Quantifying Uncertainty in Baseline Projections of CO_2 Emissions for South Africa

Activity 3 Report: Improvements made to SATIM for Monte Carlo Simulation

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ERC

ENERGY RESEARCH CENTRE
University of Cape Town

FIRM

Facilitating Implementation and Readiness for Mitigation

Introduction

Two main modifications were made to the existing South African TIMES Model (SATIM) to be able to handle Monte Carlo Simulations:

- Monte Carlo Framework development
- Reduction of Model size

Monte Carlo Framework

A Monte Carlo framework was developed around the SATIM model to handle multiple simulations. The framework was developed in the GAMS language, the same language that the TIMES model is developed in. Monte Carlo Simulations involves running the model several hundred times each time with a different coherent set of assumptions, drawn from distributions established for each of the uncertain parameters. The distributions were either established via expert elicitation or from literature. At this stage, these samples were generated either in R or in excel or obtained directly from providers of sample data (e.g. population, oil price, etc.). The samples are all stored in an excel workbook. The samples are currently fixed in that results for simulation x will always contain the same data and so yield the same result.

The process that is repeated for each simulation can be summarised as follows:

1. Read in sample data for simulation x
2. Prepare input files for SATIM
3. Run SATIM
4. Extract relevant results from SATIM, process and store

The actual GAMS code that was written to do this is in the appendix.

Reduced Model Size

The South African TIMES model (SATIM) is a full sector optimisation model which represents the South African energy sectors and subsectors – both on demand and supply side. To represent a full year where energy demand changes during different periods of the year, 20 slices of time (timeslices) are used to categorise the year and the energy profiles of each sector. However, with higher levels of resolution (more timeslices) the computing demand increases exponentially and where numerous model runs are needed for analysis the computation time is large draw back. This is a comparison of a version of SATIM where 8 timeslices are used instead of 20 in order to improve on computing time.

Figure 1 shows the demand profile for electricity in MW for the shortened timeslice profile of SATIM. This is compared with the regular 20 timeslices of SATIM as shown in Figure 2.

The SATIM model is run for a reference scenario (REF) for the model with 20 timeslices and the same scenario in the 8 time slice version (REF 8TS).

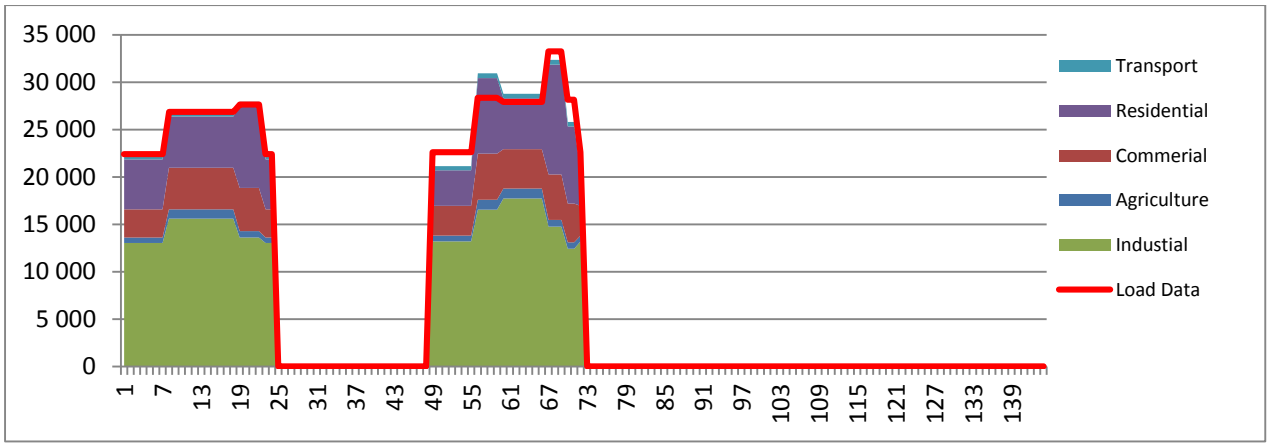

Figure 1 : The short timeslice demand profile in MW (for electricity) version of SATIM.

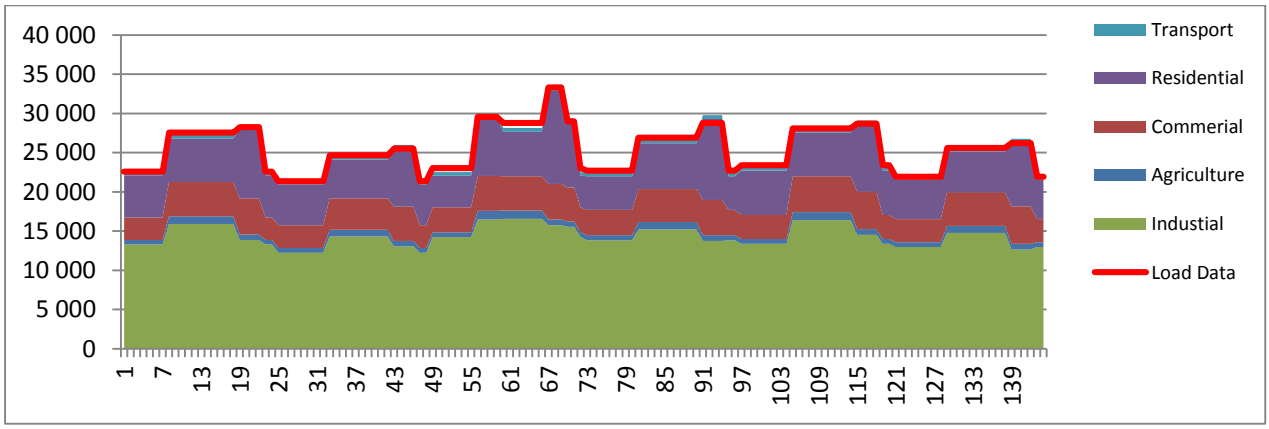

Figure 2: The 20 timeslice demand profile in MW (for electricity) in SATIM.

