External costs of power generation

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The social benefits of power so far exceed the social 'external' costs that one can conclude that power generation is well-merited, even from coal.

There has been growing concern about the external costs of power generation, particularly the generation of power from coal. A major effort by a team from the European Union produced the ExternE study, which concluded that the external costs were a strong function of such variables as the population density in the area around the power station, the local climatology and the level of pollution control employed. There was therefore a wide range of external costs.

Other studies have ignored the ExternE, and attempted a number of shortcut methods which have had a doubtful theoretical basis. Typically, they have relied on an assumption of linear no-threshold, which in effect states that no matter how low the dose, harm will result. The assumption almost certainly overestimates the impact and therefore the external costs. The linear no-threshold theory is therefore examined, and it is concluded that it is most unlikely to be valid.

In economics, an external cost (or benefit) arises from an activity that has some impact upon someone who had not chosen to incur the cost (or receive the benefit). So, for example, diesel fumes may settle on buildings, which therefore require more frequent cleaning. The extra cost of cleaning falls on the owners of the buildings, not on the owners of the diesel vehicles. That extra cost is therefore an external cost. In the same vein, the city may decide to provide lights in your street, and you would benefit from improved security at night even though your contribution to the cost of the lighting installation was minimal.

There is an economic philosophy which holds that for goods or activities that have external costs, market prices do not reflect the full social cost of the goods or activities. The market is therefore believed to be inefficient, because goods or activities which have high external costs could be sold at a lower cost than competitive goods or activities that have low external costs. Should one, for example, prefer cheap electricity generated from coal combustion over relatively expensive electricity generated from renewable sources, when it is clear that the coal-generated electricity has some external costs associated with it, whereas the primary external cost of renewable energy is the cost of public relations to overcome objections to the relatively large footprint they have.

These concepts can be illustrated graphically. In *Figure 1*, the impact of an external cost is shown. If the impact of an activity on society is ignored, then the costs will be purely the private costs. Demand will vary with price. Where the private cost intersects the demand line, the equilibrium demand Qp will determine the equilibrium price Pp.

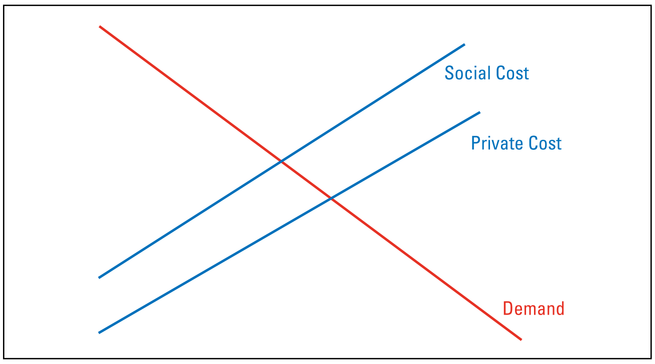

Figure 1: Price-demand and external costs [1].

However, an external cost will increase the private cost to the social cost. The price should then rise to Ps and the demand will reduce to Qs. The problem, however, is how to determine these external costs. Taking the simple example of the diesel fumes above, one needs to know how often the buildings would have been cleaned if there had been no diesel fumes, because it is only the additional cleaning that incurs the external cost. Establishing a baseline from which the external costs may be estimated is therefore necessary. This task may be made difficult by the natural background, which itself is variable.

Facing this difficulty, in 1991 the European Union set up a programme, ExternE, to estimate the external costs of energy generation. It took more than 50 teams from 20 countries to develop these estimates. As the final report in 2006 notes:

ERF - Exposure Response Functions
ESP - Electrostatic Precipitator
GLC – Ground Level Concentration

Abbreviations

'The effects of energy conversion are physically, environmentally, and socially complex and difficult to estimate, and involve very large, sometimes ultimately unresolvable, uncertainties, unpredictabilites, and differences of opinion.' Despite these difficulties, ExternE has become a well-recognised source for method and results of externalities estimation.

The ExternE programme has had ongoing work since 2006, but the methodology developed has been essentially unchanged. The further work has concentrated on improving the various estimates of the effects.

In this article therefore, the methodology is reviewed, and other attempts to determine external costs are considered in the light of that review.

