

# EVALUATING THE ENVIRONMENTAL IMPACT OF THE SOUTH AFRICAN FREIGHT SYSTEM'S ENERGY TENDENCIES

T E LANE and M J W A VANDERSCHUREN

Centre for Transport Studies, University of Cape Town, Private Bag 7701, Rondebosch

## ABSTRACT

Sustainable development is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for future generations. The term was used by the Brundtland Commission which coined what has become the most often-quoted definition of sustainable development as: development that "meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED, 1987; Smith and Gareth 1998).

Transport, in general, is a major contributor to negative environmental impacts. These impacts range from air pollution and energy consumption, to soil erosion and the like. Freight transport, specifically, accounts for many negative environmental impacts that make it unsustainable in the long term. The freight energy demand from non-renewable sources, for example, accounts for about 40% of total transport energy demand.

This study defines the term environment as the representation of the core elements in nature required to sustain life on earth. These elements are grouped into the following four categories: earth (e.g. soil and mineral deposits), water (oceans and groundwater), air and the climate. An assessment of freight transport's negative impacts on these four categories is discussed in this paper.

## 1 INTRODUCTION

On 11 December 1997, the Kyoto Protocol was adopted. The protocol is an international agreement linked to the United Nations Framework Convention on Climate Change. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialised countries and the European community for reducing greenhouse gas (GHG) emissions. The target fixed in the Kyoto Protocol is an eight percent reduction of emissions in all sectors of the economy compared to 1990 levels by 2008-2012 (UN, 1998). The follow-up of Kyoto, the United Nations Climate Change Conference held in Copenhagen in December, did not lead to the type of conclusions and proposed actions needed to combat unsustainable climate change trends. Furthermore, climate change is only one of the environmental aspects threatened by transportation in general, and freight in particular.

The transport sector is the fastest growing and second largest source of greenhouse gas (GHG) emissions in the world, accounting for 13% of the total GHG emissions. Global energy supply is the largest source. The transport sector consumes approx 20% of global energy reserves and up to 90% of oil reserves (Tran:SIT, 2007). As indicated, the freight sector in South Africa accounts for 40% of the total transport energy demand.

The aim of this paper is to estimate the environmental impacts of the status quo which favours road above all other (even more energy efficient) transport modes. The analysis takes place on a national level, although the authors realise that there might be local

differences. Five potential freight modes, namely, road, rail, air, water and pipeline are considered.

## 2 OVERVIEW OF THE ENVIRONMENTAL EFFECTS OF FREIGHT TRANSPORT

The core definition of sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). For the purpose of this study, the term environment is meant to represent the core elements in nature required to sustain life on earth. These elements can be grouped into one of the following categories: earth (e.g. soil and mineral deposits), water (oceans and groundwater), air and the climate.

### 2.1 Freight transport’s impacts on earth

Gilbert and Perl (2008) relate the notion of sustainability to the prevalent use of non-renewable fossil fuels (such as coal, natural gas and oil) in transportation systems globally. The argument is that the excessive use of these primal energy sources may deplete them, and deprive future generations’ use of it as a source of energy. **Consumption of, and dependence on non-renewable natural resources** is considered a major negative impact of transport on the earth.

The **uptake and fragmentation of land** for infrastructure is deemed a negative environmental impact as it causes habitat fragmentation and divides the ecosystem into smaller, partially isolated units (OECD, 1997). This can result in the destruction of habitats, injury to, or killing of, animals and threats to the survival of populations of individual species. Furthermore, the diversity of species in ecosystems is a function of the total size of the area of habitat, thus dividing this area with a road can cut diversity in half, rather than reducing it only by the actual area used by the infrastructure (OECD 1997).

**Soil pollution** is another negative environmental consequence of transport. This can be caused by leaks from underground fuel storage facilities (Gilbert & Perl, 2008). Airports cause land and water pollution when chemicals used for de-icing seep into the ground. Other environmental impacts generated by airports include the treatment of waste (generated by airport activities), land take and local development associated with the airport and impacts associated with road and rail access to the airports (Williams et al, 2007). Pipeline accidents can cause spills of petroleum products, which can contaminate land, surface water or ground water. Accidental escapes of natural gas, apparently, do not pose a significant environmental threat, because it is light and disperses quickly in the atmosphere (OECD, 1997).

