



Community of Metros
CoMET



© CoMET and Nova Benchmarking Groups, Imperial College London, September 2009

Maximizing the potential for metros to reduce energy consumption and deliver low-carbon transportation in cities

Draft Working paper on behalf of the CoMET & Nova Benchmarking Groups by:

Richard Anderson, Rory Maxwell and Dr. Nigel G. Harris

Railway and Transport Strategy Centre at Imperial College London

1. Introduction

Policy makers and metro managers are questioning the extent to which metros are indeed 'environmentally friendly' and what can be done to ensure that they remain environmentally, economically and socially sustainable in the long term. In constraining operating costs, most Asian metros are primarily concerned with optimizing the deployment of labour as wages rise. But in the future, the impact of falling energy reserves, carbon pricing and efforts to decarbonise electricity supply are likely to challenge metros with rising energy costs.

This paper has been written by the Railway and Transport Strategy Centre (RTSC) at Imperial College London on behalf of the CoMET and Nova metro benchmarking groups and is based on their recent benchmarking research and analysis. We firstly introduce the CoMET and Nova benchmarking groups before explaining why climate change and energy issues are important for existing metros and those under construction. The 'carbon footprint' of metros is then discussed, considering the immediate and wider environmental impacts of metros, before exploring the best practices and strategies available to metro managers and developers in minimizing metro energy consumption. Indeed, what do new metros under development in Asia need to learn from existing metros?

1.1 Introduction to the CoMET and Nova benchmarking Groups

The CoMET and Nova groups are ongoing programmes of international railway benchmarking. The CoMET group is made up of a consortium of large metro systems from around the world - Beijing, Berlin, Hong Kong, London, Mexico City, Madrid, Moscow, New York, Paris, Santiago, Shanghai and

Sao Paulo. The Nova group consists of 15 small to medium sized urban railways from the cities of Bangkok, Barcelona, Buenos Aires, Delhi, Glasgow, Lisbon, Milan, Montréal, Naples, Newcastle, Rio de Janeiro, Singapore, Taipei, Toronto and Sydney.

The objectives of the CoMET and Nova benchmarking groups are:

- To identify and share best practices in metro operations and management
- To provide comparative information both for metro management and its stakeholders
- To use this information to prioritise areas for improvement and to support decision making

In CoMET and Nova, there has been a strong focus on results that can be implemented, performance improvement, and on informing strategy. For this reason, benchmarking group members undertake a variety of detailed case studies each year in wide-ranging but focused areas of metro management. Many studies identify best practices in operations and management; others offer key insights that can drive strategy and policy and provide information to support better dialogue with city governments, regulators, and other stakeholders. Between the groups, over 60 case studies and 120 shorter clearinghouse studies have been undertaken since the CoMET and Nova groups' inception in 1994 and 1997 respectively.

The longevity of the benchmarking programmes is owed to their clear objective and the significant benefits that members have achieved in reducing costs, improving productivity and service quality and assisting them in their dialogue with government and other stakeholders.

1.2 The role of the Railway and Transport Strategy Centre at Imperial College London

Since their inception, the CoMET and Nova groups have been facilitated by the RTSC at Imperial College London. The RTSC undertakes all analysis, research and administers the groups on an ongoing basis.

Established in 1992 with funding from British Rail, the RTSC now focuses its research in three key themes:

- Benchmarking & performance measurement
- Urban public transport operations
- Transport economics & policy

The RTSC's activities include applied and academic research, consultancy and teaching.

1.3 Recent Research

In recent years, 2 case studies have been undertaken to examine metro energy efficiency. In addition to these, the first phase of a study examining the carbon footprint of metros was completed in 2008 and further research is now ongoing. Recent research for metros has focused on:

- Best practices and technologies in energy reduction
- Understanding and estimating the carbon footprint of metros
- Identifying strategies to ensure metros remain competitive with other transport modes on a carbon basis

This paper draws on the key messages from these studies.

