

# ENVIRONMENTAL AND ECONOMIC BENEFITS OF RAILWAY ELECTRIFICATION OF SOUTHERN AFRICAN COUNTRIES

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## ABSTRACT

The Southern African region is made of nine countries, each with own local railway network. Most of the countries have railway links with neighbouring countries resulting in the formation of a wide railway network. Majority of the locomotives currently in use in most of these countries are diesel powered despite efforts made by some countries such as South Africa and Zimbabwe of electrifying some of their domestic railway routes. The focus of the research article is on the economic and environmental benefits that Southern African countries can draw from an electrified railway network. It is expected that there would be reduced railway locomotive exhaust fumes-related pollutants in the environment resulting in cleaner air. High-speed associated with electric trains would encourage the use of railway transport for both passenger and heavy goods movement which at the moment are dominated by road and air transport. The use of comparatively safe and cost-effective railway transport would not only improve trade among member countries but also attract foreign investment. It is expected that transportation of industrial raw materials and finished products would not only be efficient but also cost-effective. Reduction of heavy goods traffic would besides decongesting the roads, but also bring down the cost of road maintenance. Finally, the damaging effects of the locomotives' exhaust fumes would be avoided if railway electrification was embarked on. In addition, trade between member countries is expected to increase due to comparatively cost-effective fast movement of goods and passengers. The region is expected to save some foreign exchange due to reduced expenditure on road maintenance and locomotive diesel imports.

*Keywords: economic and environmental benefits, railway electrification, Southern Africa*

## 1 INTRODUCTION

The importance of railway transport in the world economy cannot be overemphasized. Most of the railway networks are not electrified; they use diesel locomotives that produce high noise levels and pollute the environment [1]. The Southern African region (stretching from Democratic Republic of the Congo to South Africa) has one of the rare railway networks in the developing world where at least nine countries are linked with uninterrupted 1,067 mm gauge railway covering a distance of 53,811 km. The region has ten trade corridors as shown in the map of Fig. 1. It has more than 3,500 diesel locomotives and 133,000 wagons [2]. As an emerging market, Southern Africa is not utilizing the terrestrial physical integration of the railway link. The railway infrastructure is generally neglected, ageing, under-utilized and overwhelmingly state-owed. There is also lack of a strong modern marketing culture and customer service. Despite having a carrying capacity of about 350 million tons per annum the region can only manage to carry 200 million tons [3].

## 2 RATIONALE

The unprecedented economic recovery being experience in Africa is responsible for the economic growth. The other growth factor is the opening of new mines, gas and oil fields and increased intra-regional and international trade. Railway transport is expected to play a



Figure 1: Southern African railway connection trade corridors (source: AET 2013).

leading role in transportation of freight over long distances. It has the advantage of energy efficiency, reduced greenhouse emissions and lower cost per tonne kilometre [4]. The existing road network cannot be able to handle the projected trade traffic volume of the Southern African countries for the next 10–30 years. Currently Southern Africa is spending more than 1.5% of its gross domestic product on road maintenance due to high rate of road deterioration resulting from hauling of heavy goods. Therefore, the projected increase in traffic can be only managed by the railway transport network [5, 6]. The current railway network is characterized by very low speed coupled with border crossing delays resulting in freight spending as much as 38 days on the north–south railway transit corridor [7]. Although railway transport seems to have comparatively lower negative environmental impact, electrification still remains the backbone of environmental record of railways [8].

The diesel locomotives that are currently commonly used in Southern Africa have a number of disadvantages which are discussed under the following subtopics:

- Efficiency
- Environmental impact
- Locomotive maintenance
- Service life
- Economic

## 2.1 Efficiency

The diesel locomotive's on-board engine runs an electric generator which supplies power to electric motors that drive the locomotive. The energy conversion from thermal to mechanical and mechanical to electrical and from electrical back to mechanical involves high-energy losses, which results in 40% efficiency [9]. One tonne of freight can cover a distance of 484 miles (778.922 km) per gallon (4.5461 litres) of fuel. The 200 million tonnes of freight which is annually transported on Southern African railways consumes 909.2 million litres of fuel [10].

## 2.2 Environmental impact

The combustion of the 909.2 million litres of fuel to run diesel locomotives produces large quantities of exhaust fumes. The major toxic gas compound found in exhaust emission includes carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO<sub>2</sub>) and sulphur dioxide (SO<sub>2</sub>). There are also small quantities of other numerous compounds that may still pose a health risk to humans [11]. Levels of certain pollutants are up to nine times higher in passenger carriages directly behind the diesel locomotives than on busy city street [12].