Finally, it needs to be mentioned that soil erosion due to road construction, is one of the negative impacts associated with the transport sector. In specific countries, such as Lesotho, soil erosion is a major concern (Pasco et al, 2008).

### 2.2 Freight transport’s impact on water

Ships are designed to move a certain load. When empty they fill their tanks with ballast water in order to weigh them down and to stabilize them. Before entering the port where they are to load up, ballast water (of which the weight will be replaced with freight) is discharged. This **ballast water** is typically contaminated with oil and possibly other wastes within the ballast tanks. Its discharge is, therefore, a source of water pollution (OECD, 1997). Segregated ballast tanks, which are required on newer tank vessels, reduce or eliminate the oily ballast problem.

A similar source of pollution is bilge water; this is seepage which collects in the hold of a ship and must be discharged regularly. On oil tankers the bilge water is typically contaminated with oil, which seeps out of the cargo tanks. Such discharges are referred to as “operational” pollution because they have long been considered a part of the normal operating procedures, both of oil tankers and of other ships, managing their fuel (OECD, 1997). Often some aquatic species form part of the ballast water and are unintentionally transported to new marine ecosystems (Corbett, 2004). Most exotic invaders do not survive in their new environment, and so do not impose significant ecological or financial costs. Some flourish, however, and can crowd out other species or radically change the balance of existing ecosystems (OECD, 1997). Quantitative data is, however, not available on the magnitude of the ballast water problem.

Accidental or deliberate **discharge of solid and liquid materials** by ships at sea is another cause of water pollution. This can comprise human and general waste (such as packaging material) and spills (mainly oil). If the discharged material does not degrade well in water, there can be long-term adverse effects which can extend over long distances if transported by ocean currents (Gilbert & Perl, 2008). Oily discharges kill marine animals and contaminate coastal facilities. The disposal of plastics at sea is a significant source of environmental harm, since the materials are both buoyant and persistent (OECD, 1997). Materials used to pack break bulk freight to keep it from shifting as the boat moves are sometimes discharged by freighters. This material, called dunnage, is typically either wood or plastic. Discarded plastics can be lethal to marine life, whilst wood used for dunnage, if not grated or pulped, can damage small boats which run into it (OECD, 1997).

**Spills** from waterborne vessels (mainly oil and chemicals) are one of the major sources of water pollution from shipping. Cargo spills frequently occur while loading or unloading in port, due to handling errors or equipment problems, but are typically relatively small in volume. Much less common, but potentially more dangerous, are cargo spills which occur when a boat runs aground or breaks up in bad weather (OECD, 1997).

The routine maintenance **dredging of ports and inland waterways** stirs up toxic sediment and frequently leads to the disposal of dredged material in the open ocean. This toxic sediment can stem from many sources other than transport, but the dredging raises the toxic material and poses the problem of where to resettle them (OECD, 1997).

Some standard **hull coatings are toxic**, slowly leaching into seawater and remaining there for long periods. However, changing hull coatings might lead to increased rates of hull fouling, which can increase fuel requirements and cause other environmental damage (Corbett, 2004).

Physical infrastructure is the main cause of negative impacts on water from road transport. The roads themselves, parking lots, driveways and other paved surfaces lead to an increase in **impermeable surfaces**, particularly in urban areas. Impermeable surfaces interrupt the filtration of rainfall into the ground water, which aggravates flood risk and leads to more pollutant run-off into surface waters in heavy rains (OECD 1997). This run-off can pollute groundwater, as it may contain build-up from fuel and lubricant losses, spillages due to accidents and material wear, dust and wind deposits (Gilbert & Perl, 2008).

Other water impacts include **lake acidification** caused by air pollution generated by the transport sector (Gilbert & Perl, 2008). The building of ports can **disrupt existing marine ecosystems**.

