Generation Expansion Model (GEM)

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Outline

- Overview of model
  - Basics
  - Objective function
  - Constraints
- Some key aspects
  - Build decision
  - Treatment of transmission losses
  - Security constraints
  - One or two contentious topics
  - Solution strategies
- Illustrative outputs
- What next?
- Further information

Overview of model

- <u>Basics</u>
- GEM is a long term capacity expansion planning model
- Formulated as a mixed integer programming problem (MIP)
- Coded using GAMS and solved with CPLEX
- Input data compiled in an Excel spreadsheet
- Output files generated as tab or comma delimited text files
- Matlab scripts used to process output files
- Publicly available
- <u>Objective function</u>
- Minimise discounted costs
  - Capital expenditure, fixed and variable operating costs
  - Penalties on potential infeasibilities

Overview of model – cont'd

- <u>Constraints</u>
- Compute costs (including HVDC charge), 3 constraints
- Build decision and capacity balance, 5 constraints (see below)
- 3 accounting equations – generation by quarter and year, and fuel by year
- Energy balance constraint
- Determine losses (see below)
- 3 security constraints (see below)
- 6 technical operating constraints – minimum and maximum capacity factors, minimum utilisation by technology type, limits on fuel availability, e.g. gas, and limit on energy from a single fuel type, e.g. wind, and hydro generation limited by inflows.
- 2 renewables targets constraints – energy and capacity
- 3 constraints to control operation of pumped hydro schemes

Build decision

```
* Ensure new station is fully built only once, if at all.
bldGenOnce(posbuild(s))..
  SUM(validbldyr(s,y), GENBLDINT(s,y)$intbld(s) + GENBLDCONT(s,y)$contbld(s) )
  =l= 1;

* If new 'integer' station is built, ensure it doesn't exceed nameplate capacity.
buildCapInt(s,y)$( posbuild(s) * intbld(s) * validbldyr(s,y) )..
  BUILD(s,y) =e= GENBLDINT(s,y) * nameplate(s) ;

* If new 'continuous' station is built, ensure it doesn't exceed nameplate capacity.
buildCapCont(s,y)$( posbuild(s) * contbld(s) * validbldyr(s,y) )..
  BUILD(s,y) =e= GENBLDCONT(s,y) * nameplate(s) ;

* Restrict aggregate new capacity built in a single year to be less than AnnMW.
AnnNewMWcap(vY(y))$( %AnnMW% <= 1000 )..
  SUM(s$( posbuild(s) * validbldyr(s,y) ), BUILD(s,y)) =l= %AnnMW% ;

* Keep track of capacity in each year.
balance_capacity(s,vY(y))..
  CAPACITY(s,y) =e= InitCap(s)$firstYr(y) + CAPACITY(s,y-1)$vYx1(y) + BUILD(s,y) -
   RETIRE(s,y) ;
```


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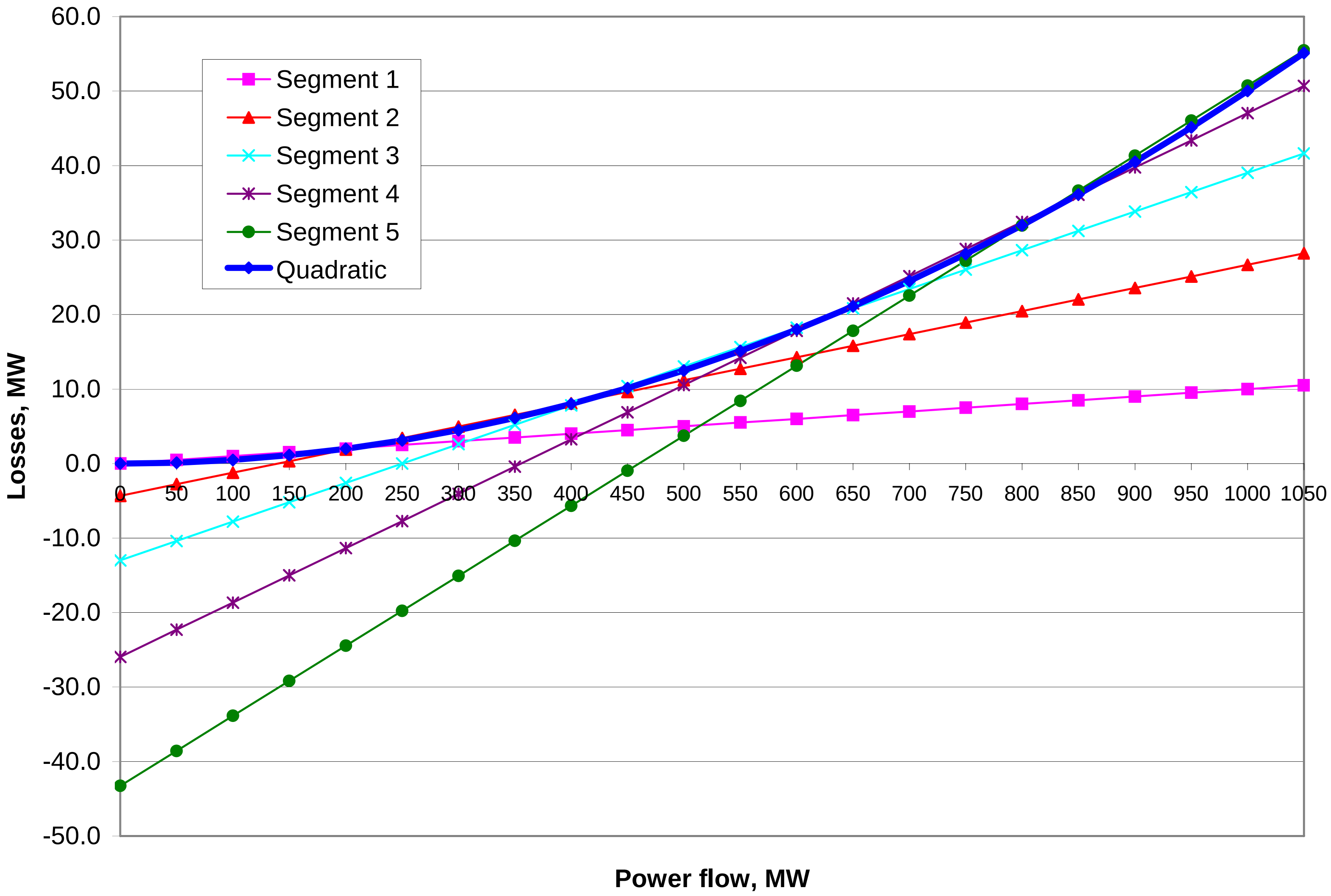
Losses – piecewise linear approximation