## 2.3 Locomotive maintenance

Diesel locomotives have comparatively a lot of mechanical movements necessitating the need for more lubricants which is 50% more than that consumed by electric locomotives. Therefore, it costs an average of 60p per 1.609 km to maintain a diesel locomotive. Track wear and tear cost 9.8p per 1.609 km for diesel locomotives. The average maintenance cost of the 3,500 diesel locomotives assuming each covers a distance of 50,000 km is £18,645,121. On the other hand, the average cost of railway track wear and tear of the current 53,811 km railway track length of Southern Africa assuming 3,500 locomotives are actively running is £117,053,138.595 [13].

## 2.4 Service life

The average life expectancy of a typical well-managed diesel locomotive is around 20 years due to high level of wear and tear [14].

## 2.5 Economic

The Southern African railways are currently operating below the capacity and function as a collection of national systems rather than as an integrated regional rail network. The north-south corridor forms the main artery supporting international trade extending from southern Democratic Republic of the Congo to Cape Town in South Africa. All railway operators along the corridor with the exception of Spoornet are operating at 10% of their capacities. The railway traffic volumes are too low to cover the high cost of infrastructure rehabilitation and track maintenance. A diesel locomotive takes about 38 days to travel a distance of 3,000 km from Kolwezi along the Democratic Republic of the Congo border to Durban in South Africa. The delays cost over \$200.00 a day representing a loss of \$120 million per year based on the current traffic volumes [15].

### 3 MERITS OF ELECTRIFIED RAILWAY

#### 3.1 Efficiency

Electric locomotives are more efficient than diesel locomotives and can generate 1.5 times more revenue. If the railway was electrified the region would save a minimum 909.2 million litres of diesel which is currently being imported. In electric railway, power is transmitted to railway locomotives and wagons using direct current or single-phase alternating current networks. Therefore, no diesel is needed for locomotive movement [16].

#### 3.2 Environment impact

All diesel motorized means of transport produce carbon dioxide (CO<sub>2</sub>) which contributes to climate change. Trains are energy-efficient carriers of both freight and passengers and hence help reduce CO<sub>2</sub> emissions if more passengers and cargo switch on to trains from the environment polluting means of transport. In 2010, the total carbon dioxide gas emission of Southern African countries was 525.08 per capital [16]. Unlike diesel locomotives, electric locomotives do not produce exhaust fumes and are less noisy. In light of increased campaign of use of cleaner energy sources and rising cost of fossil fuel, railway electrification help in improving efficiency and reduction of operational cost [17].

Electric locomotives, health benefits double those of diesel–electric, as the emissions would only be restricted at the electric power generation source while the electric locomotive would not produce any emissions.

#### 3.3 Locomotive maintenance

Maintenance cost of electric locomotives is 50% less than that of diesel locomotives which is as a result of reduced oil and lubricant consumption and comparatively minimal wear and tear of moving parts [19].

Figures 2–4 show that electric railway system has higher initial cost compared with diesel railway system. It is attributed to high cost of laying overhead cables, fixed substation installation along the rail track and related protection circuits. In the long run, the high upfront capital cost for electrification is offset by reduced daily maintenance activities that typically consist of remote monitoring of the power utility and the catenary. Considering that the cost of electricity tends to be more stable than oil prices, the operation of an electrified system is expected to be more profitable after the infrastructure costs have been incurred. Studies done in the United Kingdom outlined the following benefits of railway electrification in relation to long-term cost:

- 50% reduction in rolling stock operation cost;
- 15% reduction in infrastructure operation cost such as track maintenance due to light-weight trains; and
- 3% increase in rolling stock availability.

Despite the low initial cost of establishing a diesel-powered railway, it becomes more expensive in the long run compared to the electric railway due to high operational and maintenance cost [19, 20].