### 2.3 Freight transport's impacts on air

Air pollution is, generally, considered to be the most important environmental threat posed by transportation (OECD, 1997). There are two main types of air pollution: the first is the **emission of gases, which affect air quality** and the second is gases, termed **greenhouse gases** (GHGs) that affect the climate (see also section 2.4). Trace quantities of additional pollutants are emitted by transportation. These include benzene (a known carcinogen), toluene, polynuclear aromatic hydrocarbons, formaldehyde, cyanide, hydrogen sulphide and dioxin, amongst others. There is very little information available on these pollutants, as they are not regulated, nor are their impacts completely understood (OECD, 1997).

The emissions most pertinent to air quality include: particulates (PM10), sulphur oxides (SO<sub>x</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO) and volatile organic compounds (VOC). Particulates are a product of combustion (mainly from diesel engines) and have been implicated in respiratory and heart diseases (Gilbert & Perl, 2008). Sulphur oxides are formed from the oxidation of sulphur contained in the fuel during combustion. It can cause respiratory disease, damage the fabric of buildings and contribute to acid rain.

Nitrogen oxides are formed when combustion takes place in the presence of air and are harmful to organisms, contribute to acid rain and are an ingredient in the formulation of ozone. Ozone is the principal ingredient in photochemical smog, which is a highly reactive form of oxygen that damages living matter and is implicated in crop damage and respiratory illness in humans. Carbon monoxide interferes with the uptake of oxygen in the blood and high concentrations are lethal. It is generated from the incomplete combustion of carbon fuels. Volatile organic compounds, in turn, arise from the evaporation of fuel and are also an ingredient in ozone production (Gilbert & Perl, 2008).

It is often difficult to estimate the full emissions impact of transport on air quality, as there are sometimes time lags between emission and detection. Furthermore, poor understanding of some biological, chemical and physical interactions and, sometimes, substantial scientific uncertainty on the source, scope and magnitude of public health or habitat damage caused, also complicates analyses (Esty, 1994).

### 2.4 Freight transport's impact on the earth's climate

The process where atmospheric gases (GHGs) trap solar energy to warm the earth, is known as the greenhouse effect. This process influences the global climate system and its stability is essential to facilitate life on earth. An increase in **greenhouse gases** (GHGs) is expected to increase the amount of solar energy being trapped, causing the earth's surface to warm up. It needs to be noted that changes in temperature, precipitation and cloud cover also impacts air quality.

The two main GHGs produced by transport are carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>). Not all greenhouse gases contribute equally to global warming. For example: the emissions from 1kg of CH<sub>4</sub> are equal to the emissions of 21kg of CO<sub>2</sub> (Zhou et al, 2007). The common unit for GHG emissions is tonnes of CO<sub>2</sub> equivalent.

Aviation contributes to levels of GHGs more radically than other modes of transport. Local emissions around the airport are a large cause of local air quality degradation. This is a combination of emissions from aircraft and from support vehicles. The main emissions

during low power aircraft movement (such as taxi manoeuvres) are carbon monoxide and hydrocarbons (Williams et al, 2007).

Globally, aviation affects the regional and global climate by increasing CO<sub>2</sub>, water vapour (H<sub>2</sub>O), and tropospheric ozone (O<sub>3</sub>), and by reducing methane (CH<sub>4</sub>) and stratospheric ozone. At cruise altitudes (in the upper troposphere) emissions of NO<sub>2</sub> increases levels of O<sub>3</sub>, contributing to global warming. In the global annual mean this is offset by cooling, due to a reduction in CH<sub>4</sub> due to the emission of NO<sub>2</sub>, but the spatial and temporal patterns mean the climate impacts are very different. Warming due to ozone is concentrated at northern hemisphere mid latitudes, whilst cooling due to reduced methane is a global effect (Williams et al, 2007). Carbon dioxide is a long-lived gas, uniformly mixed in the atmosphere. The location or altitude of emission will have no impact on its contribution to climate change. In contrast the climate impact of nitrogen oxides is heavily dependent on altitude, latitude, season and on background levels of atmospheric species. Emissions on or near the surface will have very different impacts than those at cruise altitudes (Williams et al, 2007).

