Futures food for thought

WWF SOUTH AFRICA

PRICING GREENHOUSE GAS AND AIR POLLUTION EXTERNALITIES IN SOUTH AFRICA

Key takeaways

1. The policy brief identifies and reviews greenhouse gas and air pollution externalities from coal based electricity production and fossil fuel based freight transport in South Africa. In addition, an economy wide carbon price required to achieve the 2^0C temperature target of the Paris Agreement is also identified from the literature. A number of methodologies available for estimating external costs are also discussed.

2. The aim of the policy brief is to provide policy makers and investors with a road map for estimating and including externalities in their decision making processes and to illustrate the significant size of fossil fuel externalities. Internalising the external costs into their decision making will enable policy makers and investors to make more environmentally sustainable decisions.

3. It is important to note that external cost estimations are extremely context specific, and dependent on a number of variables. **The reported figures should be used only as a guideline** to begin to encourage the wider use and reporting of externalities in policy and investment decision making.

Greenhouse gas and air pollution externalities in South Africa

Activity	Unit	External cost
Rail Freight	ZAR c/t.km	1.18*
Road Freight	ZAR/t.km	10.42
Coal-based electricity	ZAR c/kWh	48.39
Economy wide carbon price	ZAR/tCO_2e	505

*Inaccurate estimations since Swarts et al (2012) combines air pollution and GHG externalities into one estimation, which is problematic. No international estimations, however, are suitable for South Africa.

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INTRODUCTION

The world's dependence on fossil fuels generates a number of social and environmental impacts that place an external cost onto society. These include climate change, biodiversity loss, ecosystem degradation and air and water pollution, amongst others (Vivid Economics, 2016).

South Africa is no exception – approximately 90 to 95% of electricity is generated from non-renewable resources, such as coal, and almost 90% of long-distance freight transport is transported by road using liquid fuels (Thopil & Pouris, 2015; Havenga, 2015). Passenger transport is also heavily dependent on liquid fuels due to inefficient public transport systems (Havenga, 2015). This presents a skewed dependence on non-renewable fossil fuels and places a significant environmental externality onto South African society.

92.75% of electricity in South Africa is produced by 13 coal fired power stations (Eskom, 2011; Thopil & Pouris, 2015).

The policy brief identifies external costs resulting from coal-based electricity production and road and rail freight transport activities in South Africa, with a particular focus on greenhouse gas (GHG) and air pollution externalities. A number of methodologies available for estimating externalities are also summarised within the brief. In addition, an economy-wide carbon price, required to prevent average global temperatures from increasing by more than 2^0C above pre-industrial levels (referred to as the 2^0C target), is identified from the literature. In the absence of local estimates, the policy brief suggests estimates from the international literature that are suitable for the South African context.

The brief aims to provide policy makers and investors with a road map for estimating and including externalities in their decision making processes and to illustrate the significant size of GHG and air pollution externalities in South Africa. The reported figures should be used **only as a guideline** to begin to encourage the wider use and reporting of externalities in policy and investment decision making.

NEGATIVE EXTERNAL COSTS

External costs, or negative externalities, are negative side-effects imposed onto a third party (or broader society) by the production and/or consumption of goods or services. By definition, these are not accounted for (or internalised) by those producers or consumers and they are a cause of *market failure* in that the market price does not reflect the *true cost* of the good or service. The external costs of fossil fuels, for example, would include those associated with health impacts from air pollution and climate change, among others along the value chain (Vivid Economics, 2016).

In an effort to correct market failure, so that producers and consumers make these side-effects part of the decision making process, governments must encourage producers and consumers to internalise the *true cost* of a particular activity. This can be achieved through regulation or market based incentives, such as a carbon tax, for example.

Current prices for coal-based electricity reflect only the private (capital investment and operating) costs of generating electricity and is, therefore, under-priced and at risk of being over-produced. Estimating the value of external costs from coal-based electricity production is the first step towards correcting this market failure by providing the necessary price signal to encourage more sustainable production and consumption. Estimating the external cost must include all external impacts and damages attributed to generating electricity from coal, including coal mining; transporting coal; power plant construction and related infrastructure; coal combustion and disposal of waste products (Grausz, 2011; Vivid Economics, 2016).

Incorporating the external cost with the private cost of coal-based electricity will increase the price producers charge per kilowatt hour (kWh) of electricity, correcting the market failure and thereby encouraging a shift away from coal-based to lower-cost renewable energy technologies. Externality valuation is, therefore, necessary for correct pricing and more sustainable investment decision making (Havenga, 2015).

One approach for governments to incorporate the external cost of climate change is to establish a carbon price and impose it onto the economy as a whole, via a carbon tax, for example. This market-based approach attempts to encourage a shift towards a more carbon efficient economy by making carbon intensive goods and services relatively more expensive (Kaufam, et al., 2016).

ESTIMATING EXTERNAL COSTS

Different approaches for estimating external costs first consider the purpose of doing so, which could be to: (1) avoid or reduce the external cost (mitigation or abatement); (2) provide alternative benefits (offset); or (3) repair negative impacts (damages). The purpose of estimating the external cost would indicate the most relevant methodology or approach to use.

There are two broad approaches to estimating external costs:

1. **Bottom-up approaches** (that estimate a per unit cost) are considered to be more accurate but more labour-intense to calculate. However, these approaches are not always suitable due to their data requirements.
2. **Top-down approaches** use economy-wide data to calculate per-unit costs. This approach is considered to be more time-efficient, but with lower levels of certainty in the estimates.

In some instances there may be inadequate data for one or more of the external cost calculations. This data problem is often solved using a *value transfer approach* that adopts data from other study sites. It is important to bear in mind that this practice brings bias into the new estimate. For example, if the value is transferred from a healthier population, then it is possible that negative health impacts are under-estimated in the recipient study. In practice, and due to data and time limitations, externality studies often use combinations of bottom-up and top-down approaches, and they often include some value transfer.

Choosing the 'best estimate' is a challenge because estimating the external costs of a particular activity is very context-specific and depends on the ability of the researcher to quantify local scenarios and site specifications (Thopil, 2013). Characteristics that determine the intensity of impacts vary between sites. These include population density, air or water pollutant concentrations and volume, traffic density, and many other variables. For example, the higher the population density in the vicinity of a coal-fired power station or coal mine, the higher the rate of incidence of people affected by the associated air or water pollution, and the higher the externality cost per unit of electricity. The lower the population density, the lower the estimated external health impacts would be.

