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Energy system externalities in South Africa

Report prepared for the Department of Energy and Shell

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Executive Summary

Energy system externalities are significant and could usefully influence policy priorities

There are significant market failures associated with the energy system, such that markets alone will not be able to deliver outcomes which maximise economic efficiency and welfare. Externalities associated with the energy system are one of the most significant of these market failures. An externality occurs when the full costs and benefits of a particular action are not factored into the decision to take that action. The costs and benefits that are not factored in are external to the decision-maker, and will be borne by someone else.

Policies can make decision-makers bear the full costs and benefits of their actions: this 'internalises' the relevant externalities. When this occurs, decision-makers will take a level of action such that the costs and benefits of the action are equal. This is in contrast to a situation where the decision-maker only bears some of the costs and benefits. Then they will take a level of action that is higher, if they do not face the full costs, or lower, if they do not face the full benefits, than would be the case if they faced the full, also known as the social, costs and benefits. However, when policy forces externalities to be internalised, the private costs and benefits will be equal to the social costs and benefits. Then the level of action that is privately optimal for the decision-maker will also be socially optimal and the outcome will maximise economic efficiency and welfare.

There are a number of ways in which externalities can be internalised. The main types of policy instrument are direct regulation, standards, or an explicit price set by a tax or a trading scheme. In general, explicit pricing mechanisms are more economically efficient, although there are instances when regulation and standards may be appropriate, for example vehicle standards, building efficiency standards and consumer product standards. The focus of this report is on explicit prices for externalities.

The energy system generates positive and negative externalities. Negative energy system externalities include: climate change, air pollution and water pollution and over-use. Positive energy system externalities include: switching to electricity, innovation spill-overs and localisation.

This report provides a guide to the scale of energy system externalities in South Africa. In particular, the value of negative externalities from electricity generation, residential fuel use and road transport are estimated per unit and the results are analysed.

There are four main conclusions:
– *energy system externalities can be significant*: for example the current externality costs of electricity from coal are estimated to be as great as the private costs of coal;
– *externalities can change the cost ordering of energy technology choices*: for example electricity from coal has one of the lowest private costs, but a combination of falling private costs for renewables and the cost of externalities from coal means that, by 2020, electricity from coal will be among the options with highest social cost;

– *regulation to manage externalities can have large benefits*: for example the external costs of road transport have decreased rapidly as modern standards have been implemented;
– *climate change is the most significant energy system externality in South Africa*: reducing Greenhouse Gas (GHG) emissions would also have the co-benefit of reducing air pollution, which is also a major energy system externality.

The main conclusions for electricity generation are:
– coal in particular has low private costs but high external costs;
– the main externality from electricity generation in South Africa is climate change;
– the proposed carbon tax will be lower than central estimates of the damage from GHG emissions;
– air pollution is also a significant externality for coal;
– water pollution and overuse from the electricity sector is an issue, especially as coal and gas resources tend to be in highly water stressed areas, but there may be more significant issues facing the water sector.

The main conclusions for residential fuel use are:
– electricity has the lowest social cost of residential fuels, so switching households to electricity has the positive externality of reducing costs, particularly health costs;
– poor households are most affected by the external costs of residential fuel use as they tend to use the most harmful fuels: paraffin and wood;
– paraffin is a particularly costly fuel, both in terms of its private cost per unit of energy and in terms of its external costs.

The main conclusions for road transport are:
– external costs of road transport decrease rapidly as modern standards are implemented, for example Clean Fuels 1, implemented in 2008, reduced the external costs per km of passenger cars by ~20 and ~75 per cent relative to 1988 for petrol and diesel respectively;
– fuel desulphurisation is responsible for the greatest reduction in external costs;
– once Clean Fuels 2 is implemented in 2017, which will reduce the external costs of passenger cars per km by ~60 and ~55 per cent relative to Clean Fuels 1 for petrol and diesel respectively, the main externality from new vehicles will be climate change.

International experience of carbon pricing is also considered. This provides a highly relevant example of ways to manage an energy system externality. Five key features of effective carbon price policies are identified from the experience of other countries:
– an explicit price should be put in place, even if the price is low this can be better than implicit prices or no price at all;
– the price should apply uniformly to as many sources of emissions as possible;
– price stability is desirable and emissions trading schemes will need a mechanism to achieve this;
– pricing policies must be credible over the long term; and
– fair levels of protection may be warranted for energy intensive, trade exposed (EITE) sectors to prevent carbon leakage.

1 Introduction

Failure to address externalities can make people worse off

This introductory section presents an overview of externalities in the energy sector and the policies available to address them. It has three parts:
– first, the concepts of market failure, public goods and externalities are defined;
– second, the policy implications of externalities are considered and the types of policy tools available are presented; and
– third, the specific issue of externalities in the energy system are examined: the energy sector has a large number of externalities, which can make an important difference to appropriate government policy.

1.1 The definition of market failure, public goods and externalities

A 'market failure' occurs when a market delivers an outcome that is inefficient, that is to say at least one person can be made better off without making others worse off. For instance, if sellers know more about a product than buyers, known as ‚information asymmetry‟, buyers may fear getting a bad deal and refrain from purchasing products that are actually high quality. The gains from trade between buyers and sellers are not realised and the result is inefficient. Product standards and warranties can help reduce inefficiency in markets with asymmetric information. As another example, if large companies have the power to dictate market prices, known as imperfect competition, they may limit supply to push up prices. The outcome is that some consumers willing to buy at a price above the seller‟s costs are unable to do so. An efficient market arrangement would be one that enables all such trades, where willingness to pay exceeds costs, to occur. Competition regulations and the authorities that enforce them in countries all around the world are designed to prevent this sort of market failure.

One important example of market failure involves 'public goods', such as fresh air, defence or street lighting. Such goods are unlike private goods because people cannot be excluded from enjoying them: they are ‚non-excludable‟, and the consumption of one person does not stop others from also consuming them: they are ‚non-rival‟. Private goods have neither characteristic. Markets often fail to provide sufficient public goods. This is because individuals have an incentive to free-ride on others who might provide some of the public good. Due to the under provision of public goods by the free market, governments normally have to step in to ensure appropriate provision.

Public goods involve *external* costs and benefits to individual decision-makers. This means that individual decision-makers do not experience all of the social costs and benefits of their actions. For example, knowledge is a public good because it is both non-rival and, at least partially, non-excludable. Researchers who generate and share knowledge create value for themselves, but also for others who can then use that knowledge – this is because knowledge is non-rival. Researchers do not capture the value accruing to others, so are not rewarded fully for the social value of their efforts – this is because knowledge is non-excludable. Hence less research is undertaken than would be ideal from society‟s point of view. If researchers were paid for the broader social benefits, for example through government funding of research or

through the award of patent protection on their ideas, they would conduct more research and society as a whole would be better off. Fresh air provides another example of a public good, and cigarette smoking that fouls the air involves external costs. A cigarette smoker experiences benefits and costs from smoking, but people nearby only experience costs. So the social cost of smoking is higher than the private cost to the smoker. As a result there is more smoking than society, overall, would like.

Externalities can be positive or negative:
– *positive externality*: in this case, one person's action produces a benefit for a different person; for example innovation can 'spill-over' from research and development (R&D) activities, which is to say that one person's idea benefits another person by enabling them to develop a further idea.
– *negative externality*: in this case, one person's action produces a cost for a different person; for example pollution from a factory can be harmful to the health of people living nearby;

Governments can regulate markets to correct for market failures, and to internalise externalities. When externalities are present, governments can steer markets to an efficient outcome by ensuring that firms and individuals pay the social costs, and receive the social benefits, of their actions. Once costs and benefits of individual actions are equal to the costs and benefits to society at large, the market can deliver an efficient outcome. Polices can be developed to achieve this, as explained in Section 1.2.

Externalities occur in the energy system and if the economy is to fully benefit from energy, these must be considered. The extraction, supply and demand of energy can generate significant externalities, both positive and negative. These are explained in more detail in Section 1.3 and the purpose of this report is to provide some guide as to the scale of energy system externalities in South Africa and draw some lessons from international experience of carbon pricing, a highly relevant example of policy to manage an energy system externality.

1.2 The policy implications of externalities

The presence of externalities provides a clear justification for policy intervention. Externalities make an economy inefficient but this can be corrected if there is some way to make the costs and benefits to a person of an action equal to each other, as explained in Section 1.1. Government can intervene in an economy with a policy that does just this. Furthermore, such policies can be justified on the basis that they make the economy more efficient – as long as the intervention is well-designed and does not itself distort the economy.

Externalities must be valued if the scale of policy intervention is to be appropriate. Consider the case of a factory that pollutes the local environment as a by-product of its production process. This pollution imposes a cost on local residents, for example through respiratory health problems. When the factory is free to pollute the price it must pay for this externality is zero and it will pollute a large amount. A price of zero is too low, as the local residents would benefit from the factory not polluting so much; if this were not the case then there would not be an externality. If the price of polluting was greater than zero this would increase the factory's cost of production, which would reduce production and so decrease pollution. However, an excessively high price, which meant that the factory had to close down, is likely to be too high as the economic damage from closing the factory down would outweigh the health damage from some production,

unless the factory's pollution was excessively damaging. There is therefore some price for the externality that balances the cost of the externality with the benefit of producing it.

Discovery of the appropriate price for an externality is complex, although though there are two important but simple pricing facts. As explored in Annex 1, there are a wide range of estimates and these estimates are often context-specific, which means their calculation requires detailed local information. That said, two important but simple facts about externality pricing are clear:

– *a price of zero is too low*: however, this is currently the most common price for externalities as many of them are unregulated;
– *a price that prevents any activity which produces an externality is likely to be too high*: this is unless the externality is very damaging, such as the externality from lead in petrol or asbestos in building materials.

There are three main types of policy intervention to manage externalities:

– *market-based mechanisms*: a market-based mechanism either directly imposes a price on an externality, as is the case with a carbon tax, or restricts the quantity of an externality that can be produced, with a price resulting when people trade for the right to produce the externality, as is the case with an emissions trading scheme. In both cases the value of an externality, positive or negative, is established as a price;
– *government spending*: the government can spend to reduce negative externalities or increase positive externalities on behalf of citizens, and then reclaim expenditure through the tax system. This is often a major reason why governments fund R&D, which produces a positive externality of knowledge spill-overs. The government will need to have an estimate of the externality price to judge whether the spending is at the right level.
– *regulation*: standards for the level of externality that can be produced can be set, for example the amount of sulphur dioxide that power plants produce per MWh is often regulated. Standards are best used when the administrative cost of a market-based mechanism would be too high, if regulated entities cause similar environmental damage and have similar abatement costs, if there are barriers preventing these entities from responding to price signals, or if there are economies of scale from collective action.

Externality pricing could be an important factor in South Africa's energy policy through the energy planning process. The Integrated Energy Plan (IEP) and the Integrated Resource Plan (IRP) are the main energy planning documents and these determine which types of energy should be invested in. Externalities are considered, but not priced, in current plans. This matters because the cost of energy is one of the criteria that influence the extent to which each type of energy will be supported. If external costs are not priced then types of energy may receive too much or too little support. Section 2 draws on the academic and policy literature to bring together estimates of the price of externalities in South Africa from different types of electricity generation, residential fuels and road transport.