Emissions of water vapour in the stratosphere (by long haul flights at high altitudes) are long lived and can have a significant warming effect. Exhaust gases mixing with surrounding air can condense (onto exhaust particulates or background aerosol) due to the cold temperatures. This rapidly freezes to form contrails. In certain conditions contrails can last for hours and spread to form extensive cirrus clouds, which are believed to have a further warming impact. During daytime the warming effect of contrails is offset by a cooling (albedo) effect, as the contrail reflects solar radiation (increasing the albedo of the atmosphere). At night the only impact is to trap heat radiated from the surface so the impact changes to warming. Contrail impacts depend on time and location of formation, the microphysics of the contrail, its lifetime, the rate at which it expands and dissipates and the drift of contrails with wind circulation. There is also seasonal variability: contrails form at lower altitudes in winter than in summer and have a greater radiative impact, with winter flights contributing a fifth of traffic, but half the annual radiative forcing (Williams et al, 2007).

Cirrus cloud enhancement could add almost twice the CO<sub>2</sub> effect of the regular CO<sub>2</sub> emissions of a flight (Gilbert & Perl, 2008). The mixture of exhaust species discharged from an aircraft perturbs radiative forcing, which are two to three times more than if the exhaust were CO<sub>2</sub> alone. Also, the impact of burning fossil fuels at altitude is approximately double that of burning the same fuels at ground level (Lee et al, 2004).

Interestingly, shipping emissions may also counteract global warming: burning high sulphur bunker fuels used for maritime shipping produces CO<sub>2</sub>, but gives rise to low-level clouds that reflect the sun's radiation. According to one source, the warming effect can be more than offset by the clouds' cooling effect, although another suggests a partial, but not complete, off-setting effect (Gilbert & Perl, 2008).

### **3 EVALUATION OF THE ENVIRONMENTAL IMPACTS OF FREIGHT TRANSPORT**

Many environmental impacts are extremely difficult to quantify. This is either due to a lack of relevant data, complexity and interactions between various impacts. A lot of uncertainty still exists with regards to the environmental impacts of certain emissions (see section 2.3). It was, therefore, decided to limit the analysis for this study to those impacts that have proven methodologies for calculation and for which data is available. These impacts include the consumption of non-renewable natural resources, the impact of transport on

land uptake, material flow analysis, emissions of air pollutants and emissions of greenhouse gases.

### 3.1 Consumption of non-renewable resources

The renewability indicator (Zhou et al, 2007) is a measure of the consumption of non-renewable natural resources. It relates to the way in which humans exploit their energy resources by taking into account the scarcity of different fossil fuels and the amount of fossil fuels consumed. Resources that are exploited at a higher rate than they are generated are considered to be non-renewable. Equation 1 represents the formula used to calculate the renewability indicator (Zhou et al, 2007). A high renewability indicator value indicates a highly unsustainable alternative.

$$RI = \sum_{i=1}^n \omega_i m_i (1 - RC_i)$$

**Equation 1**

RI = renewability indicator

$\omega_i$  = the scarcity factor of one kind of non-renewable resource (i).

$m_i$  = the consumption amount of one kind of non-renewable resource (i)

$RC_i$  = recycle ratio of non-renewable resource (i)

The formula to calculate  $\omega_i$  is represented in equation 2.

$$\omega_i = \frac{100}{RE_i}$$

**Equation 2**

$RE_i$  = the remaining amount of one kind of non-renewable resource (measured in years to become extinct)

Table 1 contains the scarcity ratios of global non-renewable fossil fuels as published by Zhou et al (2007).