Due to the differences inherent in each site and context, there are no universal estimates of external costs arising from particular activities. Therefore, the figures reported in this paper **only provide an indication** of the value of selected externalities, which policy makers and investors could expect and use in initial project planning. More detailed analysis of site specific externalities would be required.

Estimating the monetary value of external costs

Estimating the monetary value of external costs can be challenging, especially for public goods, such as clean air, that are not sold in a market. Methodologies for calculating monetary values of externalities are divided into two broad categories:

1. **Non-market** valuation techniques, and
2. **Market-based** valuation techniques (Thopil, 2013).

Non-market valuation techniques

Non-market valuation techniques are used when there are no existing markets for socially valued goods, such as clean air, which has no market price. These techniques are generally prone to some uncertainty and ambiguity and include methods such as the contingent valuation method, hedonic pricing method and travel cost method, described in Table 1 (Thopil, 2013).

The contingent valuation method is commonly used to price effects on individuals. For example, an individual's *willingness-to-pay* to avoid noise annoyance, or willingness-to-pay for less traffic congestion created by an increased number trucks on the road. There is also an individual's *willingness-to-accept* time delays created by congestion. The willingness-to-pay concept is broadly accepted to be a best approach to the valuation of external health costs.

The hedonic pricing method is often used to price changes to environmental qualities by using a change in property prices. For example, the loss of a scenic view due to a newly built power station might reduce property values. This is an example of a compensation cost approach to estimate the loss by these property owners and, therefore, the external cost of the power station on property values. The travel cost method utilises individuals' travel expenditure to infer the value of a recreational activity that does not have a market price.

Table 1: Non-market valuation techniques

Contingent valuation method	Involves surveying people on how they interpret or value damages that occur to the environment and is based on either their *willingness-to-pay* for an improved situation or *willingness-to-accept* compensation for a worse situation. Referred to as a *stated preferences* method.
Hedonic pricing method	Values environmental goods and services based on market related services and property. Often used to value environmental amenities that affect property prices and, therefore, prices will reflect the value of a set of environmental characteristics.
Travel cost method	Generally used to evaluate recreational areas by calculating people's expenditure on traveling to and participating in the particular recreational activity in question. Referred to as a *revealed preferences* method.

Source: Thopil (2013)

Market based valuation methods

Market based valuation techniques make direct reference to costs already evident in a market and are, therefore, prone to less ambiguity. For example, environmental damage can be valued by the cost to repair damages from a particular event. Market based mechanisms are further divided into *abatement or control cost* methods, and *damage cost* methods (Thopil, 2013).

The abatement/control cost method

The abatement/control cost method estimates the cost to avoid or control a particular external cost. This approach assumes that the cost-effective external cost is the point at which marginal abatement costs are equal to marginal damage costs. It also assumes policy makers and environmental regulators have accurate information on the avoidance costs before an externality occurs (Mahapatra, et al., 2012; Thopil & Pouris, 2015).

Abatement/control costs are often used as a proxy value for damage costs because they are relatively straightforward to derive and can be applied to most environmental externalities or impacts. Dividing the cost of mandated environmental controls by the GHG emissions or pollution reduction achieved by said controls, the unit control costs can be calculated. Until more accurate damage cost methods are developed, this methodology is a reasonable starting point for rough estimates of environmental externalities, despite its limitations as a proxy value (Mahapatra, et al., 2012).

The damage cost method

The social cost of carbon is defined as "the present value of future damages associated with an incremental increase in carbon emissions in a particular year" (OECD, 2015, p. 12).

The *damage cost* method uses actual resource costs (and non-market estimates where appropriate) to estimate the value of external costs. For air pollution, the damage cost is broadly accepted to be the preferred methodology.

Damage cost methods are further divided into top-down, and bottom-up approaches. Top-down approaches rely on highly aggregated data, such as calculations that use national or global data to give an average estimate of the external cost in question. The "Social Cost of Carbon", which is a unit cost per tonne of carbon dioxide (and carbon dioxide equivalent for other GHGs), is an example of a top-down damage cost estimate (OECD, 2015).

A range of Integrated Assessment Models have been developed to assess the impacts and damage costs of climate change associated with increase carbon emissions. They combine information on the natural mechanisms that underpin climate change with economic impact estimates to produce monetary values for the social cost of carbon (OECD, 2015). The disadvantage is that these models do not account for the differences in technologies and resulting emissions, nor can they account for site specific effects/impacts of different GHG emission levels between countries, for example. (Mahapatra, et al., 2012). Thus the social cost of carbon is still contested globally and there is no universally agreed upon carbon price.

The bottom-up approach considers specific conditions within a particular context. For example, the specific conditions at a power plant site or the specific conditions of a particular category of freight vehicle. This method is more precise and gives potential for differentiation. It is considered to be the best practice approach for estimating air pollution externality costs.

Table 2: Market valuation techniques

The abatement/control cost method	Estimates the cost to avoid or control a particular activity that results in an external cost. It also assumes policy makers and environmental regulators have accurate information/values for the avoidance or damage cost before an externality occurs
The damage cost method	Utilises actual damage costs (and employs non-market estimates where appropriate) to estimate the value of external costs arising from a particular activity.

Sources: Thopil (2013); Mahapatra et al. (2012); Thopil and Pouris (2015)

The Impact Pathway Approach

The Impact Pathway Approach (IPA) is an example of a bottom-up approach where environmental costs and benefits are estimated by following the pathway from the externality source (via quality changes in air, water or soil, for example) to physical impacts. The IPA was initially developed within the External Cost of Energy or ExternE project series by the European Commission from the 1990's to the mid-2000's (ExternE, 2014). The project developed the ExternE methodology as a tool to investigate the cost and benefits of different policies and to compare different technologies. The significance of this tool is that it transforms impacts and costs into common units of measurement, which allows for comparison between policies and technologies (ExternE, 2014).