The power sector

The power sector new build is shown in Figure 3.

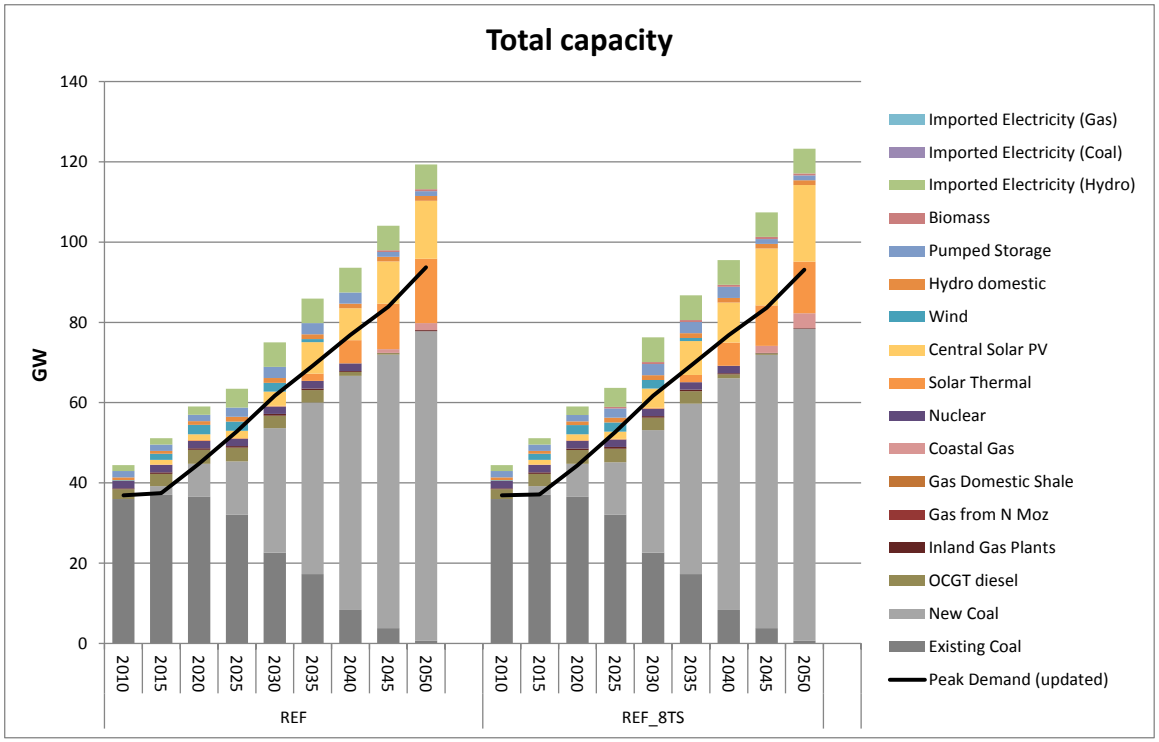

Figure 3: The new build capacities for the power sector for the regular profile SATIM and the version with shorter timeslices.

There are some minor differences between the two models. These differences are highlighted in Table 1 below.

Table 1: The difference in total capacities (in GW) between the two versions of the SATIM model.

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Existing Coal									
New Coal			0.0	-0.2	-0.5	-0.3	-0.6	-0.1	0.6
OCGT diesel									
Inland Gas Plants								0.1	-0.1
Gas from N Moz									
Gas Domestic Shale									
Coastal Gas								0.8	2.0
Nuclear									
Solar Thermal								-1.2	-3.1
Central Solar PV				0.0	1.3	0.6	2.0	3.7	4.6
Wind									
Hydro domestic									
Pumped Storage									
Biomass				0.4	0.5	0.5	0.5	0.1	
Imported Electricity (Hydro)									
total	**0**	**0**	**0**	**0.2**	**1.2**	**0.8**	**1.9**	**3.3**	**3.9**
% of total capacity	0%	0%	-0.04%	0.29%	1.64%	0.91%	2.03%	3.19%	3.30%

Table 2 shows the emissions from the power sector between the two models and highlights the very minute changes between the two versions of the model in terms of total emissions.

Table 2: The total power sector emissions in Mt CO2 eq. This includes the contributions of NOx and CH4

	2010	2015	2020	2025	2030	2035	2040	2045	2050
REF	242.5	254.3	305.9	330.5	384.8	428.3	472.3	508.1	548.7
REF 8TS	243.4	256.2	308.0	328.9	381.0	426.2	468.2	507.9	553.7
% difference	0.4%	0.7%	0.7%	-0.5%	-1.0%	-0.5%	-0.9%	0.0%	0.9%

The total model emissions for all sectors on both supply and demand are shown in Figure 4 and in Table 3 below.