Externality pricing can also have a major role in South Africa's energy policy through the proposed carbon tax. The carbon tax is likely to have a significant effect on the energy sector, as fuel combustion, fugitive emissions from fuel and transport were responsible for 82 per cent of South Africa's GHG emissions in 2000 (Treasury, 2013). The design and price level of the carbon tax will determine the degree to which the tax reduces GHG emissions without distorting the economy in other ways. Section 3 describes international experience of carbon pricing.

1.3 Energy sector externalities

The energy sector is a major source of externalities, both positive and negative. For instance, in Europe the energy sector is responsible for approximately two thirds of industrial GHG and air pollution externality costs (EEA, 2011). Figure 1 presents the major energy system externalities. Externalities can arise at the extraction, supply and demand stages of the energy system, and there can be both positive and negative externalities, as explained below.
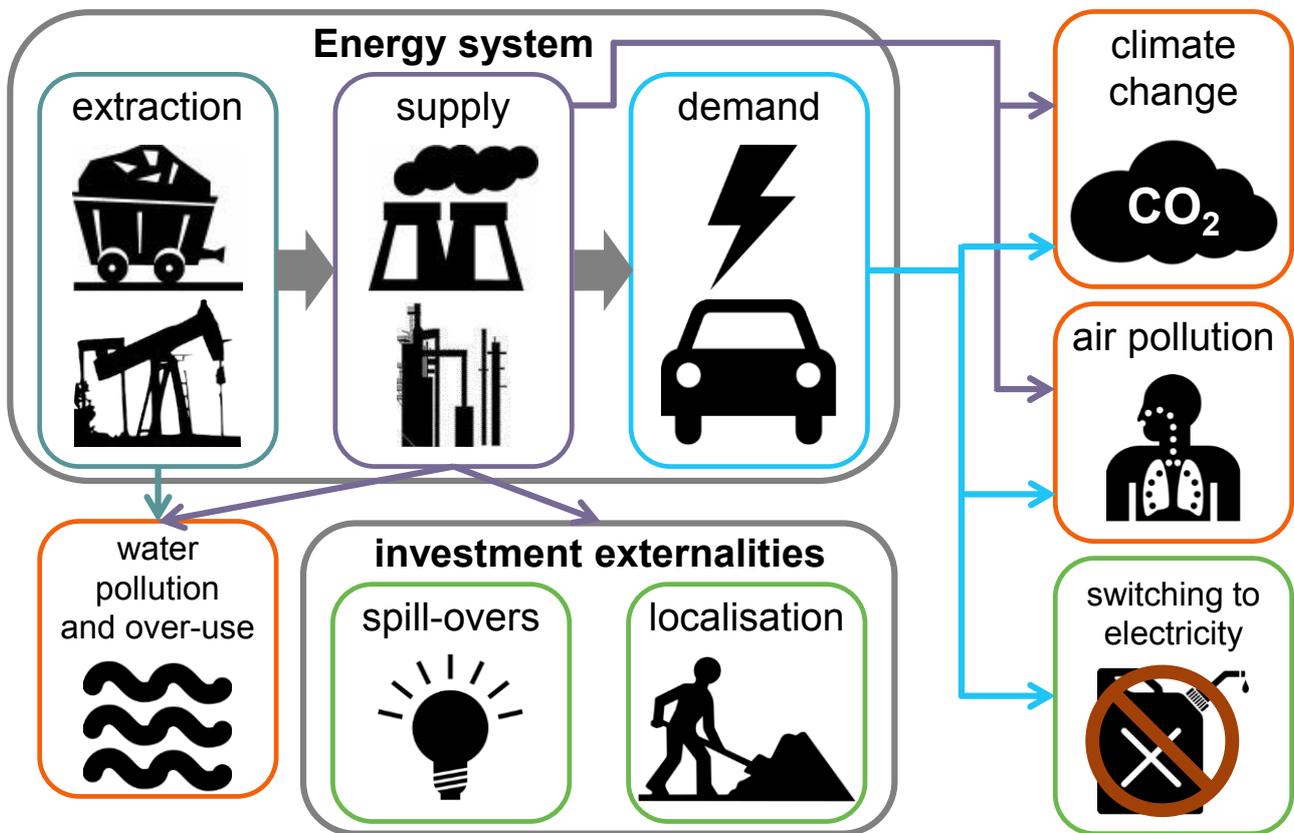
Negative energy system externalities:
– *climate change*: GHG emissions, which primarily come from the combustion of hydrocarbons, such as coal, gas, petrol and diesel, cause climate change. Climate change affects people across the globe and also in the future. It imposes costs on people as they adapt to the changing climate or if they suffer from increased extreme weather events, among other costs.
– *air pollution*: sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM) all cause respiratory problems and are among the most damaging air pollutants from energy (EEA, 2011); electricity generation, residential fuel use and road transport results in air pollution, primarily due to the combustion of hydrocarbons;
– *water pollution and over-use*: the energy system pollutes water if, for example, mine tailings leach into it. Water is also rarely, if ever, priced such that the costs and benefits of its use are equal, which results in an externality. The cost of water use is often less than the benefit and this leads to over-use. The energy sector uses water during extraction and supply.

Positive energy system externalities:
– *switching to electricity*: 8 per cent of households in South Africa use paraffin for cooking, which can cause fires and burns and results in some air pollution; 13 and 1 per cent of households use wood and coal respectively (StatSA, 2011). Use of these solid fuels causes air pollution and, as this pollution is often released indoors, the harm it can do is high relative to outdoor air pollution. If households can switch to electricity then these external costs of residential fuel use will decrease;
– *innovation spill-overs*: investment in the energy system may require dedicated R&D or provide learning-by-doing; both of these activities can provide an opportunity for innovation spill-overs, that is to say they will provide knowledge that others can build upon;
– *localisation*: investment in the energy system will require the employment and training of local labour; the benefits of this may be internalised through the wage that is paid, but other benefits from localisation, such as the greater likelihood of future work and support of the wider local economy could be external benefits.

Climate change and air pollution externalities are both produced from combustion of hydrocarbon fuels; so reducing one reduces the other. This inter-linkage means that a policy that targets one of the negative externalities has additional value as it will also control the other. This is known as a co-benefit and these should be considered when deciding upon the stringency of a policy, as co-benefits increase the value of policy action.

Figure 1. **Energy system externalities can be negative (orange) or positive (green)**

2 Energy system externalities in South Africa

The values of energy system externalities are approximated

There are two main steps to calculating the value of energy system externalities. These steps are:
– *estimate the physical quantity of an externality produced per unit of activity*, for example electricity from coal results in 0.936 tonnes of CO_{2e} per MWh of electricity;
– *value the cost or benefit of the physical quantity*, for example GHG emissions are estimated to result in $40 of damage per tonne of CO_{2e}.

These two values are then multiplied together to give the external cost or benefit per unit of activity, for example one MWh of electricity from coal has a negative climate change externality that is valued at 0.936 x 40 = $37.44 per MWh.

Estimates of the physical quantity of an externality per unit of activity are South Africa specific. Official sources, from the IRP, IEP and legislation, provide the majority of data on the physical quantity of an externality per unit of activity.

The value of the cost or benefit from an externality must be estimated indirectly. There is no market price for an externality, unless government has intervened to create a market, otherwise it would not be an externality. Therefore values must be estimated indirectly, for example by asking people how much they would be willing to pay to have an externality reduced. This estimation process is often a major undertaking and suffers from significant uncertainty. This report draws on the most reputable of such studies to provide a guide to the value of energy system externalities in South Africa, but there remains great scope for uncertainty and debate.

There has been limited estimation of the value of externalities in South Africa, requiring estimates to be transferred from other countries. Other than some studies on externalities from residential fuels (ERC, 2010; Spalding-Fecher, 2005) there is not much publicly available research that monetises the effects of energy system externalities in South Africa; although it is understood that some studies on the value of air pollution in South Africa have been undertaken but are not publicly available. Therefore valuations are transferred from the United Kingdom and adjusted for differences in income, as per guidance in (OECD, 2012), and for urban and rural population where appropriate. The external cost of GHG emissions, the damage from climate change, is a globally applicable number.

The results presented in this section should be taken only as a guide to how external costs change the ranking of energy options. The aim of this section is to illustrate two things: first, that externality costs can be significant relative to private costs, and, second, that these external costs can be large enough that the energy option with the lowest private cost is not necessarily the energy option with the lowest social cost, where the social cost is the private cost plus external costs. The magnitudes of estimated costs are robust to

comparisons with similar studies; however the actual monetary values presented here would require significantly more research before they could be used in other policy work. Indeed, results show that further research may be warranted, given that externality costs appear to be significant.

2.1 Electricity generation

Coal has low private costs but high external costs. As Figure 2 shows, the current value of externalities from Eskom‟s coal fleet in 2013 is equal to the private costs of coal generation; so the social cost of coal is currently double the private cost. In 2020, dry-cooling and Flue Gas Desulphurisation should reduce water and sulphur dioxide externalities of coal, but the social cost remains high. Indeed, if gas fuel costs are less than $17 per MMBtu in 2020, as assumed in the IRP 2010, perhaps at $11 per MMBtu, which is the estimated cost of gas from the Karoo (Wood Mackenzie, 2013), then coal will continue to have the lowest private cost but the highest social cost of electricity generation.