Text box 1: The basic principles of the ExternE methodology

1. The assessment or weighting of impacts is only possible using *quantitative* figures and procedures, because only quantitative algorithms ensure the necessary transparency and reproducibility of results.
2. The common unit into which impacts are transformed is a monetary unit. This has a number of advantages: units are conceivable, monetary values are transferable from one application to another and to compare costs with benefits, it is necessary to convert benefits into monetary units.
3. The assessment of impacts is based on the measured preferences of the affected population.
4. The interviewed persons (respondents) have to understand the change of benefit that occurs as a result of the impact to be assessed, to get meaningful results. This implies that it is important to value *damage*, not a pressure or effect.
5. The methodology should, therefore, be capable of calculating site and time dependent external costs.
6. Depending on the nature of the policy question, average or aggregated external costs can then be calculated.

Adapted from: ExternE (2014).

Figure 1 provides an illustration of the main steps to using the IPA methodology to cost the human health and ecosystem impacts of industrial emissions and pollutants. This approach compares the impacts and costs of two emissions scenarios; a reference scenario (where there is no change in technology or policy) and a case scenario (to calculate the change in impact or cost as a result of a new policy or technology). This is done by applying a concentration-response function to the difference in environmental quality between the case and reference scenarios in order to estimate the physical impacts on public health, crops or building material, for example (ExternE, 2014).

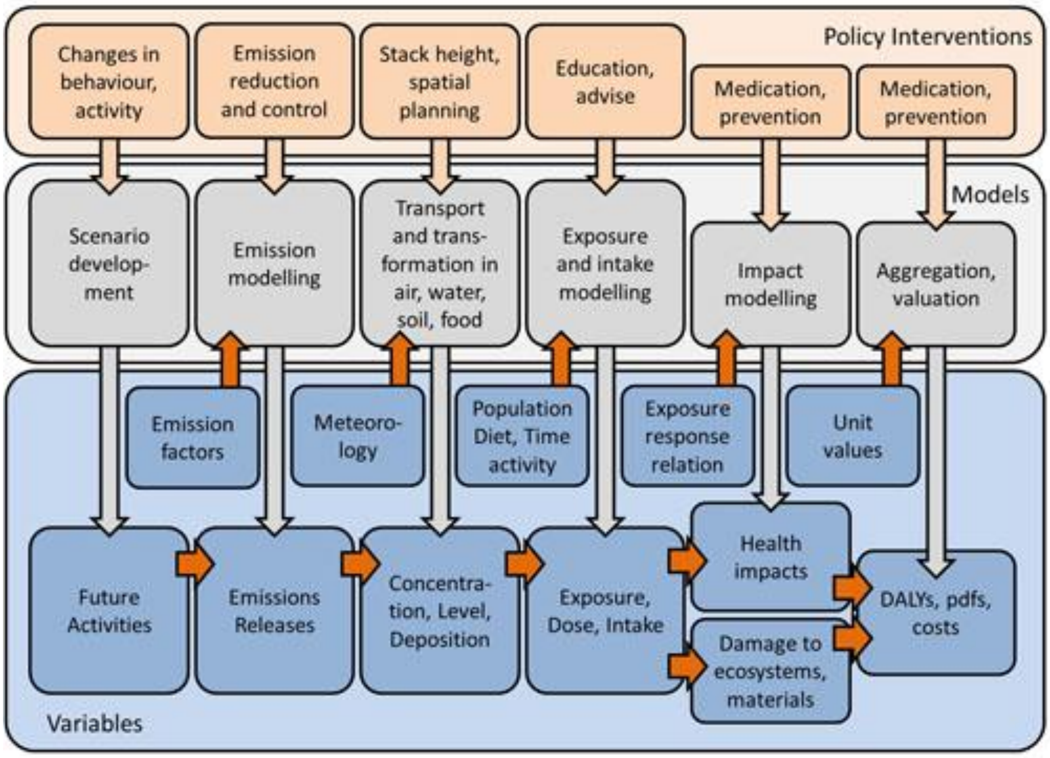

Figure 1: Impact Pathway Methodology

Source (ExternE, 2014)

It must be noted that because pollutants are transformed and transported hundreds of kilometres away, and impacts can occur at different scales, estimating impacts of pollutants requires local, regional, and hemispheric modelling (ExternE, 2014). The final step places a monetary value on the estimated physical impacts using appropriate market or non-market valuation techniques (ExternE, 2014). Table 3 describes the four principal steps that IPA follows.

Table 3: The principal steps of the IPA for air pollution impacts

Emission	Specification of the relevant technologies and pollutants emitted by a power plant at a specific site, for the whole life cycle, which is from construction to dismantling, including fuel extraction and transportation
Dispersion	Calculation of increased pollutant concentrations in all affected regions, using models of atmospheric dispersion
Impact	Calculation of the cumulated exposure from the increased concentration, and calculation of impacts (damage in physical units) from this exposure using an exposure-response function
Cost	Valuation of these impacts in monetary terms

Adapted from: ExternE (2014)

Estimating external costs per unit of activity

There are two fundamental steps in estimating the per unit cost of external costs:

i. Estimate the physical quantity/impact of an externality per unit of activity (for example: tonnes of air pollution/kWh of electricity);
ii. Value the cost of the physical quantity/impact (for example: health costs/tonne of air pollution)

Multiplying the two estimated values together will provide the external cost per unit of activity that generates the externality.

The value transfer approach

It is common for external cost studies in developing countries to face data limitations. This necessitates the transfer of values, damage functions or estimates of external costs from existing studies, or "study sites" to another context, or "policy site" (Johnston, et al., 2015).

The transfer of externality valuations between countries should take into account differences in typical values within different economies. The OECD recommends using the following formula to transfer externality valuations from one country or site to another, based on OECD (2012) in Vivid Economics (2016):

$$\textit{per unit damage valuation at study study site} \times \left(\frac{\textit{GDP per capita in South Africa}}{\textit{GDP per capita in study site country}}\right)^{\textit{income elasticity of the value of statistical life}}$$

This formula adjusts estimated damage costs in the study site country by the difference in GDP per capita, purchasing power parity (PPP) and the degree to which the willingness-to-pay to avoid damages changes as income changes (Vivid Economics, 2016). Preference should be given to valuations from studies and locations that have a high level of similarity in characteristics to the recipient study.

