New problems in energy optimization: the Consultant-working-in-power-markets perspective

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  - Provision of a GB electricity dispatch model for the Scottish Government
  - Feasibility of the MYTO load allocations for Discos in Nigeria: Application of load flow modelling capability
- New problems
  - What new tools would be beneficial?

Provision of a GB electricity dispatch model for the Scottish Government (2012-13)

Important questions (at the time!)

- **Meeting legal requirements under the Climate Change Scotland Act**
  - Specific area-wide emissions target set as constraints
- **Understanding the impacts of consenting of power plants**
  - Limiting entry, altering construction delays or setting planned entry
- **Understanding the challenges of meeting 100% renewables ambition**
  - Specific area-wide renewables target (% of demand)
  - Production analysis
- **Impact of EMR, in particular EPS and CfDs**
  - EPS: limits on production for emissions intensive plant
  - CfDs intended to reduce risk of investment

Two models

- **Long term investment model**
  - Long term planning, 2012-50
    - **Period**: E.g., years, **Stages**: E.g., Seasons, **Blocks**: E.g., Load-duration
  - Includes investment and production costing
- **Short-term "operational" model**
  - Short term operation, unit commitment (generator scheduling)
    - Half-hourly chronological dispatch for representative weeks
  - Production costing much more detail
- Both are mathematical optimization models
  - Objective to minimize cost, implements principles of a perfectly competitive markets
  - Subject to various constraints

Why two models?

- Key to successful market modelling is to simplify the problem enough to solve in a reasonable time, while getting robust and meaningful results
- For this reason we used two versions of the model:
  - The long term model simplifies the dispatch (treats demand as “blocks” of energy) to be able to optimise the generation and transmission expansion over **planning timescales** (i.e., at least one investment cycle or with some target date in mind – 2050?)
  - The short term model does not consider new build (short timescales). Instead it allows more processing power to be devoted to the dispatch, including reserves, detailed thermal efficiencies etc – can check the **feasibility of long term model results**

Long-term modelling

- Represents the supply-demand balance in the long-run
  - Input data on demand (yearly) and on the costs of generation
  - Input data on the transmission system and constraints
- But that is not all it can represent
  - Retirements
  - New build (optimal generation and transmission expansion)
  - Security of supply (capacity margin, always meeting demand)
  - Reserves (always meeting demand)
  - Policy/externalities (renewables, carbon dioxide)
  - Etc….

How long term and short term model differ (summary)

Long term model	Short term model
Not chronological	Chronological
Demand simplified to load duration blocks	Demand can vary by half hour, full chronological information
Representation of renewables and emissions policy through targets or prices	Representation of renewables and emissions policy through prices only
Optimised network expansion	Generation capacity for a specific year is an input
Both	
Optimised production costing (much more detailed in short term)	
Representation of transmission network possible (constrained or unconstrained)	
14 nodes (or regions)	

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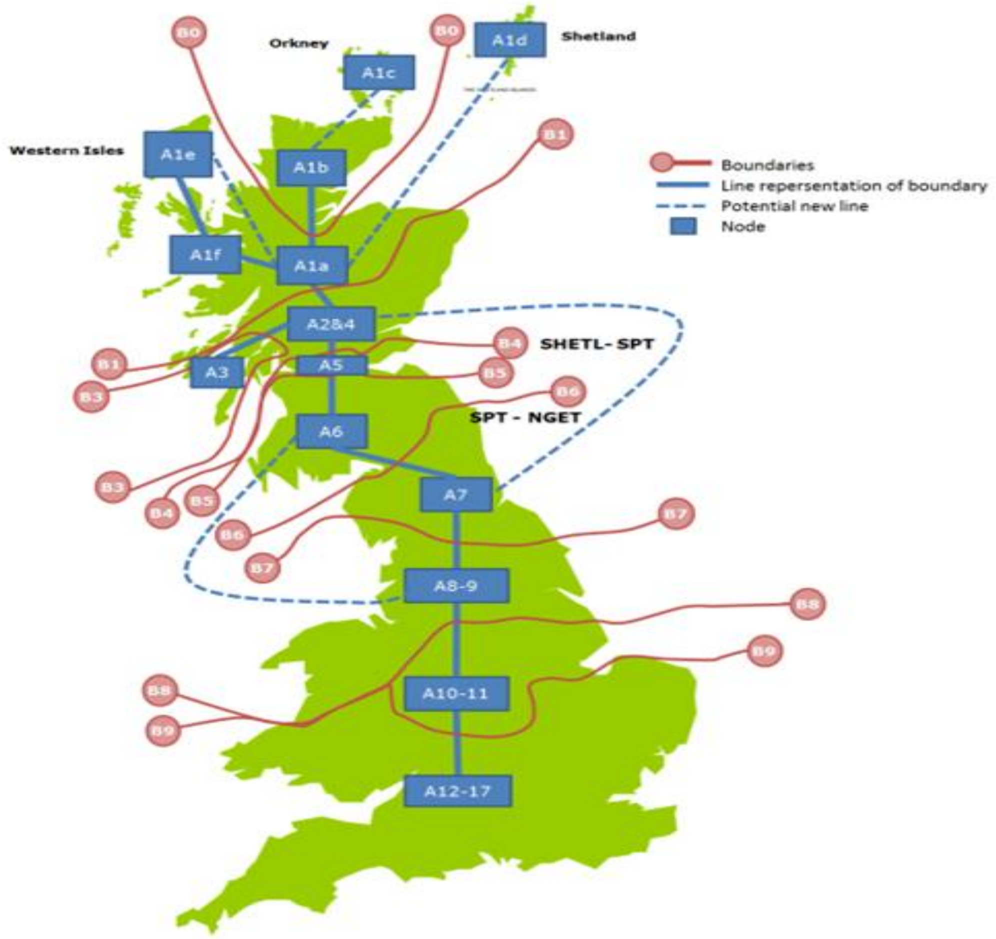
Network

