Quantifying Uncertainty in Baseline Projections of CO_2 Emissions for South Africa

Draft Final Report

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FIRM
Facilitating Implementation and Readiness for Mitigation

Contents

Introduction: Baselines

Framing domestic climate change policies and national positions in global climate negotiations requires the best possible information about possible future outcomes. Defining this position is made by trading-off emission reductions and economic growth. Policy makers' efforts in this regard are focused on achieving low carbon development at the lowest possible cost to the economy. This cost of mitigation is calculated as a difference in costs (defined in monetary units) between a baseline situation and a new one characterized by lower emissions, (Hourcade 1996). For most developed countries the emission reduction is calculated relative to a benchmark date in the recent past. Usually in studies of developing countries, emission reduction is calculated in terms of a percentage reduction from an emission level in a baseline trajectory at a specified future date, often several decades in the futures. The definition of a baseline trajectory is problematic:

- **Uncertainty**: the baseline trajectory is driven by many uncertain factors
- **Definition**: which existing policies and effort are to be included in the baseline?
- **Mitigation and Development**: for developing countries issues of poverty, inequality, and education goals need to be traded-off against mitigation goals. Are development goals and aspirations met in the baseline?

This study deals mainly with the first item: Uncertainty. A central purpose of policy research and policy analysis is to help identify the important factors and the sources of disagreement in a problem, and to help anticipate the unexpected. And yet many policy studies are carried out with very little emphasis on the underlying uncertainty that policy decisions would be sensitive to.

Energy-economic and environment (E3) models are simplified representations of the complex energy-economic and environment systems that we are part of. These models are useful in that they help to organise information about the system in a systematic way. They help decision makes and stakeholders better understand the system, both in terms of how different courses of action impact on the system and help meet objectives, and how the system responds to different uncertain and uncontrollable situations. These models can be used for projecting national baselines given input assumptions and their inherent uncertainty, provided it can be quantified.

Overall Objective

The objective of this project is to quantify the uncertainty associated with key model inputs as well as characterise arising from the structure of the model to develop a probability distribution of baseline emissions for South Africa over the 2015-2050 period. This objective is to be met in two phases. In the first phase, the most important and uncertain input parameters were selected for uncertainty analysis, and the associated uncertainty was described. In the second phase the uncertainty in inputs is propagated via an E3 model of South Africa to obtain the probability distribution for the baseline emissions of South Africa, over the period of interest. This report focuses on the second phase of the analysis.

Overview of Methodology

We stress that we are not only interested in forecasting the most likely trajectories for each of these quantities over the period 2015-2050. We are also interested in assessing the uncertainty around the most likely trajectory. Forecasting this far into the future is an extremely, perhaps impossibly, complex task. We use a combination of methodological approaches to do this, triangulating between these approach in an attempt to arrive at some kind of consensus projections.

The approach followed here is to assess uncertainty on a small number of key drivers influencing the energy system, and hence GHG emissions associated with it. We assess distributions over possible values that these drivers can obtain in the future, and pass these values to the E3 model. For each combination of possible inputs, the model returns outputs for quantities like GHG emissions. By submitting many possible inputs to SATIM, a range of possible outputs is obtained. This process takes the form of a Monte Carlo simulation.

Scenarios

We do this for one “no mitigation” scenario for South Africa but for two different scenarios of mitigation outside of South Africa:

1. Little/no international mitigation
2. Ambitious international mitigation

The international mitigation scenarios are made explicit because of the nature of the data we draw on for global energy commodity prices and solar technology costs. See section xxx for more details.

Uncertain Key Drivers

We assess uncertainty on seven key drivers:

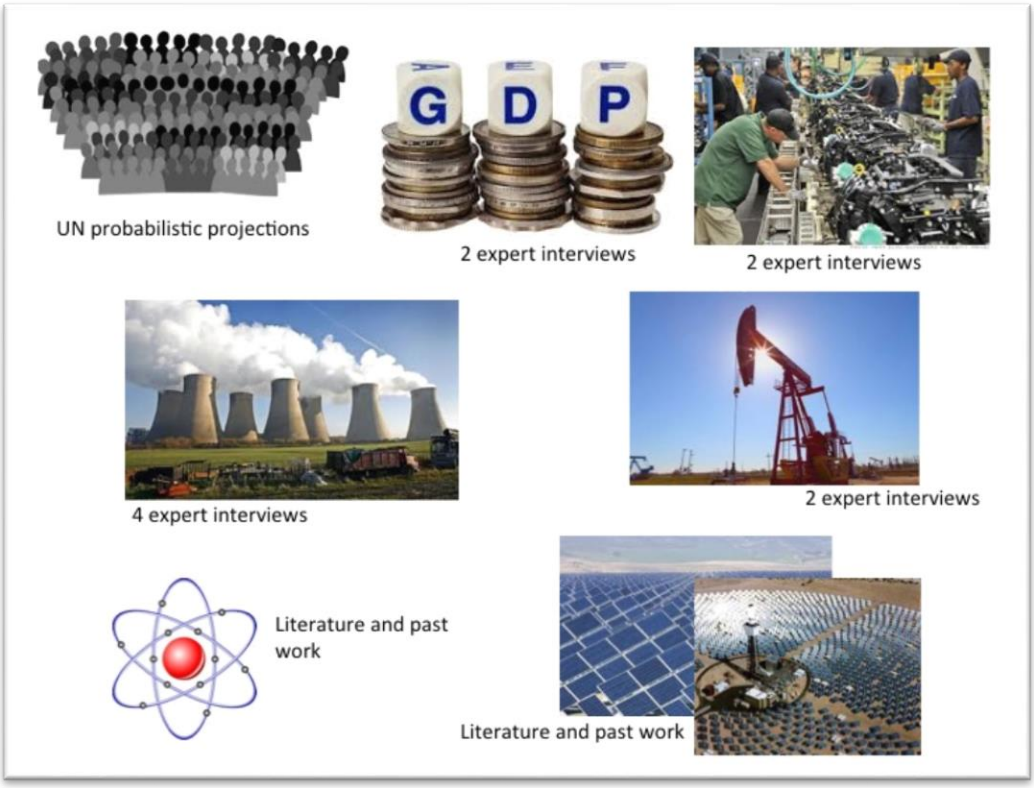
- Population growth
- GDP growth
- GDP distribution (tertiary vs other sectors)
- Domestic Coal prices (Central Basin and Waterberg)
- Overnight investment costs of Nuclear
- Overnight investment costs of Solar power (2 global mitigation scenarios)
- International Coal, Oil and Gas prices (2 global mitigation scenarios)

Expert Elicitation

Elicitation of probability information from experts via structured interview techniques is an established method in complex or long-term forecasting, for which quantitative models are unavailable or extremely unreliable. We make substantial use of this approach. We developed an interview protocol based on the the 3 protocols described in Chapter 7 of "Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis" (the Stanford/SRI protocol, the authors' (Morgan and Henrion's) own protocol, and Wallsten/EPA protocol; with some refinements to take into account more recent evidence on probability judgments.

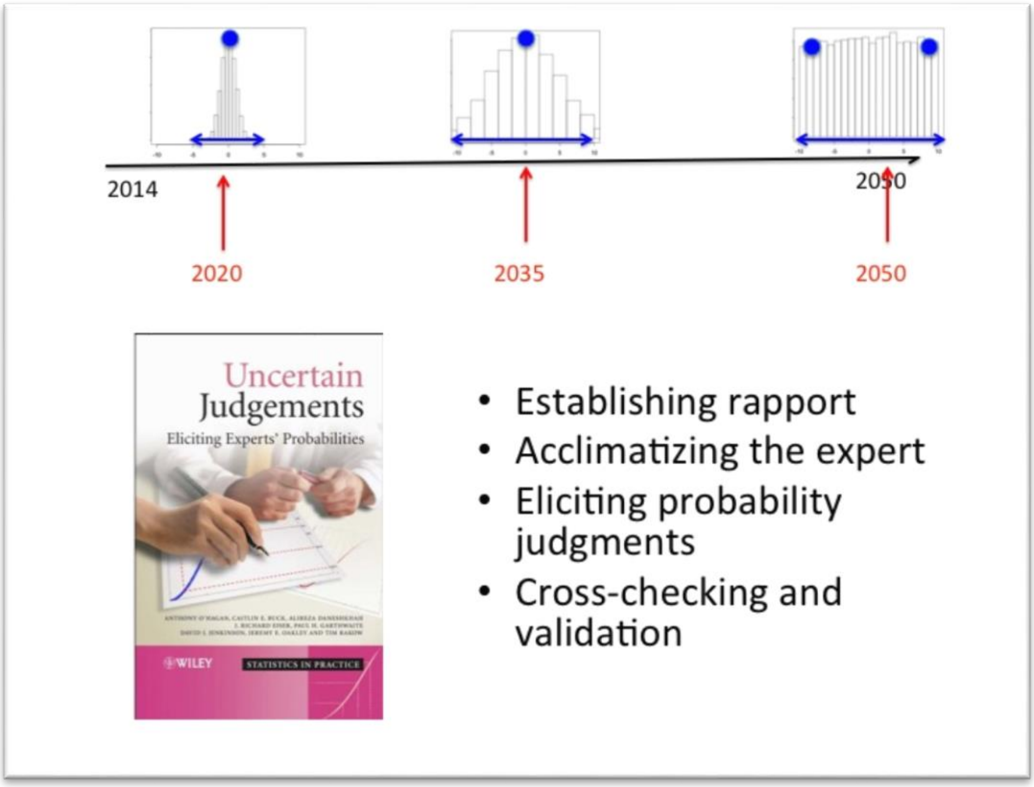
The protocol is divided into four stages: establishing rapport with the expert; acclimatizing the expert to the elicitation problem; eliciting the expert's probability judgments; and cross-checking those judgements to verify that they are both consistent and accurately reflect the expert's beliefs. Although these stages are executed in a sequential order, it should be stressed that there is in most cases substantial back-and-forth between the stages. The full protocol is given in an appendix.