The benefits of this approach allow for data shortages to be overcome, and it is relatively cheaper, easier and quicker to conduct relative to a full analysis of external costs (Johnston, et al., 2015). There are, however, some disadvantages and limitations. The method can easily be misused, with the added risk of transfer errors and does not fully account for the differences in contexts between the two sites, thus leading to inaccurate valuations of external costs (Johnston, et al., 2015).

In practice, most studies make use of combinations of approaches and value transfer is a feature of most externality costing studies. For this reason, it is important to investigate the studies from which data is transferred to gain understanding of whether the values might yield under- or over-estimations in local studies.

GREENHOUSE GAS AND AIR POLLUTION EXTERNALITIES IN SOUTH AFRICA

The following presents selected estimates of freight transport and coal-based electricity production external costs for South Africa, particularly focusing on GHG and air pollution external costs. A range of carbon prices required to meet the 2^0C target are also presented. Preference was given to local externality estimates that reported external costs on a *per unit cost* basis. Where local estimates could not be verified or where there were methodological or data inadequacies, international estimates were considered.

A study by Havenga (2015), which employed the abatement cost method, estimated that total transport externalities add an additional 18% to total transport costs in South Africa.

The aim was to provide a road map for investors and policy makers on how best to use external cost estimations, identify the latest external cost estimations and to illustrate two important points:

i. External costs from South Africa's dependence on fossil fuels can be significant in relation to private costs.
ii. External costs can be larger than private costs - enough to make the energy option with the lowest initial private cost become the most expensive energy option, or have the highest social cost, after accounting for external costs.

However, estimating externalities is extremely context specific and, therefore, the reported figures should be **taken only as a guide** as to what current externality estimations are and how they change the ranking of energy options. Actual monetary values are not generic and require significantly more research before they can be used in other policy work.

Freight transport externalities

A number of studies have quantified and valuated externalities from transport and logistics operations in South Africa. However, the practice is still very much in its infancy (Havenga, 2015), and few studies provide per unit cost estimations for different external cost categories.

Two key pieces of local literature, Swarts et al. (2012) and Jorgensen (2009), estimated externalities resulting from accidents; emissions and congestion from road and rail freight activities in South Africa, amongst others. Table 4 summarises these external cost estimations, which were adjusted for inflation and reported in 2019 Rand cents per tonne kilometre (c/t.km) prices.

Table 4: Road and rail based freight externalities in South Africa

Externality	Road freight (ZAR c/t.km)		Rail freight (ZAR c/t.km)		References
	Low	High	Low	High	
Accidents	7.47[A]	11.21[B]	0.22[B]	0.59[A]	[A] *Estimates from Swarts et al. (2012)* [B] *Estimates from Jorgensen (2009)*
Emissions	7.06[A]	11.96[B]	1.18[A]	2.69[B]	
Congestion	2.91[A]	4.67[B]	0.00	0.00	

Note: Methodology notes and assumptions for reported figures are available in Table 12 of the Appendix.

Road freight externalities are significantly higher than those associated with rail freight, suggesting a switch to a rail dominated freight system will have significant social benefits, or at least avoid such high external costs. External costs from road accidents (11.21c/t.km) and emissions (11.96c/t.km) are the largest externalities associated with road freight (Table 4)

These local freight externality estimates are low by international standards. In general, valuations of morbidity and mortality tend to be relatively lower in South Africa due to factors such as lower on average levels of income, higher levels of unemployment and shorter lifer expectancy compared with the developed countries in the international literature (Hammitt & Robinson, 2011).

These local estimates provide a valuable starting point for local freight external cost estimates. However, taking into account the methodological and data limitations outlined in Table 14 in the Appendix, these figures can be strengthened. For example, one improvement would be to estimate externality costs of air pollutants and GHG emissions independently. The impacts of these external costs are experienced at different geographic locations and time-scales and policy approaches to address them would differ. GHG emissions might be offset, but for an exposed population air pollution should be avoided. Jorgensen's (2009) discussion paper provides an excellent basis for understanding the South African context; however the use of these estimates would require more information about its sources of data.

Therefore, to complement local estimates, freight externality costs were identified from international literature and reported in Table 5. This was done on the basis that sufficient information was provided to convert these estimates into local values, and to understand some of the bias introduced by using these values.

Table 5: International road and rail freight externalities applicable to South Africa

Externality	Road freight (ZAR c/t.km)		Rail freight (ZAR c/t.km)*		References
	Low	High	Low	High	
Accidents	1.49[C]	689.56[C]	0.30[C]	1.78[D]	[C] *Estimations from Korzhenevych et al.* (2014) [D] *Estimations from ECORYS* (2004)
Air pollution	4.48[C]	844.79[C]	1.19[C]	13.43[C]	
GHG emissions	3.31[D]	197.02[C]	3.88[C]	5.86[D]	
Congestion	28.77[D]	6029.93[C]	0[D]	2.99[C]	

**Note: International rail freight figures for climate change and human health externalities reported in Table 6 are unsuitable to transfer to the local context because no country shares South Africa's unique rail energy source profile of mostly coal-fuelled electricity and a small proportion of diesel (8.5%* (DoT, 2004). *Methodology notes and assumptions for reported figures are available in Table 13 of the Appendix.*

Despite the relative differences in estimated externality values between local and international studies, their fundemental message is the same: road freight transport in South Africa generates more external costs than rail freight. This should encourage investors, policy and decision makers to begin to shift road freight onto rail.

For example, a quick estimaton illustrates the significant savings that can be achieved by shifting freight transport from road onto rail: Assuming rail and road freight GHG emissions and air pollution external cost are 1.18 cents/t.km and R10.24/t.km respectively, and the distance between Johannesburg and Durban was roughly 600km. If all road freight was shifted onto rail, there would be a savings of R6 136.92/t transported between Johannesburg and Durban. This significant savings is avoided GHG and air pollution external costs from road freight between the two cities, and does not include external costs from accedents and congestion. Taking into account all external costs from raod freight tranport would increase the savings substantially.

Electricity externalities

The production of coal-based electricty generates significant externalities along its value chain, from mining to the combustion of coal through to the eventual disposal of coal waste products. While there are several studies that have estimated external costs from coal-based electricity in South Africa, few appear to report on the various catagories of external costs and/or report external costs on a *per unit* measurement basis, such as cost per kWh.