- Modelled network simplifies the problem
- Accurate representation of constraints at key boundaries of importance to Scottish Government
- No power electronics, just flow balance
- Transfer limits consistent with NG planning standards / seven/ten year statements



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Reflecting policy targets

Target	Implicit	Explicit
Security of supply (capacity)	Value of Lost Load – cost associated with failure to supply	“Derated capacity margin” (as Ofgem and DECC)
Renewables	Subsidy payments – acts as a decrease in variable (or fixed) cost for “green” generator	Renewables target as a % of model demand
Carbon	Carbon price (EU ETS) – acts as an increase in variable cost for emitting generator	Carbon limit MT CO_2

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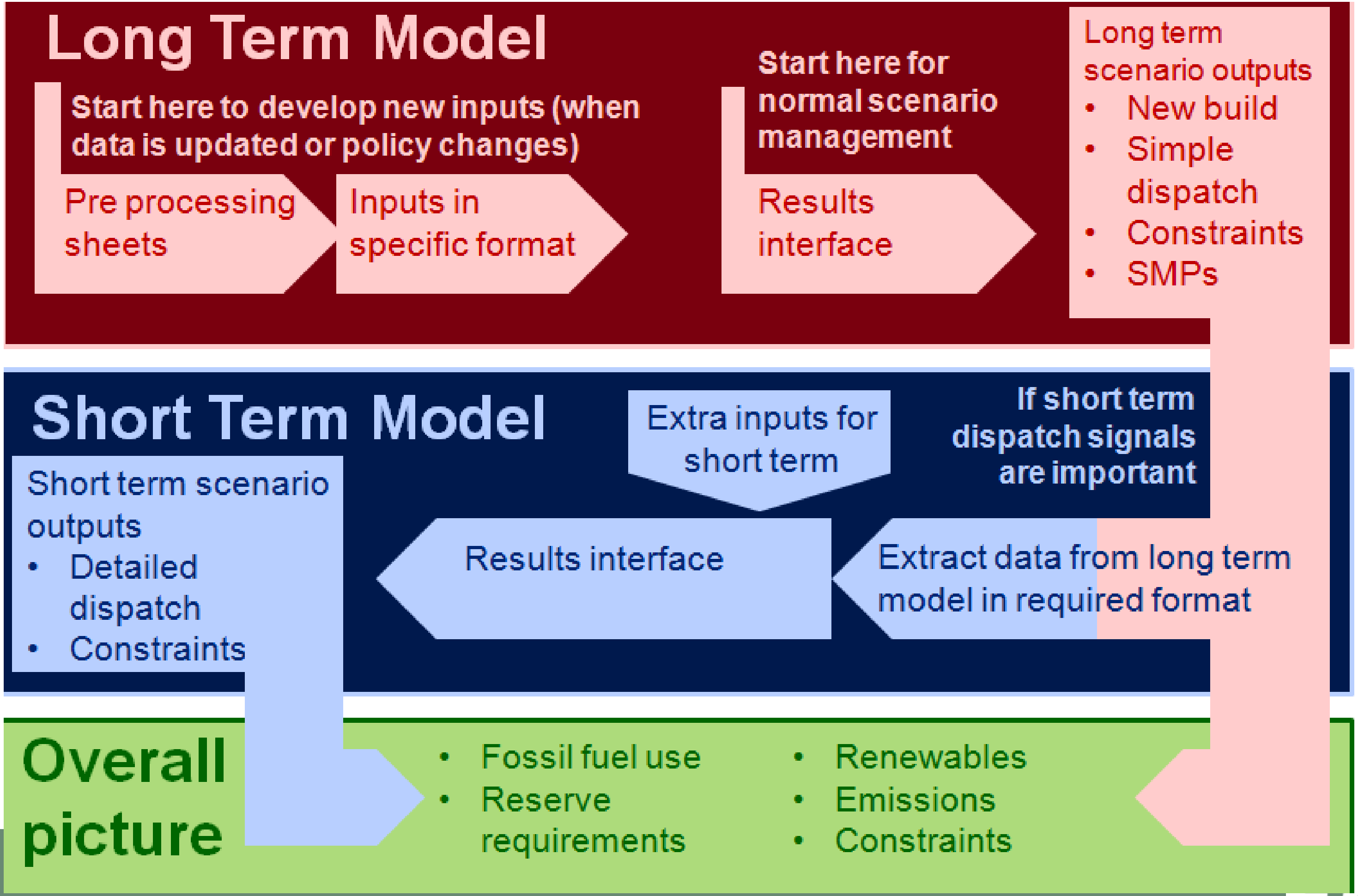
Long Term Model
Start here to develop new inputs (when data is updated or policy changes)
Pre processing sheets
Inputs in specific format
Start here for normal scenario management
Results interface
Long term scenario outputs
• New build
• Simple dispatch
• Constraints
• SMPs
Short Term Model
Extra inputs for short term
If short term dispatch signals are important
Short term scenario outputs
• Detailed dispatch
• Constraints
Results interface
Extract data from long term model in required format
Overall picture
• Fossil fuel use
• Reserve requirements
• Renewables
• Emissions
• Constraints

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Model framework is flexible

- The underlying model is entirely transferable to any market
- **In practical terms, that means anything that can vary between power markets is an input and can be changed**
- (If you can name it, it can almost certainly be adjusted)