Where available, the local interview were supplemented with results obtained from the literature.



For each of the seven key drivers, forecasts are established in the following way:

- Population growth: a Bayesian probabilistic projection model developed specifically for UN forecasts. In the South African case, special allowances must be made for high HIV prevalence. These and other developments are described in …
- GDP growth: interviews and related quantitative assessments made by two experts
- GDP distribution (tertiary vs other sectors): interviews and related quantitative assessments made by two experts
- Coal prices: interviews and related quantitative assessments made by four experts, as well as external information supplied to us
- Gas prices: interviews and related quantitative assessments made by two experts
- Nuclear costs (overnight investment costs): a combination of local and international literature. Elicitations and quantitative assessments of costs have been conducted for over 40 experts in the US. As relatively few nuclear plants have been constructed, particularly recently, we felt this data could be transplanted to a South African context. We modify these assessment slightly using local literature on current estimated costs.
- Renewable costs (overnight investment costs): similar to the nuclear case, we use a combination of expert assesments conducted in the US and reported in the literature, and local knowledge.

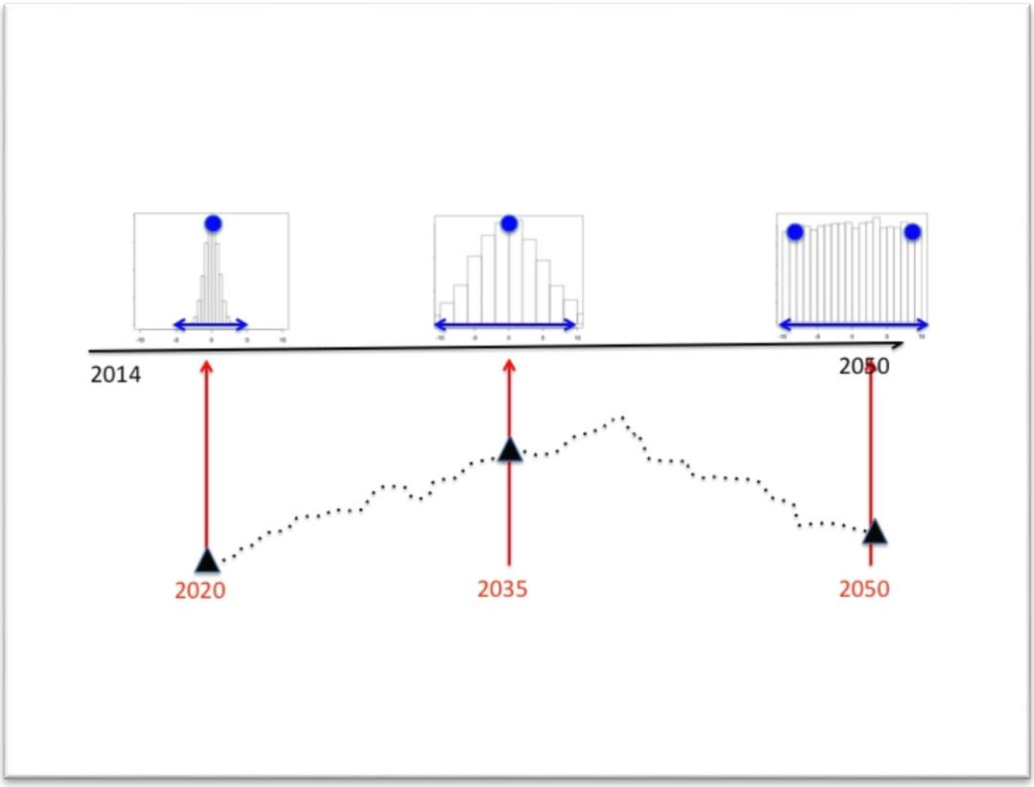


Even with a structured interview approach, the elicitation of values from experts is a daunting prospect. Time constraints prevent us from assessing uncertainty continuously from 2014 to 2050. Therefore, we assessed distributions of possible outputs at three distinct time periods: 2020, 2035, and 2050. In each case, experts had to provide qualitative reasons justifying their quantitative choices. These story-lines will be made available in the final report; one is given in an appendix to the current document.

For simplicity, we assessed three-point distributions at each of the three time points, representing the perceived minimum, mode, and maximum at that point in time. Since it has been well established that people are typically conservative when making extreme judgments, the minimums and maximums should be interpreted with this in mind i.e. not as absolute extremes but rather as plausible "unexpectedly large" and "unexpectedly small" values.

Correlational information (i.e. whether periods of high values should be followed by periods of high or low values) was also assessed in a qualitative way and built into the resulting computations.

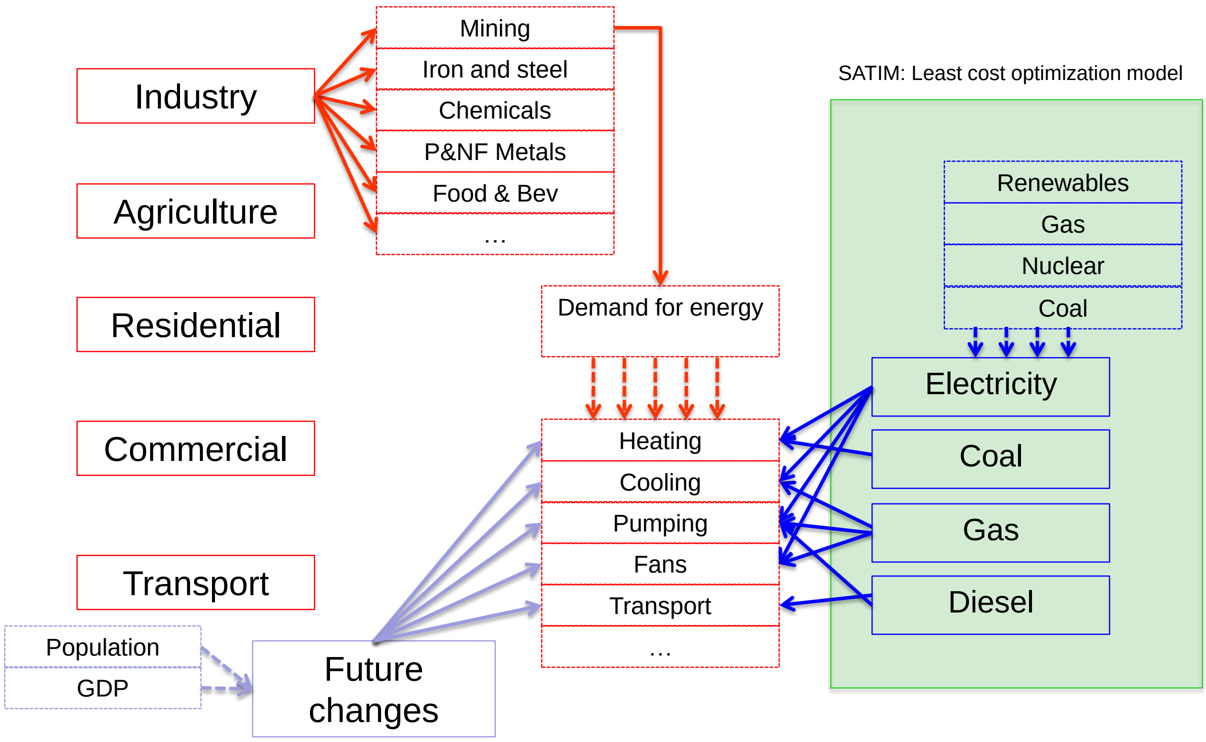
Where multiple experts were consulted, estimated had to be aggregated over the experts. Because we deal with relatively few experts, we preferred a simple additive aggregation model, weighing each expert's opinion equally. We perform some sensitivity analysis around this important assumption.



Because the E3 model requires inputs at regular intervals (annually or 5-yearly), we needed to interpolate between the three time points at which we assessed information from our experts. We developed a number of relatively simple but innovative tools for performing this interpolation. Most simply of course, intermediate values can be found by linear interpolation. This, however, overstates the stability of the underlying processes, which may have unanticipated consequences for subsequent modelling. As a result, we use a random-walk like approach in which end-points (the values generated at 2020, 2035, and 2050 from the probability distributions assessed by experts) are joined by a process which contains a linear drift but may also jump up or down within some specified limits.