Nkambule and Blignaut (2017) estimated the *total value* of external costs from Kusile power plant to range between R1 449 billion to R3 279 billion, equivalent to R0.91/kWh and R2.05/kWh. Table 6 summarises the various external costs and stages of the coal fuel cycle from Kusile power plant.

However, these were not reported on a per kWh basis for each of the various external impacts and, therefore, not utilised within this policy brief.

Table 6: Estimated external costs of Kusile Power Plant over its 50 year life span

Externality	Units	Higher externality estimation
GHG emissions	ZAR billion	379.5
Human health (air pollution)		749.6
Water usage		2 142.6
Total*		3 279
Levelised externality cost of coal-based electricity	ZAR/MWh	2 051,6

**Note: The total externality value is inclusive of other external cost not reported in the table, such as water pollution, fatalities and ecosystem loss. Source: Nkambule and Blignaut (2017, p. 8).*

From a policy perspective it is important to include and evaluate externalities associated with various stages of the coal-fuel life cycle. For example, if a policy seeks to improve water use efficiency, or reduce the impacts on human health, reporting externalities for each life cycle stage will allow policy and decision makers to target problematic areas and achieve their goals. Nkambule and Blignaut (2017, p. 7), suggest that *coal mining* and *plant operations* consume the most water resources (36.6% and 30.7% respectively) and should therefore be targeted first for improving water use efficiency, for example.

Thopil and Pouris (2015) found *total* external costs of non-renewable electricity production to be between R0.09/kWh to R0.59/kWh. Table 7 provides a summary of external cost estimates for selected impact categories from non-renewable electricity production. Again, these values were not reported on a per kWh basis, for each external impact and thus omitted from this policy brief.

Table 7: Aggregated external cost estimates

Externality	Higher externality estimation (ZAR million)
GHG emissions	66 651.8
Human health (air pollution)	8 770.4
Water usage	819.75
Total*	76 260.93

**Note: The total externality value is inclusive of other external cost not reported in the table, such as occupational health and nuclear externalities related to public and occupational health. Source: Thopil and Pouris (2015, p. 505)*

Thopil (2013), however, provided external costs estimations for various external impacts from coal-based electricty on a per kWh basis, and was thus included in the policy brief (Table 8). Human health impacts from air pollution are estimated to be as much as 5.55c/kWh, while externalities from to GHG emissions are as much as 42.48c/kWh. Water consumption externalities were estimated at R3/m^3, the largest external cost from coal based electricity in South Africa.

Table 8: Electricty externalities in South Africa

Externality	Units	Coal based electricity external cost	Reference
GHG emissions	ZAR c/kWh	42.84	(Thopil, 2013)
Human health (air pollution)	ZAR c/kWh	5.55	
Water	R/m^3	3.00	

**Note: Methodology notes and assumptions for reported figures are available in Table 14 of the Appendix.*

Externalities and electricity prices

Estimating externalities becomes more meaningful to policy and decision makers in the context of existing market prices. To this end, Thopil and Pouris (2015) compared external costs of electricity with 2008 consumer electricity tariffs. The average external costs (estimated within a specific context) were added to average electricity tariffs (Table 9) to obtain an average internalised electricity price. This resulted in an average tariff increase of between 30% and 181% for 2008 electricity tariff prices. This is equivalent to a 2019 internalised electricity tariff of between R0.43/kWh and R0.92/kWh for coal-based electricity. Note that these externality estimations differ from those reported in Table 8 due to the specific context of the study by Thopil and Pouris (2015).

Table 9: Internalisation of total average costs to average overall tariffs

Estimate	Average external costs (c/kWh)	Internalised average tariff (c/kWh)	% increase on 2008 prices
Low	5.86	25.45	30
Central	13.43	33.02	69
High	35.36	54.59	181

Adapted from: Thopil (2015)

The price increases observed in Table 9 are, once again, only an indication of how accounting for external costs can increase the cost of electricity. Ideally, the external costs generated by coal-fired power plants still need to be effectively integrated into the price structure of electricity. Nkambule and Blignaut (2017) suggest a conservative account of external costs from coal-derived electricity doubles to quadruples the electricity price, consequently making renewable energy options more attractive alternatives.

The 2^{0}C carbon price

A number of studies have estimated the carbon price required to prevent average global temperatures from exceeding 1.5^{0}C and/or 2^{0}C targets. These are often based on very complex scenario analyses, with various assumptions that ultimately influence the carbon price. These assumptions might include projected energy demand, fuel prices, mitigation targets, available technologies, policy assumptions and socio-economic conditions (Fifita, et al., 2018).

There are also a number of studies that attempt to quantify the social cost of carbon, which is based on the damage costs associated with climate change and are not related to the 1.5^{0}C and 2^{0}C temperature targets. These estimates of the social cost of carbon are not included in the policy brief since they do not speak to a carbon price level required to achieve the 1.5^{0}C and/or 2^{0}C target (Fifita, et al., 2018). Table 10 summarises most recent estimates of global carbon prices required to achieve the two temperature targets in 2020 and 2030 (in 2019 prices).

Table 10: Global carbon prices required to achieve the 1.5^{0}C and 2^{0}C targets

Source	Target	2020 carbon price (R/tCO_2e)		2030 carbon price (R/tCO_2e)	
		low	high	low	high
IPCC 1.5^{0}C Report 2018	1.5^{0}C	R 826.74	R 33 681.89	R 1 395.54	R 56 855.48
High level commission on carbon prices 2017	2^{0}C	R 505.63	R 1 011.63	R 853.51	R 1 707.64
World Energy Outlook 2015	2^{0}C	R 238.15	na	R 1 190.74	na

Sources: IPCC 1.5℃ report 2018 (Fifita, et al., 2018); High level commission on carbon prices 2017 (CPLC, 2017); World Energy Outlook 2015 (IEA, 2015). Please see Table 15 in the appendix for assumptions and methods.

According to the IPCC 1.5^{0}C Special Report, global carbon prices (in 2020) required to achieve the 1.5^{0}C temperature target range between R826/tCO_2e and R33 681/tCO_2e (Fifita, et al., 2018). Such a wide range is indicative of the range of assumptions and influencing factors that impact carbon price estimations.