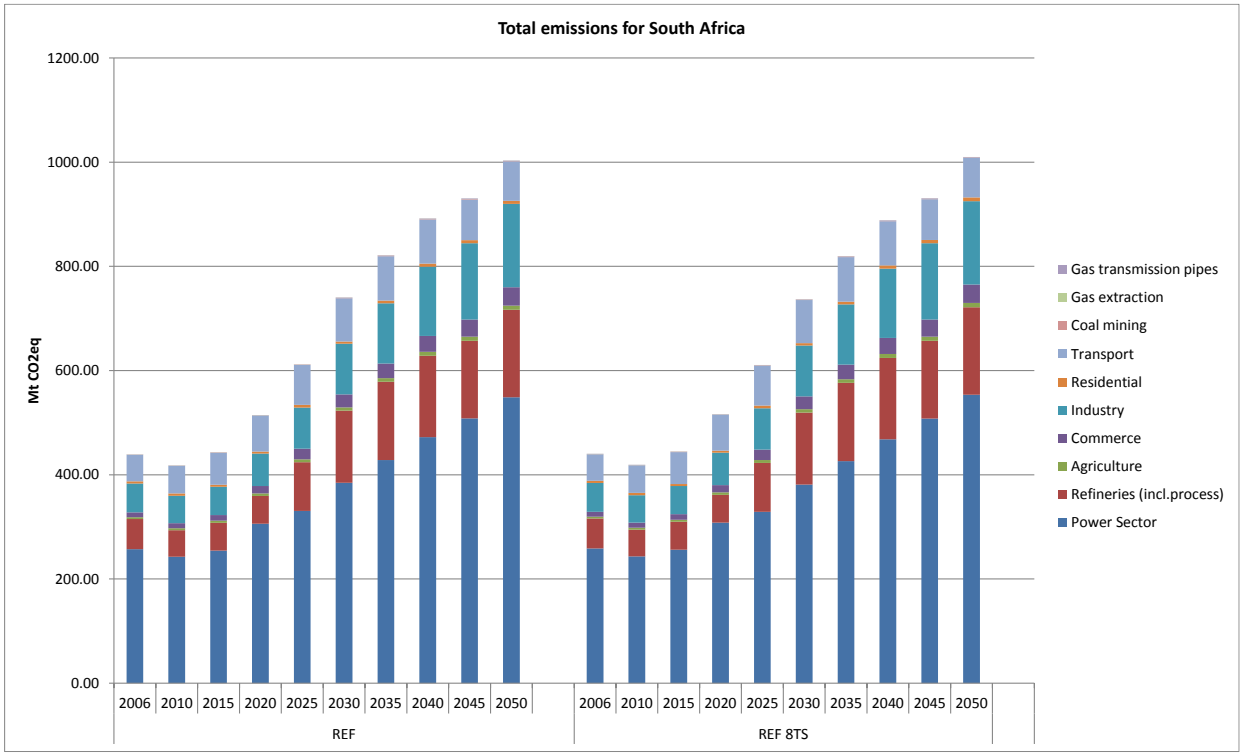

Figure 4: The total emissions by sector for South Africa between the two models.

Table 3: The total emissions difference between the two models (in Mt CO2eq)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Power Sector	0.94	1.87	2.11	-1.58	-3.71	-2.12	-4.14	-0.15	5.05
Refineries (incl.process)					0.03	0.05	0.05	0.01	-0.11
Agriculture									
Commerce	0.09	-0.23	-0.34	0.01	0.06	0.11	0.19	0.19	0.42
Industry		-0.16	-0.22	-0.03	-0.04	-0.04	-0.04	-0.14	-0.02
Residential	0.09	-0.06	0.09	0.24	0.24	0.26	0.35	0.43	1.14
Transport						-0.01	-0.01	0.03	0.03
Coal mining									
Gas extraction									
Gas transmission pipes									
Total REF	**418**	**443**	**515**	**612**	**740**	**821**	**892**	**930**	**1 003**

Total REF 8TS	**419**	**444**	**516**	**611**	**737**	**819**	**888**	**931**	**1 010**

Demand side

Overall the total final energy (all fuels) consumption is 0.05% less in the shorter timeslice model by 2030 and this is difference increases to 0.43% by 2050.

Tables 3 to 5 show the difference in fuel consumption patterns for the sectors which showed any change in fuel consumption. These changes analysed were only for those greater than 1% change.

Industry

Apart from 2010 industry has no major changes in fuel consumption. This may be partly attributed to the fact that industry has a much flatter demand profile than the other sectors and would thus be less impacted by a change in the time resolution of the model.

Table 4: The total difference in % of fuels for the industrial sector.

	2010	2030	2050
Coal			
Natural Gas			
Diesel			
Gasoline			
Kerosens/Paraffin			
LPG	38%		
HFO	-9%	3%	1%
Biomass&Waste	7%		
Electricity			

Commercial sector

The largest changes in consumption for the commercial sector is in natural gas and gasoline (petrol). The change in gasoline largely comes from 'other' end uses in the commercial sector – these are mainly office equipment and large devices/technologies not included in other end uses or in other sectors – such as incinerators or large scale dryers etc. Gasoline makes up approximetly 1% of the commercial sector. The drop in kerosene is almost for the exact same reason as for gasoline.

Natural gas change however comes largely from the embedded trigeneration/cogeneration within the sector – about 670MW of cogeneration in the shorter timeslice model as opposed to about 290MW in the regular timeslice length model.