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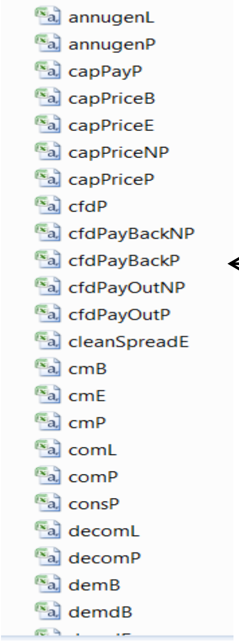
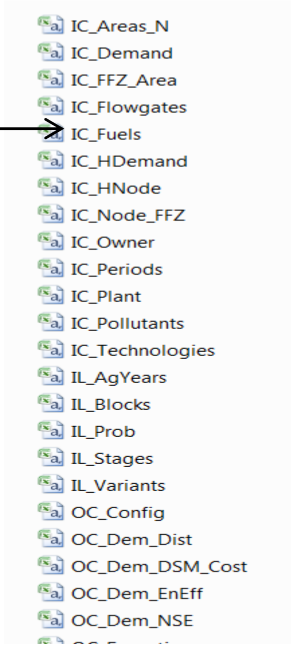
Model flexibility was needed

- Available modelling modes:
  - **Single bus**
  - **Unconstrained network** – line/transfer limits relaxed
    - Generators are charged £/kW/year to be connected at each node (consistent with TNUoS)
    - The transmission system does not "cost" the model anything so model is minimising generation and demand costs only (i.e., expanding generation only)
  - **Constrained network** - line/transfer limits in place
    - Line can be upgraded (candidates)
    - Generators are not charged to connect, BUT…
    - The transmission system adds an additional cost so the model is minimising generation, demand and transmission costs
    - By doing this the model will hedge between upgrading lines and building generation close to demand

Communicating with the model



- Mathematical model requires a set of csv files defining the problem
- The model runs and produces a set of csv files
- Users need to deal with a lot of files
- Benefit is this can provide an intimate understanding of the model



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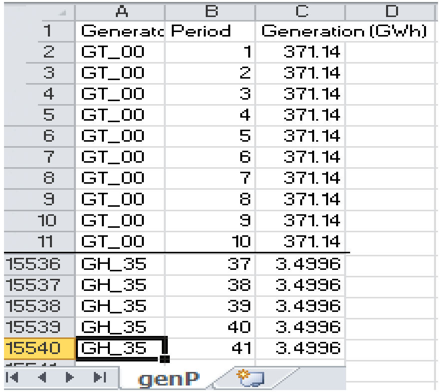
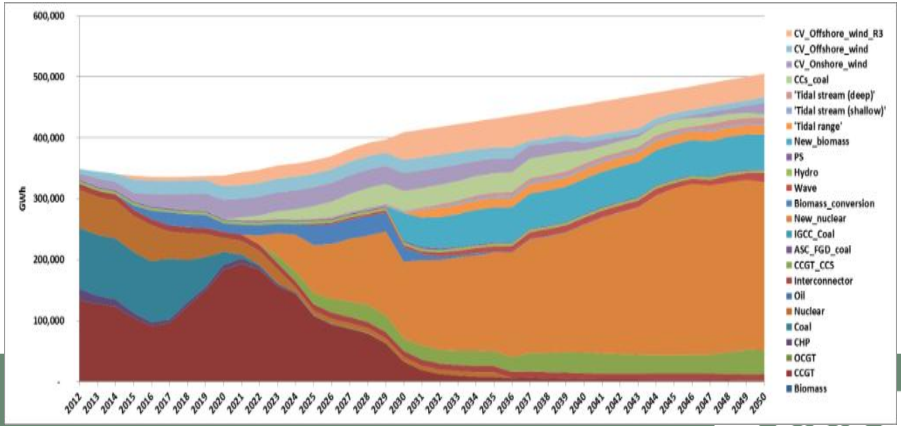
Results interface was needed

- Needed to create a user-friendly way to set model inputs and view model outputs
- The output spreadsheets have been created to display results which will be looked at most frequently
- Free to develop own outputs viewers…



	A	B	C	D
1	Generato	Period	Generation (GWh)	
2	GT_00	1	371.14	
3	GT_00	2	371.14	
4	GT_00	3	371.14	
5	GT_00	4	371.14	
6	GT_00	5	371.14	
7	GT_00	6	371.14	
8	GT_00	7	371.14	
9	GT_00	8	371.14	
10	GT_00	9	371.14	
11	GT_00	10	371.14	
15536	GH_35	37	3.4996	
15537	GH_35	38	3.4996	
15538	GH_35	39	3.4996	
15539	GH_35	40	3.4996	
15540	GH_35	41	3.4996	

genP



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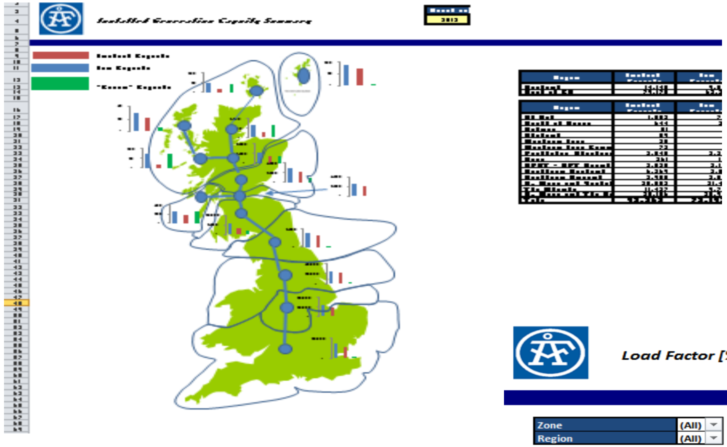
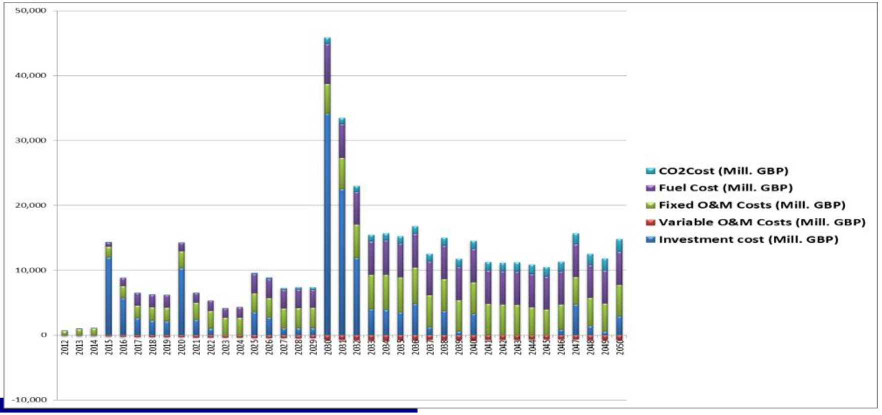
Outputs viewer