In summary, for each of the seven key drivers, we (a) obtained a qualitative story about the influences on that driver, currently and in the future, (b) elicited or otherwise obtained the probability distributions assessed from experts or from the literature, for the periods 2014, 2020, 2035, 2050, (c) randomly generated values at each of these time periods; (d) interpolated between these points to obtain a simulated time series for the period 2014-2050; (e) repeated steps (c) and (d) until we had constructed a set of 1000 time series, each representing a possible trajectory that the key driver could take. These trajectories are shown for some of the drivers below. Red lines indicate lower and upper 95% trajectories (i.e. trajectories such that there is only a probability of 0.025 of being below or above these); blue lines indicate 80% trajectories, and green lines indicate the modal trajectory.

E3 Model: South African TIMES Model: SATIM



The ERC's SATIM model provides a comprehensive modelling platform for identifying the combination of fuels that optimally (in terms of cost) satisfies a given demand for energy services. That is, given a set of inputs (energy demands) it produces an optimal set of outputs (supply levels of different fuels, and related infrastructure). From these outputs, key metrics such as GHG emission can be quantified, also from within SATIM.

In this paradigm, uncertainty about outputs like GHG emissions are primarily driven by uncertainty about inputs i.e. uncertainty about the demand for energy services. This is turn is driven by uncertainty about a smaller number of key variables influencing the demand for energy services – for example, population, economic growth, etc.

SATIM is an inter-temporal bottom-up partial equilibrium optimization energy-sector model of South Africa. SATIM uses linear or mixed integer programming to solve the leas-cost planning problem of meeting projected future energy demand, given assumptions about the retirement schedule of existing infrastructure, future fuel costs, future technology costs, and constraints such as the availability of resources. SATIM can either run in 'full sector' mode (SATIM-F) or in 'supply only' mode (SATIM-S and SATIM-el for electricity supply only). In SATIM-F, used in this project, demand is specified as useful energy demand (e.g. demand for energy services e.g. cooking, lighting, process heat), and final energy demand is calculated endogenously based on the optimal mix of demand technologies. This more detailed model allows for trade-offs between demand and supply sectors, explicitly captures structural changes (different sectors growing at different rates), process changes, fuel and mode switching (in the case of transport), and technical improvements (mainly relating to efficiency gains). The result of the optimisation is both the supply and demand technology mix (capacity, new investment, and production/consumption) that would result is the lowest discounted system cost for meeting the project energy demand over the planning horizon subject to imposed constraints. More detailed documentation of SATIM can be found at:
http://www.erc.uct.ac.za/Research/esystems-group-satim.htm.

Results Part 1: Inputs

Sample Data from literature

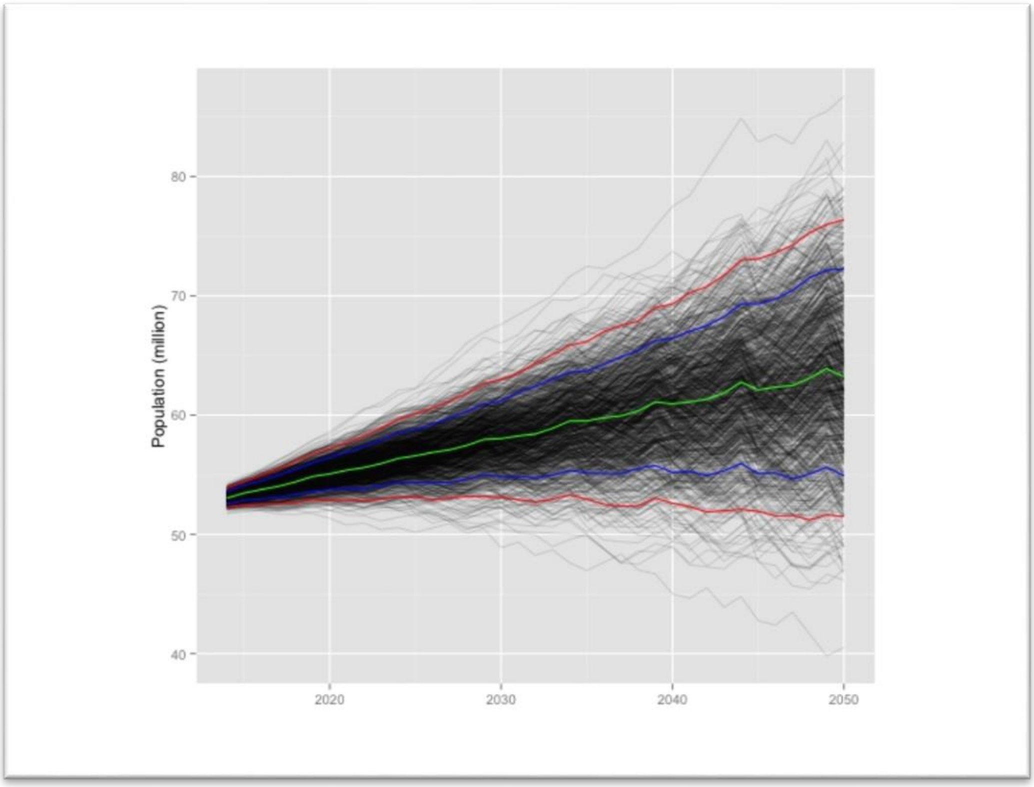


Figure 1 Bayesian probabilistic projection of population of South Africa

Figure 1 shows the Bayesian probabilistic projection of population of South Africa using the model developed specifically for UN forecasts, for 1000 simulations. The mean, shown by the green line, reaches around 64m in 2050 with a 10% standard deviation. The blue and red lines show the 80% and 95% percentiles.