Table 5: The total difference in % of fuels used in the commercial sector.

	2010	2030	2050
Coal	4%		

Natural Gas	-6%	12%	102%
Diesel	4%	-23%	20%
Gasoline	5%	-6%	-63%
Kerosens/Paraffin	-11%	5%	-34%
LPG	-45%	-2%	10%
HFO		-4%	-2%
Electricity			

Residential sector

Table 6: The total % difference of fuels used in the residential sector.

	2010	2030	2050
Coal	9%		19%
Natural Gas		-14%	-14%
Diesel			
Gasoline			
Kerosens/Paraffin		27%	227%
LPG		2%	
HFO			
Biomass&Waste			1%
Electricity			3%

Discussion

The change in the year timeslice profile largely affects electricity demand profiles of each sector, with some sectors having a larger change than others.

In terms of the differences in the demand side sectors, the main changes occur in the commercial sector and the residential sector. The commercial sector has a representation of embedded generation in the form of cogeneration – gas engines producing electricity and exhaust heat being utilised to meet heating demands. The industrial sector has a largely flat profile, as opposed to residential which has a sharp peak, and has a very minor energy consumption changes between the model versions.

- Overall, the **demand sectors show minor changes** in energy consumption patterns (as well as overall energy consumption),
- the **power sector has very minor changes in build investment** plan to 2050, with less coal capacity, and more solar and gas power coming into the mix in the model version with less timeslices,
- **Emissions differences** between the models are very small – on the order of **about 1%**, and
- The **time to compute** the model with shorter timeslices and for a model period of 5 year increments to 2050 was approximately **20seconds** as compared to the 2minutes and 30seconds for the same model with 20 timeslices.

In summary, the shorter timeslice model version of SATIM with just 8 timeslices to represent the year behaves very similarly to the same model run with 20 timeslices, but computes in about a seventh of the time.