ExternE methodology

The ExternE study started by identifying the site of a specific form of pollution, and determining the technology employed and any mitigatory measures already in place. This allowed estimation of the emission, eg kg of pollutant per year. It then addressed the way in which the emitted pollutant was dispersed, taking into account the atmospheric conditions ruling at various times of year. Fairly sophisticated atmospheric dispersion models were necessary to allow for seasonal changes in weather patterns. Because some pollutants have a considerable lifetime in the atmosphere, it was necessary for the dispersion models to be able to model a wide area, perhaps as large as a hemisphere, as well as modelling the lifetime of the various species and the way in which that lifetime might be affected by weather. Atmospheric chemistry had to be taken into account, because some species changed their nature during atmospheric transport. The output of this stage was the change in the pollutant concentration at receptor sites, eg μg/m^3 of particulates. Strictly this should have been as a function of time, but a degree of simplification was introduced by considering only annual averages. Pollution of soil and water was taken into account in addition to direct atmospheric pollution.

It was necessary to do the dispersion study both for a baseline, with no local emissions included, and with the case of the local source. It was found that the background concentration of pollutants was critical for the baseline, particularly for pollutants affected by residence time in the atmosphere or pollutants whose impact was non-linear.

The third step was to introduce dose-response functions for each pollutant. Many pollutants have an impact on living species that varies with the duration of the exposure and the concentration of the pollutant during the exposure. The difference between the air quality calculated for the baseline and for inclusion of the local source was then used with the dose response functions to determine the changes in public health, crop performance or similar measure of pollution. *Figure 2* illustrates this for one pollutant and one impact.

This figure illustrates how necessary it is to establish a baseline. Because the response is non-linear, a 50% increase in the dose doubles the impact. In the case considered in *Figure 2*, the dose-response is always positive, but some species can have a negative impact (ie a positive response) at low doses.

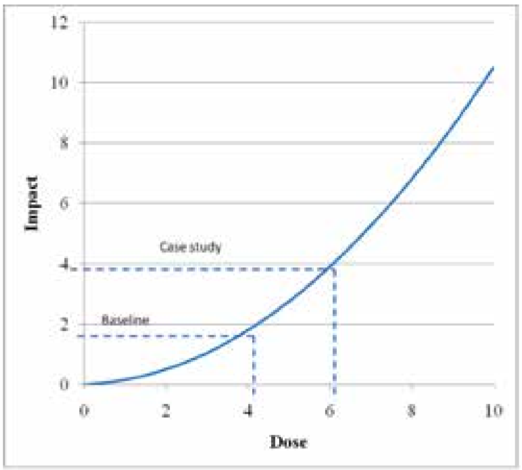

Figure 2: Dose response curve and impact over baseline.

For instance, many plants have an absolute need for some sulphur. Wheat, for instance, requires sulphur in order to produce gluten, a sulphur compound. Most rain carries some sulphur naturally, which replenishes that removed by harvesting the wheat. However, the concentration in rain is low, so it is essential to allow fields to lie fallow for a few years after several wheat crops have used the available sulphur. Alternatively it may be necessary to add some sulphur compound – typically gypsum – to the field to restore productivity. A little sulphur in rain is beneficial; too much can be harmful.

For the example given in *Figure 2*, the net impact is the difference between the case studied and the baseline, a little over two in this case (in whatever units are appropriate). Having determined the net impact, it is then necessary to give this impact a monetary value. For instance, epidemiology may have shown that an increase of two units in the sulphur dioxide concentration may cause a 10% increase in the number of those who suffer from asthma, and it is then necessary to estimate a) how many asthma sufferers were impacted at the baseline and b) what the lifetime cost of asthma to the individual might be.

Finally, to obtain the external cost it is necessary to integrate the cost of all impacts over all impacted areas. Of course, not all impacts are those on humans – there may be impacts on crops or the biosphere. As ExternE noted:

'For some of the impacts (crops and materials), market prices can be used to evaluate the damages. However, for non-market goods (especially damages to human health), evaluation is only possible on the basis of the willingness-to-pay or willingness-to-accept approach that is based on individual preferences. The monetary values recommended in ExternE by the economic expert group have been derived on the basis of informal meta-analysis (in the case of mortality values) and most recent robust estimates.'