It is justifiable that South Africa should aim for a 2020 carbon price of R505/tCO_2e, as suggested by the High level commission on carbon prices 2017 report (CPLC, 2017). The reason for advocating such as price is that South Africa is a developing country and taking into account the "differentiated responsibilities and respective capabilities" of the Paris Agreement, need not commit to higher estimates of carbon prices. In addition, given the country's poor economic growth, coupled with the social ills of high unemployment, poverty, inequality, climate change policy should avoid imposing too great a shock on the economic via too high a carbon price. The carbon price, as reflected by the proposed carbon tax rate of R120/tCO_2e (RSA, 2017), however, is not nearly high enough to achieve the 2^{0}C target, let alone the 1.5^{0}C.

CONCLUSION

We continue to live in a carbon intensive world where the combustion of coal and liquid fuels places a number of external impacts on the environment and society. The cost of these externalities can be significant, with several studies suggesting they can double or quadruple the private cost of electricity, for example.

Therefore, to correct the market failure that results in the over production of carbon intensive goods an efficient price signal needs to be communicated to producers and consumers. Estimating the monetary value of the external cost of fossil fuels is the first step in developing this price signal. Estimating an economy wide carbon price is an alternative means by which climate change policy can encourage a shift towards a more carbon neutral economy.

When external costs are accounted for, the price of carbon intensive goods increases to reflect their true price or social cost. This inevitably makes renewable sources of energy more economically attractive, for example, and will encourage policy makers and private investors to begin investing in such technologies.

Estimating externalities is extremely context specific and, therefore, the reported figures presented in the policy breif should be **taken only as a guide** as to what current GHG and air pollution externality estimations are and how they change the ranking of energy options. Actual monetary values are not generic and require significantly more research before they can be used in other policy work.

WWF-SA recommends the following external costs for GHG and air pollution externalities from the combustion of fossil fuels in South Africa. These are likely to be severe underestimations of the *total* external cost from the listed externalities, since they do not include all associated external costs from the activities in question. **These figures are to be used only as a guide** to encourage the wider use and consideration of externalities in policy and decision making in government and the private sector. In doing so, more environmentally sustainable decisions and investments can be made.

GREENHOUSE GAS AND AIR POLLUTION EXTERNALITIES IN SOUTH AFRICA:

R10.24/t.km

the greenhouse gas and air pollution external costs for road freight transport in South Africa per tonne kilometre

1.18 cents/t.km

the greenhouse gas and air pollution external costs for rail freight transport in South Africa per tonne kilometre

R505/tCO2e

the 2020 South African carbon price required to achieve the 2ºC temperature target of the Paris Agreement

R6 136.92/t

the savings for every tonne of freight transported between Johannesburg and Durban on rail instead of road. This savings is equivalent to the avoided greenhouse gas and air pollution external costs from shifting freight transport off roads and onto rail.

48.39 cents/kWh

the greenhouse gas and air pollution external costs for coal based electricity in South Africa per kilowatt hour

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Table 11: Externality experts in South Africa

Name	Biography
Blignaut, James	**Professor in the Department of Economics, University of Pretoria:** James is an environmental and resource economist with seventeen years of experience. He is a part-time Professor in the Department of Economics, University of Pretoria, and director of Beatus, ASSET Research, and JAINSA. He specialises in the restoration of natural capital, renewable energy and economic development (ASSET Research, 2010).
Edkins, Max	**Acting Manager, Connect4Climate Program at World Bank Group:** Max's expertise include climate policy & finance; climate mitigation & adaptation; natural resource management; renewable energy systems and policy; energy modelling and environmental economics amongst others (LinkedIn, 2018).
Havenga, Jan	**Logistics Professor at Stellenbosch University – Supply Chain Management Centre:** Jan Havenga is a leading researcher in the field of macro-logistics. Macro-logistics researches the cost and structure of national logistics systems and suggests solutions in order to reduce the total cost of ownership of economies. These solutions could relate to policy, infrastructure or systemic changes (CSIR, 2018).
Jorgensen, Allen	**Transport Consultant:** Allen has authored and co-authored several books and papers. Research interests include railway and road transport energy use, environmental matters and overall costs; transport cost externalities; energy efficiency and use, and logistics and modal operating costs (LinkedIn, 2018).
Keen, Samantha	**Researcher in the Energy Research Centre (ERC) at the University of Cape Town:** Samantha's research interests include impact pathway analyses of climate and energy policy on public health, and on the costing of energy externalities, and the linking of models in this work (ERC, 2018).
Marquard, Andrew	**Senior researcher in the Energy Research Centre (ERC) at the University of Cape Town:** Andrew's current research focuses on energy-related climate change mitigation, as well as South African energy policy and governance, and draws on a wide range of skills, including energy analysis and modelling and policy analysis (ERC, 2018).
Nkambule, Nonophile	**Department of Economics, University of Pretoria:** Previous research includes "The external costs of coal-fired power generation: The case of Kusile Part 2"; "Externality costs of the coal-fuel cycle: the case of Kusile Power station" and "The external costs of coal mining: the case of colleries supplying Kusile power station" (UP, 2018).
Pouris, Anastassios	**Professor at Institute for Technological Innovation:** The ITI performs research on the management of technology and technological innovation, technology policy and related issues (UP, 2018).
Spalding-Fetcher, Randall	**Senior Advisor: Carbon & Energy at Carbon Limits:** Randall has more than 20 years' experience in energy and climate change analysis, following three and a half years of strategic management consulting experience. He has special expertise in GHG mitigation and project development, climate finance program development, and international rules on carbon markets (LinkedIn, 2018).
Swarts, Stefaan	**Analyst & Researcher at GAIN Group Pty Ltd:** Stefaan Swarts is able to translate the intricate complexities of real-life problems into detailed models. This ability to focus on detail without losing sight of the bigger picture has stood him in good stead while obtaining his Master's degree in Operations Research and has made him a valuable team member for the conceptualisation and development of new models (GAIN Group, 2018).
Thopil, George	**Senior Lecturer, Researcher and Consultant at University of Pretoria, Department of Engineering and Technology Management:** George's expertise lies in the areas of energy analysis, impact assessment and monetary and emission analysis. His work has enabled him to interact and liaise with personnel within industrial and governmental organisations such as Eskom, CSIR, Department of Energy, Department of Environmental Affairs, The Compensation Commissioner and few others; which has helped him gain an understanding of academia, industry and public sector (LinkedIn, 2018).