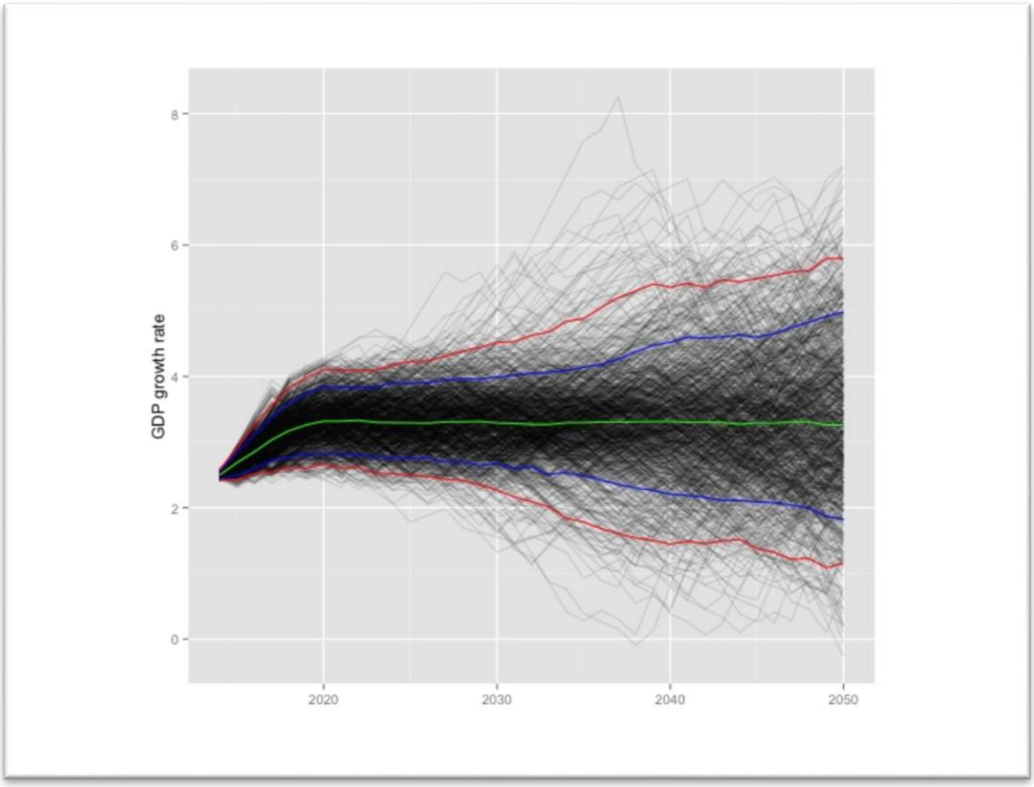
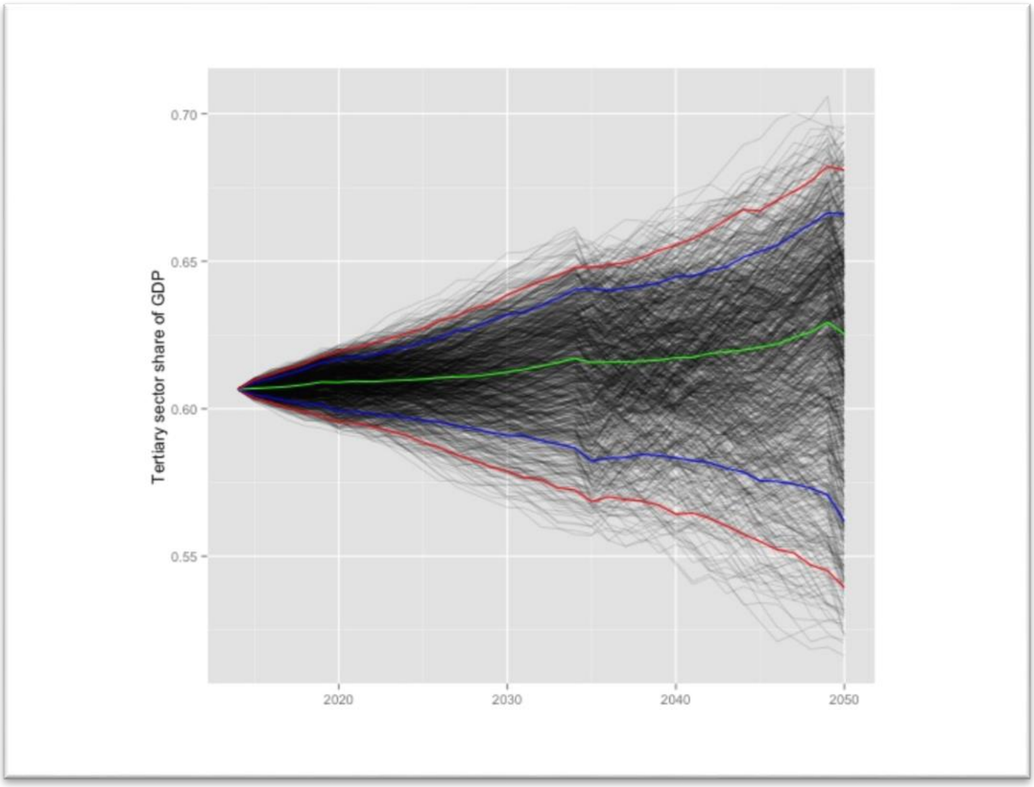
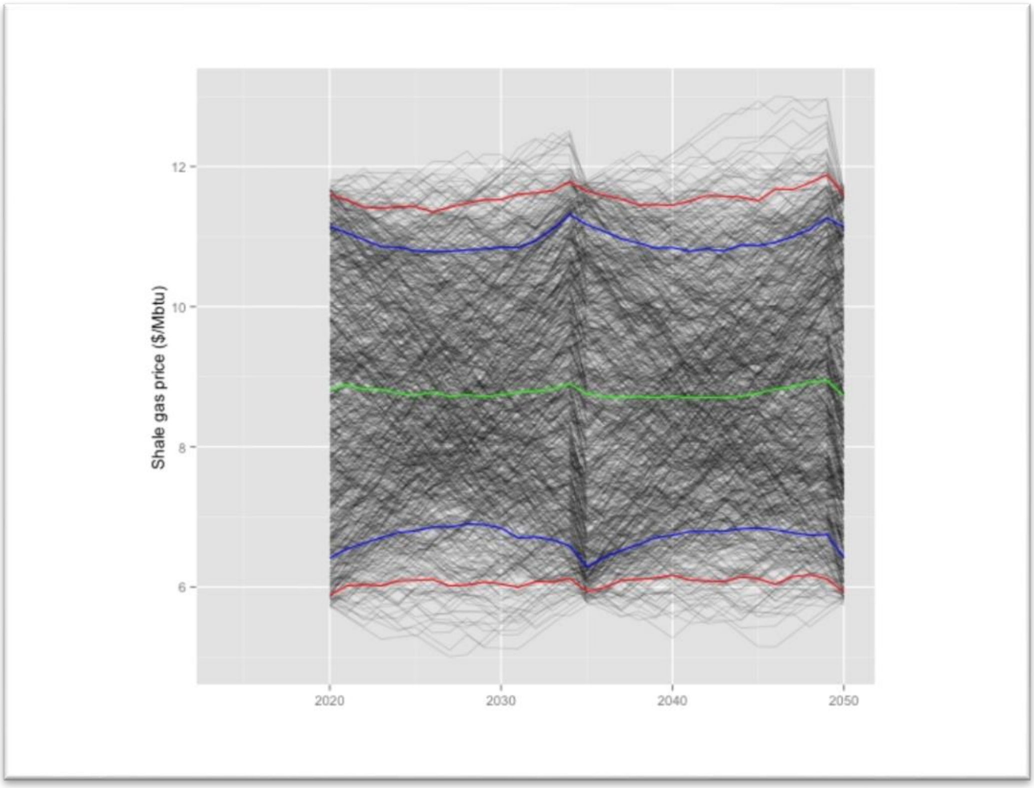


Figure 2 Projection of GDP growth rate based on elicited experts

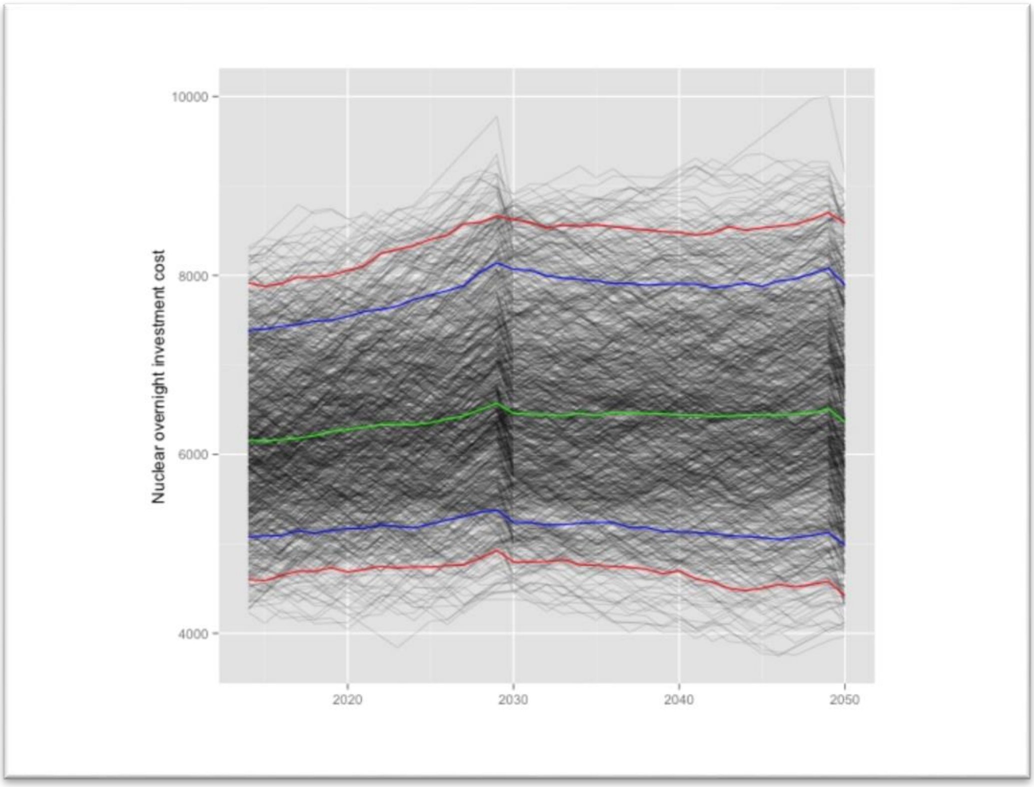
Figure 2



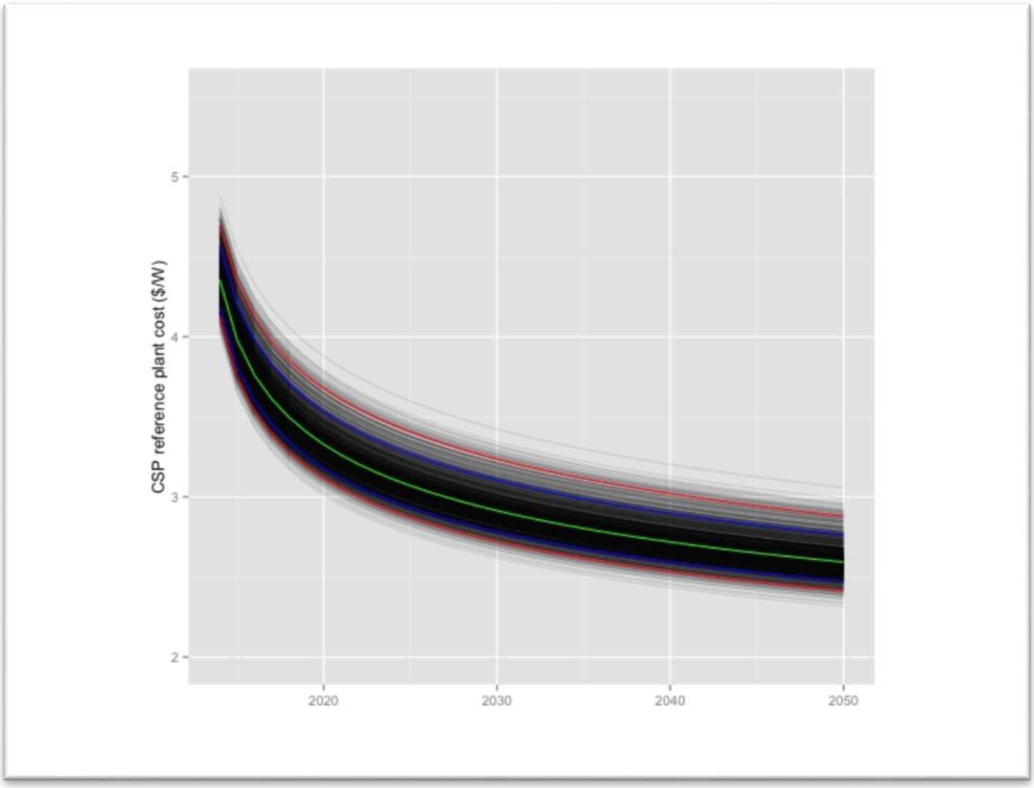
0.70
0.65
0.60
0.55
Tertiary sector share of GDP
2020
2030
2040
2050