Load Factor [%]

Zone	(All)
Region	(All)

Load Factor (%)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Biomass	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%	84%	82%	79%	79%	79%	86%
CCGT	63%	60%	57%	52%	49%	48%	46%	53%	52%	49%	35%	29%	29%	24%	24%	22%	22%	21%	16%
OCGT	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CHP	74%	66%	61%	56%	49%	45%	29%	21%	15%	5%	4%	3%	3%	3%	3%	4%	4%	4%	1%
Coal	40%	40%	43%	43%	62%	62%	60%	32%	23%	19%	3%	2%	1%	1%	1%	1%	1%	1%	1%
Nuclear	71%	71%	71%	71%	71%	71%	71%	71%	71%	71%	71%	69%	68%	65%	65%	63%	62%	62%	65%
Oil	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Interconnector	42%	7%	15%	24%	25%	36%	36%	34%	28%	32%	94%	89%	86%	81%	75%	71%	69%	67%	77%
CCGT_CCS	0%	0%	0%	0%	0%	0%	0%	0%	0%	93%	93%	93%	93%	91%	91%	89%	88%	88%	93%
ASC_FGD_coal	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
IGCC_Coal	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
New_nuclear	0%	0%	0%	0%	0%	0%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%
Biomass_conversion	0%	0%	0%	0%	0%	0%	0%	0%	86%	86%	86%	86%	86%	86%	86%	85%	85%	85%	49%
Wave	0%	0%	0%	0%	0%	0%	0%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
Hydro	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%

CostSummary(Grid) | Emissions(Tech) | Emissions(Fuel) | LoadFactor | SRMC(Summary-14) | SRMC(Outputs) | Dema

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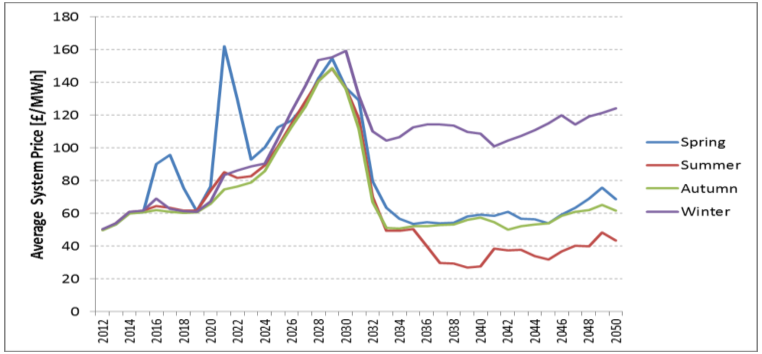
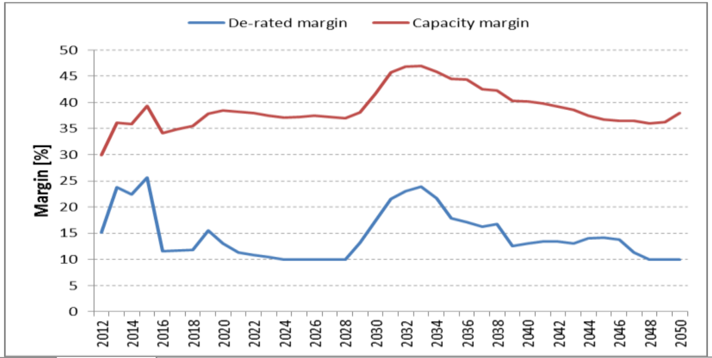
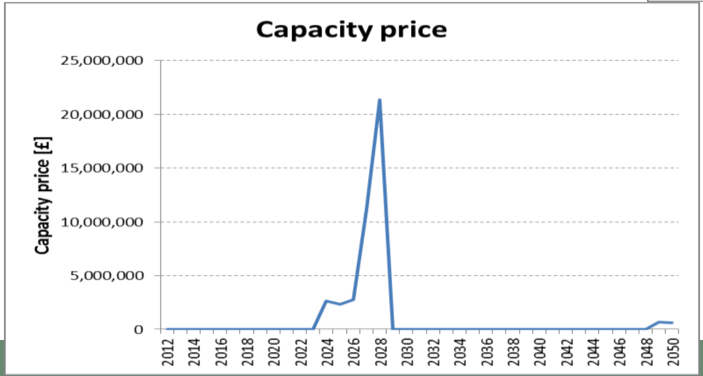
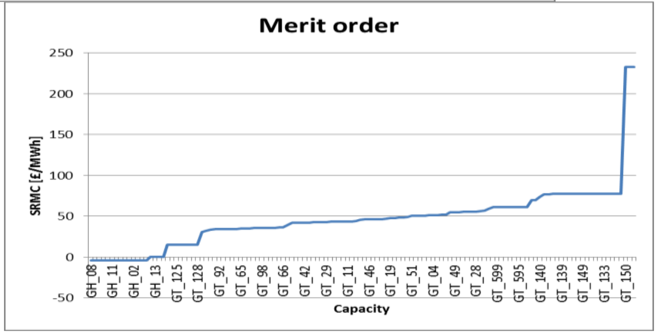
Outputs viewer









