the energy profile of urban mobility in such ways that would make cities less susceptible to climate-related stresses.

Meanwhile, the research has definite shortcomings. It uses aggregate indicators at the level of the city as a whole and is unable to show spatial inequalities or isolate the impact of bus electrification among other policy and structural changes. It also relies on energy proxies instead of metrics of service reliability, exposure or health outcomes. The future studies would need to integrate sectoral energy data with GIS-informed analysis of bus networks, land use and climatic hazards as well as more official causal designs across cities or operators. Nevertheless, the paper demonstrates that even the transformation of these changes in the relationship between economic growth and transport energy consumption could be identified using simple indicators of statistical yearbooks. Other Global South cities in hot climates can use these low-cost approaches to indicator techniques as an early measure to assess electrified public transport as an adaptive infrastructure when more comprehensive data are still out of access.

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