Figure 2. **Currently, coal has the lowest private cost but the highest social cost of electricity generation**
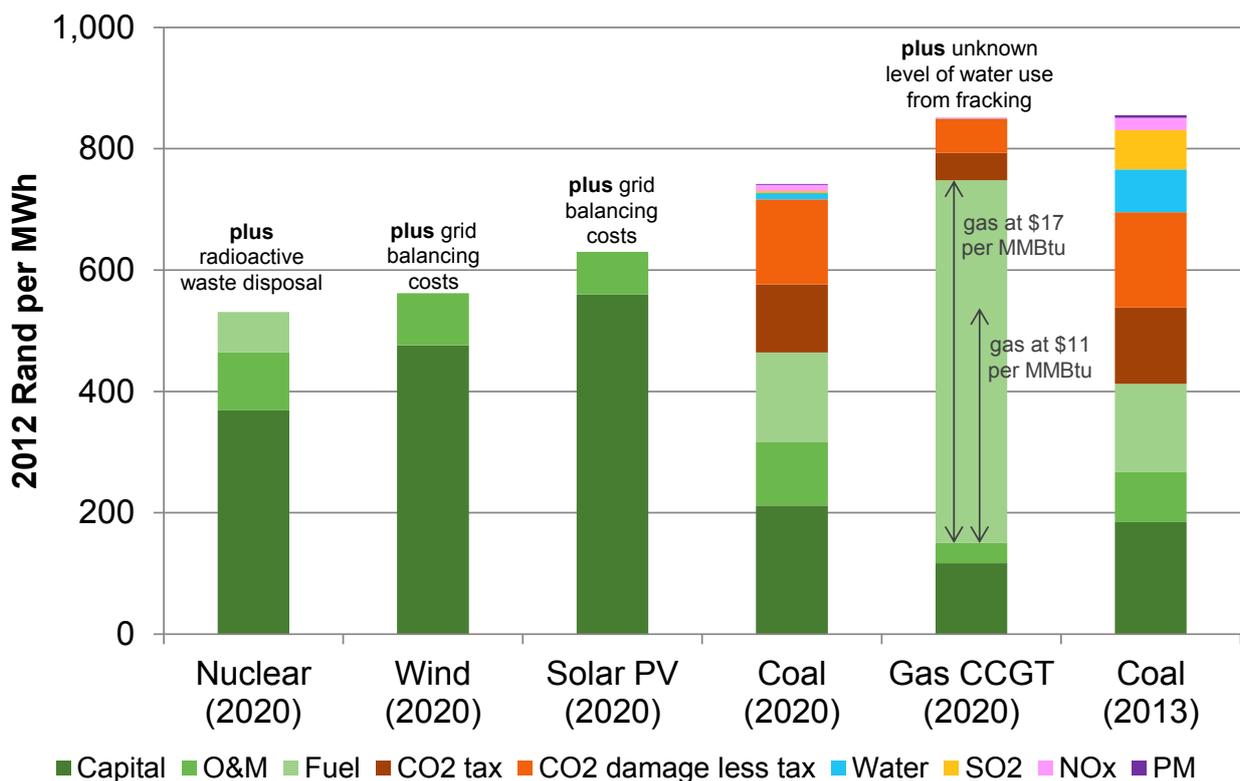
Source: *Vivid Economics based on DOE, IRP 2010 data for capital, O&M, fuel, water use and levels of CO_2, PM, SO_2 and NO_x pollution in 2020 (levelised cost of electricity estimates in 2020 are not provided in the IRP 2013 and pollutant levels are similar); coal (2013) data uses DOE IRP 2010 data for capital, O&M and fuel – reduced for lack of Flue Gas Desulphurisation according to (EPRI, 2010), but not reduced for lack of dry cooling as no update-to-date estimates could be found, and Eskom „Environmental implications of using or saving electricity‟ for water use and pollutant levels; value of water is 45 Rand per m³ to reflect desalinisation costs, CO_2 tax is 120 Rand per tonne, CO_2 damage is*

$40 per tonne (2012 USD) from US EPA (2013), PM, SO$_2$ and NO$_x$ damage from UK Defra (2013), adjusted for South Africa‴s income per person as per method in OECD (2012)

There are a number of other key findings. These are discussed in more detail in Annex 2:
– the main externality from electricity generation in South Africa is climate change;
– the proposed carbon tax will be lower than central estimates of the damage from GHG emissions;
– air pollution is also a significant externality for coal;
– water pollution and overuse from the electricity sector is an issue, but not the most significant issue facing the water sector.

The scale of the climate change externality from electricity in South Africa is large. As Figure 3 shows, South Africa‴s electricity generation is currently among the most carbon intensive in the world. This is because coal is used to produce 90 per cent of South Africa‴s electricity (DOE, 2011). Therefore serious treatment of externalities in South Africa could require a significant change in the electricity generation mix.

Figure 3. **Electricity in South Africa is particularly carbon intensive due to the almost exclusive use of coal**
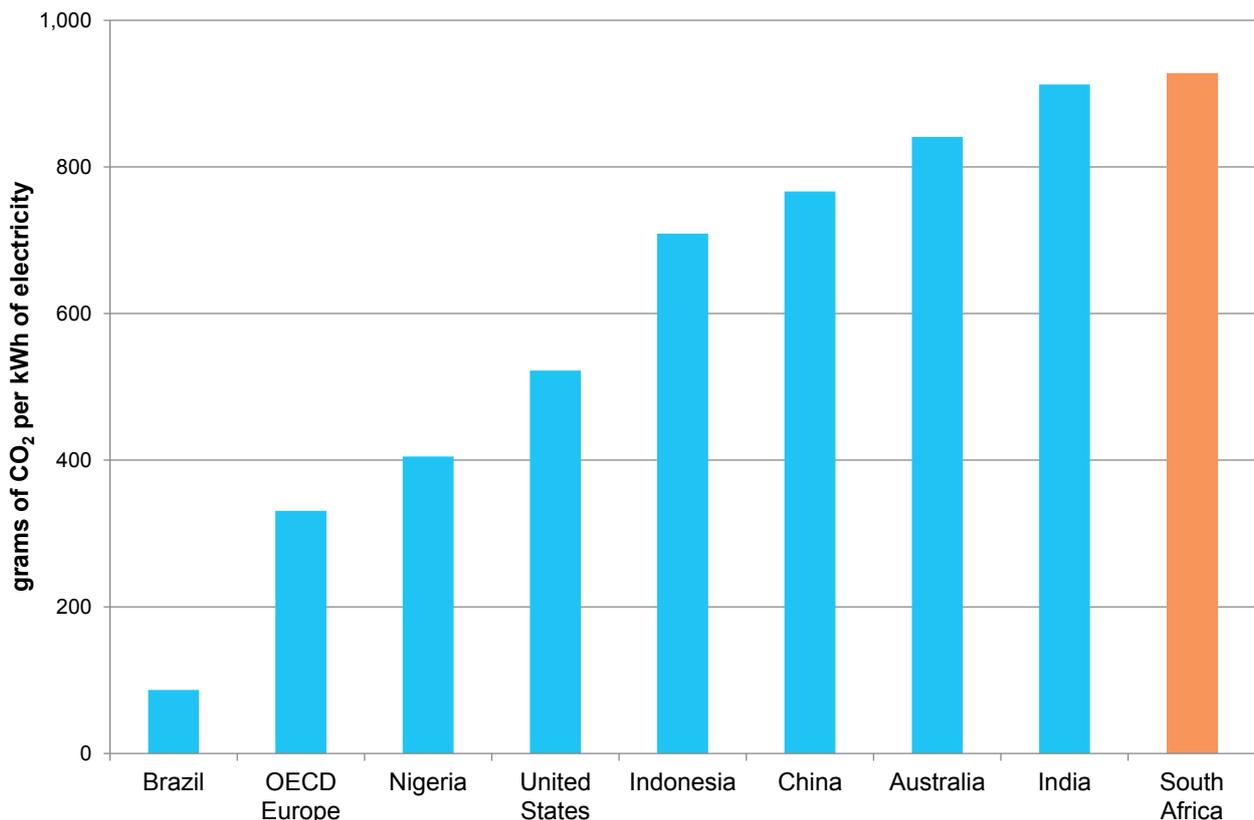
Source: *Vivid Economics based on EIA, International Energy Statistics*

Concerns over water use by coal are already been internalised through the use of dry cooling technology. While other sectors, such as agriculture and urban areas, put more stress on the water system in general than the electricity system does, both coal and gas resources are in highly water stressed areas. This increases the external cost of water. In recognition of this, all new coal power plants, including Medupi and Kusile, will be dry cooled. This is more expensive than wet cooling, although by how much is unclear. This is an example of government policy internalising an external cost – a higher price is being paid for electricity but less water is being used.

A number of electricity generation externalities are not estimated:
– *disposal of radioactive nuclear waste*: this can result in an externality if the costs of disposal are not reclaimed through the sale of electricity but are instead left to the tax-payer;
– *variable renewables, such as wind and solar, can impose both positive and negative „grid‟ externalities*:
  – the negative grid externality of variable renewables is the cost incurred to make sure that enough electricity is available to meet demand when the output of variable renewables is low;
  – the positive grid externality occurs when variable renewables can help supply peak demand because their output is correlated with periods of peak demand.
– *positive externalities from investment in electricity generation*: benefits of localisation are explored in a companion report and the benefits of switching to electricity are described in Section 2.2; innovation spill-overs are not estimated here as they require detailed scenarios of local R&D investment;
– *potential water overuse from fracking for gas*: extracting shale gas from the Karoo is likely to require significant amounts of water, however the amount of water required and the degree to which its use could impose an externality are currently unknown.

2.2 Residential fuel use

The majority of households use electricity, but a significant number, almost always poor, use wood and paraffin. As Figure 4 shows, the majority of South African households use electricity for cooking, heating and lighting. However, 21 and 24 per cent still use paraffin and wood for cooking and heating respectively. The poor are the main users of these fuels, with those living on less than 54 Rand per day making up about two thirds of non-electricity using households, even though they account for just 44 per cent of households.

Electricity has the lowest social cost of residential fuels, so switching households to electricity has the positive externality of reducing costs, particularly health costs. As Figure 5 shows, electricity has the lowest social cost of residential fuels per unit of energy; although work done, rather than energy, would be the ideal measure, as discussed below. The costs of electricity shown in Figure 5 are taken from Section 2.1.

Paraffin and wood, the other main residential fuels, have significant externalities. This is of particular concern as poor households are the main users of these fuels. The externalities, and their calculation, are discussed in more detail in Annex 2, but in brief:
– *paraffin use can lead to burns and poisoning*: burns are caused by fires from knocked-over stoves and poisoning results from ingestion of paraffin by children;
– *wood results in serious indoor air pollution*: wood is burnt indoors and this results in high exposure to pollutants; as a consequence the health effects are high and thus the value of the externality is high.

Furthermore, these health effects fall disproportionally on women as they are main cooks in low income households.