ExternE attempted to address all significant impacts, but as the work progressed, the team became aware of gaps and uncertainties in the current knowledge. Nevertheless, they felt reasonably confident that they had addressed most of the environmental and global warming impacts (the latter on an avoided-cost basis), accidents (except those of very low frequency and potentially very high impact, for which no methodology of quantifying the costs has yet been evolved) and energy security. There were some issues that were – at least in the opinion of the ExternE team – not external costs, such as impacts on employment and the depletion of non-renewable natural resources, and which were consequently not included. What this makes apparent is that:

- The estimation of external costs is not a trivial exercise, and
- In evaluating the impacts, baseline and dose response are critical

Local studies

One of the earliest studies was that of Dutkiewicz and de Villiers [3], who estimated a cost of the order of 1 c/kWh in 1994 Rand. van Horen (1996) [4] estimated between 5 and 8 c/kWh, also in 1994 Rand. Unfortunately, his study suffered from a disastrous arithmetical error – in calculating the impact, he employed the wrong set of data, with the result that the costs were overstated by a large factor. Spalding-Fecher and Matibe (1999) [5] estimated that external costs were between 1 and 9 c/kWh in 1999 Rand. Interestingly, they assessed the health benefits of electrification at between -0.1 and -1,4 c/kWh, and the pollution and health effects at between 0,5 and 0,9 c/kWh. However, climate change impacts were large, with costs between 1 and 9,8 c/kWh, and therefore dominated the overall externalities. Recently, Riekert and Koch [1] have attempted to estimate the external costs of generating power by coal-fired plant. They found a wide range, between 0,1 and 6,8 c/kWh, for health impacts from air pollution alone.

One reason for the difference from earlier studies is the effect of inflation, and Riekert and Koch cited the earlier study of Tophil and Pouris [6] who inflation-accounted the earlier studies to a common 2006 base date. Thus Spalding-Fecher and Matibe's estimate of external costs was 0,4 – 2,7 USc/kWh in 2006 money, for all damage including health impacts, whereas Riekert and Koch focussed only on health impacts.

Riekert and Koch's study was not without problems. For instance, they assumed that they could use data on PM10 emissions from Kendal power station, but Kendal is only equipped with electrostatic precipitators, and Kusile will employ high-temperature baghouses [7], which will reduce the emissions by a factor of at least 10. They assumed a range of stack heights from 150 to 310 m, but managed to include the actual height of Kusile's stacks, 220 m. They presented data on As, Cr(VI), Pb and Ni in their Table 8, but this table was not referenced in the text in any way, and there was no indication of the source of the data. It is suspected that they employed some relationship to the PM10 which, as already noted, is itself in error.

In any event, arsenic is effectively absent from South African coal – indeed, a recent review [8] concluded that:

'In Africa, arsenic contamination is most remarkable for its general absence.' Similarly, the source of the Cr(VI), Pb and Ni in Riekert and Koch's Table 8 does not appear to have a solid base. Finally, there is a feature of Riekert and Koch's analysis that must be questioned. In general, they followed the methodology employed in ExternE, However, when they came to consider the dose response, they employed a single model. The expected outcomes are given by Sakulniyomporn et al (2011:3467) and Thomas and Scorgie (2006:2.16), based on the assumption of zero-threshold linear ERFs.'

Zero-threshold linear exposure

Zero-threshold linear exposure response is relatively widespread in epidemiological circles. However, its scientific validity has been seriously questioned. It entered epidemiological thinking via radiation exposure. A major driver for its acceptance was the simplification that it allowed – the dose accumulated over any given period such as a year could readily be calculated. The US National Academy of Sciences has concluded that: 'The preponderance of information indicates that there will be some risk, even at low doses.' [9]

However, there is debate over this matter even as regards radiation. In France, the Academy of Sciences rejected the linear no-threshold model, preferring a threshold for any response to a dose of radiation [10]. The Society of Health Physicists states [11]:

'There is substantial and convincing scientific evidence for health risks following high-dose exposures. However, below 50 -100 mSv (which includes occupational and environmental exposures), risks of health effects are either too small to be observed or are nonexistent'.