- A simple convex formulation works well, as losses are implicitly costly
- User selects number of line segments to use – currently using 5

```
* Piecewise linear transmission losses.
boundTxloss(ild,ild1,vY(y),t,blk,nsegment(n))$vTx(ild,ild1,y)..
  LOSS(ild,ild1,y,t,blk) =g=
  intercept(ild,ild1,y,n) + slope(ild,ild1,y,n) *TX(ild,ild1,y,t,blk) ;
```

- A more complex formulation was trialed using SOS2 variables
  - Has the advantage that it works with non-convex functions (not an issue with transmission losses), and min or max objective functions
  - Seemingly high computational overhead, i.e. ~1000 SOS2 sets each with 6 members, but solved in similar time to simple formulation using CPLEX

Losses – cont'd



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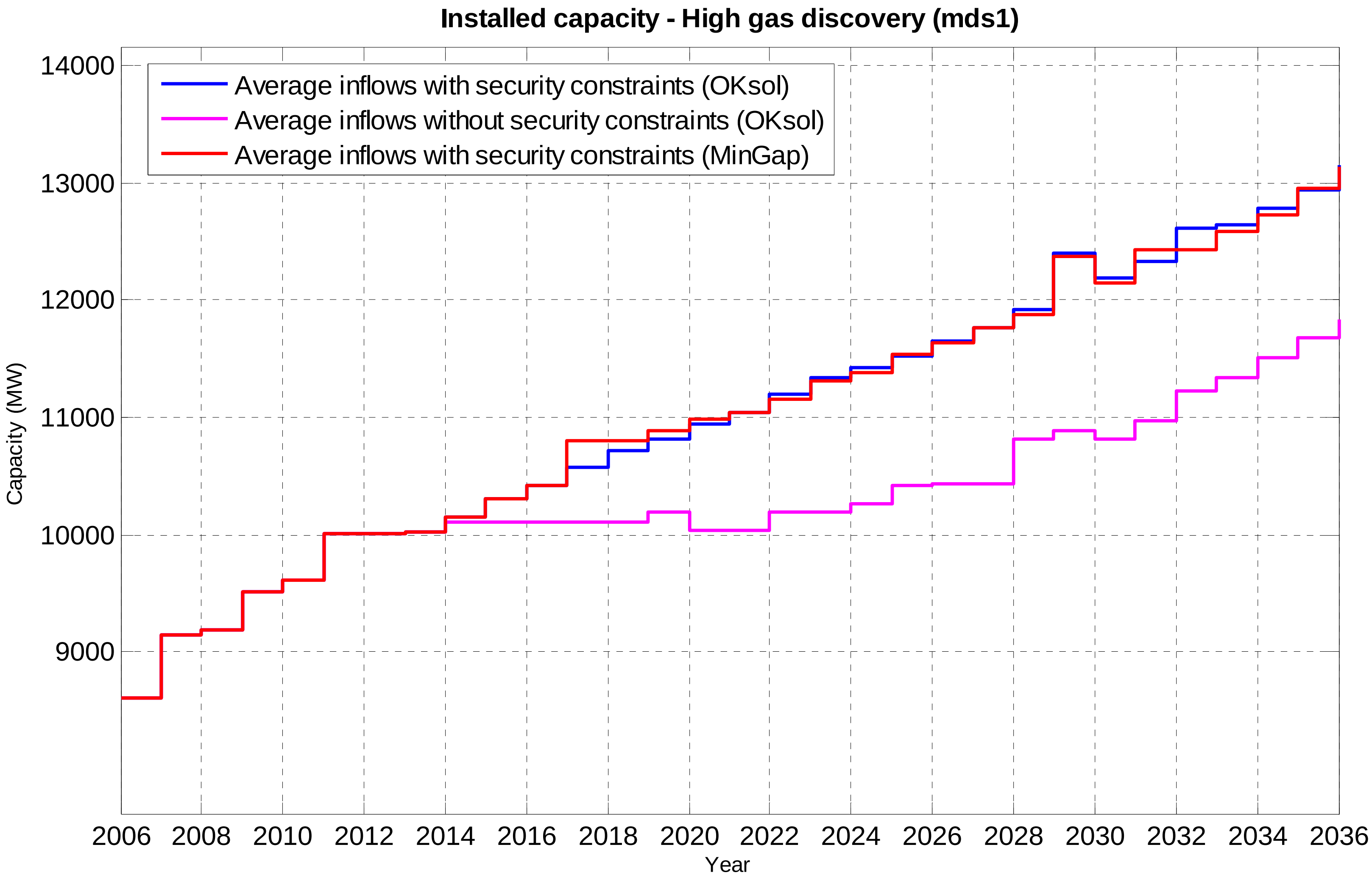
Security constraints

```
* Ensure enough NZ available peak capacity to meet NZ peak.
bal_security_NZ(vY(y))$UseSecurityCon..
  SUM(s, CAPACITY(s,y) * peakcontribution(s) ) -
  largestNIgen(y) - largestSIgen(y) - NxtLrgstNIgen(y) –
  freqKeepNI(y) - freqKeepSI(y) -
  maxTxLosses(y) * txcap('si','ni',y) + NZSECURITYSLACK(y)
  =g= peakload(y,'NZ_peak') ;

* Ensure enough NI available peak capacity to meet NI peak demand, considering HVDC losses.
bal_security_NI1(vY(y))$UseSecurityCon..
  SUM(nigen(s), CAPACITY(s,y) * peakcontribution(s) ) -
  largestNIgen(y) - NxtLrgstNIgen(y) - freqKeepNI(y) +
  txcap('si','ni',y) * (1 - maxTxLosses(y)) + NI1SECURITYSLACK(y)
  =g= peakload(y,'NI_peak') ;

* Ensure enough capacity to meet NI peak demand if one pole is out.
bal_security_NI2(vY(y))$UseSecurityCon..
  SUM(nigen(s), CAPACITY(s,y) * peakcontribution(s) ) -
  largestNIgen(y) - freqKeepNI(y) +
  txcapPo('si','ni',y) * (1 - maxTxLossesPO(y)) + NI2SECURITYSLACK(y)
  =g= peakload(y,'NI_peak') ;
```