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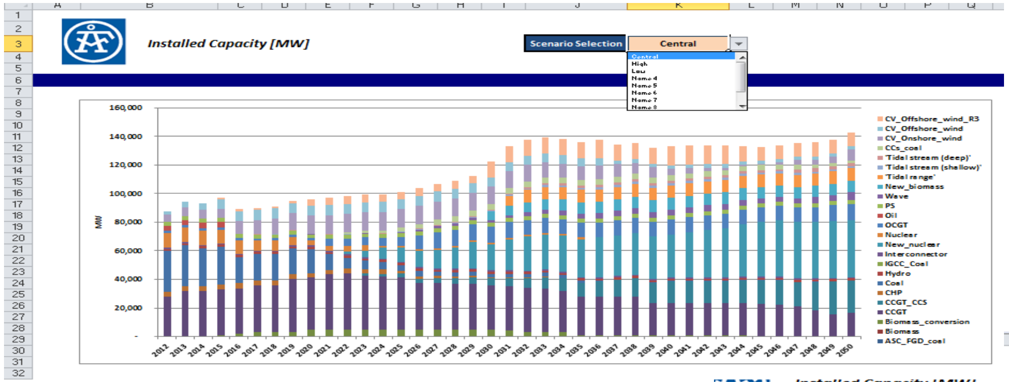
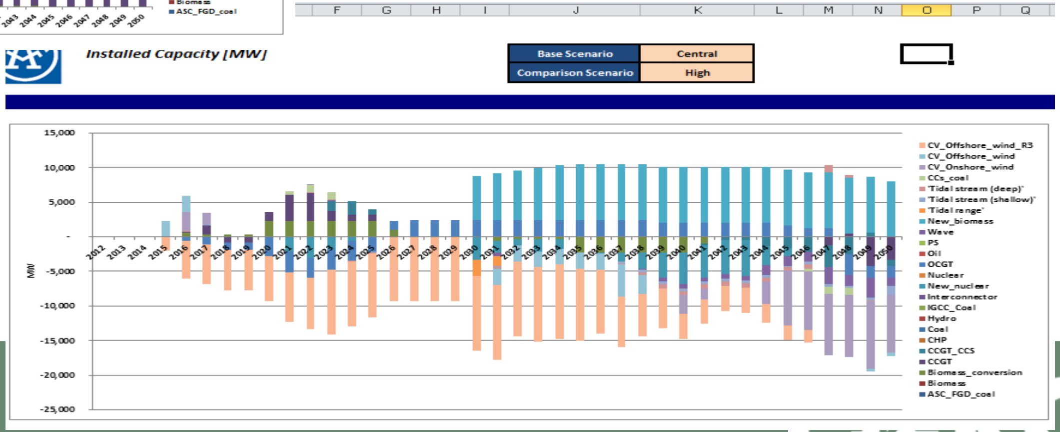
Comparing outputs





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Constraints viewer

- Constraints can be viewed in the traffic light sheet
- Red may be of interest, indicates where the shadow cost of a constraint is other than 0

Lesson learned

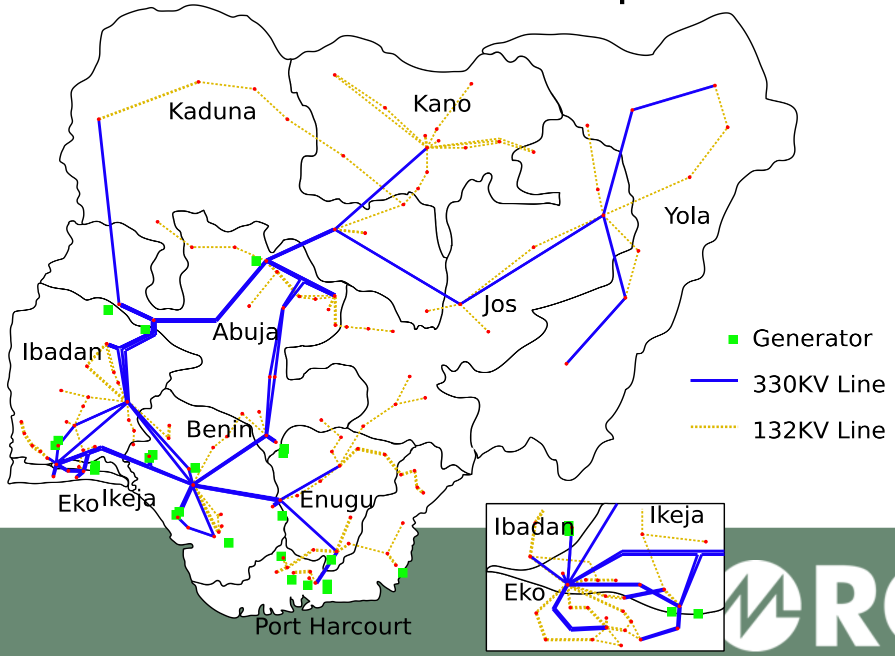
- A complex model is not always what is needed – being able to turn features on/off is handy
- Making sense of results – can it all be explained in a single graph?!
- Can certainly do more to make interaction with the model more straight-forward
- Our models are flexible so the tools need to be transferable also

Feasibility of the MYTO load allocations for Discos in Nigeria: Application of load flow modelling capability (2015-16)

The questions

- Are the load allocations used by the Nigerian Electricity Regulator feasible?
- Or will system balancing compensation continue to be required?