2. Climate Change and Energy: Issues of Critical Importance for Metros

Why should metros and Asian metros in particular, be concerned with energy issues and the impact of the metro on the environment? In simple terms there are three reasons: firstly, energy costs in the medium to long term are likely to rise, not fall and metros must respond to this; secondly climate change policies will impact on transport policy and spending priorities and thirdly, policy change offers metros with opportunities as well as new business risks.

2.1 The Carbon Footprint of a Metro

The UK's Carbon Trust defines a 'Carbon Footprint' as

"The total set of greenhouse gas emissions caused directly and indirectly by an [individual, event, organisation, product] expressed as CO₂e"¹

What is a metro's carbon footprint? In most cases the largest component of a metro's carbon footprint relates to its electricity consumption because most electricity is currently generated from the combustion of fossil fuels. This cannot be ignored: the fact that metros are powered by electricity does not make them carbon-zero emitters. Electricity use will typically constitute 90% of a metro's carbon footprint.

In addition to electricity, a metro will also consume materials and procure other services for other regular operational activities which have a carbon impact. These include waste management, gas consumed in offices stations and depots, the operation of road fleets, water and paper use and

¹ ". UK Carbon Trust. 2009. "[What is a carbon footprint?](http://www.carbontrust.co.uk/solutions/CarbonFootprinting/what_is_a_carbon_footprint.htm)"

employee travel. London Underground has estimated that these constitute 18% of its carbon footprint².

Greenhouse gas emissions caused by the original build of the metro and the renewal of its assets also need to be considered. Very few metros have been able to measure this, but ongoing work by Manchester Metropolitan University has suggested that this 'embedded carbon' may have constituted a further 5% of greenhouse emissions for the Glasgow Subway over its 100 year lifespan.

However, this is not the whole story because it is widely considered that metros deliver potentially large, wider greenhouse gas savings for cities which are not easily measurable. We consider this issue in more detail in later sections.

2.2 The Policy Context in the Medium to Long Term

Depending on the outcome of negotiations at the forthcoming Climate Change conference in Copenhagen, it is probable that more stringent national and international carbon reduction targets will be introduced and this will have an impact on transport policies, priorities and spending. In the longer term, competing modes (cars, buses) may become more energy efficient. It is therefore essential that policy-makers understand the wider environmental benefits of metros.

Some metros might incorrectly consider that the largely positive, wider environmental impacts of metros are reason enough to not worry about the metro's carbon footprint. However, as Figure 1 below shows, today, energy costs are typically 20% of an Asian metro's operating costs. This compares with only 5% to 10% in Europe and North America. The larger air conditioning requirements of Asian metros partly explains this disparity.