Build schedule, mds1

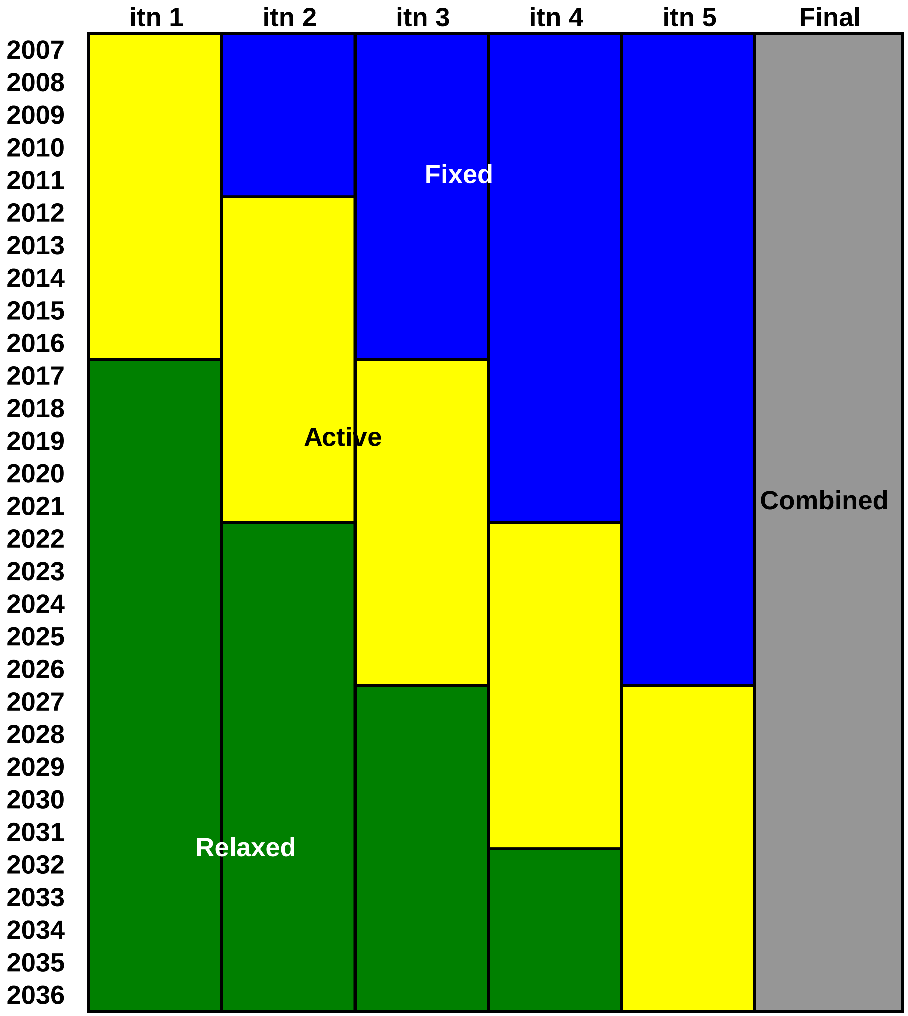


One or two contentious topics

- Revenue and/or generation adequacy?
- Least cost (central planner) v market behaviour?
  - Australian ‘GIT’ requires a least cost expansion plan…
- Implied market design?
  - Energy and/or capacity, or both
- Implied prices
  - Energy prices are straightforward
  - Capacity prices are complicated