Disco	Load allocation (%)	Benchmark (MW)
Abuja	11.5%	517.5
Benin	9.0%	405.0
Eko	11.0%	495.0
Enugu	9.0%	405.0
Ibadan	13.0%	585.0
Ikeja	15.0%	675.0
Jos	5.5%	247.5
Kaduna	8.0%	360.0
Kano	8.0%	360.0
PH	6.5%	292.5
Yola	3.5%	157.5
Total	**100%**	**4500**



Amounts in question are not insignificant

- TCN is obliged to pay Imbalance penalties to those discos who did not receive their MYTO load share (and had not refused load)
- Discos are collectively owed ₦1bn/month for Balancing Compensation
- TCN is consequently incurring a liability to Discos of ~ ₦1bn/month without being given any additional income in MYTO to pay this – but the Discos need this money for financial survival – revenue recovery is dependent on load allocation being achieved
- We believe the grid cannot deliver the MYTO load shares

2015	August	September	October
Energy received (actual - kWh)	685,596,974	1,036,072,329	924,486,957
Energy received (if load share met - kWh)	843,348,532	1,132,700,299	1,070,219,957
Weighted average BCM tariff of short Discos in month (N/kWh)	6.73	6.74	6.56
Compensation due from TCN (₦ Bn)	1.06	0.65	0.96

How to answer it

Application of our Transmission Modelling and Evacuation Studies

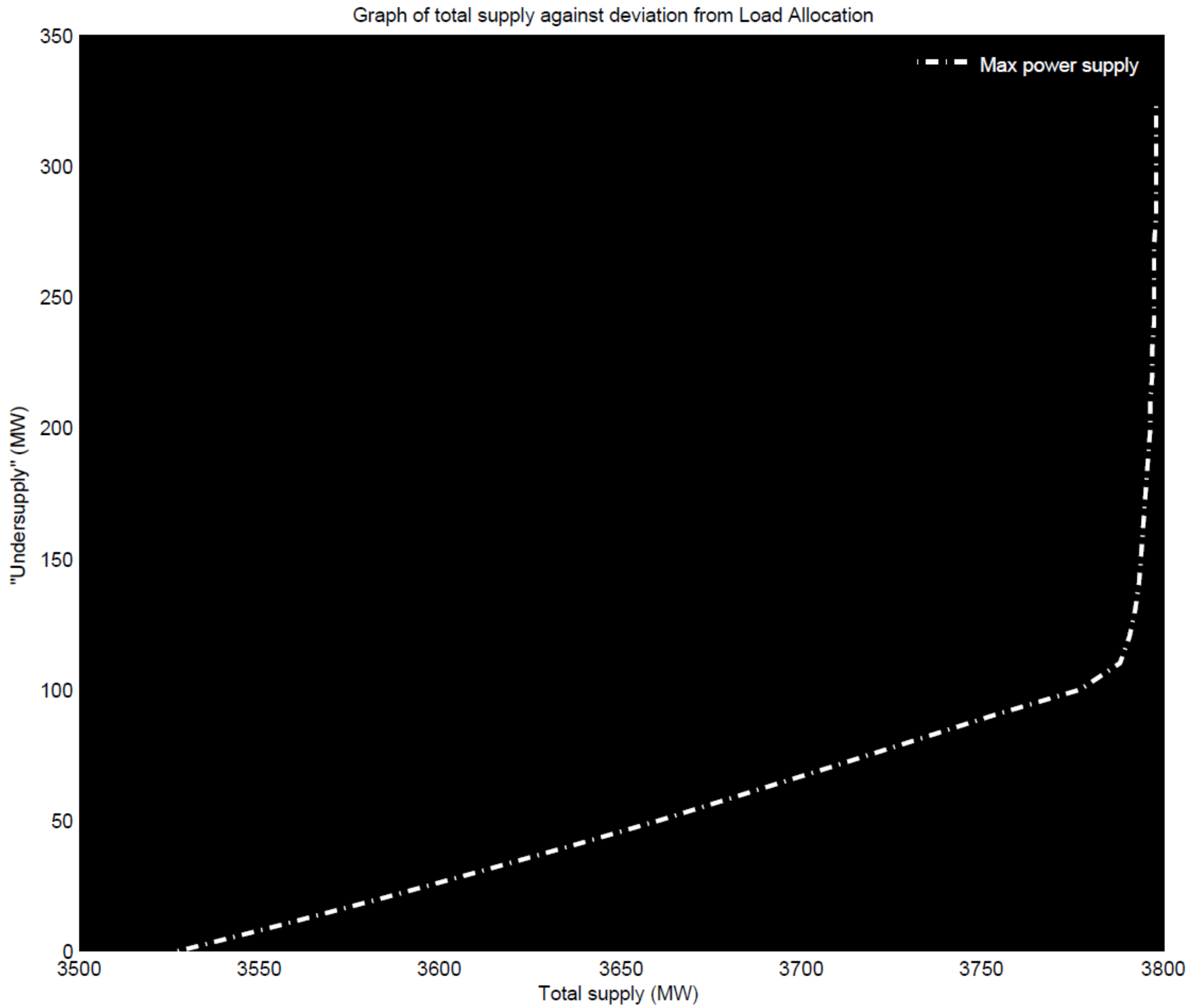
- Model I – Our Transplan model: PSS/E power flow
- Model II – Optimal Load shedding (Collaboration with the University of Edinburgh, UK)