12
10
8
6
Shale gas price ($/Mbtu)
2020
2030
2040
2050



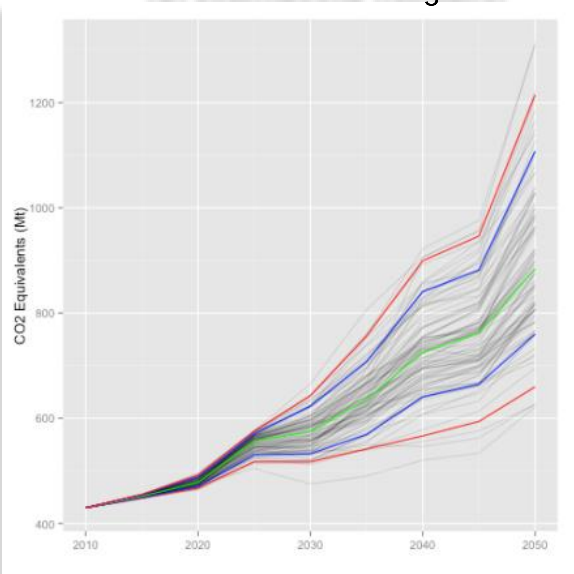
Nuclear overnight investment cost
10000
8000
6000
4000
2020
2030
2040
2050



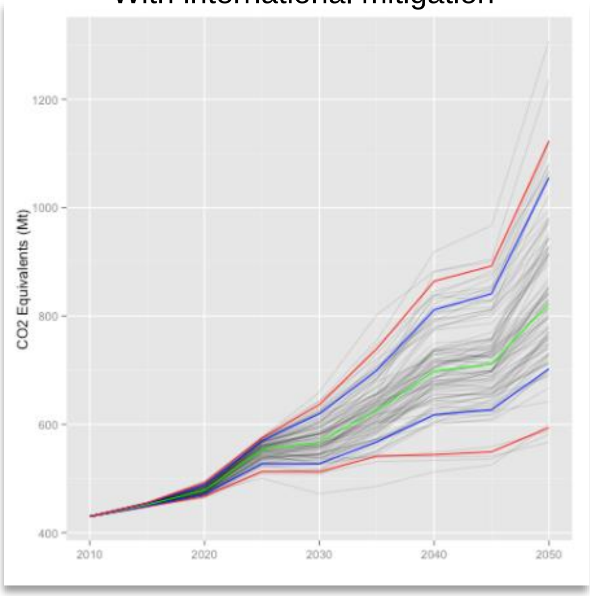
CSP reference plant cost ($/W)
5
4
3
2
2020
2030
2040
2050

Results Part 2: Outputs

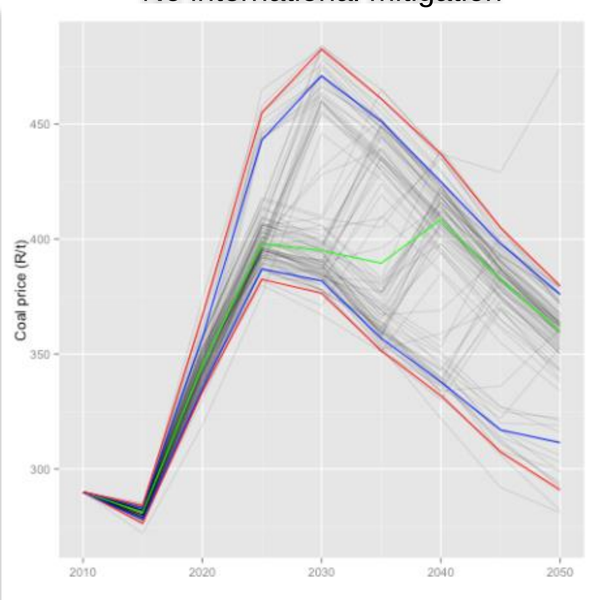
No international mitigation



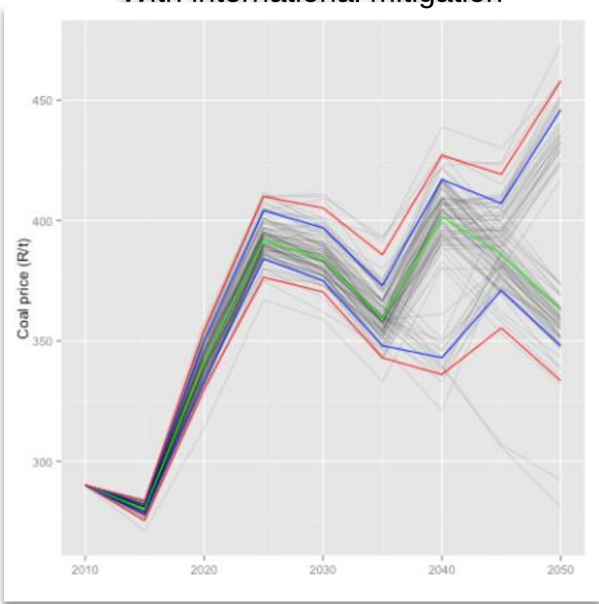
With international mitigation



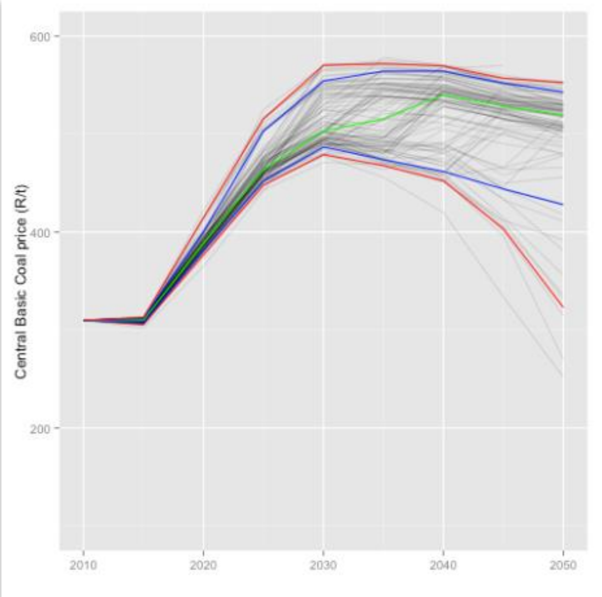
No international mitigation



With international mitigation



No international mitigation



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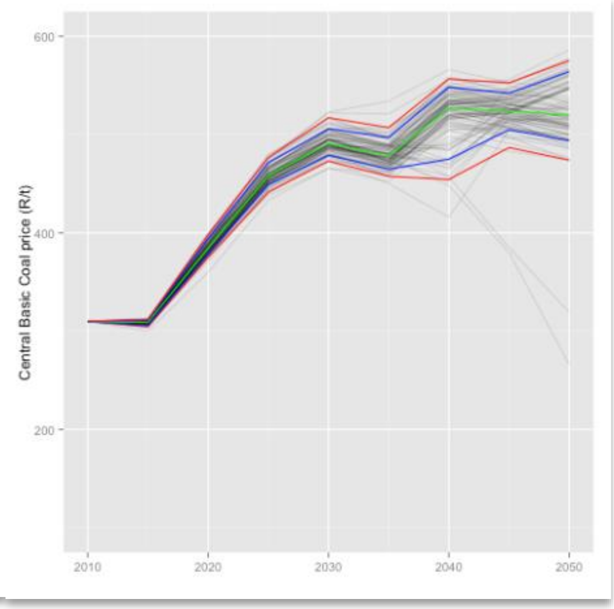