Solution strategies

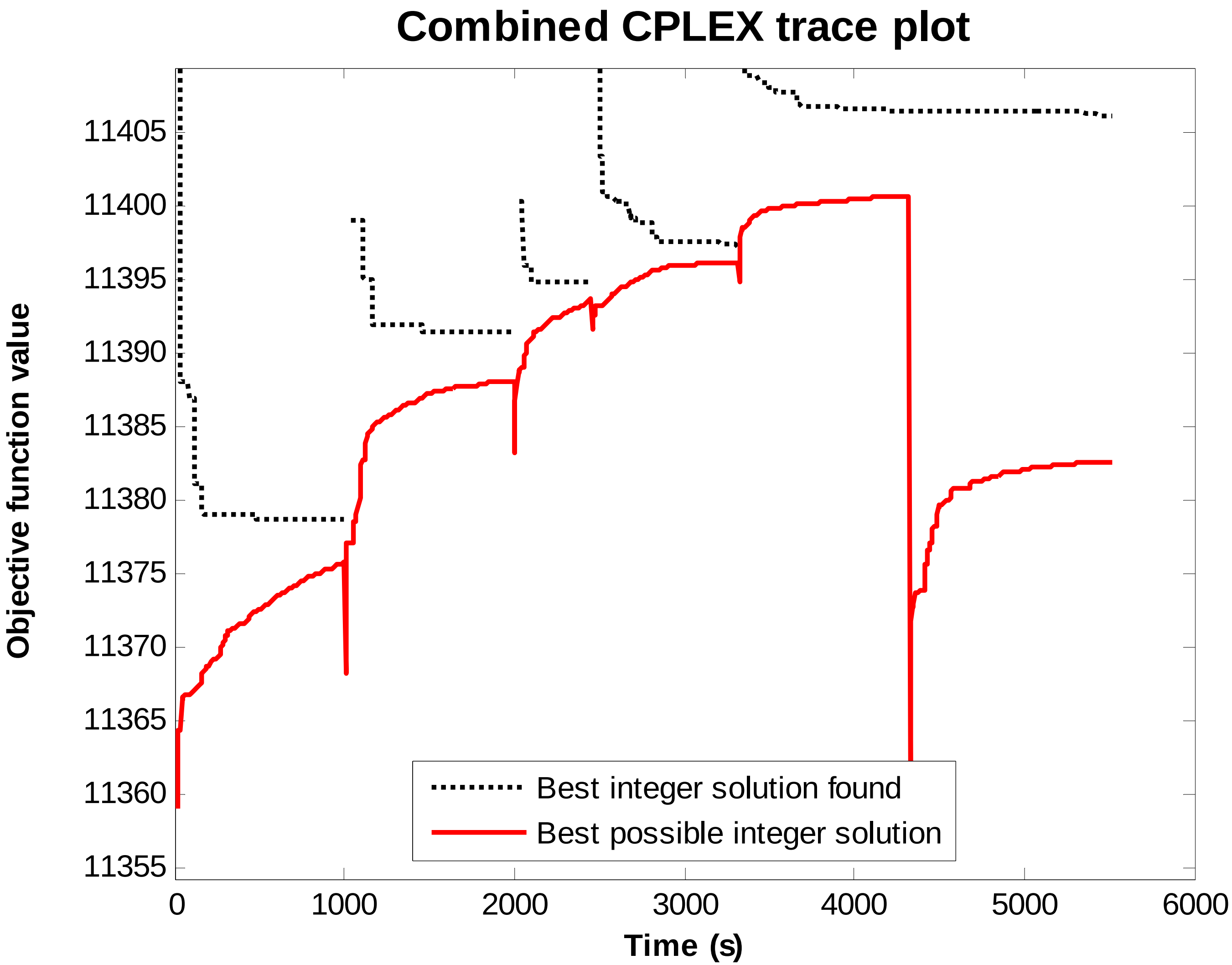
- QDsol – quick and dirty
  – Entire horizon
- OKsol – obtain o.k. solutions
  – Entire horizon
  – Rolling horizon
- MinGap – prove optimality
  – Entire horizon
  – Rolling horizon