Appendix: Monte Carlo GAMS code

```
*s=MCSimulation gdx=MCSimulation
SETS
* Overall sets
  X                     simulations      /1*1000/

* SATIM sets
  REG                   TIMES regions    /REGION1/
  ALLYEAR               All Years
  T(ALLYEAR)            Active time periods in TIMES run
  T1(ALLYEAR)                 TIMES first year
  T2(ALLYEAR)                 TIMES second year
  TO(ALLYEAR)                 TIMES other years
  S                     TIMES timeslices
  PRC                   TIMES Processes
  COM                   TIMES Commodities
  DEM                   TIMES Demand Commodities
  DEM1(COM)             TIMES Demand Commodities for REGION1
* Fuel processes
  FUELP(PRC)            TIMES Fuel Processes
  FUELPC(PRC)           TIMES coal processes
  FUELPCPWR(PRC)        TIMES coal for power
  FUELPCPWR_CB(PRC)     TIMES coal for power central basin
  FUELPCPWR_A(PRC)      TIMES coal for power waterberg
  FUELPG(PRC)           TIMES gas processes
  FUELPO(PRC)           TIMES oil liquid fuel processes

* Power Plant processes
  TECHS                 TIMES power plant subsets
  TECHC(PRC)            TIMES power plants whose cost are MC simulated
  ETC(PRC)              TIMES Coal Plants
  ETCA(PRC)              TIMES Coal Plants waterberg
  ETG(PRC)              TIMES Gas Plants
  ETGIH(PRC)            TIMES Gas Plants Shale
  ETN(PRC)              TIMES Nuclear Plants
  ERH(PRC)              TIMES Hydro Plants
  ERSOLP(PRC)           TIMES PV techs Central
  ERSOLPC(PRC)           TIMES PV techs Central
  ERSOLPR(PRC)           TIMES PV techs Rooftop
  ERSOLT(PRC)           TIMES CSP techs
  ERW(PRC)              TIMES Wind Plants
  ERB(PRC)              TIMES Biomass Plants
* e-SAGE(cge) sets
  FH              cge household groups
  INS             cge household incomes
  FS              cge sectors (for TIMES)
  XC              cge scenarios
  TC(ALLYEAR)     cge years

* Emissions sets
  CO2SET(COM)           Sectoral emissions

* MC sim specific sets
  FS_L(FS)        Linked subsectors ie excl com agr ele
  FS_U(FS)        Other subsectors that are not linked ie com agr ele

  COEF            Oil Price coefficient / a, b/
;
ALIAS (ALLYEAR,AY), (ALLYEAR,TP);

PARAMETERS
*Overall Parameters
  XRATE(X,T)               Real Exchange Rate R per $

* Parameters imported from a base CGE run
  SFORE(FS,XC,TC)

* Parameters imported from a base TIMES run
  COM_PROJ(REG,ALLYEAR,COM) Useful Energy Demand from TIMES
  COM_PROJ_BY(COM)          Useful Energy Demand in the base year
  FUELPO_BY(PRC)            Base year fuel prices for oil products
  TVACTELC(T,S)             Electricity output of transmission
  TVCOMBAL(T,COM)           Annual Marginals
  TVCOMBALELC(T,S)          Electricity marginals

* Monte Carlo Simulation parameters drawn in from Excel
* Main Drivers
  SIM_GDP_Y(X,AY)           GDP growth
  SIM_COM_S(X,T)           Share of commerce in GDP
  SIM_POP(X,T)             Population

* Data from Demand Model (spreadsheet-based at this stage)
  SIM_DEMX(COM,AY)          Demand extracted from excel

* Fuel Price Combined Data
  SIM_FUELP(PRC,X,T)       Combined Fuel Price data

* Technology Cost Combined Data
  SIM_TECHC(PRC,X,T)       Combined Tech overnight Cost data

* Coal Mining Costs
  COAL_CV(PRC)             Coal calorific value
* Coal to Power Plants Central Basin
  SIM_CLE1(X,T)            Coal from Existing Mines in Central Basin Type 1 (conveyor)
  SIM_CLE2(X,T)            Coal from Existing Mines in Central Basin Type 2 (rail-truck)
  SIM_CLN(X,T)             Coal from New Mines in Central Basin
```

```
* Coal to Power Plants in Waterberg
  SIM_CLE_A(X,T)           Coal from Existing Mines in Waterberg
  SIM_CLN_A(X,T)           Coal from new Mines in Waterberg

* Coal to Synthetic Fuels
  SIM_CLS(X,T)             Coal from Existing Mines in Central Basin to synthetic fuels
  SIM_CLS_A(X,T)           Coal from New Mines in the Waterberg to synthetic fuels

* Metallurgical Coal existing
  SIM_COA(X,T)             Coal from Existing Mines supplying other industries