When considering the health impacts of other agents such as pollutants, the evidence for a zero-threshold linear response is equivocal. Consider, for example, the question of exposure to sulphur dioxide, and one million people being exposed to an additional 1 ppb due to a coal-fired power station. According to the zero-threshold linear response, that is the equivalent of one person being exposed to one million times 1 ppb, or 1 000 ppm, 0,1%, which would be fatal within an hour. So the impact of 1 ppb SO_2 above background is assumed to be one death per million exposed. Is this reasonable?

Consideration of the part played by sulphur in nature makes it seem most unlikely. Most plants contain around 0,25% S, and sulphur is a fertiliser with a potency similar to that of potassium. Under natural circumstances, plants that die recycle their sulphur for use by the next generation. However, harvesting a crop for food will remove the sulphur, and the essential element will be removed from the field. In former times, it was the practice to allow fields to lie fallow for a period after a few harvests, in order to allow the sulphur and other nutrient levels to be restored.

It transpires that, in the tropical and temperate zones of the world, all rain contains quite a lot of sulphur, either as dissolved SO_2 or as sulphite/sulphate. The annual flux is about 10 – 20 kgS/ha, somewhat higher closer to the sea. But plants are clever - if there is insufficient in the ground, they can always scavenge some directly from the air [12]. This is one reason why the fertility seems to be so good near volcanoes; and there can be insufficient sulphur in both ground and air. Interestingly, the decision to use flue-gas desulphurisation in Britain led to poor wheat in Western Europe 13:

'Deficiency of sulphur (S) has been recognised as a limiting factor for crop production in many regions in the world. In particular, incidence of S deficiency has increasingly been reported in Brassica and cereal crops in Western Europe over the last decade, mainly as a consequence of a massive decrease of atmospheric S inputs.'

Gluten is a sulphur compound, and lack of sulphur in the wheat-fields resulted in a low-gluten wheat that gave a loaf perceived to be markedly inferior to one made with normal-gluten wheat. A natural flux of 10 – 20 kgS/ha from the atmosphere requires an ambient concentration of 0,7 - 1,4 ppm SO_2. If this is the effectively natural background of SO_2, is it reasonable that 1 ppb SO_2 could be in any way harmful? It seems most unlikely.

The difficulty of employing the zero-threshold liners impact response model can also be illustrated by considering the dose-response similar to that shown in *Figure 2*.

In this case, a 50% increase in the dose only increases the impact by 50%, whereas in the case considered in *Figure 2*, it doubled the impact. For low concentrations it certainly seems more reasonable that the impact would increase faster than the dose, rather than in direct proportion to the dose.

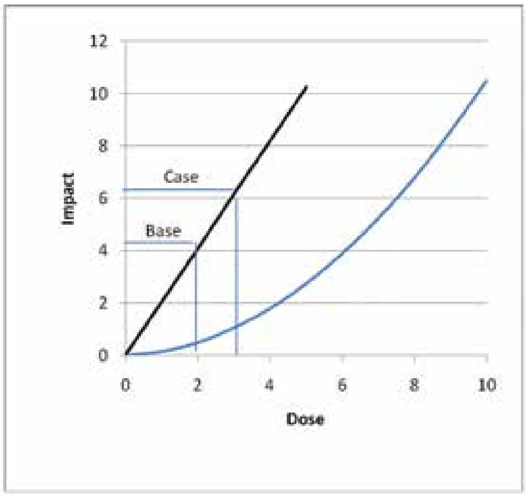

Figure 3: Dose-impact for zero-threshold response.

Corrections to Riekert and Koch

The stacks at Kusile will be 220 m high, and it seems most reasonable to assume a flue gas desulphurisation efficiency of 90%, so following Riekert and Koch, at the maximum ground level concentration (GLC) and at Phola, the nearest conurbation would be increased by:

	GLC, µg.m^{-3}.	Phola, µg.m^{-3}
SO_2	6,2	6,2
NO_2	1,8	3,1
PM10	0,1[a]	2,2[a]
As	0,76E-07[b]	1,68E-06[b]
Cr(VI)	1,50E-06	3,30E-05
Pb	2,93E-07	6.,4E-06
Ni	4,35E-07	9,56E-06

Table 1: Additions to background levels at two conurbations near Kusile

- [a] – reduced by a factor of 10 due to use of bag filters in place of electrostatic precipitators (ESPs)
- [b] – all ions scaled from PM10

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