**Table 1: Global outlook for non-renewable fossil fuels**

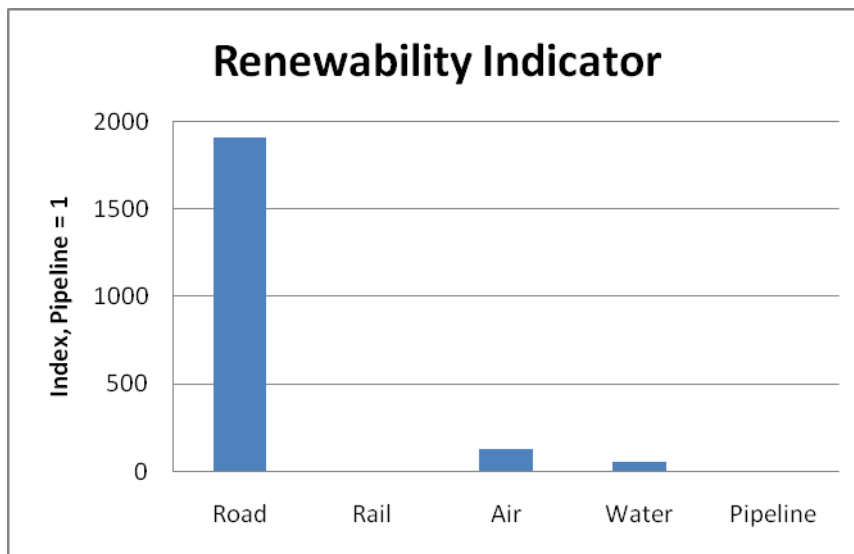
	<b>COAL</b>	<b>NATURAL GAS</b>	<b>CRUDE OIL</b>
Remaining years to being exhausted	250	50	40
Scarcity ratio of resources	0.4	2	2.5

Source: Zhou et al, 2007

The South African freight system is entirely dependent on two non-renewable fossil fuels as a source of primary energy. These fuels are coal and crude oil. Virtually all electricity generated in the country is generated by coal power stations. Additionally, coal is used to produce liquid fuels for transport.

Figure 1 illustrates the difference in the renewability indicator values for different modes of freight transport in South Africa. It is not surprising that the modes that are dependent on electricity (rail and pipeline) are considered more sustainable than the modes dependent

on liquid fuels. This can be expected for two reasons: firstly, the scarcity factor of oil is much higher than that of coal. Even if equal volumes of coal and oil were required, the indicator for transport reliant on oil would still be higher. Secondly, road transport is the dominant transport mode in South Africa and is completely dependent on liquid fuels.



**Figure 1: The renewability indicator values for different modes**

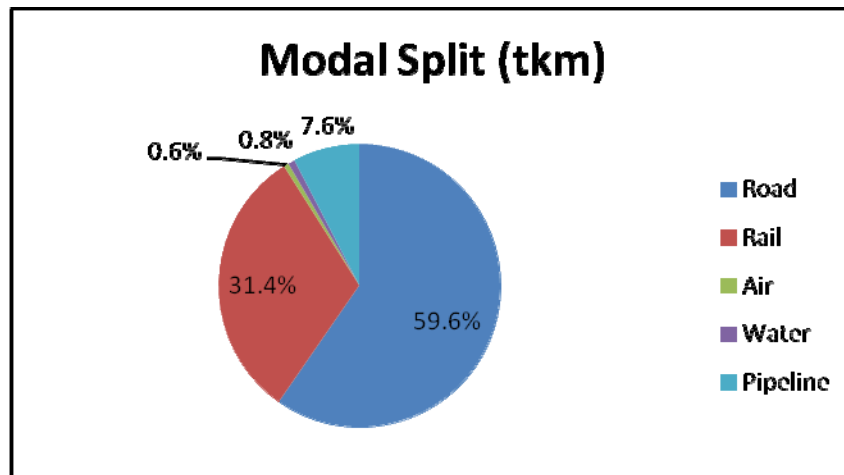
### 3.2 Uptake of land

Uptake of land can be determined by estimating the size of infrastructure required by each mode. For road transport this is estimated as the space taken up by roads. Similarly, the space consumed by rail tracks is used to estimate rail's uptake of land. Pipeline land uptake will be calculated in the same fashion. Buildings and facilities (such as terminal buildings, parking lots or harbours) are excluded from this analysis, which renders the land uptake of aviation and water transport zero.