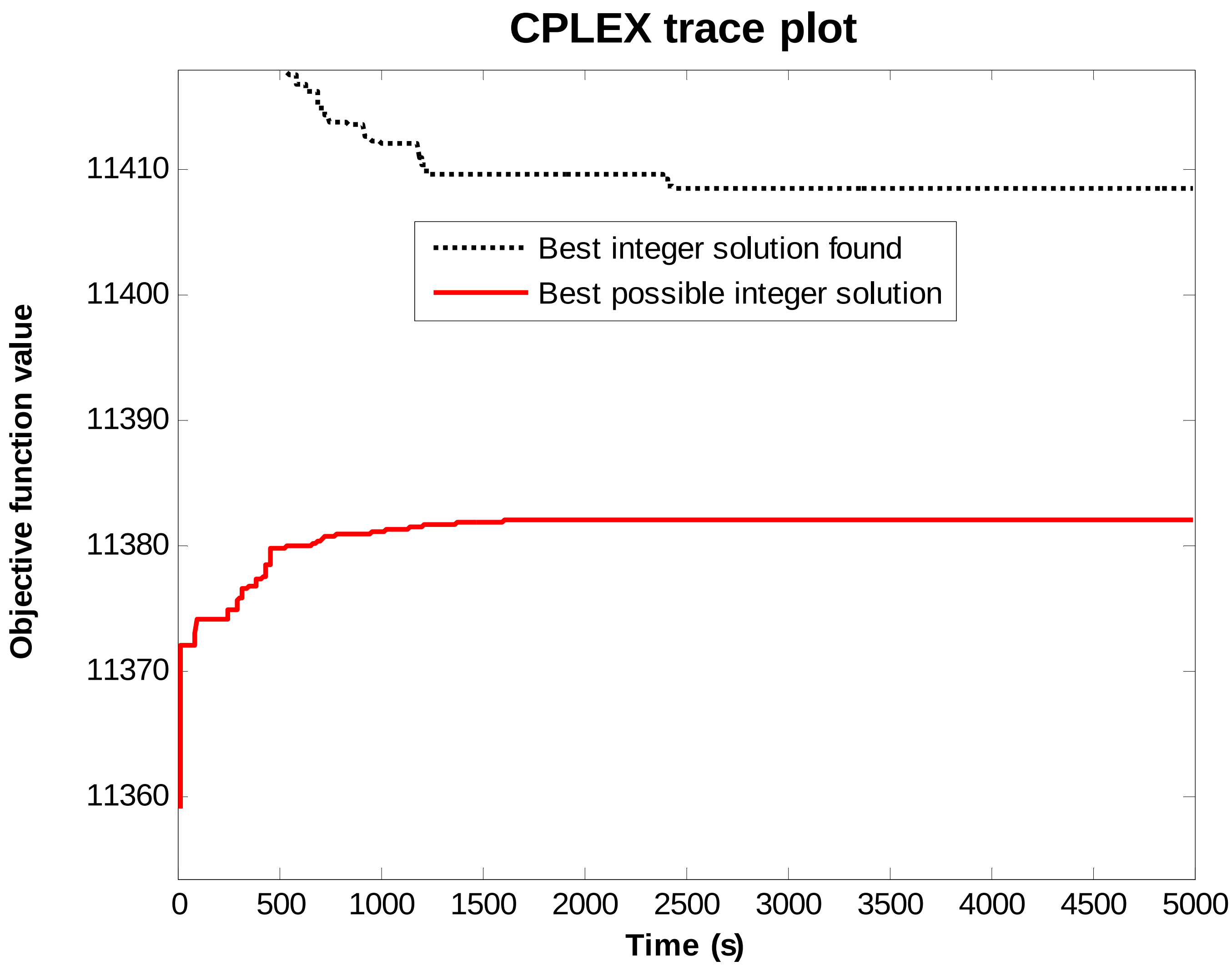
Solution strategies compared, mds3

		Actual	Best	Gap	Gap%	Secs	# bin vars	Options
Oksol	Itn 1	11,378.8	11,375.8	3.0	0.03	1,000	371	2
(rolling horizon)	Itn 2	11,391.5	11,388.1	3.4	0.03	1,000	748	3
	Itn 3	11,394.8	11,393.7	1.1	0.01	453	894	3
	Itn 4	11,397.3	11,396.2	1.1	0.01	869	1,000	3
	Itn 5	11,406.5	11,400.7	5.8	0.05	1,000	1,121	3
	Final	11,406.2	11,382.6	23.6	0.21	1,200	2,386	4
						5,522		
OKsol (entire)	Final	11,408.5	11,382.2	26.2	0.23	*5,000*	2,386	6
MinGap	Itn 1	11,378.7	11,375.8	2.9	0.03	1,000	371	2
	Itn 2	11,391.3	11,387.8	3.5	0.03	1,000	748	3
	Itn 3	11,394.6	11,393.5	1.1	0.01	402	894	3
	Itn 4	11,397.2	11,396.0	1.1	0.01	819	1,000	3
	Itn 5	11,405.7	11,400.7	4.9	0.04	1,000	1,121	3
	Final	11,405.5	11,391.2	14.3	0.13	7,200	2,386	5
						11,421		
QDsol (entire)	Final	11,468.2	11,377.8	90.4	0.79	*261*	2,386	8

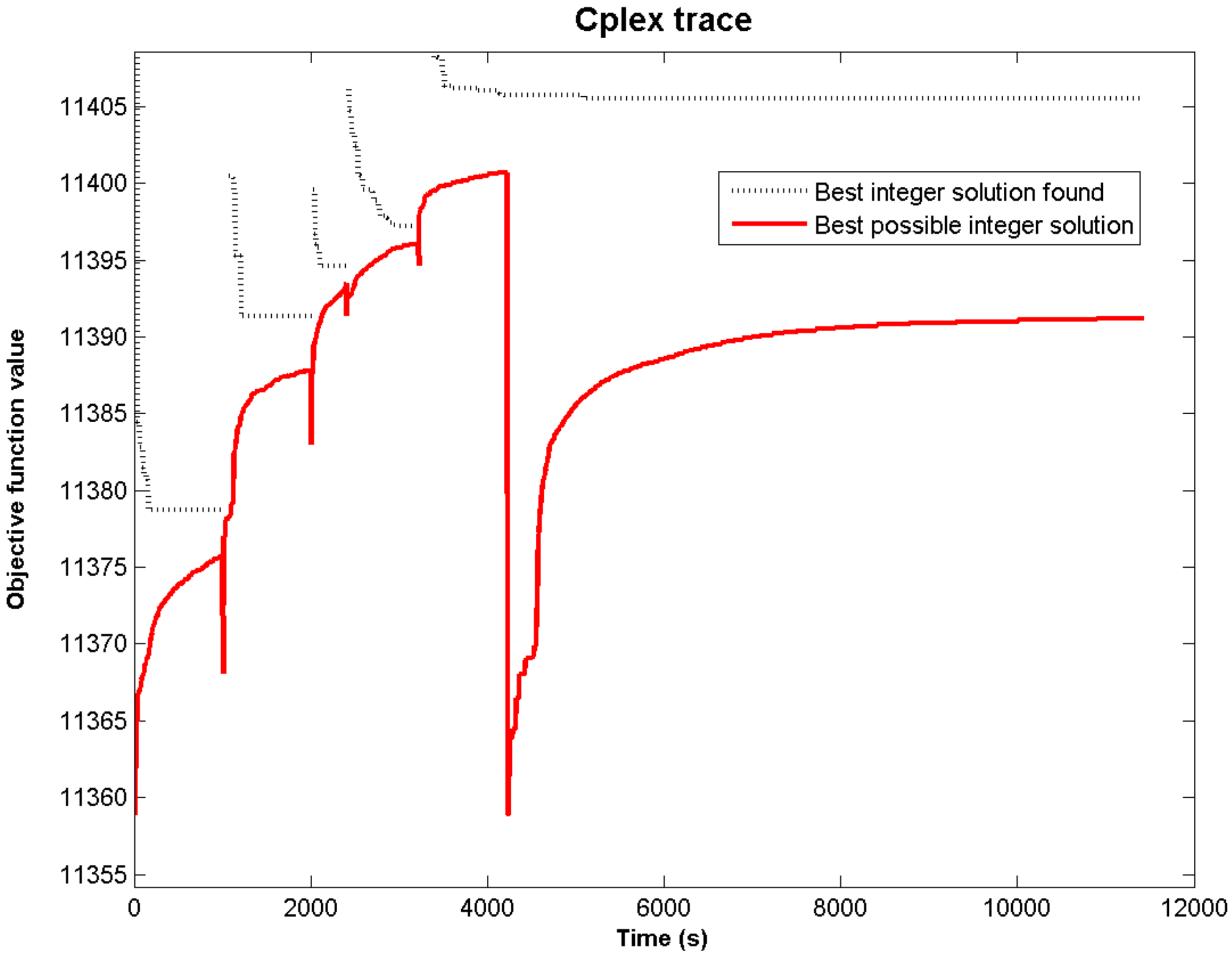
Solution trace, OKsol, rolling horizon (mds3)