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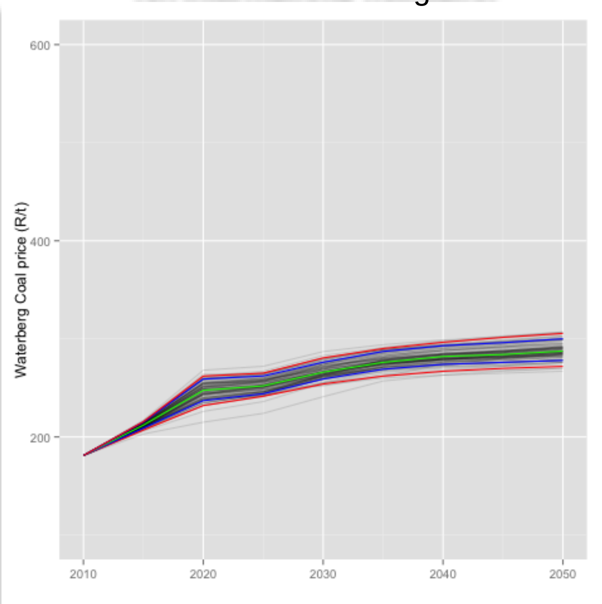
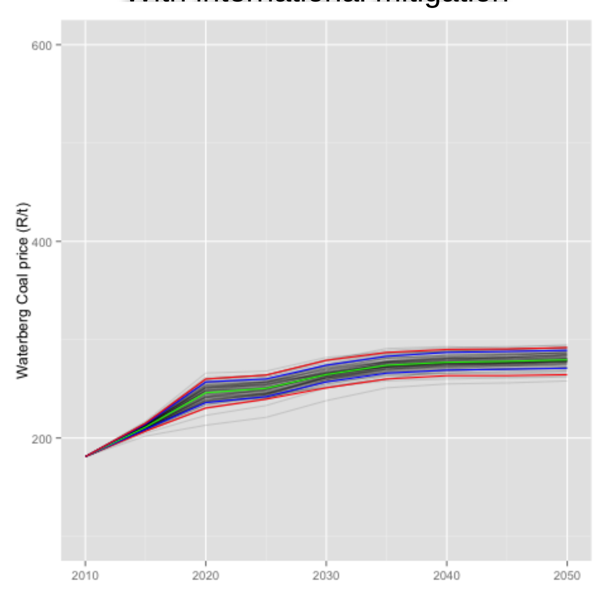
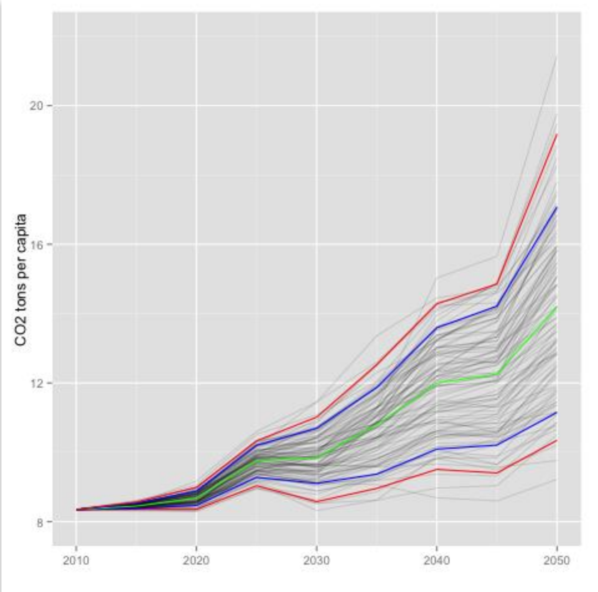


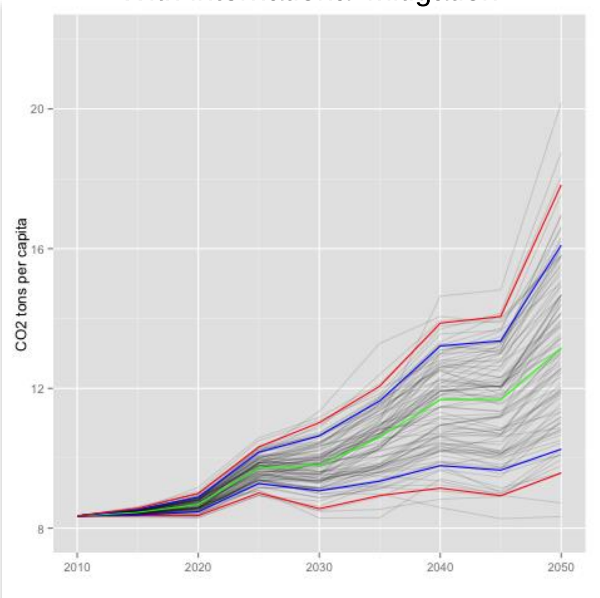
With international mitigation



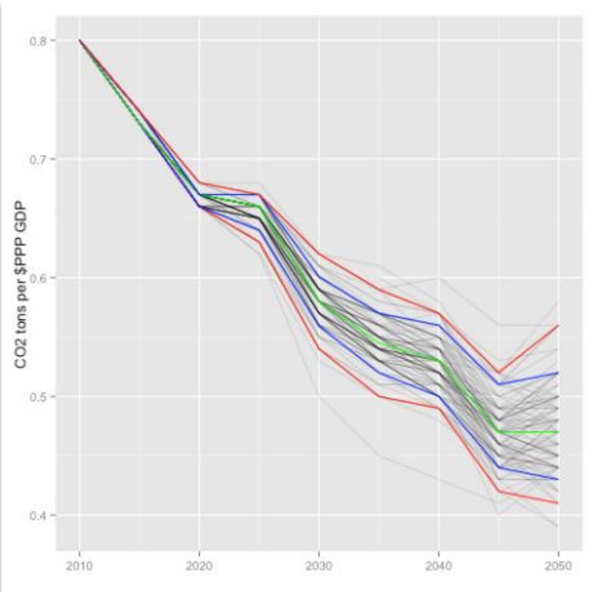
No international mitigation



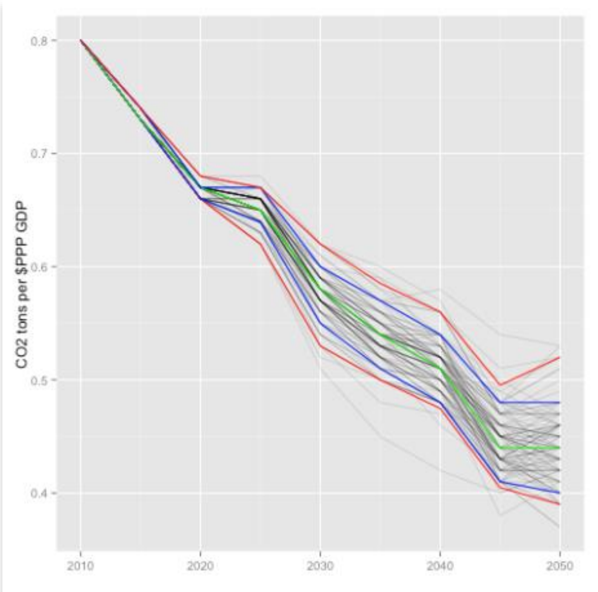
With international mitigation



No international mitigation



With international mitigation



Conclusions

How efforts to characterise the uncertainty in the baseline (and mitigation) scenarios are going to support the policy process

- Projections (if single lines) often misinterpreted as predictions
- Quantifying uncertainty makes explicit the implications of different assumptions
- Can reduce fear of ‘gaming’ of national baseline
- A central purpose of policy research and policy analysis is to help identify the important factors and the sources of disagreement in a problem, and to help anticipate the unexpected
- Decision making around climate and energy policy, and infrastructure planning that takes account of uncertainty is better than decision making that doesn’t

APPENDIX A: Suggested protocol for probability assessments

This is largely a summary of the 3 protocols described in Chapter 7 of "Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis" (the Stanford/SRI protocol, the authors' (Morgan and Henrion's) own protocol, and Wallsten/EPA protocol; with some refinements to take into account more recent evidence on probability judgments.

The protocol is divided into four stages: establishing rapport with the expert; acclimatizing the expert to the elicitation problem; eliciting the expert's probability judgments; and cross-checking those judgements to verify that they are both consistent and accurately reflect the expert's beliefs. Although these stages are executed in a sequential order, it should be stressed that there would probably be substantial back-and-forth between the stages.

STAGE 1: Establishing rapport

The aim here is simply to introduce the elicitation team to the expert and provide an overview of the reason for the elicitation and the underlying problem at hand.

- Introduce the elicitation team
- Briefly explain the TIMES/MARKAL model and the projections to be made
- Explain the uncertainty around the inputs to the model, and hence the need for probabilistic forecasts.
- Explain the quantities that the expert has been asked to assess, and reasons why the expert has been asked. The expert may have some input into the unit of measurement, if this will make his or her task easier and is possible without creating ambiguities for the model.
- Clearly state that the difficulties of projecting so far into the future are recognized, and that these uncertainties will necessarily be large, but that this is better than doing no formal analysis at all.
- State that if the expert at any stage truly feels unable or uncomfortable making numerical probability judgements, this can be discussed as it arises – other coarser techniques are available in the extreme case that no judgment can be given.
- Describe the problem of motivational biases, and assess whether this may be a problem here (some of these may be discussed directly with the expert, others are more difficult to assess):
    - Are there any conflicts of interest that may lead the expert to want to influence any policy decisions that may arise from this work?
    - Will the expert be evaluated in any way based on his or her responses?
    - Does the expert have a strong desire to appear knowledgeable?
    - Could the expert be reluctant to modify his or her existing views in the light of the evidence provided with the elicitation task (see below)? This could happen if the expert has made strong public claims.
- Attempt to remedy motivational biases where possible. Since there is no real incentive structure here, our only real recourses are disaggregating the quantity to be assessed, or changing experts.

STAGE 2: Acclimatization

The aim here is to get the expert to think critically about the problem at hand, and to explicitly express their views, albeit in a qualitative way. These views, which may well be at least partially constructed or modified as part of the process, will form the justification for the later quantitative elicitation.