Table 12: Methodology, assumptions and critique of South African road and rail freight externality studies

Source	Methodology and assumptions	Critique
Swarts et al. (2012)	Swarts et al. (2012) made advances for freight externality estimations in South Africa and applied a logistics model approach. **Accident externalities:** The methodology was adapted from a study by CSIR Transportek (DoT, 2004) to reflect freight vehicle accidents only. Damage costs were used to estimate road accident externalities and included vehicle damages, insurance, towing, fatalities, legal and medical expenses etc. **Emissions externalities:** Due to lack of data, a top-down approach was used to estimate emissions externalities from road freight transport. The newly developed method used in this study was based on the offset cost of emissions from the European Union, (Van Essen, et al., 2008), converted through PPP-adjusted GDP per capita and empirical data sourced from the Freight Demand Model (FDM) for South Africa, as applied in the Logistics Cost Model (Havenga, 2010) used in tandem with vehicle data from the (RFA, 2011). **Congestion externalities:** A conservative approach was used to estimate congestion externalities from road freight transport and was based on national vehicle statistics. The methodology assumed that, on average, most people drive at the speed limit. The difference in average speed observed and the speed limit are therefore attributable, under the assumptions, to congestion.	**Accident externalities:** Accident externalities reported in Swarts et al. (2012) are low in comparison to those in international studies (Demir, et al., 2015). Reasons include that, on investigation of the source of the estimate (Transnet Annual Report 2010), the rail freight estimate appears to be the Transnet internalised cost of accidents. Description of this cost in Transnet sustainability reports explains that this loss does not include costing for most, if not all, public fatalities for which Transnet would have no liability, for example accidents in which victims ignore signals to clear a level crossing, trespass or are involved in criminal activity. Transnet costs also exclude losses by family or friends who give up school or work to care for disabled victims of accidents. The road freight estimate excludes amounts paid out or anticipated to be paid out by the Road Accident Fund, as is generally accepted practice. **Emissions externalities:** Swarts et al. (2012) combines the air pollutants and GHG emissions externalities as a single estimate. However, calculations for estimating climate and health externalities must be done independently for reasons that the type and scale (in time and space) are different. For this reason policy approaches to these problems will differ. For example, Swarts et al. (2012) uses an offset approach which is suitable for climate externalities but not for human health. Illness and fatality impacts of harmful pollutants in one area cannot be avoided by reducing emissions in other location, whereas climate impacts can. Swarts et al. (2012) calculations can be improved by accounting for carbon dioxide equivalence of freight nitrous oxide emissions. Rail freight emissions estimate would be improved by including diesel emissions. The International Energy Agency estimates that electricity accounts for approximately two thirds and oil products for around a third of rail energy consumption in South Africa (IEA & UIC, 2012).
Jorgensen (2009)	Jorgensen (2009) provides a discussion paper that explains the local context well and provides expert opinion on freight externalities. The reported externality costs from this study utilised externality estimates from both local and international research thought to be applicable to and reflective of the South African case. The study utilised a value transfer approach, where external add-on cost figures were used and assumed to reflect local conditions. The paper reported external costs for accidents, emissions and congestion for two sites in South Africa: (1) the forestry traffic in the Natal Midlands, and (2) the Johannesburg – Durban N3 corridor.	While Jorgensen provides a very useful basis for understanding the South African context and limitations in terms of South African studies, the paper is not peer-reviewed and the level of information on sources, methods and data do not provide a basis on which to assess the reported estimates.

Table 13: Methodology, assumptions and critique of international road and rail freight externality studies

Source	Methodology and assumptions	Critique
Korzhenevych (2014)	The best practice estimation of congestion costs is based on speed-flow relations, value of time and demand elasticities. For air pollution costs, the impact pathway (or damage cost) approach is broadly acknowledged as the preferred methodology. The valuation of the respective health effects is based on the willingness to pay concept. Marginal accident costs were estimated using the risk elasticity approach and values of statistical life. Given long-term reduction targets for GHG emissions, the abatement cost approach (in contrast to the damage cost approach used for other environmental impacts) is the best practice for estimating climate cost. The range in estimated externalities is due to the inclusion of different size trucks (between 7,5t and 32 tonnes) and roads (urban, suburban, rural, motorways). The study used EURO II fuel specification values for climate externality estimations and is considered to be an update and improvement on the 2008 Handbook on estimating externalities from transport (Maibach, et al., 2008).	It must be noted that international rail freight figures for climate change and human health externalities reported in Table 6 are unsuitable to transfer to the local South African context because no country shares South Africa's unique rail energy source profile of mostly coal-fuelled electricity and a smaller proportion of diesel (DoT, 2004).
ECORYS (2004)	Air pollution, global warming, , accidents and congestion externalities are quantified using *marginal l* costs estimates from former Director General for Energy and Transport (DG TREN) research (UNITE, RECORDIT, REALISE) and other sources. The 2013 Euro c/km estimates were modelled from DG TREN.	It must be noted that international rail freight figures for climate change and human health externalities reported in Table 6 are unsuitable to transfer to the local South African context because no country shares South Africa's unique rail energy source profile of mostly coal-fuelled electricity and a small proportion of diesel (8.5% (DoT 2004)), (IEA 2012). External impacts reported in ECORYS (2004) are not restricted to the period 2007-2013; the impacts are also valid beyond the year 2013. Therefore the calculated impacts represent the minimum value, the actual impacts are higher.