Figure 4. **The majority of households in South Africa use electricity, but 21 and 24 per cent still use paraffin and wood for cooking and heating respectively**
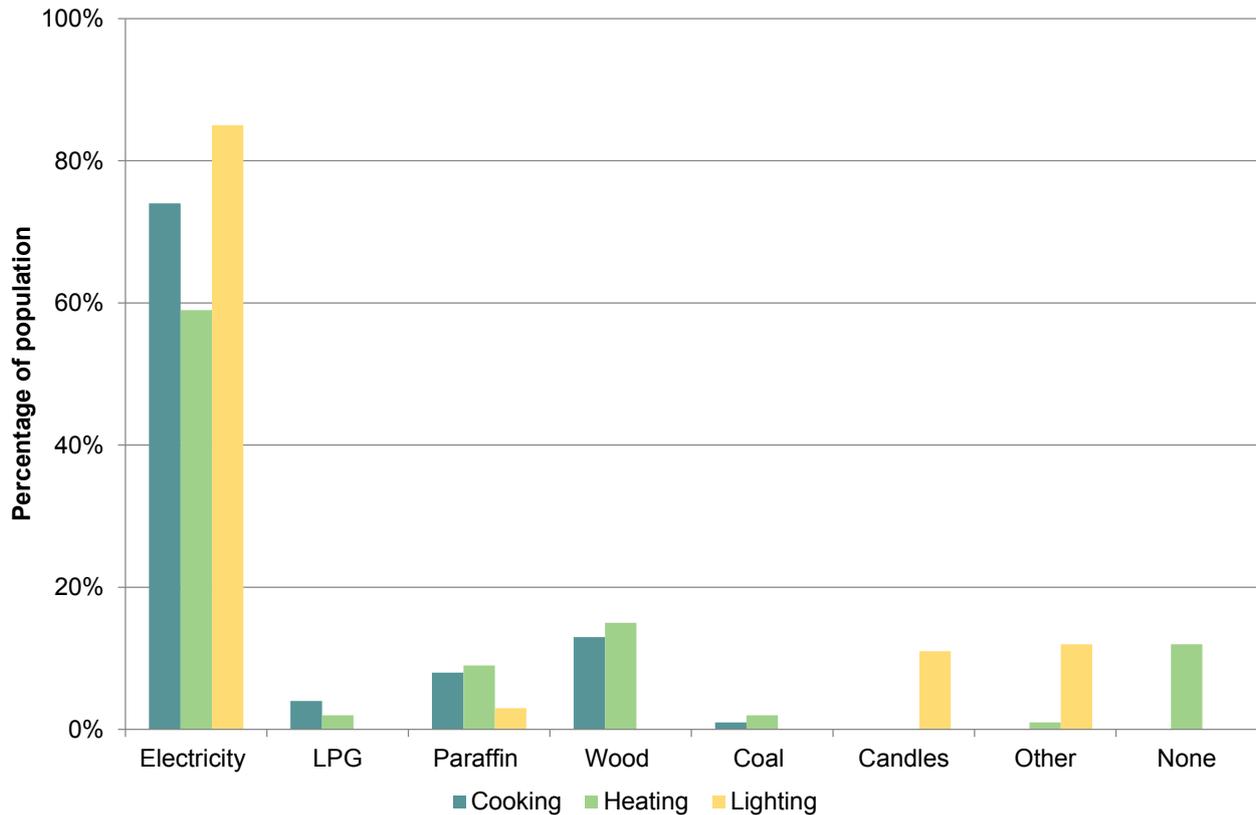
Research is required to estimate the costs on the basis of work done rather than energy. Results in Figure 5 are shown per gigajoule, which is a unit of energy rather than a unit of work done, such as boiling a litre of water. External costs in units of work done would give a better guide to the actual costs. For example, if boiling a litre of water with wood requires twice the energy as electricity then the external costs per unit of work would be twice as high. However, conversion of energy into work done depends on the conversion efficiency of the device, such as a cooker or a heater. This naturally varies by device and no consistent data could be found. Research could be conducted to test the efficiency of appliances. In the absence of such research, the estimates provided here still give a guide to the relative scale of externalities across different residential fuel types.

Figure 5. **Switching the 21 and 24 per cent of South Africans who use paraffin or wood for cooking and heating respectively could reduce local health problems from air pollution, poisoning and burns**
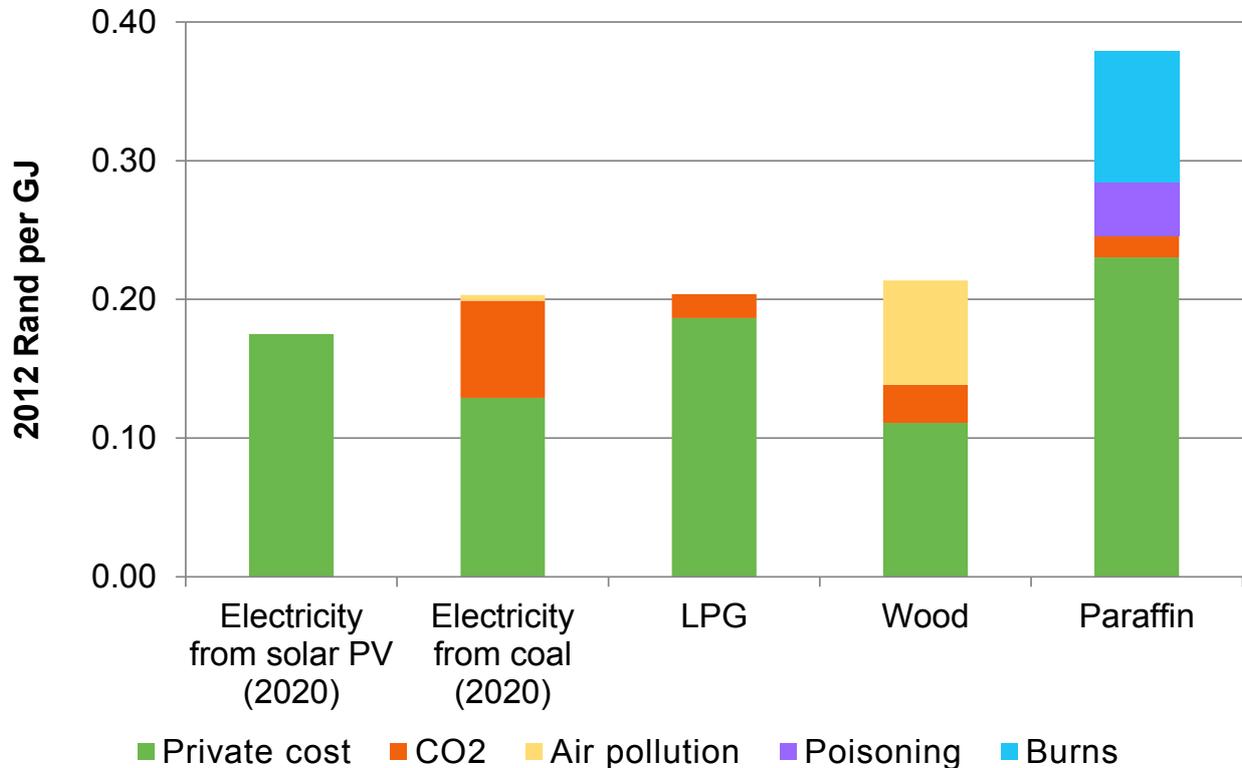
*Note:* The private cost of wood is the cost of collecting wood.

Source: Vivid Economics based on sources presented in Section 2.1 for electricity generation data, DMR (2013) for coal private cost, DOE (2011) for LPG and paraffin private cost, WHO (2006) and Department of Labour (2013) for wood private cost; CO_2 emission factors from WHO (2006), coal and wood air pollution costs and paraffin poisoning and burns costs from Spalding-Fecher (2005)

2.3 Road transport

External costs of road transport decrease rapidly as modern standards are implemented. As Figure 6 shows, the current standards, Clean Fuels 1, implemented in 2008, reduced the external costs per km of passenger cars by ~20 and ~75 per cent relative to 1988 for petrol and diesel respectively. Cleans Fuels 2, to be implemented in 2017, will further reduce external costs of passenger cars per km, by ~60 and ~55 per cent relative to Clean Fuels 1 for petrol and diesel respectively.

Fuel desulphurisation is responsible for the greatest reduction in external costs. In 1988, the sulphur content of diesel was 5,500 ppm and 1,000 ppm for petrol. In 2008 it was required to be 500 ppm for both diesel and petrol. In 2017 it will be required to be 10 ppm. These advances require investment by refiners, but as Figure 6 illustrates, they yield significant health benefits.

Figure 6. **Desulphurisation of fuel is responsible for the greatest reduction in external costs from road transport**
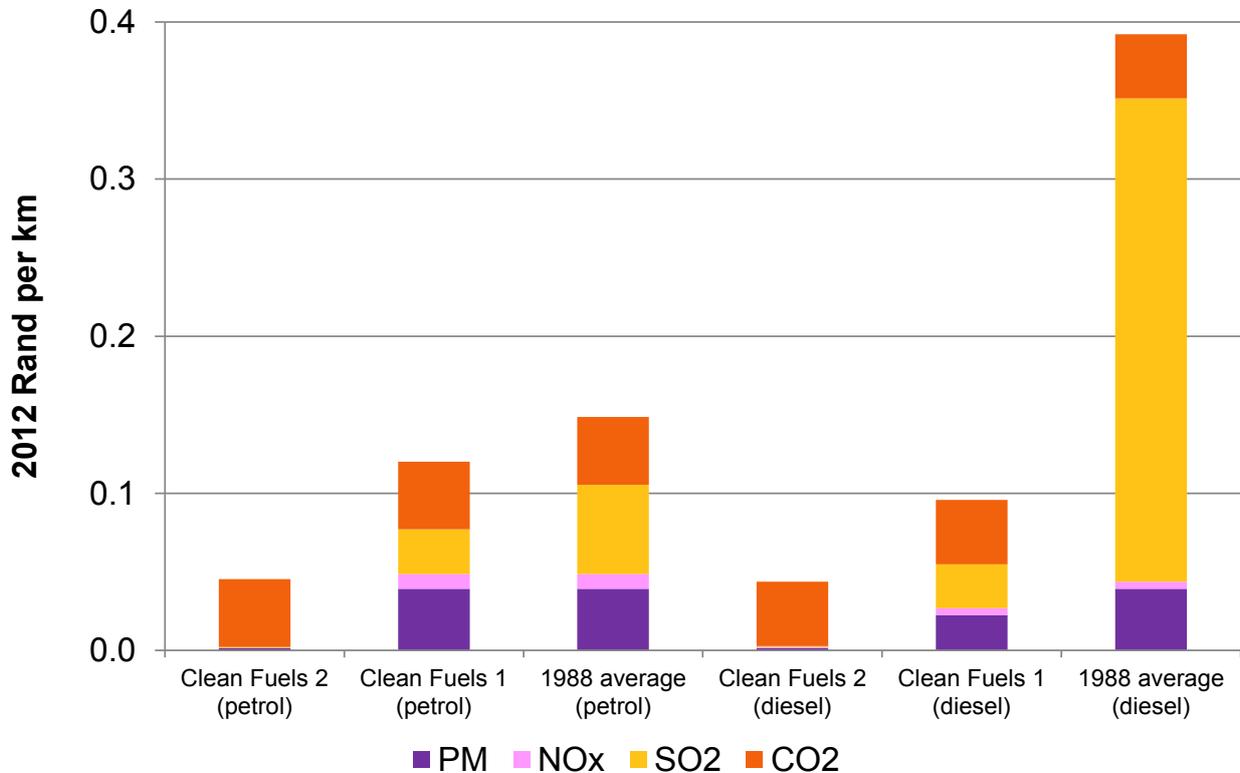
Note: The Clean Fuels 1 and 2 standards are equivalent to the Euro 2 and 5 standards respectively. Sulphur levels in diesel and petrol are 10 ppm and 500 ppm under Clean Fuels 1 and 2 respectively

Source: Vivid Economics based on DOE (2011), DOE (2013), European Commission (2007) and Delphi (2013) for emission factors; CO_2 damage is \$40 per tonne from US EPA (2013), PM, SO_2 and NO_x damage from UK Defra (2013 , adjusted for South Africa''s income per person as per method in OECD (2012), with PM damage weighted by percentage of population that is urban and rural

Once Clean Fuels 2 is implemented, the main externality from new vehicles will be climate change. The Clean Fuels 2 standard is equivalent to Euro 5 while Clean Fuels 1 is equivalent to Euro 2. Euro 5 is the current standard in force in the European Union, where only one more advance, Euro 6, is currently proposed. Therefore, by 2017, South Africa''s vehicle emission standards for new vehicles will be among the most stringent in the world, leaving only GHG emissions as a significant emission; although old vehicles will continue to pollute at old levels, except for lower sulphur emissions. GHG emissions per km from transport are hard to reduce. This can be achieved by increasing energy efficiency, blending in biofuels – although this can have externalities, or switching to electric vehicles, which would be ineffective while South Africa''s electricity generation is carbon-intensive. South Africa also has the option of halting production of liquid fuels via coal-to-liquid technology. This would reduce the lifecycle emissions of fuel in South Africa, of which combustion emissions, shown in Figure 6, are just a component, as coal-to-liquids is among the most carbon intensive methods to produce liquid fuels.