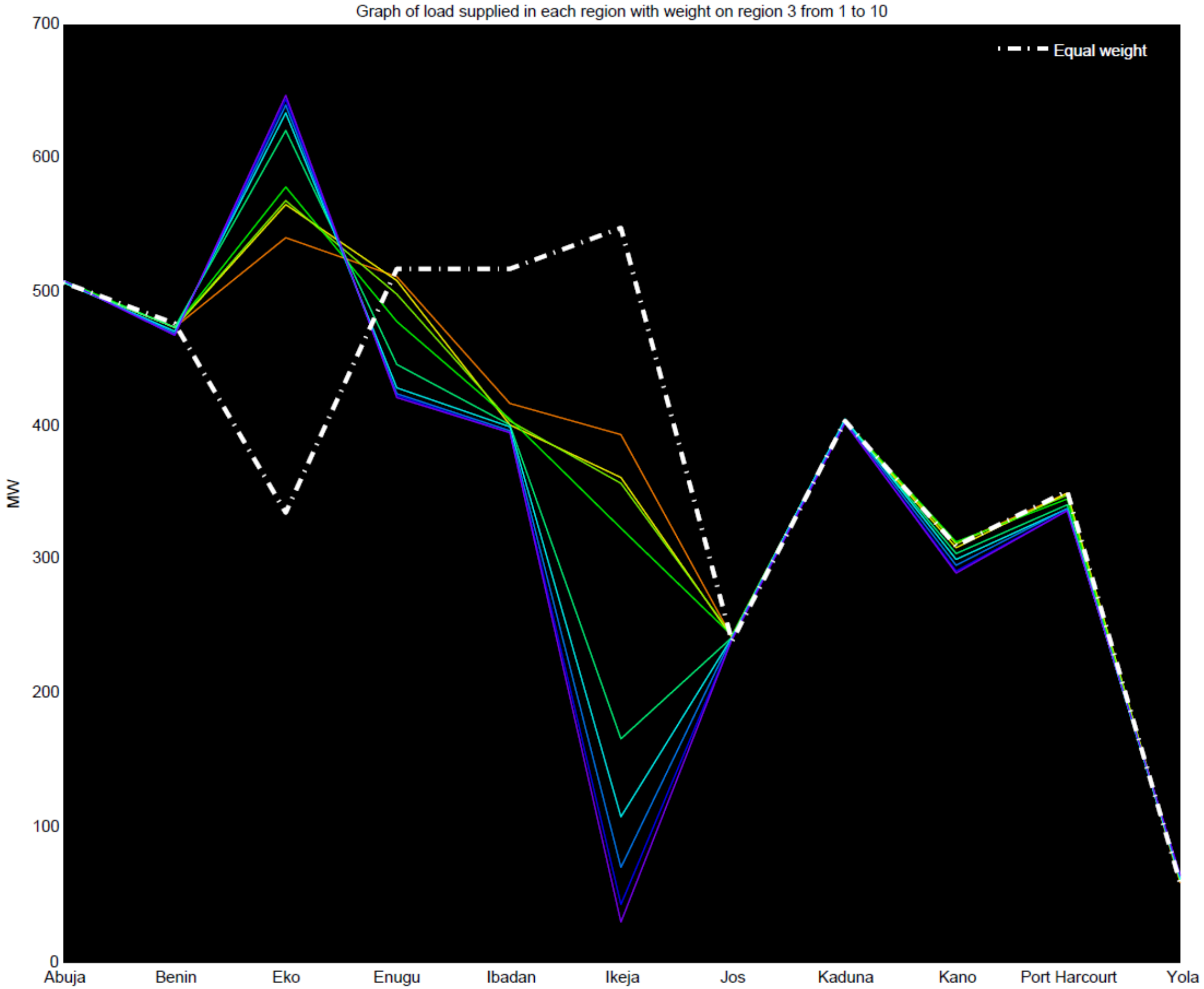
Results of load share analysis

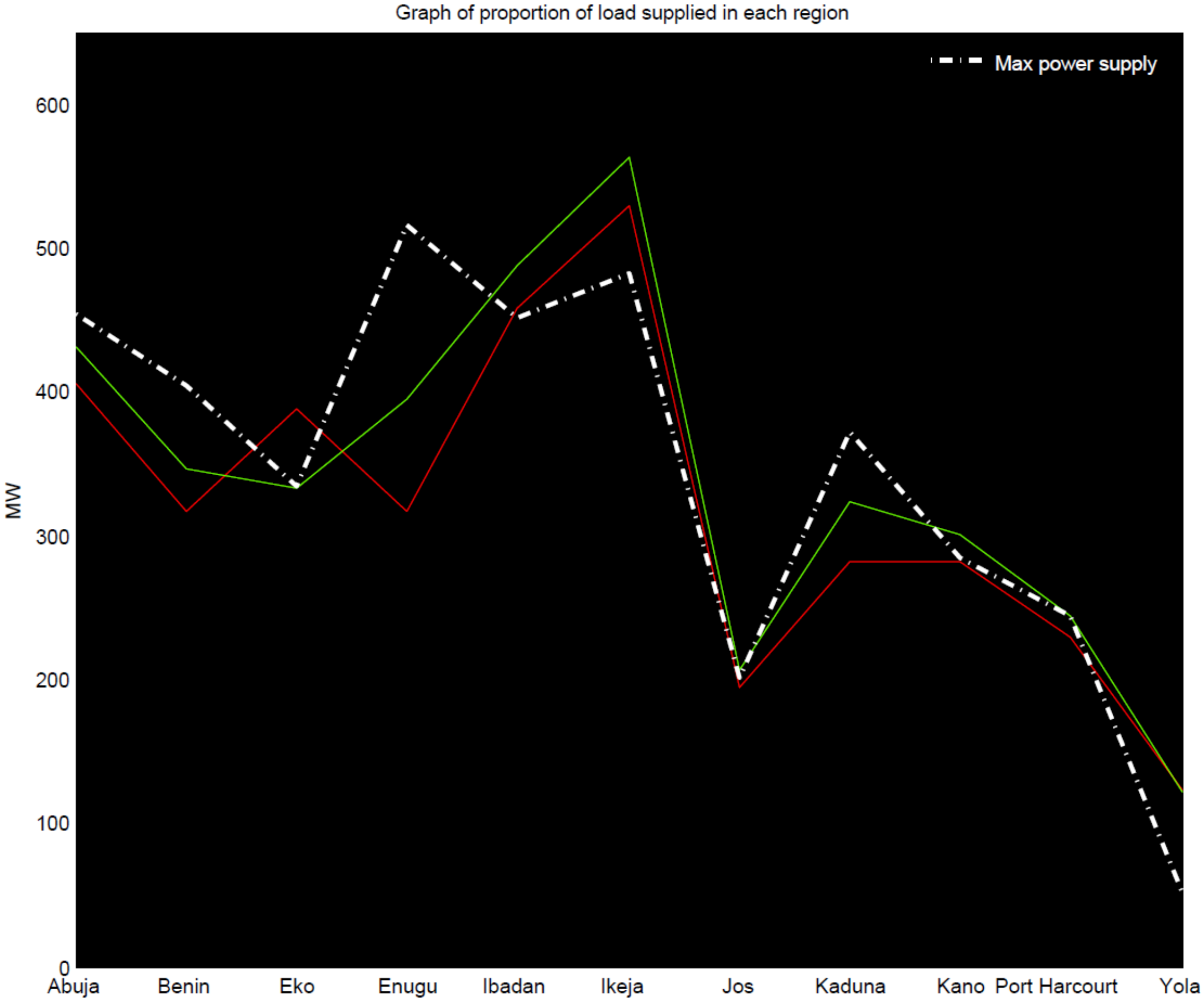
- The **grid in its current form it is not viable for TCN to deliver the MYTO load shares instantaneously** without massive load shedding