Table 14: Methodology and assumptions for electricity externality estimates reported in the policy brief

Source	**Methodology and assumptions**
Nkambule and Blignaut (2017)	Nkambule and Blignaut (2017) report various external costs from the coal-fuel cycle of Kusile power station over its 50 year life span. The Kusile power plant presents an interesting case in that it is unique among the rest of South Africa's coal-fired power stations. Kusile uses wet flue-gas desulphurisation (FGD) technology, which reduces sulphur emissions but increases water and coal demand, thereby increasing GHG emissions.
Thopil and Pouris (2015)	Thopil and Pouris (2015) provide relatively low cost estimates for mortality compared with morbidity and chronic bronchitis. This is due to a material error where they adopt a Value of Life Year (VOLY) estimate from an ExternE study and use it as a Value of Statistical Life (VSL).
Thopil (2013)	It must be noted that Thopil (2013) estimated external costs for each coal fired power station in South Africa individually. External costs from GHG emissions, human health impacts from air pollution and water consumption from Thopil (2013) were aggregated, adjusted for inflation and reported in 2019 Rand cents per kWh (c/kWh) prices in Table 9. Inflation adjustments made according to South Africa's Historical CPI inflation (Stats SA, 2018). The reported figures in Table 9 are not based on a Life Cycle Anaysis and only focus on the generation stage of electricty production. Thopil's (2013) analysis doesn't take into account nitrous oxides (NO_x), which are subject to regulation both as pollutants and GHGs. Only two of the 14 power stations reviewed in this analysis (Kendal and Matimba) are complient with National Minimum Emissions Standards for NO_x and thus the reported external costs can be regarded as **conservitive estimates**. For this reason, 'high estimates' of the external costs for GHG emissions, public health impacts and water usage reported in Thopil (2013, pages 109, 90 and 117 respectively) were selected for the policy paper. These 'high estimates' were aggregated, adjusted for inflation and reported in Table 9. **GHG emissions externality:** GHG externality estimations based on IPA and ExternE methodology, where values were converted to Rand using PPP exchange rate for 2008. **Human health externality:** Human health externality estimations (from air pollution) were based on damage cost estimates and dose response functions for different pollutants at each coal fired power plant. **Water usage externality:** The economic value of water for this study was chosen from King 2002 in (De Wit & Blignaut, 2004). A value of R3/m^3 was based on a WTP approach.

Table 15: Methodology and assumptions for global carbon price estimates required to achieve the 1.5⁰C and 2⁰C temperature targets

Source	Methodology and assumptions
IPCC 1.5⁰C Report 2018 (Fifita, et al., 2018, pp. 78-81)	The estimated carbon price within the IPCC 1.5⁰C Report 2018 is fundamentally different to the concepts of the social cost of carbon and a cost-benefit analysis of the carbon price. Under the cost-effective analysis modelling framework, used within the report, the carbon price reflects mitigation requirements at the margin. This provides a marginal cost of mitigation of one extra unit of emission to achieve a particular temperature target. The carbon price varies substantially between models and scenarios within the report and increases with mitigation effort. This wide range of carbon prices depends on a number of influential variables, including methodologies, mitigation targets, projected energy demands, fuels prices, technology and policy assumptions, and socio-economic conditions. It is necessary to note that while the price of carbon is important to encourage deep mitigation required for 1.5°C consistent pathways, complementary policies are also required.
High level commission on carbon prices 2017 (CPLC, 2017, p. 2; 22; 32)	The high level commission on carbon prices examined carbon prices that would be consistent with achieving the temperature objectives of the Paris Agreement. This included a review of multiple lines of evidence and scenarios on technology road maps, national development and mitigation pathways and global Integrated Assessment Models (IAMs). IAMs were used to produce future scenarios of technological and socio-economic development that were consistent with different global temperature goals, including both the 1.5°C and 2°C targets. Due to IAMs being global models, they do not have the same level of detail as national level exercises. IAMs are also limited in their ability to capture some important aspects of economies of scale, learning and technology change that are known to be of vital importance. However, these models can investigate the timing of mitigation actions and emissions reductions, as well as interactions between sectors and countries to provide global emissions scenarios and global cost estimates.
World Energy Outlook 2015 (IEA, 2015, pp. 32-33;35; 42)	This report used the World Energy Model as the principal tool for producing energy projections. This model is a large-scale simulation tool designed to replicate how energy markets function (a complete description of the WEM is available at *www.worldenergyoutlook.org/weomodel/*). The report uses a scenario analysis to provide long-term energy trend projections and corresponding carbon prices. There were three core scenarios in this report, which have different assumptions on energy-related policies and trends. These included the New Policies Scenario; the Current Policies Scenario and the 450 Scenario. One of particular interest is the 450 Scenario, which adopts a different approach by establishing a specified outcome of limiting the rise of global average temperatures to 2°C. Various assumptions are made to reflect the extent of policy interventions required to curb emissions and achieve the temperature target.

This paper is one in a set of 'Futures food for thought' papers from the 'Low-carbon development frameworks in South Africa' project. It makes the case that external costs from carbon-intensive activities and goods need to be factored into decision-making processes to account for their true price or social cost, manifest in climate change and local air pollution impacts. Costing the externalities makes sustainable options more economically attractive and will encourage public and private procurement and investment to invest in low-carbon technologies and initiatives.

The climate change mitigation debate in South Africa needs to move from improving efficiency within a projection of the existing economy, to innovation and options beyond the constraints of the current dispensation and structure of the economy. It may take step changes in the development path to achieve mitigation adequate to South Africa domestic and international commitments, and maximise economic development and social wellbeing. Business models presently unconsidered may be waiting in the wings.

The project seeks to deepen understanding of, and reveal opportunities for, transitions to a low-carbon economy. It facilitates and develops contributions at the intersection of climate change mitigation, economic development and socio-economic dimensions, across immediate, medium and long-term horizons.

Working variously with government, business and labour, the project reaches from providing input to emerging government mitigation policies and measures; through investigating the business and socio-economic case for selected mitigation initiatives which hold growth potential in energy, transport, industry, waste, and land use; to analysing potential future economic trajectories and the systemic opportunities offered by these.

The project is funded by the International Climate Initiative (IKI) of the Federal Ministry for the Environment (BMUB) of Germany, and implemented by WWF South Africa.

WWF South Africa's Policy and Futures Unit undertakes enquiry into the possibility of a new economy that advances a sustainable future. The unit convenes, investigates, demonstrates and articulates for policy-makers, industry and other players the importance of lateral and long term systemic thinking. The work of the unit is oriented towards solutions for the future of food, water, power and transport, against the backdrop of climate change, urbanisation and regional dynamics. The overarching aim is to promote and support a managed transition to a resilient future for South Africa's people and environment. The organisation also focuses on natural resources in the areas of marine, freshwater, land, species and agriculture. wwf.org.za

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To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

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