² Transport for London. 2008. LU Carbon footprint report 2008

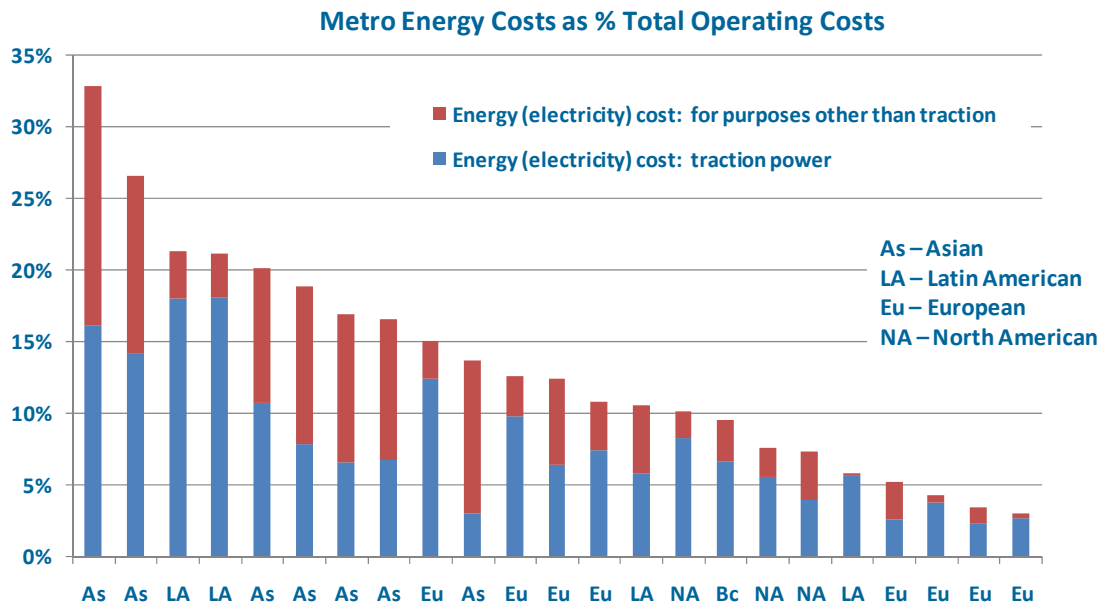


Figure 1: CoMET and Nova metro energy costs as a percentage of total metro operating costs

Energy prices are therefore a risk to the control of operating costs in Asian metros. Energy costs are likely to rise as electricity production becomes de-carbonised (through increased nuclear and renewable generation and carbon –capture), as carbon pricing and taxes are deployed and as fossil fuel sources become depleted.

Ensuring that low-energy consumption is designed into new metros and then adapting electricity use as new technologies become available would be a prudent strategy. Existing metros should implement energy and carbon reduction strategies to minimize carbon footprints and energy costs.

Carbon pricing and cap-and-trade may offer metros future opportunities for funding and financing investments, but perhaps only if the external, wider environmental impacts of metros are understood and quantified. Recent research by the Nova group³ has argued that the current United Nations’ Clean Development Mechanism does not offer significant opportunities for metros.

2.3 Understanding and Quantifying the Wider Greenhouse Gas Benefits of Metros

The carbon footprint of metros must be framed in the correct context. Where cities have developed without any significant levels of investment in mass transit, development has sprawled (as in Los Angeles and later, Bangkok), laying the perfect breeding ground for high levels of car ownership,

³ Nova Group of Metros, RTSC at Imperial College London. 2008. Energy Costs, Renewables and CO2 Emissions, Phase 10 Case Study. (Confidential to CoMET and Nova Members)

long distance commuting and congestion as incomes rise. Developed, dense cities over a particular size are not economically and environmentally sustainable without the provision of mass transit and in particular metros. Hong Kong and London simply could not operate as effective, productive cities without their metros.

Higher levels of urban density (inhabitants per unit of area) are associated with lower emissions from private transport. Recent research by the RTSC at Imperial College London⁴ has shown that a 10% increase in urban density corresponds with a 3.5% reduction in vehicle fuel consumption. Higher urban density is also associated with smaller, less energy intensive houses and buildings.

Metro development, particularly when integrated with land-use planning can increase the capacity of cities to develop higher levels of density. Of course, metros can increase the modal share of public transport, lowering dependency on, and associated emissions from, private motorised vehicles. The effectiveness of metros in attracting passengers and achieving higher levels of mode shift depends on the level of integration with other public transport modes (notably bus, light-rail and suburban rail services). Metros can therefore have far wider environmental benefits than are immediately measurable and can lower the whole urban carbon footprint, but their success often depends on the level of integration with land-use and the transport network as a whole.

Although important research is only just emerging to quantify their wider environmental impacts, it seems clear that metros facilitate compact and sustainable cities and this message should be heard in any discussion about metros' carbon footprint.

APTA⁵, UITP and Imperial College London, are all currently developing methodologies to measure the wider carbon impact of mass transit.

2.4 Energy Policy and Transport Policy

The UK government is legally bound to reduce CO₂ emissions by 80% of 1990 levels by 2050⁶. Many other countries will be bound by similar targets in the near future. In order to achieve such reductions in CO₂, emissions from the transport sector must be reduced significantly.