* Global Commodity Prices
  SIM_GCOAL(X,T)           Global Price for Coal in 2010 $ per ton
  SIM_GGAS(X,T)            Global Price for Gas in 2010 $ per Mbtu
  SIM_GOIL(X,T)            Global Price for Oil in 2010 $ per barrel

* Oil products
  OCRFAC(FUELPO,COEF)      Coefficients for mapping from oil to product prices

* Natural Gas
  SIM_GIH(X,T)             Shale Gas Production Cost $ per Mbtu

* Solar PV
  SIM_PV_Module(X,T)       PV Module Prices in 2010 $ per W
  SIM_PV_BOS(X,T)          PV Balance of System Cost in 2010 $ per W
  PV_CRATIO(PRC)        Ratio of BOS cost for other PV systems to Central Fixed system

* Solar CSP
  SIM_CSP(X,T)             CSP Cost in 2010 $ per W
  CSP_CRATIO(PRC)       Ratio of reference CSP cost to other CSP techs

* Nuclear Costs
  SIM_NUCLEAR(X,T)         Overnight Nuclear Cost $ per kW

* Intermediate parameters

  SFORE_S(FS,AY)        Value added shares of GDP for TIMES sectors obtained from cge run
  GDP_CGE(AY)           GDP from cge run
  GDP_CGE_FS_S(FS,X,AY) Sector GDP shares from cge run
  GDP_CGE_FS_S_Sum(X,AY)   Sum of linked sectors shares from cge run

  GDP(X,AY)                 Overall GDP
  GDP_FS(FS,X,AY)           Sector GDP
  GDP_FSX(FS,AY)            Sector GDP for simulation X
  GDP_FS_S(FS,X,AY)         Sector GDP shares
  GDP_FS_S_Sum(X,AY)        Sum of linked sectors shares

  POPX(T)                   Population for simulation X

  SIM_ERSOLP(X,ERSOLP,T)   PV costs going to SATIM
  SIM_ERSOLT(X,ERSOLT,T)   CSP costs going to SATIM

* Parameters extracted from TIMES run results
  TVCOMNET(T,COM)          Emissions from SATIM
  TVCAP(T,PRC)             Capacity from SATIM
  TVACT(T,PRC)             Activity from SATIM
  TVACTELC(T,S)            Electricity output from transmission
  TVBOMBALELC(T,S)         Electricity marginals downstream of transmission

* Results kept for all simulations
  SIMO_CO2S(CO2SET,X,T)            CO2 emissions
  SIMO_PWRCAP(TECHS,X,T)     Capacity of power plants GW
  SIMO_PWRACT(TECHS,X,T)     Production of power plants TWh
  SIMO_COAACT(FUELPC,X,T)  Production of coal mines tons
  SIMO_COATRA(X,T)         Coal Transfers from Waterberg to CB tons
  SIMO_COAP(X,T)           Average Coal Price for power plants R per ton
  SIMO_COAPA(X,T)          Average Coal Price for power plants in waterberg R per ton
  SIMO_COAPB(X,T)          Average Coal Price for power plants in central basin R per ton

  SIMO_GASACT(FUELPG,X,T)   Production of natural gas

  SIMO_OBJz(X)             SATIM Objective function

  SIMO_DMD(COM,X)          Final year demand by end-use

  SIMO_PEAKELC(T,X)        Electricity peak (GW downstream of transmission)
  SIMO_ELCDMD(T,X)         Electricity demand (TWh downstream of transmission)
  SIMO_ELCP(T,X)           Electricity price
* Other Parameters
  TGAP(AY)                   TIMES Gaps


* Set Allocation
  PWRSET(PRC)              Power Plants set allocation

;
scalar POBjz;

* File declarations
FILE SIM_COMCOST_FILE /".\satm\Gams_WrkTI\sim_comprice+REGION1.dds"/;
FILE SIM_PRCCOST_FILE /".\satm\Gams_WrkTI\sim_prccost+REGION1.dds"/;
FILE SIM_DEM_FILE /".\satm\Gams_WrkTI\sim_dem+REGION1.dds"/;

* Import sets and parameters from Base TIMES run
$gdxin  .\SATM\Gams_WrkTI\Gamssave\run02_MC.gdx
$load PRC COM DEM ALLYEAR T S COM_PROJ

DEM1(COM) = DEM('REGION1',COM);

* Base year demand
COM_PROJ_BY(COM) = COM_PROJ('REGION1','2006',COM);
```

```
* Import sets and parametes from Base CGE run
* $gdxin  output1_bu.gdx
$gdxin  simulation1.gdx
$load XC TC FS FH INS SFORE

* Set Exchange Rate (Constant for now-based on differential inflation rate differentials)
XRATE(X,T) = 8.23;

* Import MC parameters and data from spreadsheet
$call    "gdxxrw i=MCSim.xlsx o=mcsim index=index!a6 checkdate"
$gdxin   mcsim.gdx
$loaddc FUELP FUELPO FUELPC FUELPCPWR FUELPCPWR_CB FUELPCPWR_A FUELPG
$loaddc TECHS TECHC ETC ETCA ETG ETGIH ETN ERH ERSOLP ERSOLPC ERSOLPR ERSOLT ERW ERB CO2SET
$load PWRSET
$load SIM_POP SIM_GDP_Y SIM_COM_S
$load SIM_GCOAL SIM_GGAS SIM_GOIL OCRFAC
$load COAL_CV SIM_CLE1 SIM_CLE2 SIM_CLN SIM_CLE_A SIM_CLN_A