- Our modelling suggests that the deviation from the MYTO shares becomes larger as total generation increases

MW	Avail. Gen.	Gen. Dispatched	Exports	Abuja	Benin	Eko	Enugu	Ibadan	Ikeja	Jos	Kaduna	Kano	PH	Yola	Total Load Supplied
Max power delivery															
Low	3238	3238	230	411	259	121	408	430	286	175	355	249	174	59	3158
Central	4003	3898	230	440	315	163	510	630	401	183	371	233	259	60	3795
High	5073	4222	230	484	329	143	524	698	421	169	402	294	286	83	4062
Respecting MYTO load share															
Low	3238	2862	230	295	231	245	231	333	384	141	205	241	166	90	2791
Central	4003	2962	230	305	239	289	239	345	398	146	212	215	172	93	2884
High	5073	3242	230	332	260	317	260	376	433	159	231	232	188	101	3119


Graph of total supply against deviation from Load Allocation
Max power supply
"Undersupply" (MW)
0
50
100
150
200
250
300
350
Total supply (MW)
3500
3550
3600
3650
3700
3750
3800

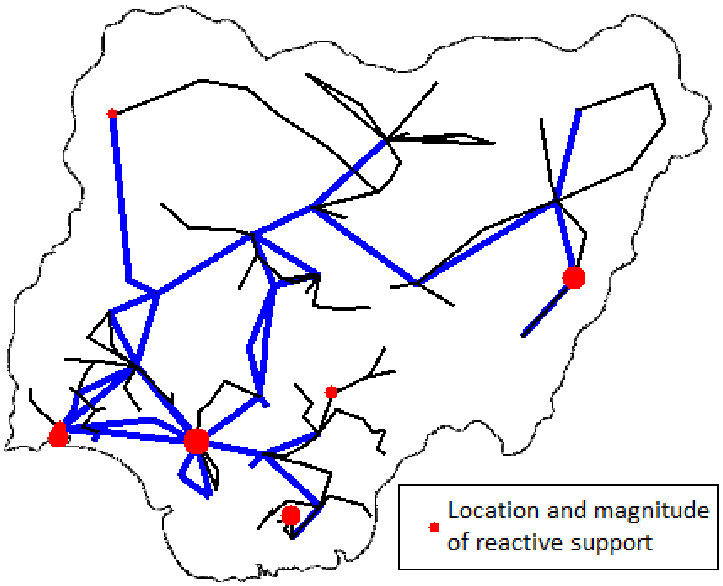

Graph of load supplied in each region with weight on region 3 from 1 to 10
Equal weight
MW
700
600
500
400
300
200
100
0
Abuja
Benin
Eko
Enugu
Ibadan
Ikeja
Jos
Kaduna
Kano
Port Harcourt
Yola



Graph of proportion of load supplied in each region
Max power supply
MW
600
500
400
300
200
100
0
Abuja
Benin
Eko
Enugu
Ibadan
Ikeja
Jos
Kaduna
Kano
Port Harcourt
Yola

Exploring possible solutions

- In the **medium term investment in the network could improve the position**
- For example – use modelling to explore deployment of reactive support
- 3561 MW delivered in total – without violating load allocation
- Size of red blob corresponds to magnitude of q support added
- Capacitors required at 11 strategic locations
- 190 Mvar reactive support in total
- Note that the modelling assumes the network is operated strictly within the rating of the equipment and it may be that TCN is able to flex these limits (e.g., overloading of transformers etc) in order to deal with the operational challenges faced



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Reactive support comparison

- The table below shows the results for each Disco of respecting MYTO load shares with and without reactive support (RS). Without reactive support, total load delivered falls to 2654MW from the "Max power delivery" case of 3565MW. With reactive support we are able to supply 3561MW while still respecting the MYTO load shares.

	Total generation available (MW)	Total generation delivered to Discos (MW)	Abuja	Benin	Eko	Enugu	Ibadan	Ikeja	Jos	Kaduna	Kano	PH	Yola
Max power delivery													
No RS	4003	3565	440	315	163	510	630	401	183	371	233	259	60
Respecting MYTO load shares													
No RS	4003	2654	305	239	289	239	345	398	146	212	215	172	93
With RS	4003	3561	409	320	392	320	463	534	196	285	285	231	125

What new tools would be beneficial?

Ideas (1/2)

- Interested in models of power markets and/or the wider energy system that run reasonably quickly and provide **robust enough** answers
- Models of this type that can be **run in combination with visualisation tools** for easy understanding of the implications (i.e., showing key output metrics) is also desirable
- Or taking a complex model and **allowing for simplifications to be easily applied** to reduce problem size (e.g., ranking variables that are increasing the problem size and/or active constraints) without too much loss of accuracy etc
- Then we can answer the question: what extra accuracy does the full functionality provide? Or alternatively: **how much is lost by using a more basic application of the model**?

Ideas (2/2)

- There is a need for flexible and stable results interface
- Interface may need to be run by experiences modellers, for in-house training and end-user clients
- Graphical tools to “get it all on one graph”


감사합니다
Nagode
Grazie
Ese
Ευχαριστίες
Dalu
Obrigado
Thank You
Köszönöm
Tack
Спасибо
Dank
Gracias
谢谢
Merci
Seé
ありがとう