The decarbonisation of transport relies on two concurrent strategies:

1. The electrification of transport (through the development and widespread adoption of electric or hydrogen fuel cell vehicles, but also by expansion of electrically powered public transport).
2. The decarbonisation of the power supply used to drive electricity-dependant transport.

⁴ Karathodorou, N., Graham, G., Noland, R. 2009. Estimating the effect of urban density on fuel demand. Energy Economics. In Press

⁵ APTA Climate Change Standards Working Group. 2009. Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit

⁶ United Kingdom Parliament. 2008. Climate Change Act 2008. The Stationery Office Ltd.

Therefore, regardless of how much metros consume in terms of CO₂ today, by nature of being electrically powered, they represent a major step forward towards the longer-term aim of decarbonising the majority of the transport sector. Metro development therefore strongly complements governments' long-term future energy strategies.

In the UK, the Committee on Climate Change (CCC) is *"an independent body established under the Climate Change Act to advise the UK Government on setting carbon budgets, and to report to Parliament on the progress made in reducing greenhouse gas emissions."*⁷

Figure 2 shows, on the left, the CCC's proposed rate of decarbonisation of electricity supply in the UK (in grams of CO₂ per kilowatt-hour)⁸ which can be achieved by a combination of increasing nuclear and renewable capacity and through carbon-capture. To the right, we see the impact of this on London Underground's current CO₂ emissions in gram per passenger kilometre⁹. The timeframe is long (to 2050), but decarbonising our economies is a 40-plus year task: coincidentally very similar to the expected lifespan of many metro assets.

Decisions to invest in public transport must therefore not only consider today's current 'grid mix' of electricity, but the expectations of decarbonising electricity supply in the medium to long term.

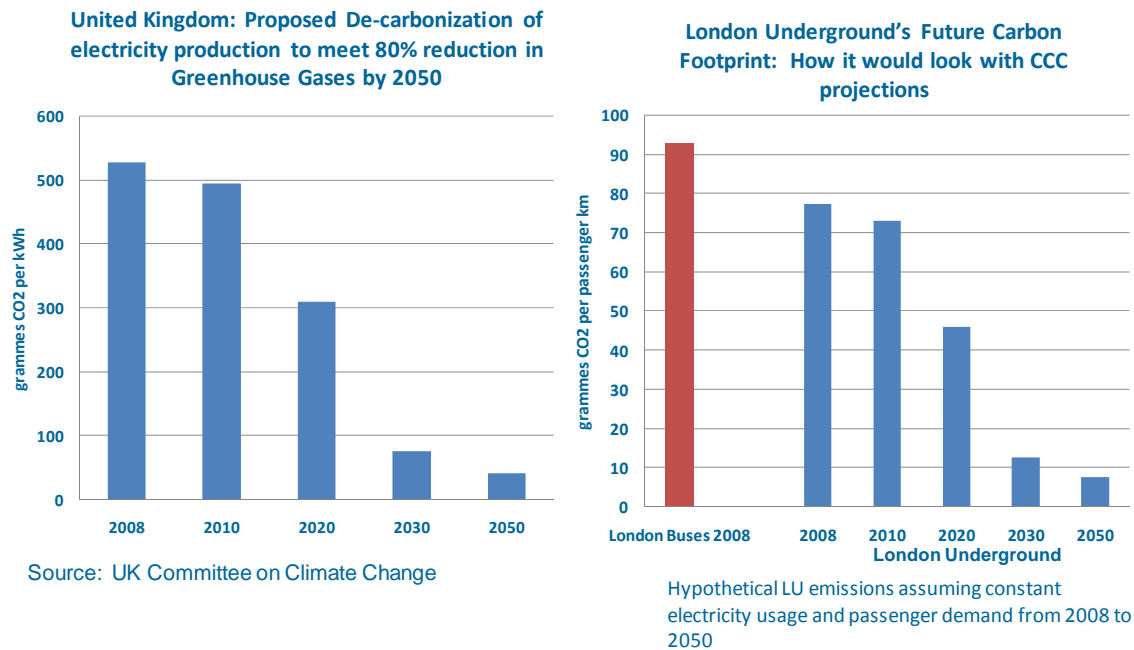


Figure 2: The impact of reducing the carbon intensity of electricity supply in the UK upon the 'Carbon Footprint' of London Underground

⁷ <http://www.theccc.org.uk/>

⁸ Committee on Climate Change. 2008. Building a low-carbon economy – the UK's contribution to tackling climate change.