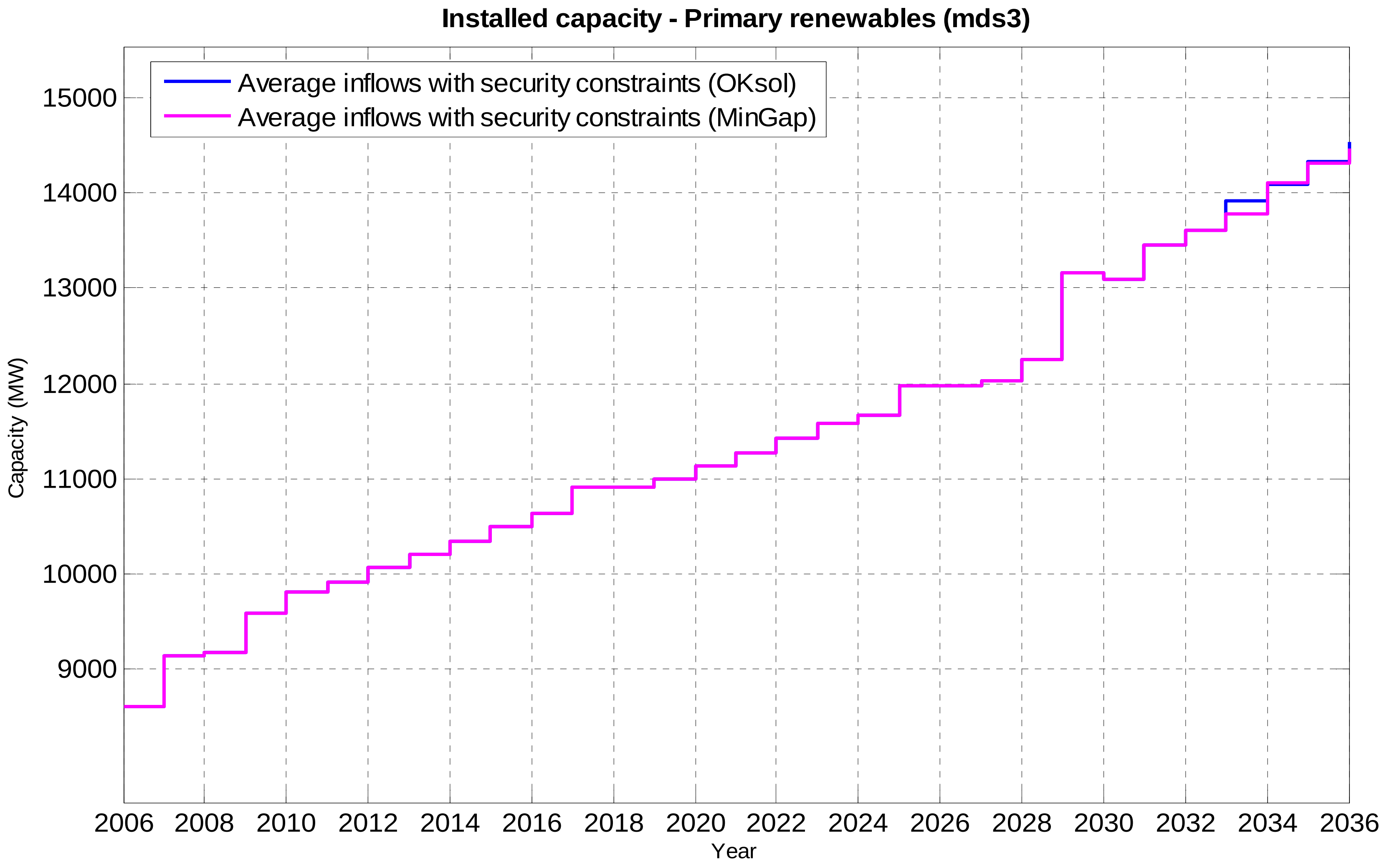
Solution trace, OKsol, entire horizon (mds3)



Solution trace, MinGap (mds3)