The extent of the South African road network is 182 000 km, the rail network 25 000 km and the pipelines 3829 km (DOT, 2008). It is clear that road transport will have a much higher impact on land use than rail or pipelines. This is exacerbated by the fact that the average width of roads is also much higher than the average space required for rail tracks or pipelines. A rough calculation indicates that roads occupy about 380 times more land than pipelines and 19 times more than rail.

### 3.3 Material flow analysis

Material Flow Analysis (MFA) is a general indicator of a system's impact on the environment. It indicates the quantity of materials of all kinds (including fuels) moved in connection with the system during its whole life. The basic unit is material input per unit of service (MIPS). It is used to measure the flows of materials into the production and use of vehicles and their infrastructure (Gilbert & Perl, 2008; Federici et al, 2009). A Finnish study (Läteenoja et al, 2006) calculated the different MIPS for different transport modes in Finland. According to their findings, air freight transport has the highest MIPS value, followed by rail, then road and lastly water freight. Applying these factors to the South African freight sector, rail transport is found to have the largest material flow association. This is followed by road, air and water transport respectively. In the Federici study of material flows in Italian transport (Federici et al, 2009) air transport had the largest material flow demand. Due to the extremely low value of air freight tonne-kilometres (tkm) compared to other transport modes in South Africa (less than 1%) (depicted in Figure 2), air travel material flows are quite small when compared to other more prevalent modes.



**Figure 2: Modal split of tonne-kilometres in South Africa**

Source: Based on various validated data sources (SAPIA, NAAMSA et al)

### 3.4 Emissions affecting air quality

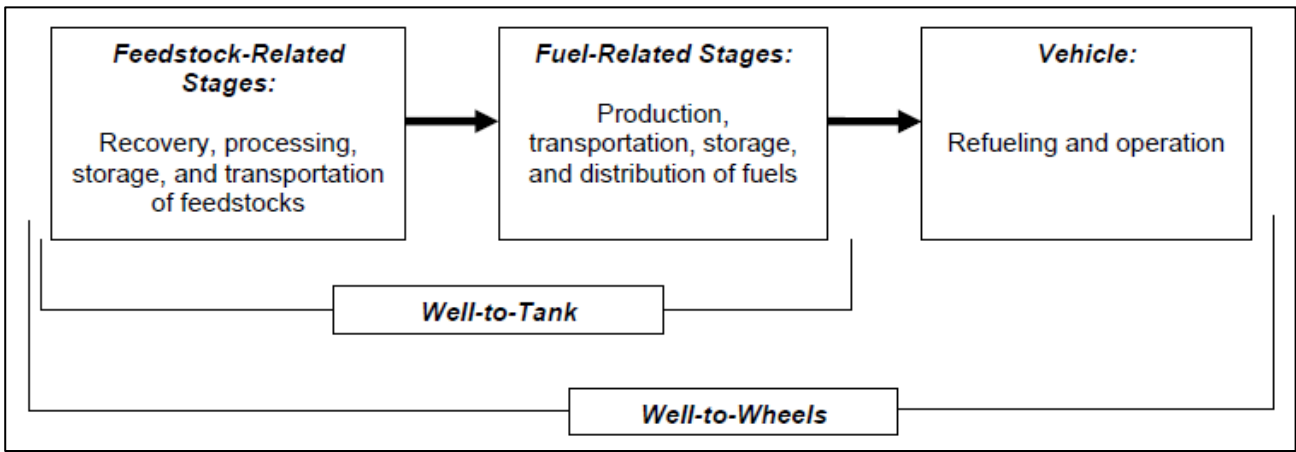
Emissions factors for SO<sub>x</sub>, NO<sub>x</sub>, particulates, CO and VOCs for each mode were obtained from OECD (1997). The unit of these factors is grams per tonne-kilometre. Even though there are discrepancies between the factors for different modes, the large distinctions between mode shares in South Africa is the deciding factor. The modes with the highest tonne-kilometres (see Figure 2) will always produce the most emissions and will thus affect air quality the most negatively.