- Provide the expert with a summary document containing an overview of the literature (to read before interview). Morgan and Henrion, for example, provided a 1-page summary of 40 important papers; we would probably give much less, but enough to give an idea of what the main issues are and the consensus (or lack of consensus) on these.
- In the interview, briefly review the document and discuss with the expert, leading into asking the expert how they would go about making judgements about the quantity in question.
- Encourage broad thinking and alternate viewpoints. Get experts to consider and then try to explain some unusual hypothetical values – to "invent scenarios". For example, they might be asked "what kinds of conditions would make the oil price R100 000 per barrel in 2040?"
- Identify and make explicit any assumptions (conditioning factors) that the expert is using when making judgments. If almost any outcome is possible, it may be necessary to fix some of these in the elicitation phase (can elicit at a variety of fixed levels though).
- Provide a summary document on heuristics and biases involved with probability judgment. Morgan and Henrion use a 60-page document (!), but we would again use something much shorter. Make the expert familiar with the dangers of subjective assessment, particularly (a) overconfidence; (b) anchoring; and (c) availability (especially confusing probability of an outcome with its severity).
- In the interview, briefly review the document and discuss with the expert. We can perform a few test problems to illustrate these biases if desired.

STAGE 3: Elicitation

The stage contains the formal/quantitative assessment of probabilities.

- Ask expert for some extreme upper and lower values.
- Ask expert to think of scenarios that would result in values more extreme than the extreme values just given. Can ask the expert to imagine they have returned to the field after a long absence, to find the true value outside of their stated bounds – how could this have happened? The point of this and the previous step is to combat overconfidence (too narrow bounds on forecasts) and anchoring to a central value.
- Take a set of values (quantiles) and use a probability wheel to assess their likelihood
    - Start with a fairly unlikely value (not a central value)
    - Start with an easy question on the probability wheel: make the area of the relevant colour much larger or smaller than the expert's prospective final answer.
    - Get justifications for the judgements wherever possible.
    - Do not assess in ascending or descending order; jump around.
    - Plot responses on CDF and note/address inconsistencies by asking additional questions where needed, but do NOT show the CDF to the expert at this stage.
    - Collect more points than you need; check consistency.
    - Use alternate question formats (lotteries, etc) if necessary.
- Use the interval technique to generate medians and quartiles, use these as a consistency check.

STAGE 4: Verification

The aim of this stage is to present the expert with their assessed probability distribution, and to check that this reflects their views accurately. If not a return to the previous stage (or further back) is required.

- Show plotted PDF and CDF to the expert and discuss, particularly any inconsistencies.

- Construct probability statements from the PDF/CDF and check with the expert if these are accurate in reflecting his or her views. Asking questions in the form of monetary bets to be made may be helpful here.
- Revise and reassess distributions as necessary.

Documents to be sent to expert before assessment

1. Document summarizing the TIMES/MARKAL model. Rough length 5-10 pages.
2. Documents summarizing the available literature and points of view, for each of the quantities to be assessed. Rough length 10 pages.
3. A document summarizing the heuristics and biases literature. Rough length 5 pages.

APPENDIX B: TYPICAL OUTPUT EXTRACTED FROM EXPERT INTERVIEW

Historical developments in coal mining in SA

Discussion began with an overview of the history of coal mining in South Africa, this being relevant to the current state-of-affairs and future prospects. Key elements of this history are:

- *Mine-Power station pairing*: in the first wave of developments in the 1970's, coal mines were tied geographically and economically to power stations (e.g. Duvha, Hendrina, Komati). Under this arrangement, transportation costs are small.
- *Quality matching*: power stations were purpose-built to use the coal quality provided by the satellite mine. Most of the coal in the Central Basin is of relatively low quality, with quality being highest in the western part of the basin.
- *Capital financing via Eskom contracts*: capital for mine development was essentially financed by contracts between Eskom and mine owners.
- *Stand-alone HG export mines*: in a second wave of development, the growth of an export market for high-grade (HG) coal led to the development of stand-alone export-focussed mines i.e. not tied to a power station, nor focussed on the domestic market.
- *The effect of washing*: coal can be "washed" – a process that shifts the distribution of coal quality, with some proportion of coal becoming higher quality and some proportion becoming lower quality. The precise proportions ("yields") and quality shifts are complex and mine-specific, but the net effect is that sometimes coal below export-grade be washed to export-grade, with the remaining lower-quality coal still suitable for power generation. Thus, some export-focussed mines can sell their secondary output ("middlings") to Eskom for power generation (sometimes this quality is too low and then is simply treated as waste).
- *Rationalising process groups HG and LG mines*: the above-mentioned washing led to a mines grouping paired (power generation) coal-mines and export-based colleries by (roughly) geographical regios, in a bid to optimise operations. Thus, some coal at export-focussed mines was exported and the remaining middlings could augment the stock at the dedicated paired coal-mines. This introduced significant transportation costs to move coal between mine and power station by rail or road. Optimisation focussed on matching middlings with power stations quality requirements and minimizing the associated transportation costs.
- *Fixed long-term Eskom contracts*: the rationalisation process included the renegotiation of contracts with Eskom. The result was a series of fixed long-term (20-30 year) contracts – export prices are allowed to vary of course, but each mine agreed to provide a certain quantity at a certain price. This was done on a "cost-plus" arrangement – the agreed-upon price being the cost-of-production plus a relatively small mark-up. Under this arrangement mine development was viewed as a relatively low-risk, low-return investment. As export prices rose, this gave the appearance of a mine's export product subsidising the LG coal provided to power station. Almost all of these contracts end within the next 5-15 years (e.g. Duvha 2030, Kriel 2030, Matala 2030, Hendrina 2018)
- *Demand for LG coal from export market*: more recently, India and China have demanded LG coal (in the 18-22MJ range) for use in their own power stations. Thus, for the first time Eskom must compete with the export market for its product. This also creates an

additional layer of complexity in the washing/export/domestic use optimization process.

The current situation

- Coal supplies at existing quality levels at the paired mines are running out. Upgrades to the power stations are necessary to keep them running, but these are hugely costly (e.g. R25 billion for Kendal).
- Mining companies will only make necessary huge capital investments if they are confident of getting acceptable returns on their investment. With export prices unlikely to go up dramatically, the most likely source is through long-term contracts with Eskom at acceptable rates of return. What is "acceptable" is determined by what the mining companies could get elsewhere – in other mining industries, in other parts of the world.
- If an investment is made, costs into power station are likely to rise substantially to recover the capital cost.
- At present Eskom buys and transports coal from many relatively smaller mines to power stations to ease current power generation problems. This is unsustainable: transportation costs are enormous, and administration/logistics is difficult. It also fails as a potential long-term solution, as most coal is already committed, and high transportation costs can only be defrayed by massive investment in improved rail infrastructure.
- Eskom's strategic dilemna is how to balance short-term contracts, which must pay a premium in order to compete with the LG export price, and are thus more expensive in the long run and subject to fluctuations in that market, and long-term contracts, which commit huge amounts of capital.

The future I: Coal in the Waterberg

- A vast amount of coal sits in the Waterberg, but mining operations here will be more difficult and hence expensive than historically in the Central Basin.
- Geologically, the coal deposits consist of an upper sequence of perhaps 70mt but with highly stratified "barcoded" deposits, with perhaps 25-30% yield. Below this is a second much larger sequence, but this will require deep and hence even more expensive mining activity.
- Coal will need to be transported much further, for power generation (in existing power stations) and export, adding to the expense.
- Suggested costs of perhaps R600/t for 22-23 MJ coal without capital and transport costs, and R850/t with these costs. Transport costs are estimated at around R200/t.
- A firm demand can be created for Waterberg coal by long-term fixed Eskom contracts. If producers could get R600/t, they will mine. Thus the essential issue is not whether there is enough coal, it is whether the price needed to leverage the coal out of the ground is politically and economically feasible.

The future II: Alternative sources of coal

- Older minedumps increasingly reprocessed for domestic coal

- Briquetting also able to make use of a potential source of 100mt
- All depends on the costs of reprocessing and price of the end-product

The main components/drivers of the price of coal

- Logistics
    - Transportation costs (mainly)
- Labour costs
- Energy inputs
    - Diesel
    - Electricity
- Capital and return-on-capital
- Environmental and social costs
    - Acid mine drainage
    - Royalties/Licensing
    - Carbon tax
- Low-grade export market
    - Determines lower bound on domestic price
- Other costs
    - Engineering costs
    - Replacement capital
    - Housing
    - Equipment
    - Other

Further notes on drivers

<u>Notes on logistics</u>
Water costs were viewed as relatively unimportant, particularly in the Central Basin but even in the water-scarce Waterberg. Water will need to be brought in, but this would typically add only a few R/t to the price.

<u>Notes on labour costs</u>
Currently labour costs rising faster than inflation, which is unsustainable in the long run. In the Central Basin there is little opportunity for technological improvements to reduce labour costs. Some reductions in labour costs may be possible in the Waterberg as this area would employ some combination of open pit and long haul mining.

<u>Notes on energy inputs</u>
Main energy inputs to coal mining are equipment and facilities fuelled by diesel or electricity.

<u>Notes on capital and return-on-capital</u>
Typical long-term Eskom contracts offer high initial returns (to compensate for capital investments), reducing over time as a function of PPI (0.5%?) and increasing as a function of an inflation-related index (typically, 50% inflation, 30-40% Eskom's cost of coal, 10% fixed).