Build schedule, mds3



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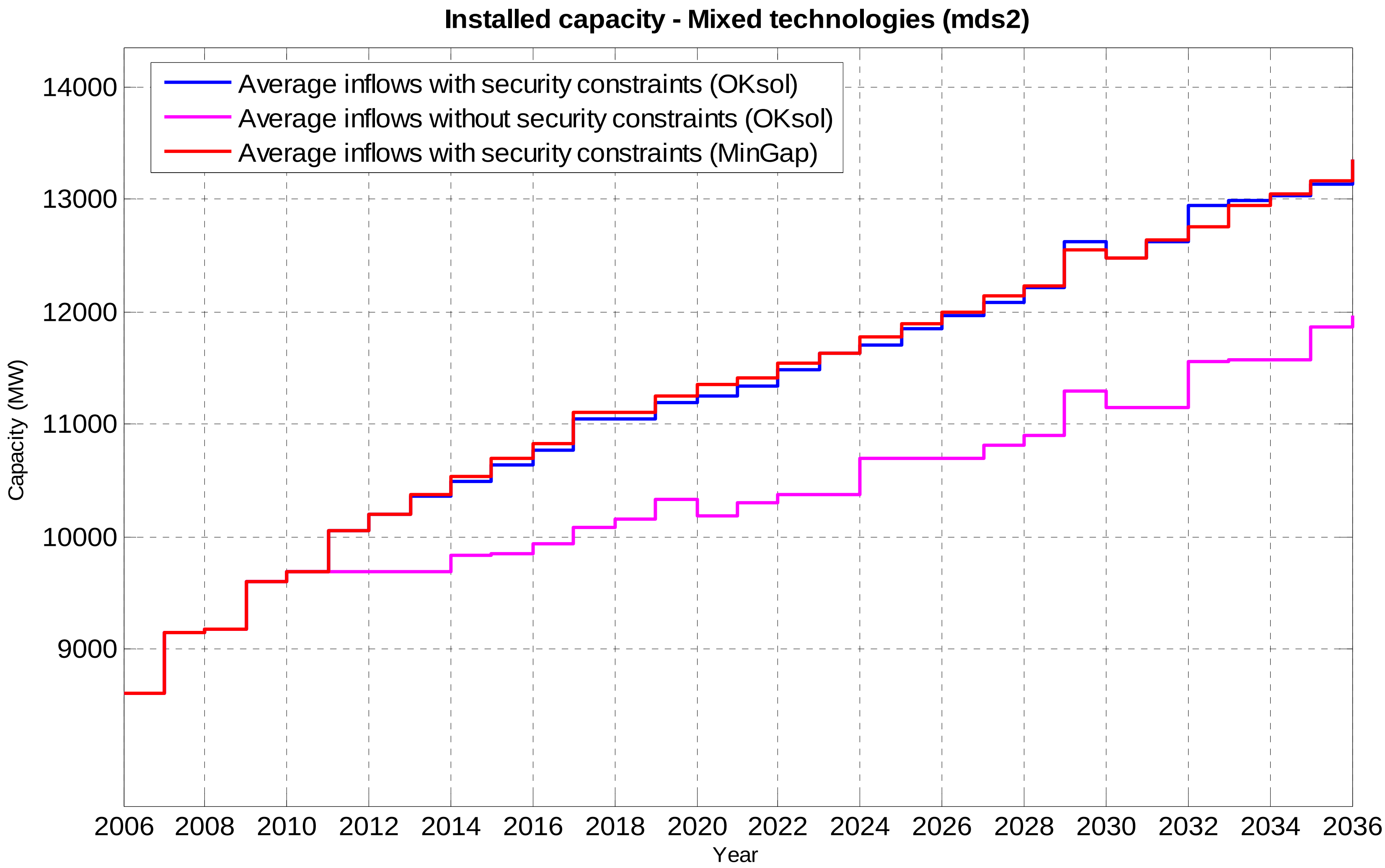
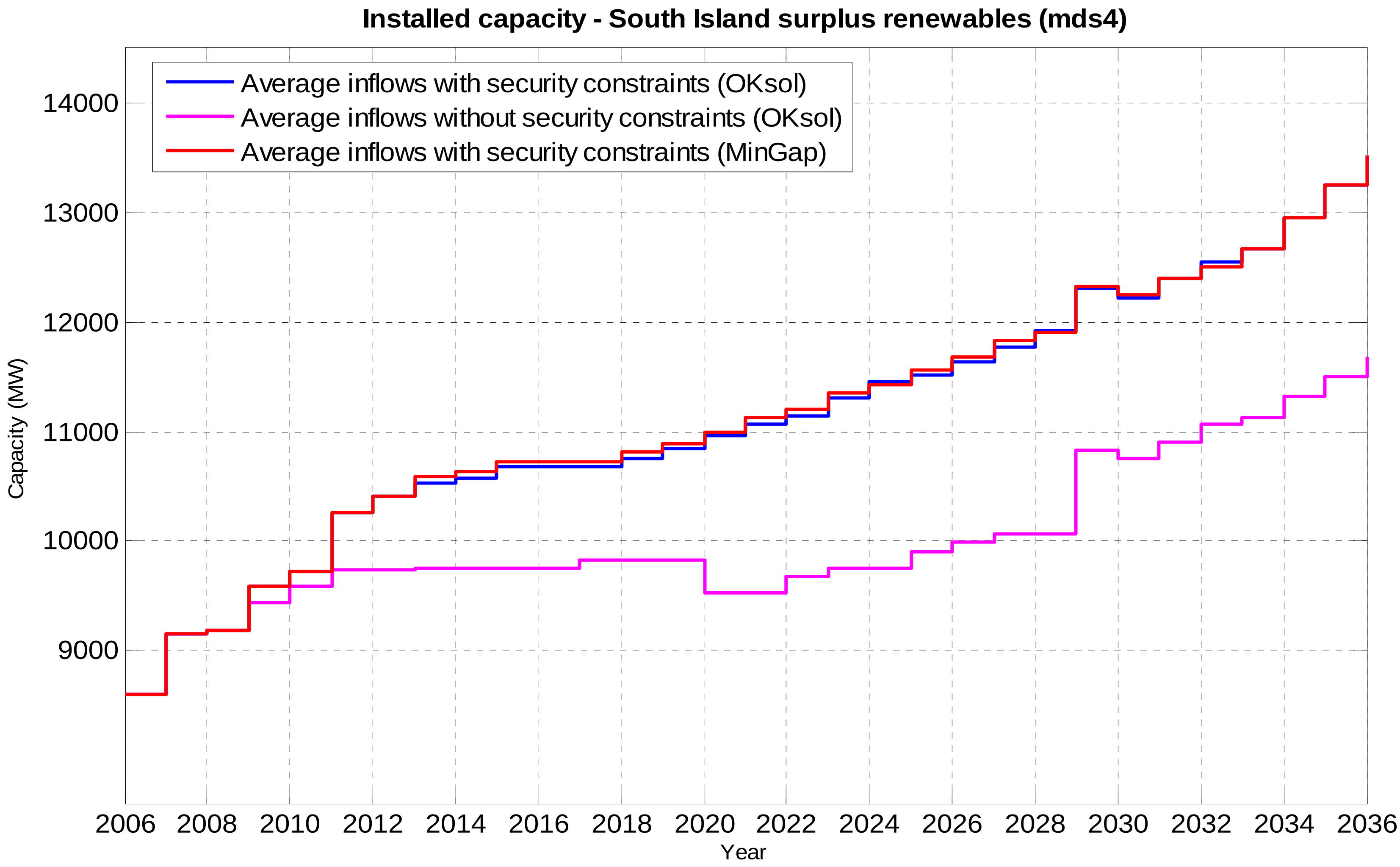
Build schedule, mds2