⁹ Based on data from: Transport for London. 2008. Environment Report.

3. The Carbon Efficiency of CoMET and Nova Metros

Figure 3 shows the variability of carbon efficiency for the CoMET and Nova metros arising from their use of electricity. The local electricity mix has been used in the calculation where data is available. The graph has been anonymized in accordance with the CoMET and Nova confidentiality agreements, but what is stark is the very large variability of the metros' carbon emissions from power consumption.

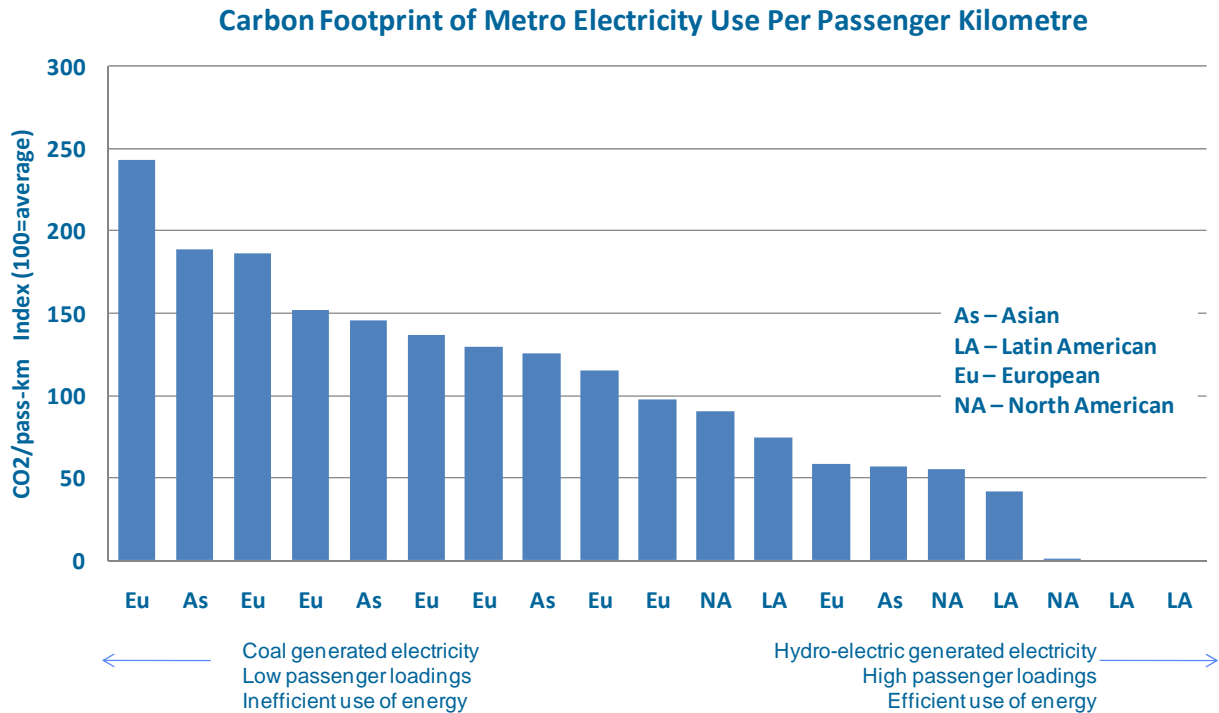


Figure 3: CoMET and Nova Metro's 'Carbon Footprints' arising from their power consumption