There are externalities from road transport, other than air pollution and climate change. These costs are unrelated to a vehicle˚s energy use and so are not considered here; these other external costs are:

- *congestion costs*: road users take up capacity on the road network and this slows down other road users, particularly at high capacity levels. There is a negative externality, the time lost due to congestion, which each road user imposes on each other road user. These costs are often low until certain capacity thresholds are reached, at which point a road becomes congested and the externality cost can be very high.
- *road infrastructure costs*: vehicles, in particular heavy vehicles, cause damage to roads. This damage must be repaired at a cost. While this cost can be reclaimed through road taxes or general taxes, it will not be equal to the damage that each road user causes.
- *noise costs*: exposure to road traffic noise can impose health costs and reduce the productivity of people local to the road.
- *accident costs*: each additional road user can increase the risk of an accident for every road user. There may be a degree to which this risk is internalised by road users, although there is no conclusive evidence. Therefore, while accident rates and costs are relatively easy to calculate, the value of the externality is harder to estimate.

3 International experience of carbon pricing

Five key features of effective carbon price policies can be identified from trial and error in other countries

There are a number of ways to control carbon emissions, either through direct regulation and standards, or via an explicit price. This section considers lessons from attempts around the world to regulate carbon emissions via an explicit price. As Figure 7 shows, a number of jurisdictions have put, or plan to put, an explicit price on carbon. There is a great deal of diversity among these schemes. The type of instrument used, such as emissions trading scheme or carbon tax, varies. Some jurisdictions, particularly in Europe, use both as regional and national policies overlap. As Table 1 shows, the price level of carbon taxes can vary significantly. There are also a number of other design features that can vary, such as linking schemes together.

Figure 7. **There are a number of carbon pricing policies currently implemented or under consideration**
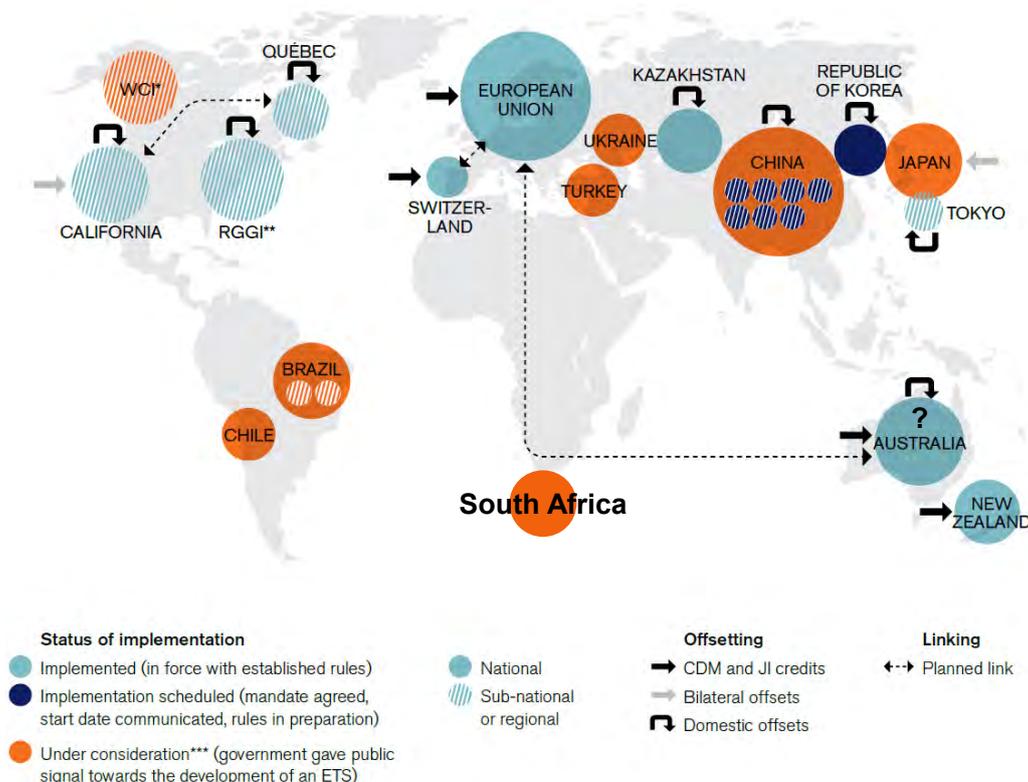
Note: *Map of schemes is not exhaustive*

Source: *(Kossoy, Oppermann, Reddy, Bosi, & Boukerche, 2013)*

Table 1. **Carbon taxes have been implemented across jurisdictions, sometimes complementing the EU ETS**

Country	Starting date	Rate	Comments
Australia	2012	US$ 24 per tCO_2 with a 2.5 per cent annual increase	Likely to be repealed by newly elected Prime Minister
British Columbia	2008	US$ 29 per tCO_2 from 2012	Positive review in 2012
Denmark	1992	Around US$ 26 per tCO_2 from 2010, varying per fuel type	Complements EU ETS
Finland	1990	US$ 39 to 78 per tCO_2 varying per fuel type	Complements EU ETS
Ireland	2010	US$ 26 per tCO_2 for natural gas and mineral oil, US$ 13 per tCO_2 for solid fuels	Complements EU ETS
Japan	2012	US$ 3 per tCO_2	Gradual increase over 3.5 years from 2012
Norway	1991	US$ 4 to 71 per tCO_2, depending on fossil fuel type and usage	Complements EU ETS
South Africa	2015	US$ 13 per tCO_2	Annual increase of 10 per cent from 2015 to 2020
Sweden	1991	US$ 163 per tCO_2	Complements EU ETS
United Kingdom	2013	Equivalent to US$7 per tCO_2	Carbon price floor, changing yearly depending on EUA price

Note: *List of carbon taxes is not exhaustive*

Source: *(Kossoy et al., 2013)*

Not all carbon price policies are well designed, and much has been learnt from trial and error.
International experience suggests five key features of effective carbon price policies, which are discussed in more detail below:
 – *explicit price*: an explicit carbon price is actually put in place, rather than an implicit price or no price at all;
 – *coverage*: the price applies to as many sources of emissions as possible;
 – *price stability*: emissions trading schemes need a price management mechanism, while a carbon tax does not;
 – *credibility*: carbon price policies need to be credible over the long term;

– *fair protection for EITE sectors*: carbon leakage that may occur from energy intensive, trade exposed (EITE) sectors due to a unilateral carbon price should be minimised in a fair and transparent way on the basis of good data.

Explicit prices are transparent and more efficient than implicit prices but often face greater opposition. The carbon price in some sectors of an economy is likely to be positive, even without an explicit policy. This is because an implicit carbon price can occur when the cost of GHG emissions is raised indirectly by a policy. For example energy taxes or air quality standards make carbon-intensive fuels more expensive to use and so, indirectly, raise the cost of GHG emissions. An explicit price, on the other hand, is charged directly per unit of GHG emissions, for example a carbon tax. The implicit carbon price can vary significantly across sources of GHG emissions, as Figure 8 shows. This means that distortions in the economy occur, as some sectors reduce GHG emissions too much while other sectors do not reduce them enough. Explicit prices avoid these distortions and so they are the preferred policy instrument to control GHG emissions. Despite the benefits, explicit prices can often face significant opposition as the rationale for controlling GHG emissions may be less clear to the public than the rationale for other taxes. The revenue raised from explicit prices can be recycled to appease concerns, and this can allow for tax reductions in other areas. However, policies that result in implicit prices for carbon should not necessarily be removed as they may combat other externalities, such as air pollution.

Figure 8. **Implicit carbon prices are often very low for a large percentage of emissions but very high for a small percentage of emissions**
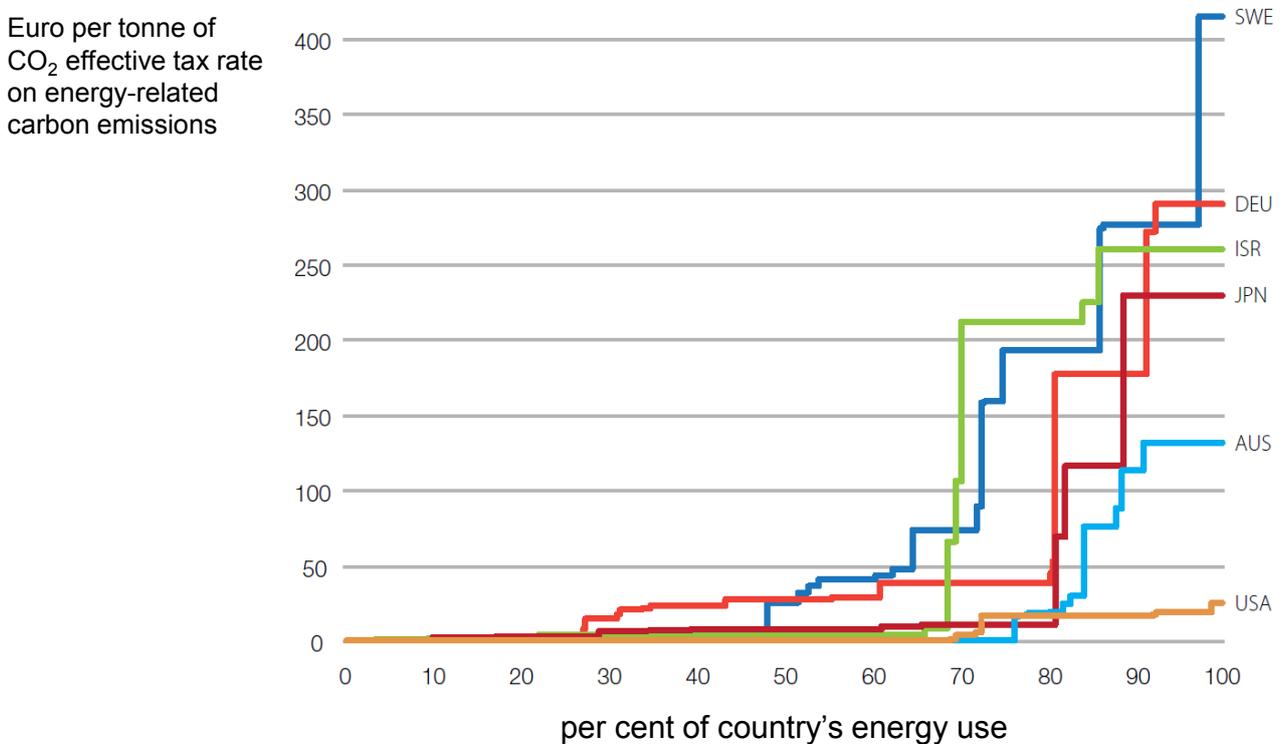

Source: *(OECD, 2013a)*

Implicit pricing regulations may be appropriate in certain circumstances. For, example, regulations and standards can be effective if the entities being regulated cause similar environmental damage and have similar abatement costs, if there are barriers preventing these entities from responding to price signals, or if there are economies of scale from collective action. For example, South Africa's fuel desulphurisation and modern vehicle standards have gone a long way towards internalising the externalities from road transport, as Figure 6 shows. Once South Africa's proposed vehicle standards, Clean Fuels 2, come into force in 2017, climate change will be the main road transport energy externality remaining.