### 3.5 Greenhouse gas emissions

The most suitable method to calculate overall greenhouse gas emissions of different transport modes is by applying the so-called Life-cycle Analysis (LCA). In the transportation field, the fuel-cycle analysis is also referred to as a Well-to-Wheels (WTW) analysis. However, unlike LCA, WTW analyses usually do not take into account the energy and emissions required to construct fuel production infrastructure or those required to produce the vehicles (Brinkman et al, 2005). A WTW analysis is often separated into two stages: well-to-tank (WTT) and tank-to-wheels (TTW) (Figure 1). WTT stages start with fuel feedstock recovery and end with fuels available in vehicle tanks. TTW stages cover vehicle operation activities.

Energy feedstocks for transportation fuel production in South Africa include crude oil, natural gas and coal for electricity generation and coal-to-liquids (CTL) fuel production. Transportation fuels for evaluation could include regular diesel, Fischer-Tropsch diesel and electricity.

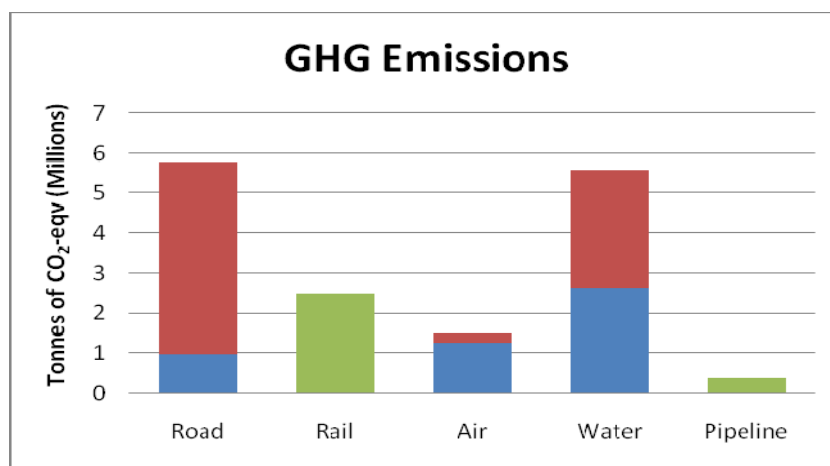




**Figure 3: Scope of a well-to-wheels analysis for fuel/vehicle systems**  
Source: Brinkman et al, 2005

For a total energy cycle analysis, additional data on the emissions produced whilst manufacturing the vehicle is required. The emissions generated from vehicle scrapping and disposing processes should also be taken into account in such an analysis.

Figure 4 shows the calculated GHG emissions per mode. For modes dependant on liquid fuels, the stacked columns indicate the two stages of a WTW analysis. The blue portion refers to the WTT analysis and the red to the TTW analysis outputs. Again, the small scale of air freight operations taints the picture somewhat. Rail and pipelines use electricity as primary energy source and, therefore, the GHG emissions were calculated based on Eskom’s published average GHG emissions level of 0.958 kg CO<sub>2</sub> eqt/kWh (Eskom, 2007).



**Figure 4: Greenhouse gas emissions from different modes**

### 3.6 Summary of emissions analysis

A summary of the environmental impacts arising from each mode of transport is provided in Table 3. From this, it is evident that road transport is has the highest negative environmental impact in all but one of the criteria. On average it is the most environmentally unfriendly mode of transport in the current freight system. It is, however, also the most widely used mode. Due to the disproportional market share between modes in South Africa, road transport has a higher negative environmental impact than other modes. This is despite the emissions factors indicating that road transport is not expected to be the main contributor to environmental damage over all the criteria. Pipeline and water

transport are overall the most environmentally friendly modes of freight transport. Perhaps most interesting is the fact that air freight is approximately middle of the road in terms of environmental impacts, despite the fact that it represents less than 1% of all freight transport.

These results found for South African freight transport are in line with an analysis of global freight environmental impacts and the relative contributions of different modes to different impacts performed by Gilbert & Perl (2008). This boosts confidence in the results of the evaluation.