Three factors govern this variability and it is argued that all of these can be altered by the metro and its governments and authorities in the long term:

- The carbon intensity of electricity supply
- The efficiency with which metros use electricity
- Passenger loadings (passengers / capacity)

4. Identifying Best Practices in Reducing Energy Consumption and CO₂ Emissions

4.1 Benchmarking Metro Energy Efficiency

Figure 4 demonstrates that regardless of passenger loadings and how electricity is generated, there are large differences in the amount of electricity consumed by CoMET and Nova metros per capacity provided (measured here as kilowatt-hours per standardized capacity kilometre).

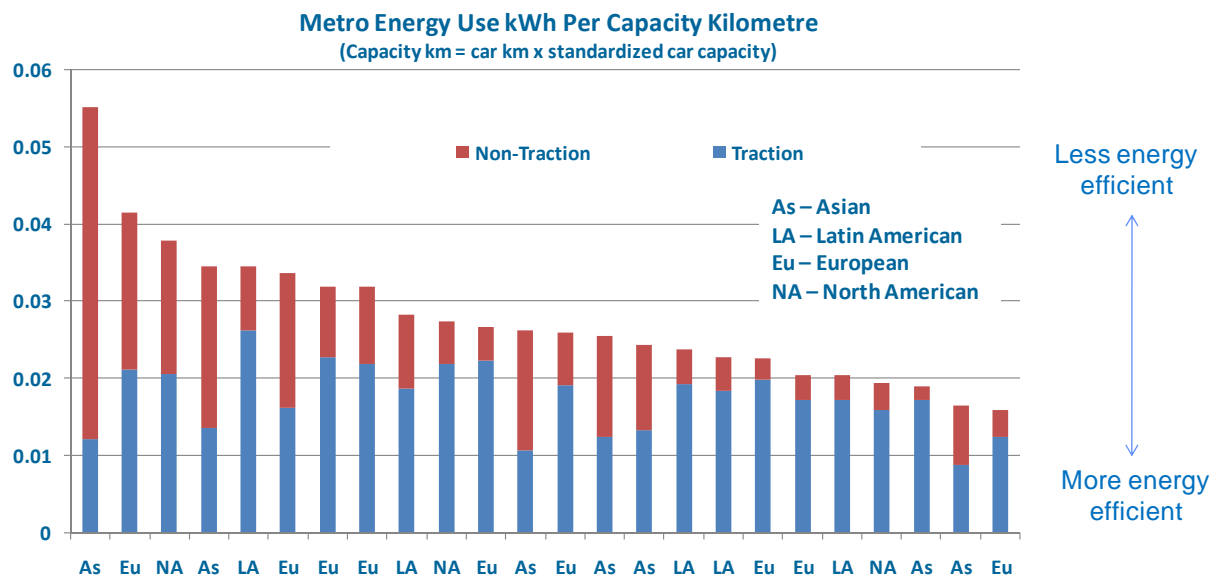


Figure 4: The Relative Energy Efficiency of CoMET and Nova Metros

The energy efficiency of CoMET and Nova metros varies by a factor of 3, demonstrating that although there are factors affecting energy efficiency outside of existing metros' control, there may be a strong potential for metros to learn from each other to become more energy efficient. As the graph demonstrates for non-traction energy, Asian metros are often affected by large station air-conditioning requirements. For many Asian metros, this has been a focus for energy saving initiatives: by altering station temperatures, adjusting chillers and by installing platform screen doors, for example.

There are many factors affecting energy efficiency, some which are not easily changed once the metro has been designed and built, others which can be affected when assets are renewed or enhanced, and many which can be altered in the short term.

4.2 Factors and Initiatives Affecting Metro Energy Efficiency and CO₂ emissions

Some of the actions and factors which can improve the energy efficiency of metros are summarised in Figure 5, below. This collection of factors is not comprehensive but it demonstrates that energy efficiency can be improved in a multitude of ways. Some initiatives may yield only small savings, but the sum of these may add up, over time, to a significant reduction in energy consumption.