An explicit price should apply uniformly to as many sources of emissions as possible. When the same carbon price is applied to the largest number of emissions in the jurisdiction, it minimises the distortions that affect implicit prices and incentivises a greater effort to reduce emissions.

Figure 9. **The volatility of the EU ETS price demonstrates the need for long term credibility and price management mechanisms for emissions trading schemes**
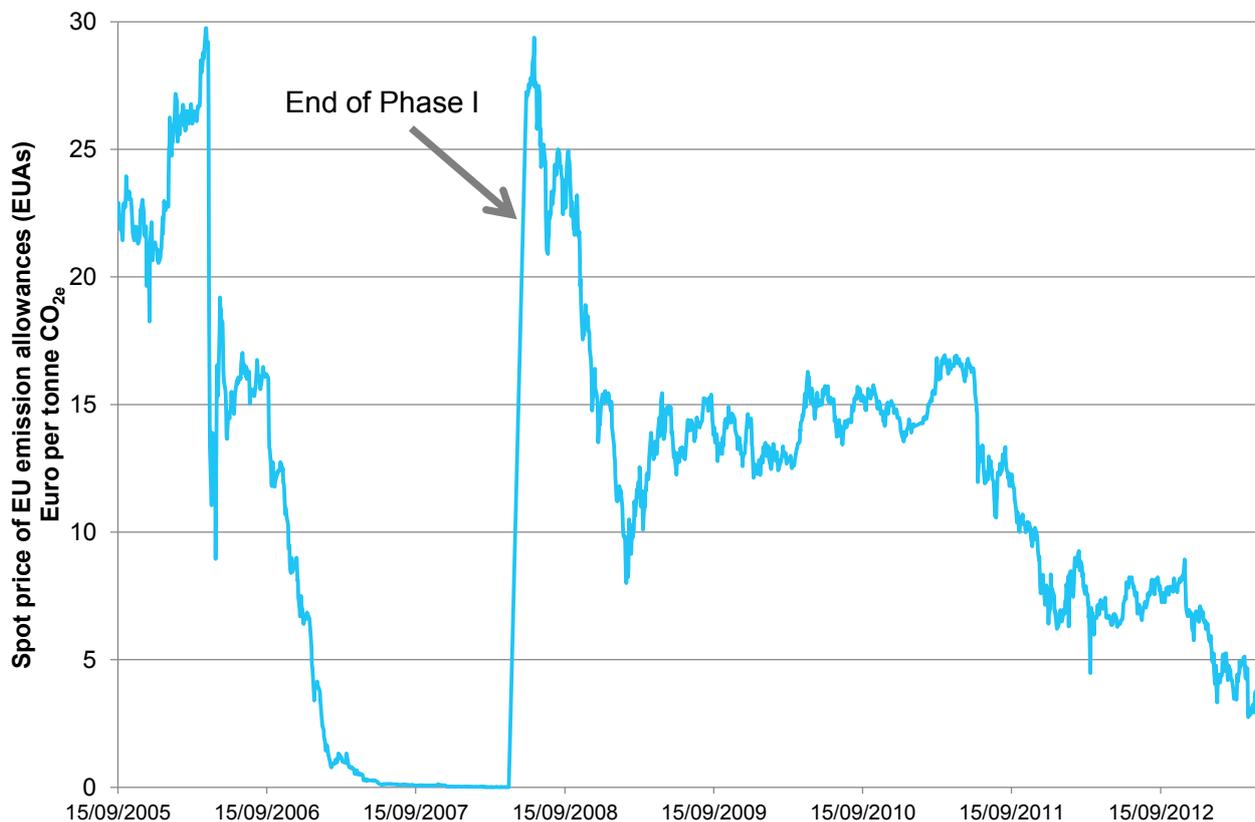
Note: *The price collapsed at the end of Phase I due to an over allocation of EUAs*

Source: *Vivid Economics based on Point Carbon data*

Emissions trading schemes require a price management mechanism while a carbon tax does not. As Figure 9 shows, the price of emissions in the European Union Emissions Trading Scheme (EU ETS) has demonstrated dramatic variability. Uncertainty over the price level caused by this variability can reduce

investment that is needed to achieve decarbonisation in the long term. Emissions trading schemes also present the risk that prices may be very low or very high. These extreme price levels are not necessarily a problem with an emissions trading scheme, the point of which is to cap the level of emissions rather than set a price. However, very low prices can undermine long term investment, while very high prices may be politically unacceptable. These issues can provide practical reasons to deviate from the absolute cap on emissions via a price management mechanism. This mechanism could, for instance, provide a price floor, which effectively tightens the cap until a price is achieved, and/or a price ceiling, which effectively loosens the cap until a price is achieved. A carbon tax avoids these issues as it fixes the price of emissions. This can reduce the administrative burden relative to an emissions trading scheme and provide investors with more certainty. However, a carbon tax does not provide as much certainty over the level of emissions as an emissions trading scheme.

Decarbonisation is a long term goal and so policies to achieve this need long term credibility. It is likely to take more than 40 years for emissions to be reduced to safe levels. Furthermore, these reductions will only be achieved if low carbon investments are made. These will only be made if investors believe that low carbon options will be worth it and this will require carbon price policies to be credible over the long term. To achieve this, emission caps, for a trading scheme, or tax levels, for a carbon tax, should be legally binding and clearly laid out for several years in to the future. In addition, the rules of reviewing caps or tax levels, and for any transition between phases of a scheme, should be announced at the start of the scheme.

The transition to a low carbon economy may lead to carbon leakage in absence of a global agreement, and so there is a case for fair levels of support. If a carbon price is imposed unilaterally, that is to say it is implemented in a country but not by that country˙'s major trading partners, then carbon intensive industries, which are often energy intensive industries, that are also large exporters, will face an increase in costs. This increase in costs may harm their competitiveness, which may lead to foreign firms increasing their output at the expense of domestic firms. If this happens then emissions in foreign countries may increase, which will cancel out the domestic reduction due to the carbon price. This is known as carbon leakage. To prevent carbon leakage, these energy intensive, trade exposed (EITE) industries may deserve some protection from a carbon price, often in the form of a rebate. However, the award of such protection must be made on the basis of good data and in a fair and transparent way. The use of benchmarks, and placing the burden of proof on firms if a particular facility is far from the benchmark, are effective ways to overcome asymmetries of information and avoid special pleading.

4 Conclusions

Explicit accounting of energy system externalities will help identify priorities in energy investment and policy choices

The analysis presented in this report is a high level guide to the value of energy system externalities in South Africa. To date, there has been little analysis of this type undertaken in South Africa. Therefore the estimates presented here are based on best available but limited evidence. So the actual monetary values presented here would require significantly more research before they could be used in other policy work. However, there are some robust conclusions from this analysis, which may warrant this further research.

There are four main conclusions from the analysis of energy system externalities in South Africa:
– *energy system externalities can be significant*: for example the current externality costs of electricity from coal are estimated to be as great as the private costs of coal;
– *externalities can change the cost ordering of energy technology choices*: for example electricity from coal has one of the lowest private costs, but a combination of falling private costs for renewables and the cost of externalities from coal means that, by 2020, electricity from coal will be among the options with highest social cost;
– *regulation to manage externalities can have large benefits*: for example the external costs of road transport have decreased rapidly as modern standards have been implemented;
– *climate change is the most significant energy system externality in South Africa*: reducing Greenhouse Gas (GHG) emissions would also have the co-benefit of reducing air pollution, which is also a major energy system externality.

International experience of carbon pricing shows that successful management of energy system externalities involves getting many implementation details right. Getting the right price for an externality is only part of the policy challenge. The way in which the policy instrument is implemented is, in practical terms, just as important. The main issue is that introducing a price for an externality changes the incentives of people and this can have unintended consequences and elicit strong political reactions, especially when the source of an externality is as pervasive as GHG emissions.

Management of externalities may often require a trade-off between getting the right price and practical considerations. The evidence from both externality valuations and practical international experience suggests that explicit accounting of externalities is useful in identifying investment and policy priorities. However the extent to which externalities can be reduced seems to depend as much on policy implementation as it does on accurate valuation of the externality.

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Annex 1: The value and scale of energy system externalities

The main body of this report analyses the value of externalities per unit for electricity generation, residential fuel use and road transport.

In this annex, to provide some context, the international values, and overall levels in South Africa, of the following externalities are considered:
– GHG emissions
– air pollutants
– water pollution and overuse

GHG emissions

Greenhouse Gas emissions (GHGs) cause climate change, which causes harm to people. Harm is caused either through the cost of adapting to the changing climate or due to loss and damage caused by sea level rise and increased extreme weather, among other impacts. Estimating the climate change that will occur and the subsequent damage that this will do is uncertain and complex, primarily due to uncertainty of how the climate will change, especially at local levels, and the complexity of the interaction between climate and human systems. Furthermore, as the people who will suffer from climate change are primarily in the future and dispersed across the globe, turning damage estimates into monetary values requires making assumptions about social preferences on behalf of people who may live in very different societies or who are not yet born.

Despite this complexity, estimates of the cost of climate change have been made and they tend to be between \$10–\$100 per tonne of CO_{2e} emitted in this decade. Notable estimates include:
– \$39 per tonne of CO_{2e} emitted in 2015 (US EPA, 2013)
– \$85 per tonne of CO_{2e} emitted in 2000 (Stern Review, 2007)

South Africa's energy system is among the most carbon intensive in the world. As Figure 3 in the main report shows, South Africa"s electricity is particularly carbon intensive. Furthermore, due to coal-to-liquids, South Africa"s liquid fuels production is also very carbon intensive.

Air pollutants

To estimate the value of air pollution externalities, five steps along the 'impact pathway' of an air pollutant must be estimated:
– *burden*: the source and quantity of pollutant
– *dispersion*: how the pollutant moves from the source
– *exposure*: the population covered by the dispersed pollutant
– *impact*: the response of the population to the pollutant, for example respiratory disease
– *valuation*: the economic valuation of the impact

Country specific data is required for the most accurate estimation. In particular, dispersion and exposure require country specific modelling. Unfortunately, in South Africa, publicly available dispersion and impact modelling that has been undertaken is not sufficient to robustly estimate impacts (Norman et al., 2007). Valuations of impacts per unit of externality can also vary across countries. This is because different societies can have different willingness to pay to avoid negative externalities or receive positive externalities and willingness to pay is the central concept used to estimate the monetary value of externalities.

While valuations may differ between countries, work done in other regions is still informative. The European Union and the United States have invested significant resources into valuing the impacts of air pollution. Such work gives a guide as to which pollutants are likely to be of greatest concern in South Africa, as Figure 10 suggests. Furthermore, these valuations can, with appropriate adjustments, be transferred to another country. This transfer of externality valuations is discussed in more detail in Annex 2.