**Table 2: Summary of environmental impacts per mode**

	Renewability Indicator	Uptake of land	Material flow analysis	Air quality impacts	GHG emissions
Road	1	1	2	1	1
Rail	4	2	1	3	3
Air	2	-	3	2	4
Water	3	-	4	5	2
Pipeline	5	3	-	4	5

1 = unsustainable; 5 = most sustainable

#### 4 CONCLUSIONS AND RECOMMENDATIONS

Freight transport is a major contributor to negative environmental impacts. Of the five modes of freight transportation, road is the least environmentally friendly – for four of the five impacts assessed, road scores the lowest. Pipeline is the most sustainable freight mode. Although not all kinds of goods can be transported by pipeline, a push towards this mode would improve the environmental sustainability of South African freight transport.

Material Input Per unit of Service (MIPS) is one of the assessment approaches recommended in the literature. Production and use of vehicles and their infrastructure are included in this approach (Gilbert & Perl, 2008; Federici et al, 2009; Läteenoja et al, 2006). It is recommended to establish appropriate South African MIPS values.

There is often a trade-off between various environmental impacts; an improvement in one impact might lead to a worsening of another. A holistic approach that assesses the overall environmental impact of various modes and mode shifts therefore needs to be adopted. The authors recognise that a holistic assessment of transport system impacts is broader than environmental impacts alone. Social and economic impacts need to be recognised as well. The work described in this paper is part of a broader study that includes social and economic impacts of the five freight transport modes. The impact of various energy management measures on social equity and economic spin-offs, are established. Future papers will report back on those findings.

## 5 REFERENCES

- Brinkman N, Wang M, Weber T and Darlington T, 2005. Well-to-wheels analysis of advanced fuel/vehicle systems – a North American study of energy use, greenhouse gas emissions, and criteria pollutant emissions, Argonne National Laboratories, USA
- Corbett JJ, 2004. Marine transportation and energy use, Encyclopedia of Energy, Vol. 3, pp. 745 – 758
- Department of Transport (DOT), 2008. NATMAP: Status Quo Report, Pretoria.
- Eskom, 2007. Annual report
- Esty DC, 1994. Greening the GATT: Trade, Environment and the Future. Institute for International Economics, Washington D.C.
- Federici M, Ugliati B and Basosi R, 2009. Air versus terrestrial transport modalities: an energy and environmental comparison, Energy, Vol. 34, pp. 1493 – 1503.
- Gilbert R and Perl A, 2008. Transport revolutions – Moving people and freight without oil, Earthscan, UK. ISBN: 9781844072484
- Läteenoja S, Lettenmeier M and Saari A, 2006. Transport MIPS, Report to the Ministry of Environment, Helsinki, Finland.
- Lee JJ, Lukachko SP and Waitz IA, 2004. Aircraft and energy use, Encyclopedia of Energy, Vol. 1, pp. 29 – 38
- OECD (Organisation for Economic Co-operation and Development), 1997. The environmental effects of freight. Online at [www.oecd.org](http://www.oecd.org)
- Pasco, 2008. Institutional Capacity for Database and Geographic Information System (GIS) in the Kingdom of Lesotho, Tokyo
- Smith, C. and RGareth (1998). Economic Development, 2nd edition. Basingstoke: Macmillan. ISBN 0333722280
- Tran:SIT, 2007. Energy, climate change and transport, Tran:SIT Update, Vol. 3
- United Nations (UN), 1998, Kyoto Protocol to the United Nations Framework Convention in Climate change, New York (US)
- WCED (World Commission for the Environment and Development), 1987. Our Common Future, Oxford University Press, London
- Williams V, Noland RB, Majumdar A, Toumi R, Ochieng W and Molloy J, 2007. Reducing environmental impacts of aviation with innovative air traffic management technologies, The aeronautical journal, Vol. 111, No. 1125, pp. 741 – 749
- Zhou Z, Jiang H and Qin L, 2007. Life cycle sustainability assessment of fuels, Fuel, Vol. 86, pp. 256 – 263