Opinions differ but in the future Eskom would probably need to offer in the region of 10-15% return on long term contracts to compete not only with the LG export market but also with copper mines and other investment opportunities.

<u>Notes on environmental and social costs</u>
Broken down into:

- Acid mine drainage
- Royalties
- Carbon tax

Acid mine drainage/water treatment
Mining companies are legally compelled to perform certain activities when shutting down a mine, including closing off of holes, demolishing certain structures, etc. The cost of this is typically around R4b. Cash provision must be made for these remedial costs. In addition, water sources must be rehabilitated – de-acidified and treated for salts. The cost of this is much higher – R20-25b – but does not currently need a cash provision. Mining companies must keep it on the balance sheet (as a liability?), but upon closing a mine will declare bankruptcy: the assets of the mine will never be sufficient to cover this amount. There is uncertainty about whether legislation might be tightened to include a cash provision. This would increase the cost of coal substantially.

Royalties
Current legislation levies a licensing fee/royalty depending on the function of a mine. Paired power-generation mines pay of order of 1%, export-focussed mines pay something like 6-7% in principle, although in practice often lower. In other countries at other times, a case has been made that the mined land belongs to the country itself, and this used an argument to increase royalty rates. In Zambia and Columbia royalties reached approximately 15% at their peak, although there were unique circumstances (e.g. use of land historically owned by a particular group).

<u>Notes on the HG export market</u>
Coal mines are traditionally large, long-lived, low cost assets. Export-focussed coal mines play a volatility game, make large profits when conditions are favourable and hoping to be sufficiently large to have the resources to wait out downturns in the export market longer than competitors.

<u>Notes on the LG export market</u>
It is unavoidable that Eskom will compete with the LG export market for its coal. Eskom can offer the benefit of reduced risk through a fixed price, a stable relationship, and a reduced reliance on transportation. The LG market also typically depends more on relationships that must be cultivated over time; the HG market is a commodities market, executed by traders. If Eskom offers the LG export price, belief is that all producers would sell to Eskom. However if the LG export price is higher, Eskom will need to pay some premium to mines to compensate for the lost opportunity cost.

Another issue for the LG export market is transportation via the Richards Bay terminal. The current situation does not favour smaller producers ("juniors"). Ships transport of order 100 000t, which might take a small mine 6 months to produce. Management of small lots of coal at the RBCT is difficult, so restrictions are set on what and when producers can send. This situation is likely to continue.

Future scenario notes

	2014			2020	2035	2050
	% of total cost	inferred cost	Notes	Notes	Notes	Notes
Logistics	10-15%	20-45	fair amount of road transport (trucks)	no change	massive changes required to transport infrastructure to maintain Central Basin power stations	transporting coal from Waterberg will result in higher transportation costs
Labour costs	30-40%	60-120	currently rising at inflation + 1-2%	no change	above inflation rise not sustainable, must flatten out at some stage probably in this period	potential for reduction due to different technologies in the Waterberg, perhaps even to 2014 levels
Energy inputs	15-20%	30-60	main inputs are diesel and electricity, current cost split is 50-50	no change (same mining methods)	no change (same mining methods)	Waterberg mining probably requires more diesel, relatively little opportunity for electrification. Diesel relatively expensive (currently)
Return on capital	3%	6-9	currently low as mines are in the latter part of their Eskom contracts (contracts reduce over time 1/2%PPI - see notes)	estimated 60% of current mines out of business without huge capital expenditure; those mines will require of order 10-15% ROC	by this time all current mines out of business without huge capital expenditure; those mines will require of order 10-15% ROC	renegotiated mines (2020-2035) will be in same situation as current mines now ("low ROC"); long-term Eskom contracts in Waterberg based on "inflation-plus" costs. Net effect: potentially lower ROC
Environment and social: acid mine drainage	0%	0	nothing currently - see notes	if legislation enacted to force mines to set aside money for these costs, will dramatically increase cost of coal	more likely that some form of legislation is in place	even more likely that some form of legislation is in place
Environment and social: royalties	1-3%	2-6	depends on mines purpose but relatively low,	potential for government to aggressively seek out	more likely that some form of legislation is in place	even more likely that some form of legislation is in place

			typically - see notes	greater royalties			
Environment and social: Carbon taxes	0%	0	nothing currently - see notes	also potential for legislation during this period, would also increase coal cost	more likely that some form of legislation is in place	even more likely that some form of legislation is in place	
Other	19-41%	38-123	currently rising at inflation + 4%	current levels also not sustainable but would probably rise at inflation + 1-4%	would need to stabilize over this interval back down to inflation + 0-1%		
LG export market	n/a	primarily sets lower bound on coal not tied up in LT contracts	LG export market affects primarily the price of coal on short-term contracts (i.e. coal Eskom has not "locked in" on a fixed long-term "cost-plus" arrangement	LT-ST split roughly 80:20. For the 20%, Eskom pays an uncertain premium - see attached calculation	Central basin still predominates industry, with some contribution from Waterberg.Central Basin tends to ST, Waterberg to LT. Hence, LT-ST split could be 60:40 to 40:60		Mostly Waterberg coal by now. Hence, LT-ST split could be 100:0 to 80:20
FINAL R/t	100%	200-300					

Quantitative estimates

See accompanying spreadsheet for calculation details and additional notes. Key: green background = parameter; bold underline = provided by expert, yellow = to be confirmed.

	2020			2035			2050		
PARAMETERS TO BE SET	**min**	**mode**	**max**	**min**	**mode**	**max**	**min**	**mode**	**max**
Legislated **royalties** as a % of total	**<u>2</u>**	5	**<u>8</u>**	6	**<u>8</u>**	10	6	**<u>8</u>**	10
Annual increase in **labour** costs over-and-above inflation	**<u>1</u>**	1	**<u>1</u>**	-1	**<u>0</u>**	1	-1	**<u>0</u>**	1
Annual increase in **other** costs over-and-above inflation	**<u>1</u>**	2.5	**<u>4</u>**	-1	**<u>0</u>**	1	-1	**<u>0</u>**	1
REQUIRED RETURN ON CAPITAL CALCULATION									
new required return	10	**<u>12</u>**	15	10	**<u>12</u>**	15	10	12	15
% mines affected	50	**<u>60</u>**	70	80	**<u>100</u>**	100	50	60	70
implied R/t	53	64	80	53	64	80	53	64	80
old required return	3	3	3	3	3	3	3	3	3
% mines affected	50	40	30	20	0	0	50	40	30
implied R/t	6	8	9	6	8	9	6	8	9
weighted avg	30	41	59	44	64	80	30	41	59
CALCULATION OF EFFECT OF LG EXPORT PRICE ON SHORT-TERM CONTRACTED COAL									
LG Export price ($)	**<u>70</u>**	85	**<u>100</u>**	60	85	110	50	85	120
Discount	16	**<u>16</u>**	16	16	16	16	16	16	16
Implied $/t	43	55	67	35	55	75	27	55	83

R/$ Exchange rate	10	**10**	10	8	10	12	7	10	13
Implied R/t	432	552	672	282	552	902	190	552	1082
Less rail freight	150	**150**	150	150	150	150	150	150	150
Implied LG export price to producer (R/t)	282	402	522	132	402	752	40	402	932
% of coal obtained from short-term contracts	**20**	20	**20**	**40**	50	**60**	**0**	10	**20**

	2014				2020			2035			2050		
INPUT COSTS	**Min %**	**Max %**	**Min R/t**	**Max R/t**	**min**		**max**	**min**		**max**	**min**		**max**
Logistics	**10**	**15**	25	45	**20**	33	**45**	**100**	125	**150**	**180**	190	**200**
Labour costs	**30**	**40**	60	120	64	96	127	55	101	148	**60**	90	**120**
Energy inputs: diesel	**7.5**	**10**	15	30	15	23	30	15	23	30	25	43	60
Energy inputs: electricity	**7.5**	**10**	15	30	15	23	30	15	23	30	12	19	25
Return on capital	**3**	**3**	6	9	30	41	59	44	64	80	30	41	59
Env&Soc: acid mine drainage	**0**	**0**	0	0	**10**	40	**50**	**40**	40	**50**	**40**	40	**50**
Env&Soc: Carbon taxes	**0**	**0**	0	0	**0**	3	**10**	10	**10**	10	10	**10**	10
Other	41	19	82	57	61	82	104	52	86	120	45	92	140
TOTAL (Excl. Royalties)			203	291	214	340	455	331	472	618	401	525	664
Royalties	**1**	**3**	2	9	4	17	36	20	38	62	24	42	66
TOTAL			**200**	**300**	218	357	491	351	509	680	426	567	730
			-	-									
OUTCOMES													
Final R/t (long-term contracts)					218	357	491	351	509	680	426	567	730
Final R/t (short-term contracts under LOW LG export price)					282	357	491	351	509	680	426	567	730

Final R/t (short-term contracts under MEDIUM LG export price)	402	402	491	402	509	680	426	567	730
Final R/t (short-term contracts under HIGH LG export price)	522	522	522	752	752	752	932	932	932
FINAL R/t (weighted average LT and ST)	255	371	493	411	550	695	426	579	743