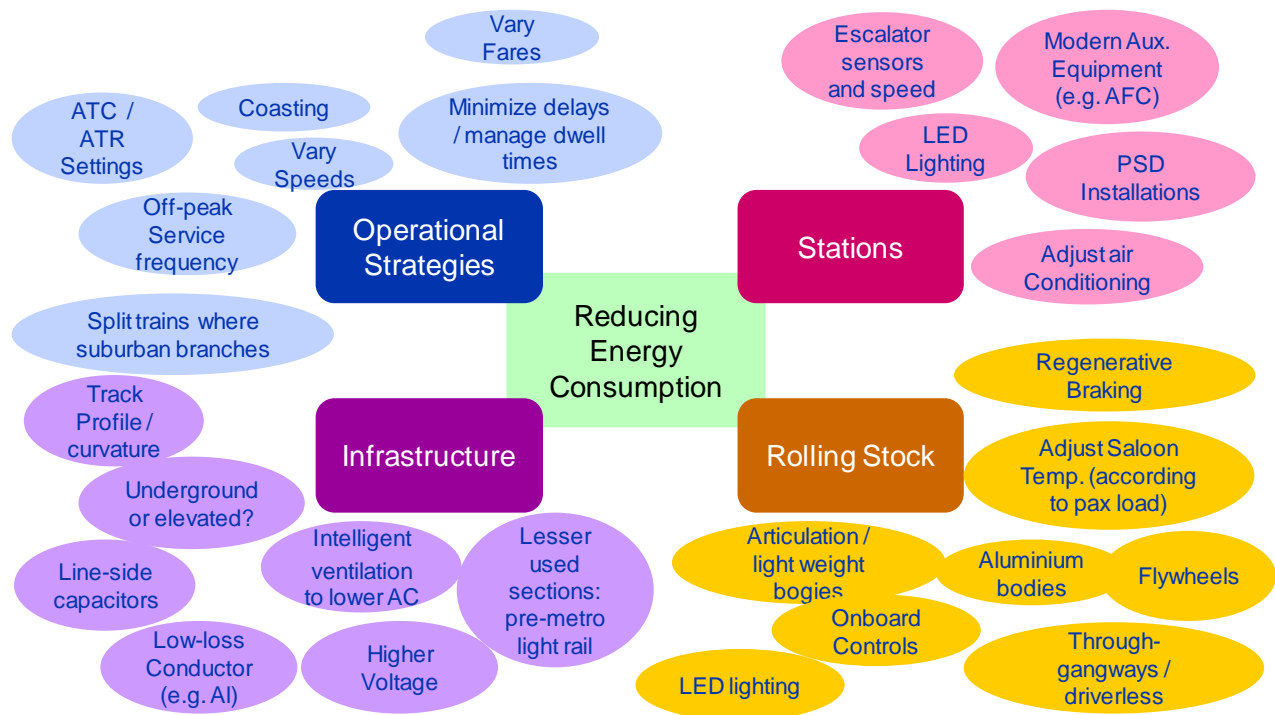


Figure 5: Initiatives to increase the energy efficiency of metros

The greatest savings may lie in having regenerative braking and Automatic Train Operation and Regulation systems which ensure that trains can run with minimum energy consumption using coasting. Ensuring that trains can run unimpeded and with minimal service perturbations and delay will reduce energy consumption from avoidable acceleration.

Managing the off-peak service provision is very important in optimising energy consumption; different ATO settings should be programmed for different times of the day (with maximum service capacity, frequency and speeds for the peak period only). However, ensuring the right level of service in the off-peak, balancing demand, service quality and operating costs (including energy consumption) should not be wholly driven by operating costs – metros should beware of the unintended consequences in losing passenger demand at the expense of reducing energy consumption.