Figure 10.   **CO_2, NO_x and SO_x are currently the most damaging industrial air pollutants in Europe and are likely to also be the most damaging in South Africa**
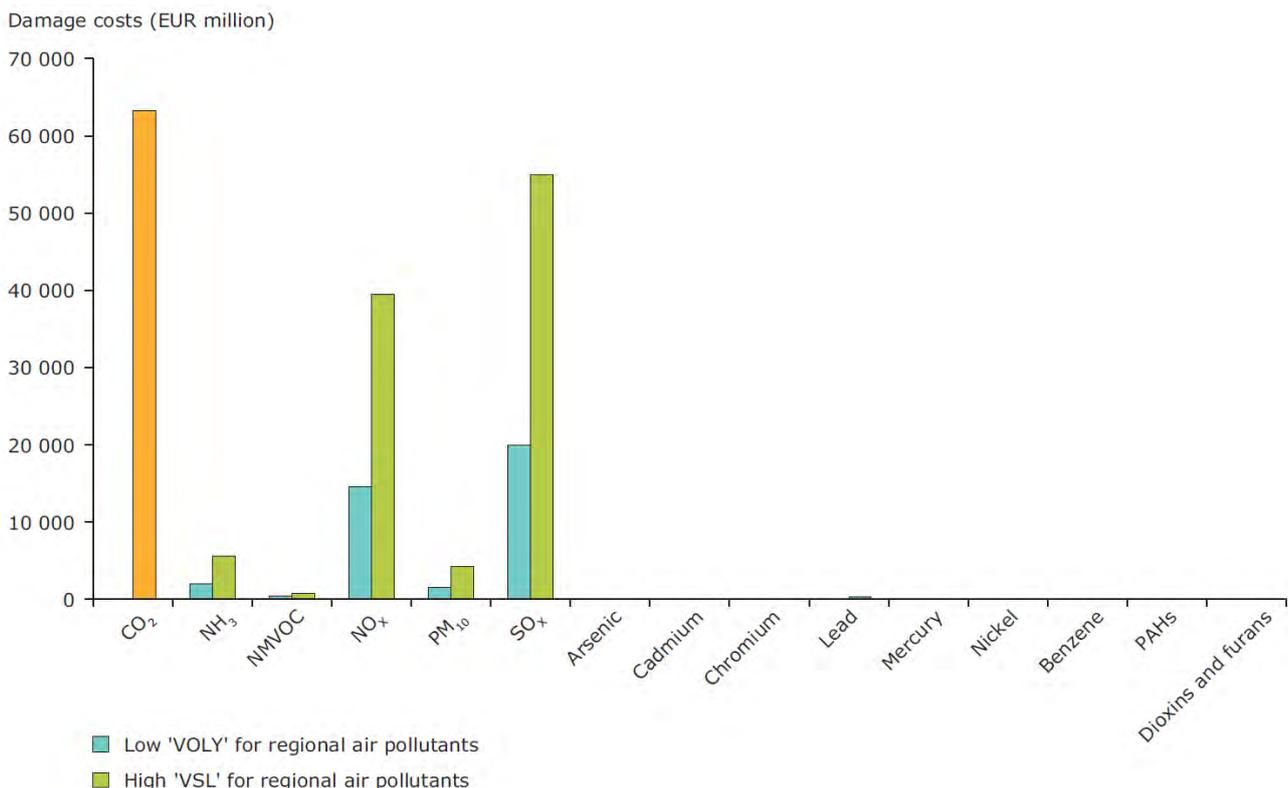
Note: *VOLY and VSL are measures of the value of mortality*
Source: *(EEA, 2011)*

In South Africa, levels of Particulate Matter pollution are rising but sulphur dioxide pollution is falling. Particulate Matter levels are, on average, near National Ambient Air Quality Standards (NAAQS),

but are often worse, and the State of the Air in South Africa Report states that „Particulate Matter is the greatest national cause for concern in terms of air quality". On the other hand, the State of the Air Report says that slowly but surely the battle against sulphur dioxide is being won, with levels below NAAQS. However sulphur dioxide limits for new power plants in South Africa are 2.5 times weaker than EU standards and further fuel desulphurisation is planned for 2017.

Water pollution and overuse

The energy sector is not a large user or polluter of water. South Africa has about 10,000 million m^3 of water available each year (DWAF, 2013). Detailed water use data is not available, but the following estimates can be made:

− Eskom used 334 million m^3 of raw water in FY 2013, or ~3.3 per cent of available water;
− in addition, 16 million m^3 of water was required to mine the 123,000 kiloton of coal burnt by Eskom in the Financial Year to 2013, assuming coal mining requires 133 m^3 of water per kiloton of coal (Pulles, Boer, & Nel, 2001);
− power generation is estimated to produce 6 million m^3 of effluent (Cloete, Gerber, & Maritz, 2010);
− the petroleum industry is estimated to use 136 million m^3 of water, or ~1.4 per cent of available water, and produce 24 million m^3 of effluent (Cloete et al., 2010);
− in comparison agriculture uses 62 per cent and urban households use 23 per cent of available water (DWAF, 2004).

However continuous water supply is essential to energy security. Most types of power generation require water for cooling, and without a continuous supply the plants would have to shut down. This risk is exacerbated by the fact that the energy sector tends to need water in areas that are already water stressed.

South Africa has a sophisticated water strategy but it has proven difficult to implement. This strategy, if fully implemented, would be in line with international best practice (OECD, 2013b). Furthermore, South Africa"s water pricing is relatively high, as Figure 11 shows, and so the country is doing relatively well, although not succeeding, in charging a price equivalent to the cost of providing water (DWAF, 2013).

*Figure 11.* **South Africa's water price is relatively high**
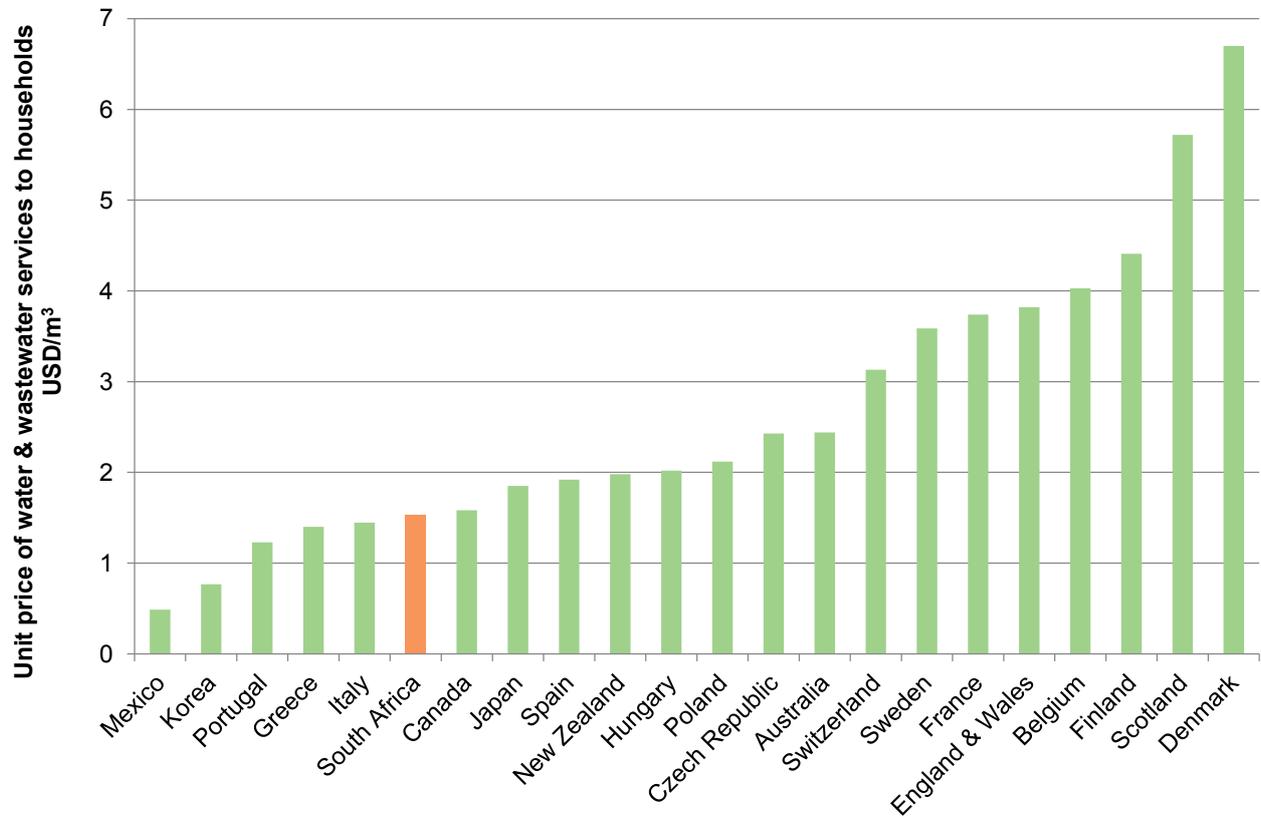
Annex 2: Detail on external cost estimates

Electricity generation

In 2020, coal is likely to have the lowest private cost but among the highest social cost of electricity generation. As Figure 2 in the main report shows, by 2020, the private levelised costs of electricity per MWh from nuclear, wind and solar PV will be 14, 21, and 36 per cent higher than the private costs of coal. Costs of wind and solar are currently much higher and are expected to fall by ~10 and ~35 per cent respectively by 2020 (DOE, 2013). However, the external costs of coal in 2020 are equal to ~60 per cent of private costs, which means that, while coal has the lowest private cost in 2020, it has among the highest social cost. The social cost of gas CCGT in 2020 is slightly higher than coal in 2020 as the cost of fuel for gas CCGT is assumed to be high, at $17 per MMBtu, compared to estimates of $11 per MMBtu from the Karoo (Wood Mackenzie, 2013).

The social cost ordering of the generation types is the same when using South Africa specific pollution levels or data from the European Commission's CASES project. Figure 12 presents the same data as Figure 2 in the main report except that estimates of CO_2, water, SO_2, NOx and PM pollution levels are taken from a major European Commission project, CASES, rather than from South Africa specific data sources. The private costs and external costs per unit are the same as in Figure 2 – it is just the number of units of externality that are different. The social cost ordering, that is which generation options are more expensive than others when externalities are included, is the same when using South Africa specific pollution levels or data from the CASES project. This suggests that the analysis presented in Section 2.1 is robust.