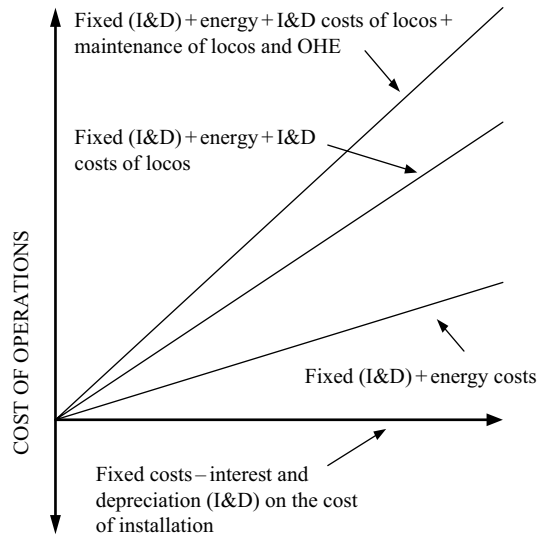


Figure 2: Cost of operation of diesel locomotives [18].

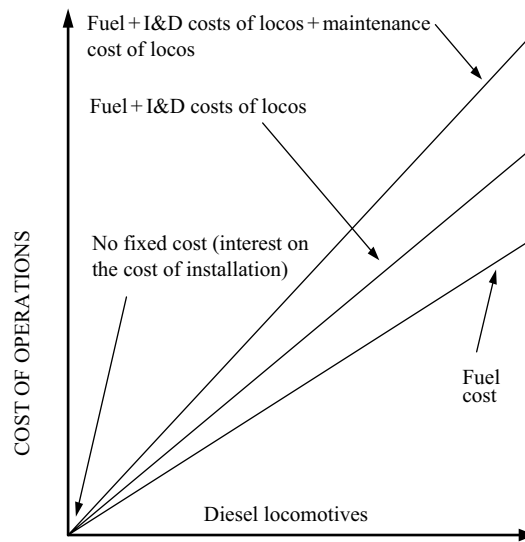


Figure 3: Cost of operation of electric locomotives [18].

### 3.4 Service life

One of the general requirements for a successful railway traction system is to have a sufficiently long service lifetime with minimal non-availability due to maintenance and standby. Compared to electric propulsion system, diesel electric has less power, with high maintenance cost. The average service life of a well-maintained electric locomotive is 40 years [21].

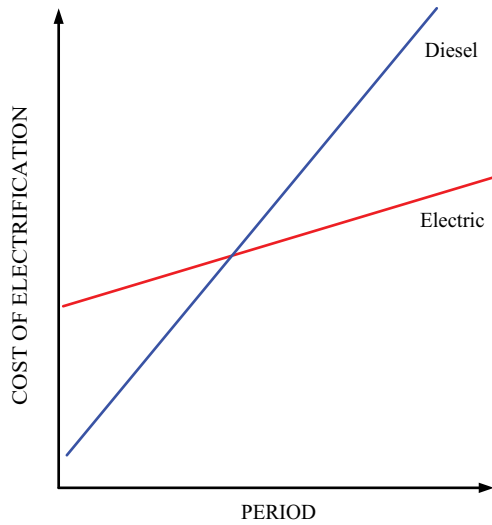


Figure 4: Comparison between electrical and diesel railway [19].

### 3.5 Trade promotion

The high speed, comfort, reliability and larger seating capacity of electric locomotives are expected to attract a lot of freight and passengers to railway transport. Regional tourism industry will benefit from the fast movement of both local and foreign visitors due to reduced travelling time. Some of the railway operational benefits that would attract both passenger and freight to use railway transport include:

- faster acceleration time due to light weight and
- improved station ambience because electric trains do not require provision for fume escape, hence can be in enclosed structures compared to diesel locomotives which produce fumes [22].

### 3.6 Cost and environmental benefits

Southern African region is expected to draw railway financial benefits (RFB) from the electrification. Figure 5 shows that a capital investment in electrification would downwardly uniformly shift the marginal curve cost. Railway operators profit would be represented by the area  $GC_2BM_2-GC_1AM_1$ . Equation (1) depicts this relationship:

$$RFB = (TR_{with} - TOC_{with}) - (TR_{without} - TOC_{without}) \quad (1)$$

where RFB is the rail financial benefit (net profit) which is gained from electrification;  $Q_{without}$ ,  $Q_{with}$  the number of rail trips without and with electrification;  $TR_{with}$ ,  $TR_{without}$  the total revenue with and without electrification; and  $TOC_{with}$ ,  $TOC_{without}$  the total operating and maintenance costs with and without electrification scheme.

Railway user benefits (RUB) include improvements to quality of service.