4.3 Examples of Best Practices in Reducing Power Consumption

Example 1: New Technologies: LED Lighting.

The Hong Kong MTR has recently developed and tested a specification for LED lighting installation in trains and stations. LED lighting will save energy and will reduce maintenance requirements. Drop-in replacement of existing lighting has been designed. A 40% saving in lighting energy has been achieved.



Figure 6: LED lighting in Hong Kong MTR stations and trains.

Example 2: Wider solutions to reduce carbon emissions: On-site and direct-feed renewable power generation

Notwithstanding governments' strategies for decarbonising electricity generation, in the medium to long term, metros can directly re-balance their energy sources towards less carbon intensive sources. A recent Nova case study demonstrated that generating 10% of a metro's energy

requirement on-site might be feasible for smaller metros through a combination of wind turbines and biomass boilers in metro depots and the installation of photovoltaic panels on depot roofs. Metros often own extensive areas of land where on-site wind generation might be feasible, especially at depots. Initial calculations¹⁰ have shown that on-site wind generation has the shortest pay-back period and offers the largest capacity potential.

Metros can also invest directly in off-site generation, but with direct feeds to the metro from the power source. Metros in cities located near wide estuaries and the coast could consider investing in off-site wind-farms with direct feeds into the metro. Indeed, albeit without a direct-feed, the city of Calgary's light rail system is now reportedly powered by 12 wind turbines¹¹.

In order to challenge metros to consider what might be possible, CoMET hypothesized in a recent study¹² that halving a metro's CO₂ emissions per passenger kilometre might be within reach in the long term, as a result of:

- 30% improvements in energy efficiency,
- 10% production of on-site renewable generation, and,
- 10% increase in passenger loadings -e.g. through optimising off-peak services, implementation of driverless, through gangway trains and by improving integration with other public transport modes.

Sourcing electricity directly from less carbon intensive sources will enable further reductions in CO₂.

5. Conclusions

The key conclusions from the recent research by CoMET, Nova and the RTSC at Imperial College London are as follows:

- Energy costs are a significant proportion of Asian metro operating costs (typically 20%) and energy prices are likely to rise in the future. Shocks in energy prices are a key risk to Asian metros' profitability.
- New metros and those responsible for metro development should build-in energy optimal design at every stage, learning from the experience of existing metros.
- Established metros should plan and implement energy and carbon reduction strategies to minimize carbon footprints and energy costs. Average carbon emissions reductions of 1 to 2% p.a. are a realistic aim. Metros are challenged to reduce their carbon footprint per passenger kilometre by 50% within 40 years.

¹⁰ Nova Group of Metros, RTSC at Imperial College London. 2008. Energy Costs, Renewables and CO₂ Emissions, Phase 10 Case Study. (Confidential to CoMET and Nova Members)

¹¹ http://www.calgarytransit.com/environment/ride_the_wind.html

¹² Community of Metros, Imperial College 2008. Keeping Metros Competitive: Costs and Carbon Footprints. CoMET 2008 Case Study (Confidential to CoMET and Nova Members)

- Operational strategies are critical in optimizing energy efficiency (ATR/ATC, coasting, off-peak speeds, minimizing delays, etc.).
- Metros should consider altering their energy supply through on-site renewable and direct-feed from off-site renewable generation.
- Metros should beware of any unintended consequences of minimizing energy consumption where it affects service quality, therefore reducing the attractiveness of the metro.
- The carbon footprint of metros is not easily quantified because the wider environmental benefits of metros are likely to be large and may off-set any direct and indirect emissions that metros generate.
- Policy makers and metros should beware of any unfair comparisons between modes (e.g. of CO₂ per passenger kilometre) until the wider environmental impacts of metros are quantified and better understood.
- Metros are electrically powered and in combination with government strategies to decarbonise electricity generation, metros in dense, urban cities strongly contribute towards the longer-term aim of decarbonising the majority of the transport sector.
- Metro development therefore strongly complements governments' long – term future energy strategies and supports sustainable cities.