Figure 12. **The social cost ordering is the same when using South Africa specific pollution levels or data from the European Commission's CASES project, shown here**
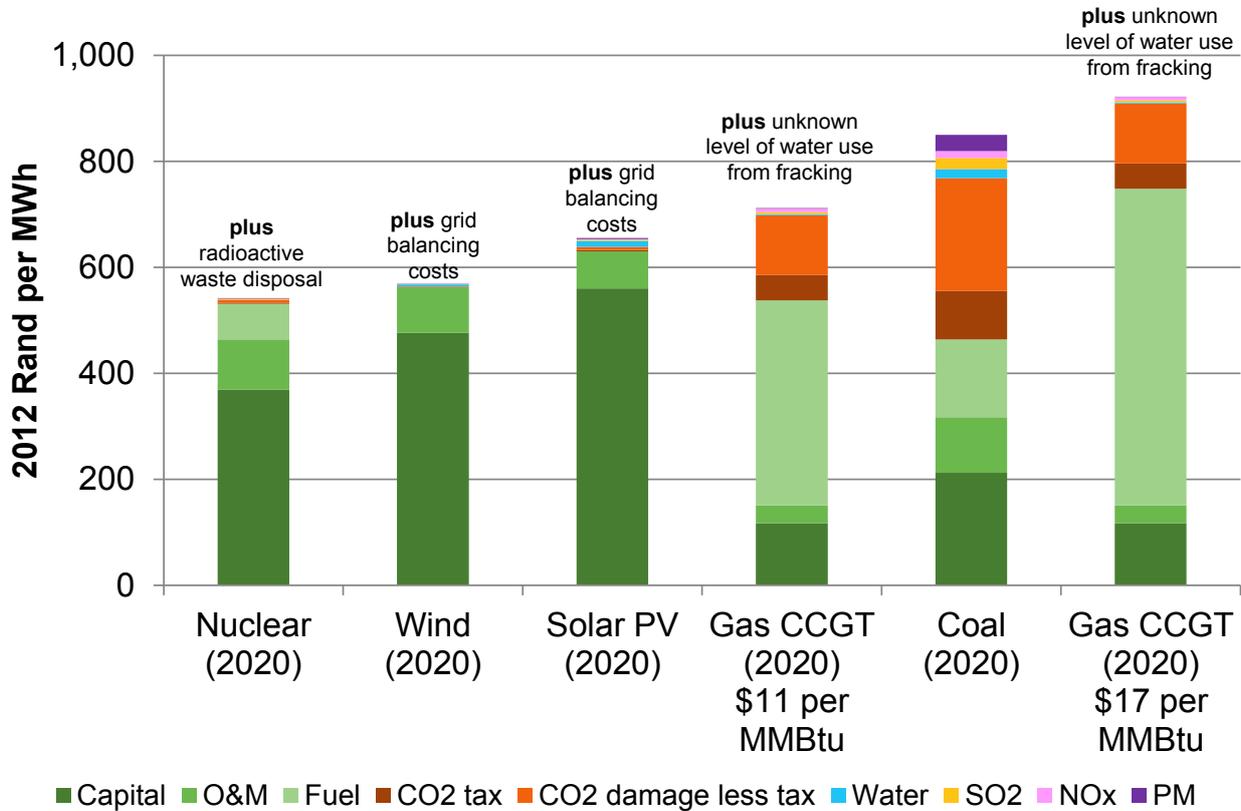
Source: *Vivid Economics based on CASES (2008) data for CO_2, water, SO_2, NOx and PM pollution levels; DOE, IRP 2010 data for capital, O&M, fuel, water use and levels of CO_2, PM, SO_2 and NO_x pollution in 2020 (levelised cost of electricity estimates in 2020 are not provided in the IRP 2013 and pollutant levels are similar); value of water is 45 Rand per m^3 to reflect desalinisation costs, CO_2 tax is 120 Rand per tonne, CO_2 damage is \$40 per tonne (2012 USD) from US EPA (2013), PM, SO_2 and NO_x damage from UK Defra (2013), adjusted for South Africa"s income per person as per method in OECD (2012)*

The main externality from electricity generation in South Africa is climate change. Electricity from gas and coal is carbon-intensive, with coal ~2.5 times more carbon-intensive than gas, while nuclear, wind and solar PV are low-carbon fuels. The cost of the climate change externality is larger than the cost of other identified externalities.

The proposed carbon tax will be lower than central estimates of the damage from GHG emissions. The costs of climate change are experienced globally and over time, rather than locally and immediately as is the case with air pollution. This can make the climate change externality easy to disregard. Despite this, South Africa has recognised the need to make a fair contribution to global efforts (DEA, 2011). The carbon tax is a way of making that contribution. However, recognising uncertainty in estimates of the damage from GHG emissions and to allow for a "relatively smooth transition" to a low carbon economy, the carbon tax is set at

a "relatively modest" level of 120 Rand per tonne of CO_{2e} in 2015 (Treasury, 2013). This is in contrast to the central estimate of damage used by the US EPA, of ~\$40 per tonne of CO_{2e} in 2015 (US EPA, 2013). So the carbon tax, excluding discounts due to tax-free thresholds, is ~2.5 times less than a central estimate of damage. Therefore the carbon tax does not fully internalise the external cost of GHG emissions, although this may be an appropriate level depending on what a fair contribution is considered to be. If the climate change externality over and above the carbon tax is not considered, then the social cost of coal is cheaper than gas CCGT and solar PV. Section 3 and Annex 1 provide more detail on carbon prices and damage estimates respectively.

Air pollution is also a significant externality for coal. Sulphur dioxide, nitrogen oxides and particulate matter result from the burning of coal and, to a lesser extent, gas. These air pollutants can, in sufficient quantities, cause significant local damage – primarily through respiratory diseases. However, in 2020, the physical quantities emitted of these pollutants are relatively low per MWh and so their contribution to external costs per MWh is low. This is in contrast to current air pollution from Eskom"s coal fleet, which demonstrates the value of investing in technology to reduce pollutants, such as Flue Gas Desulphurisation.

Water pollution and over-use from the electricity sector is an issue, but not the most significant issue facing the water sector. South Africa has approximately 10,000 million m^3 of water available each year (DWAF, 2013) and the electricity sector uses ~3.5 per cent of this (Eskom, 2013; Pulles et al., 2001) and pollutes just 6 million m^3 of water (Cloete et al., 2010). In comparison, agriculture and urban households use 62 and 23 per cent of available water respectively. Therefore the electricity sector does not impose a significant burden on overall water availability. However, coal, and shale gas if developed, is extracted in particularly water stressed areas and South Africa is in general a water scarce country. As a result, Medupi and Kusile are dry-cooling power plants and new nuclear power plants will be built on the coast so that they can be cooled using sea water. Even though electricity generation does not use much water, it faces a low price for water and so may be over-using it. In 2010, the electricity generation sector paid 3.4 Rand per m^3 (StatsSA, 2010), while households paid ~8 Rand per m^3 for water and ~5 Rand per m^3 for wastewater services (OECD, 2013b). Even households tariffs do not cover costs (DWAF, 2013) and the estimated cost for desalination, considered the backstop option for providing water, is between 15 and 70 Rand per m^3 depending on the region to be supplied (DWAF, 2010). The cost of water assumed in this report is 45 Rand per m^3, which reflects a mid-point in desalinisation cost estimates. This is an appropriate estimate for the value of the externality from water over-use because desalinisation provides an unlimited quantity of water, which means that one person"s use of water would not affect another person, and the mid-point of desalination costs is ~45 Rand per m^3.

Intermittent renewables can impose both positive and negative 'grid' externalities. Some renewables, particularly wind and solar power, vary in the power they provide as their „fuel", the wind and sun, varies; these are known as intermittent renewables. This is in contrast to other types of electricity generation, such as coal, gas and nuclear, where fuel can be constantly supplied. This variability has costs and benefits that variable renewables operators do not bear, that is to say there are externalities. These externalities are known as „grid" externalities as the costs and benefits are borne by the power market in general, that is to say entities connected to the power grid.

The negative grid externality of variable renewables is the cost incurred to make sure that enough electricity is available to meet demand when the output of variable renewables is low. This backup supply can come from either spare baseload capacity or from electricity storage. Managing this variable supply can also require more sophisticated transmission and distribution networks. These extra infrastructure costs must be borne, at least initially, by the institution responsible for ensuring system adequacy, which in South Africa is currently Eskom.

The positive grid externality occurs when variable renewables can help supply peak demand because their output is correlated with periods of peak demand. For example solar PV is often at its maximum output when use of air conditioning is at its maximum. This provides a benefit to the system operator because it removes the need for generation capacity that would otherwise sit idle at non-peak times. In addition, *distributed* variable renewables, that is renewables that are not connected to the grid, such as solar PV on residential roofs, remove the need for extra transmission and distribution infrastructure to manage peak demand. The size of this positive externality can be significant. For example, in Australia, solar PV could help avoid the following costs that air conditioners place on the energy system: „it is estimated that the installation of a 2 kilowatt reverse-cycle air conditioner can cost a consumer around $1,500, but imposes costs on the energy system of up to $7,000 when adding to peak demand – costs that are spread across all customers" (Australian Government, 2012).

Residential fuel use

Further information and assumptions relevant to Section 2.2 are provided below:
– the private cost of electricity does not reflect residential tariffs; instead it is the private cost of supplying electricity from coal in 2020 or solar PV in 2020. This is for consistency with the analysis presented in Section 2.1. In 2012, Eskom charged residential customers 0.8 Rand per kWh, equal to 800 Rand per MWh, on average. This is in contrast to private costs of generation from coal and solar PV in 2020 of 464 and 630 Rand per MWh respectively – although this excludes transmission and distribution costs.
– the main risks from paraffin are burns as a result of fires from knocked-over stoves and poisoning resulting from ingestion by children. Paraffin should produce relatively little air pollution when burnt in well-designed appliances. That said, many paraffin appliances in South Africa are thought to be of poor quality (PASASA, 2012), although there is not enough information to monetise the air pollution externality from these poor quality stoves.

Road transport

Further information and assumptions relevant to Section 2.3 are provided below:
– there is no information on PM levels in the 1988 study, so Euro1 standard levels of PM are assumed. This is likely to be a conservative estimate of PM levels in South Africa in 1988.
– under the Euro 2 and Clean Fuels 1 standards, which are equivalent, there is no specified NO_x level, so 1988 levels of NO_x are assumed. This effectively assumes that there is no improvement in NO_x levels between 1988 and 2008. This may result in an overestimate of NO_x costs in 2008 as imported vehicles may meet NO_x standards set in other countries.

- emission standards regulate the maximum level of emissions that is allowable on a „test cycle", so actual on-the-road emissions may be different.
- catalytic convertors, which reduce carbon monoxide, NO_x and unburnt hydrocarbon emissions, must remain fixed to vehicles if emissions are to actually be reduced. However there is a high prevalence of catalytic convertor removal in South Africa.

Transfer of externality valuations

To transfer externality valuations from one country to another, in this case from those made for the UK by Defra to valuations suitable for South Africa; the OECD recommends the following formula is applied (OECD, 2012):

$$per\ unit\ damage\ valuation\ in\ UK\ \times \left(\frac{GDP\ per\ person\ in\ South\ Africa}{GDP\ per\ person\ in\ UK}\right)^{income\ elasticity\ of\ the\ Value\ of\ Statistical\ Life}$$

This adjusts the UK damage valuation by the difference in GDP per person, on a purchasing power parity basis, and the degree to which willingness to pay to avoid harm changes as income changes – this latter factor being known as the income elasticity of the Value of Statistical Life.

The ratio of GDP per person between South Africa and the UK in 2010, on a purchasing power parity basis, was 0.3. The OECD recommend a value of 0.8 for the income elasticity of the Value of Statistical Life. Therefore UK damage valuations are multiplied by 0.4 when applied to South African externality valuations in this report.

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