$load SIM_GIH
$load PV_CRATIO SIM_PV_MODULE SIM_PV_BOS CSP_CRATIO SIM_CSP SIM_NUCLEAR

* Preparation of cge input data
  FS_L(FS) = YES;
  FS_L('agr') = no;
  FS_L('elec') = no;
  FS_L('com') = no;

  FS_U(FS) = not FS_L(FS);


*Count gap between TIMES years
set TA(ALLYEAR)           TIMES years /2006*2050/;
T1(T)$(ORD(T) EQ 1) = YES;
T2(T)$(ORD(T) EQ 2) = YES;
TO(T) = yes;
TO(T1) = no;

TGAP(AY)$(T(AY) AND NOT T1(AY)) = ORD(AY) - SMAX(TP$T(TP), ORD(TP)$(ORD(AY) GT ORD(TP)));

* set inital and following years' shares equal to shares in cge run
GDP_CGE(TC) = sum(FS, SFORE(FS,'base',TC));
SFORE_S(FS,TC) = SFORE(FS,'base',TC)/GDP_CGE(TC);
*GDP_FS_S(FS,X,TO) = 1;
GDP_CGE_FS_S(FS,X,TO) = SFORE_S(FS,TO);
GDP_CGE_FS_S(FS,X,T1) = GDP_CGE_FS_S(FS,X,'2010');

* Calculate GDP shares for all simulations
GDP(X,'2006') = 1;

*loop(T$(NOT T1(T)),
loop(TA$(NOT T1(TA)),
*  GDP(X,T) = GDP(X,T-1)*((1+SIM_GDP_Y(X,T))**TGAP(T));
  GDP(X,TA) = GDP(X,TA-1)*((1+SIM_GDP_Y(X,TA)));

);


* set all shares equal to that of cge
GDP_FS_S(FS,X,T) = GDP_CGE_FS_S(FS,X,T);
GDP_CGE_FS_S_Sum(X,T) = sum(FS_L, GDP_CGE_FS_S(FS_L,X,T));

* set 'com' shares equal to that of sim
GDP_FS_S('com',X,T) = SIM_COM_S(X,T);
GDP_FS_S_Sum(X,T) = 1-sum(FS_U, GDP_FS_S(FS_U,X,T));

* set 'linked' sector shares equal in proportion to what's in cge
GDP_FS_S(FS_L,X,T) = GDP_CGE_FS_S(FS_L,X,T)/GDP_CGE_FS_S_Sum(X,T)*GDP_FS_S_Sum(X,T);

* calculate sector GDP
GDP_FS(FS,X,T) = GDP_FS_S(FS,X,T)*GDP(X,T);

* Set Fuel Prices/Costs
* Coal mining/exports (x/0.8+35 is washing costs and yield effect)
* 0.95 on exports assumes a 5% royalty
SIM_FUELP('MINCLE1',X,T) = SIM_CLE1(X,T);
SIM_FUELP('MINCLE2',X,T) = SIM_CLE2(X,T);
SIM_FUELP('MINCLE3',X,T) = SIM_CLE2(X,T)/0.8+35;
SIM_FUELP('MINCLN',X,T)  = SIM_CLN(X,T);
SIM_FUELP('MINCLE-A',X,T) = SIM_CLE_A(X,T);
SIM_FUELP('MINCLN-A',X,T) = SIM_CLN_A(X,T);
SIM_FUELP('MINCLS',X,T) = SIM_CLE1(X,T);
SIM_FUELP('MINCLS-A',X,T) = SIM_CLN_A(X,T);
SIM_FUELP('MINCOA',X,T) = SIM_FUELP('MINCLE3',X,T)/0.8+35;
* Exports
SIM_FUELP('PEXCME',X,T) = SIM_GCOAL(X,T)* 0.95 * XRATE(X,T) * (-1);

* Convert coal prices from 2013 R/ton to 2010 R/GJ
SIM_FUELP(FUELPC,X,T) = SIM_FUELP(FUELPC,X,T)/COAL_CV(FUELPC) / 1.172;

* Oil and derivatives prices
SIM_FUELP(FUELPO,X,T) = SIM_GOIL(X,T) * XRATE(X,T) * OCRFAC(FUELPO,'a') + OCRFAC(FUELPO,'b');

* Natural Gas Techs, +1, +0.5 for GWL and GRL are the transport costs
* the 0.95 for the export price is a royalty fee
SIM_FUELP('MINGIH',X,T) = SIM_GIH(X,T) * XRATE(X,T) / 1.055;
SIM_FUELP('IMPGWL',X,T) = (SIM_GGAS(X,T)+1) * XRATE(X,T) / 1.055;
SIM_FUELP('IMPGRL',X,T) = (SIM_GGAS(X,T)+0.5) * XRATE(X,T) / 1.055;
SIM_FUELP('PEXGAS',X,T) = SIM_GGAS(X,T)*0.95 * XRATE(X,T) / 1.055 * (-1);

* Allocate Power Plant Techs Sets - can't get this to work
*ERSOLT(PRC)$(PWRSET(PRC) eq 5)=yes;
*ERSOLP(PRC)$(PWRSET(PRC) eq 6)=yes;
```

```
* Calculate Solar costs based on 2010 ratios and smpled data, assuming ratios stay the same
* and converting to R/kW as needed by SATIM
SIM_TECHC(ERSOLP,X,T) = (PV_CRATIO(ERSOLP) * SIM_PV_BOS(X,T) + SIM_PV_MODULE(X,T)) * 1000 * XRATE(X,T);
SIM_TECHC(ERSOLT,X,T) = CSP_CRATIO(ERSOLT) * SIM_CSP(X,T) * 1000 * XRATE(X,T);

* Calculate Nuclear Cost converting from 2010 $ to 2010 R
SIM_TECHC(ETN,X,T) = SIM_NUCLEAR(X,T) * XRATE(X,T);




scalars
  EFVAL                 temporary values stored here
  XLTEST
;



LOOP(X,

* Processing of spreadsheet input before exporting to TIMES

* Calculate Sectoral GDP

  GDP_FSX(FS,T) = GDP_FS(FS,X,T);
  POPX(T) = SIM_POP(X,T);

  execute_unload "MCDem.gdx" POPX COM_PROJ_BY GDP_FSX
$ontext
  execute 'xlstalk.exe -m DMD_PRJ_MC.xlsm';
   XLTEST = ERRORLEVEL;
  IF(XLTEST = 1,
    execute 'xlstalk.exe -c DMD_PRJ_MC.xlsm';
  );
  IF(XLTEST = 2,
    execute 'xlstalk.exe -s DMD_PRJ_MC.xlsm';
  );
$offtext
  execute 'gdxxrw.exe i=MCDem.gdx o=DMD_PRJ_MC.xlsx index=index_G2E!a6';

*  execute 'xlstalk.exe -o DMD_PRJ_MC.xlsm';

  execute 'gdxxrw.exe i=DMD_PRJ_MC.xlsx o=mcdem2.gdx index=index_E2G!a6 checkdate'

  execute_load "mcdem2.gdx" SIM_DEMX