$GC_2$  and  $GC_1$  of Fig. 5 are the generalized cost of travelling by rail with and without electrification.  $Q_2$  and  $Q_1$  are the number of trips with and without electrification. The area  $GC_1ABGC_2$  represents railway passenger's surplus gain which includes both old customers and new travellers transferring from road (Fig. 6).

The mathematical expression is as follows:

$$RUB = 1/2(GC_{without} - GC_{with})(Q_{without} + Q_{with}) \tag{2}$$

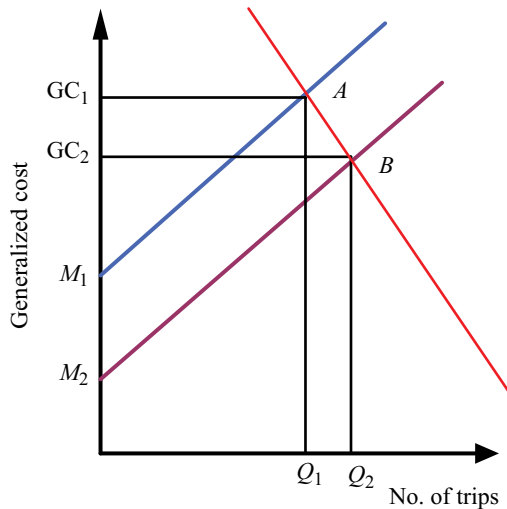


Figure 5: Improvement in the quality of railway service [19].

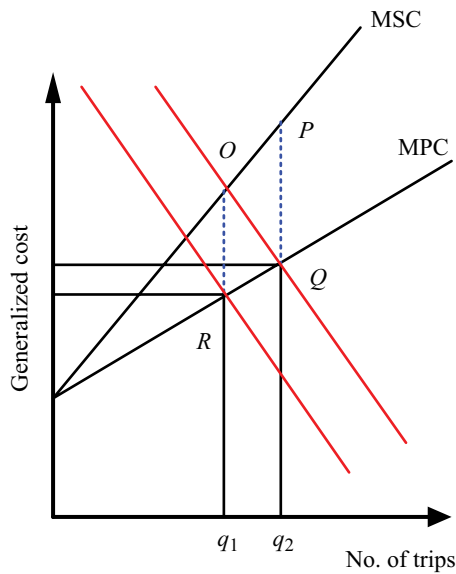


Figure 6: Improvement in the quality of road service [19].

The returns on investment would attract more investment in railway transport and other regional investment due to the availability of cost-effective reliable railway transport [19].

## 4 ECONOMIC FORECASTS

### 4.1 Current and projected economics status

The integration of the electric railway of Southern Africa would promote regional integration of countries. Neighbouring countries would jointly market and promote their diverse tourism products as single destination. In the year 2013 the travel and tourism industry of Southern Africa made a direct contribution of US\$19.2 billion (2.9%) to the world gross domestic product. Regional railway electrification is expected to boost tourism by more than 30% with an income of more than US\$24.96 billion. Electric trains are expected to be cheaper because they do not run on imported diesel and have lower maintenance cost. They are 54% cheaper to run on per kilometre basis than the diesel locomotives [23, 24].

The population of Southern Africa is approximately 272 million and expected to grow at a rate of about 1.7% per annum to reach approximately 350 million by 2027. The population increase will put pressure on the transport sector, hence the need to consider cost-effective reliable freight and passenger mode of transport such as the electric trains. To ensure availability of electric power in the region, significant strides are being made by respective governments through regional bodies such as Southern African Development Community in establishment of regional infrastructure in the electricity subsector through interconnection of nine countries to the regional power pool, the Southern African Power Pool (SAPP). Southern Africa should improve its infrastructure to be able to handle the projected approximately 58% of the total continental traffic by 2027. Economic growth is between 4% and 7% propelled by rising external demand, high international metal prices, rising global income, resurgent capital flows and sound macroeconomic policies [25].

## 5 CONCLUSION

The research article has shown that the Southern African 1,067 mm railway gauge operating as national railways in respective countries can have both environmental and economic benefits to countries in the region if it is electrified and integrated as one railway network. Electrification would result in savings in railway equipment and track maintenance and fuel imports. Furthermore, there would be reduction in environmental pollution due to reduced atmospheric pollutants emanating from diesel locomotive exhaust fumes.

## 6 RECOMMENDATIONS

It is recommended that the Southern African countries consider electrifying their railways and form an integrated regional railway network.

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