* Fuel Price DDS file
 PUT  SIM_COMCOST_FILE;
 SIM_COMCOST_FILE.pc = 2;
 SIM_COMCOST_FILE.nd = 5;
 SIM_COMCOST_FILE.ap = 0;

 PUT 'PARAMETER AACT_COST /' /;

LOOP((FUELP,T),
  EFVAL = SIM_FUELP(FUELP,X,T);
  if(EFVAL,
    PUT "REGION1.", FUELP.TL, ".", T.TL, EFVAL /;
  );
);

PUTCLOSE "/;";

* Tech Cost DDS File
 PUT  SIM_PRCCOST_FILE;
 SIM_PRCCOST_FILE.pc = 2;
 SIM_PRCCOST_FILE.nd = 5;
 SIM_PRCCOST_FILE.ap = 0;

PUT 'PARAMETER ANCAP_COST /' /;

LOOP((TECHC,T),
  EFVAL = SIM_TECHC(TECHC,X,T);
  if(EFVAL,
    PUT "REGION1.", TECHC.TL, ".", T.TL, EFVAL /;
  );
);
PUTCLOSE "/;";

*$ontext
* Demand DDS File
 PUT  SIM_DEM_FILE;
 SIM_DEM_FILE.pc = 2;
 SIM_DEM_FILE.nd = 5;
 SIM_DEM_FILE.ap = 0;

PUT 'PARAMETER ACOM_PROJ /' /;


LOOP((DEM1,TC),
  EFVAL = SIM_DEMX(DEM1,TC);
  if(EFVAL,
    PUT "REGION1.", DEM1.TL, ".", TC.TL, EFVAL /;
ELSE
    PUT "REGION1.", DEM1.TL, ".", TC.TL, "EPS" /;
  );
);
PUTCLOSE "/;";
*$offtext
```

```
* Run TIMES model
  execute ".\satm\gams_wrkti\RUNTIMES2.CMD"

* Extract Results from TIMES run
  execute_load ".\links\1timesoutput.gdx" TVCOMNET TVCAP TVACT TVACTELC TVCOMBAL TVCOMBALELC POBJz;
*TVNCAP TVNCAPF TVCAP TVFLO TVACT NCAP_ILED OBJ_ICOST TVCOMBAL TVCST_INVC TVCST_ACTC TVCST_FIXC;

* Emissions
  SIMO_CO2S(CO2SET,X,T) = TVCOMNET(T,CO2SET);

* Power plants
* Capacity (GW)
  SIMO_PWRCAP('ETC',X,T) = sum(ETC, TVCAP(T,ETC));
  SIMO_PWRCAP('ETCA',X,T) = sum(ETCA, TVCAP(T,ETCA));
  SIMO_PWRCAP('ETG',X,T) = sum(ETG, TVCAP(T,ETG));
  SIMO_PWRCAP('ETGIH',X,T) = sum(ETGIH, TVCAP(T,ETGIH));
  SIMO_PWRCAP('ETN',X,T) = sum(ETN, TVCAP(T,ETN));
  SIMO_PWRCAP('ERH',X,T) = sum(ERH, TVCAP(T,ERH));
  SIMO_PWRCAP('ERSOLPC',X,T) = sum(ERSOLPC, TVCAP(T,ERSOLPC));
  SIMO_PWRCAP('ERSOLPR',X,T) = sum(ERSOLPR, TVCAP(T,ERSOLPR));
  SIMO_PWRCAP('ERSOLT',X,T) = sum(ERSOLT, TVCAP(T,ERSOLT));
  SIMO_PWRCAP('ERW',X,T) = sum(ERW, TVCAP(T,ERW));
  SIMO_PWRCAP('ERB',X,T) = sum(ERB, TVCAP(T,ERB));

* Production (TWh)
  SIMO_PWRACT('ETC',X,T) = sum(ETC, TVACT(T,ETC));
  SIMO_PWRACT('ETCA',X,T) = sum(ETCA, TVACT(T,ETCA));
  SIMO_PWRACT('ETG',X,T) = sum(ETG, TVACT(T,ETG));
  SIMO_PWRACT('ETGIH',X,T) = sum(ETGIH, TVACT(T,ETGIH));
  SIMO_PWRACT('ETN',X,T) = sum(ETN, TVACT(T,ETN));
  SIMO_PWRACT('ERH',X,T) = sum(ERH, TVACT(T,ERH));
  SIMO_PWRACT('ERSOLPC',X,T) = sum(ERSOLPC, TVACT(T,ERSOLPC));
  SIMO_PWRACT('ERSOLPR',X,T) = sum(ERSOLPR, TVACT(T,ERSOLPR));
  SIMO_PWRACT('ERSOLT',X,T) = sum(ERSOLT, TVACT(T,ERSOLT));
  SIMO_PWRACT('ERW',X,T) = sum(ERW, TVACT(T,ERW));
  SIMO_PWRACT('ERB',X,T) = sum(ERB, TVACT(T,ERB));
  SIMO_PWRACT(TECHS,X,T) = SIMO_PWRACT(TECHS,X,T)/3.6;

* Coal Mine Production
  SIMO_COAACT(FUELPC,X,T) = TVACT(T,FUELPC)/COAL_CV(FUELPC);
* Coal Transfers from Waterberg to CB
  SIMO_COATRA(X,T) = (TVACT(T,'UXLE-AB')+TVACT(T,'UXLE2-AB'))/COAL_CV('MINCLE1');
* Coal Price Calculation
* Average over all plants (we need to subtract the coal used by other sectors)
  SIMO_COAP(X,T) = (sum(FUELPCPWR, (TVACT(T,FUELPCPWR)*SIM_FUELP(FUELPCPWR,X,T)))+(SIMO_COATRA(X,T)*252/1.172))
                   / (sum(FUELPCPWR,TVACT(T,FUELPCPWR))/COAL_CV('MINCLE1')+SIMO_COATRA(X,T))*1.172;
* Central Basin Price (we need to subtrac the caol used by other sectors)
  SIMO_COAPB(X,T) = (sum(FUELPCPWR_CB, (TVACT(T,FUELPCPWR_CB)*SIM_FUELP(FUELPCPWR_CB,X,T)))+(SIMO_COATRA(X,T)*252/1.172))
                   / (sum(FUELPCPWR_CB,TVACT(T,FUELPCPWR_CB))/COAL_CV('MINCLE1')+SIMO_COATRA(X,T))*1.172;
* Waterberg Price
  SIMO_COAPA(X,T) = (sum(FUELPCPWR_A, (TVACT(T,FUELPCPWR_A)*SIM_FUELP(FUELPCPWR_A,X,T))))
                   / (sum(FUELPCPWR_A,TVACT(T,FUELPCPWR_A))/COAL_CV('MINCLE1'))*1.172;

* Gas Production
  SIMO_GASACT(FUELPG,X,T) = TVACT(T,FUELPG);

* Final year demand
  SIMO_DMD(DEM1,X) = SIM_DEMX(DEM1,'2050');

* Electricity demand TWh
  SIMO_ELCDMD(T,X) = sum(S, TVACTELC(T,S))/3.6/0.961;
* Electricity Peak demand GW
  SIMO_PEAKELC(T,X) = TVCAP(T,'ETRANS')/0.961;
* Electricity price 2013 R/kWh
  SIMO_ELCP(T,X) = sum(S, TVACTELC(T,S)*TVCOMBALELC(T,S))*1.172*3.6/1000000;

* Objective function
  SIMO_OBJz(X) = POBJz;

  Display X;

);
```