Build schedule, mds4



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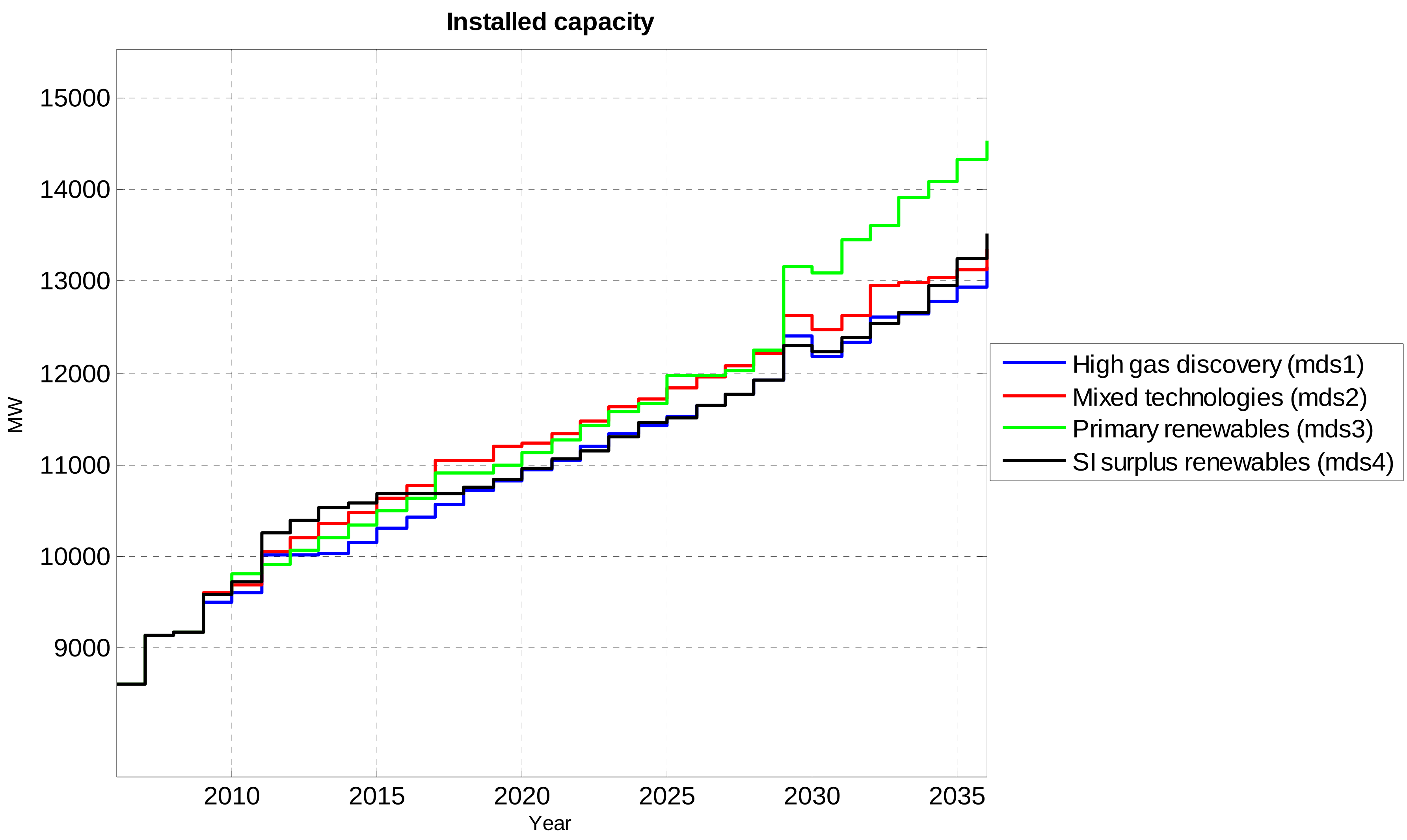
GEM outputs – build schedule



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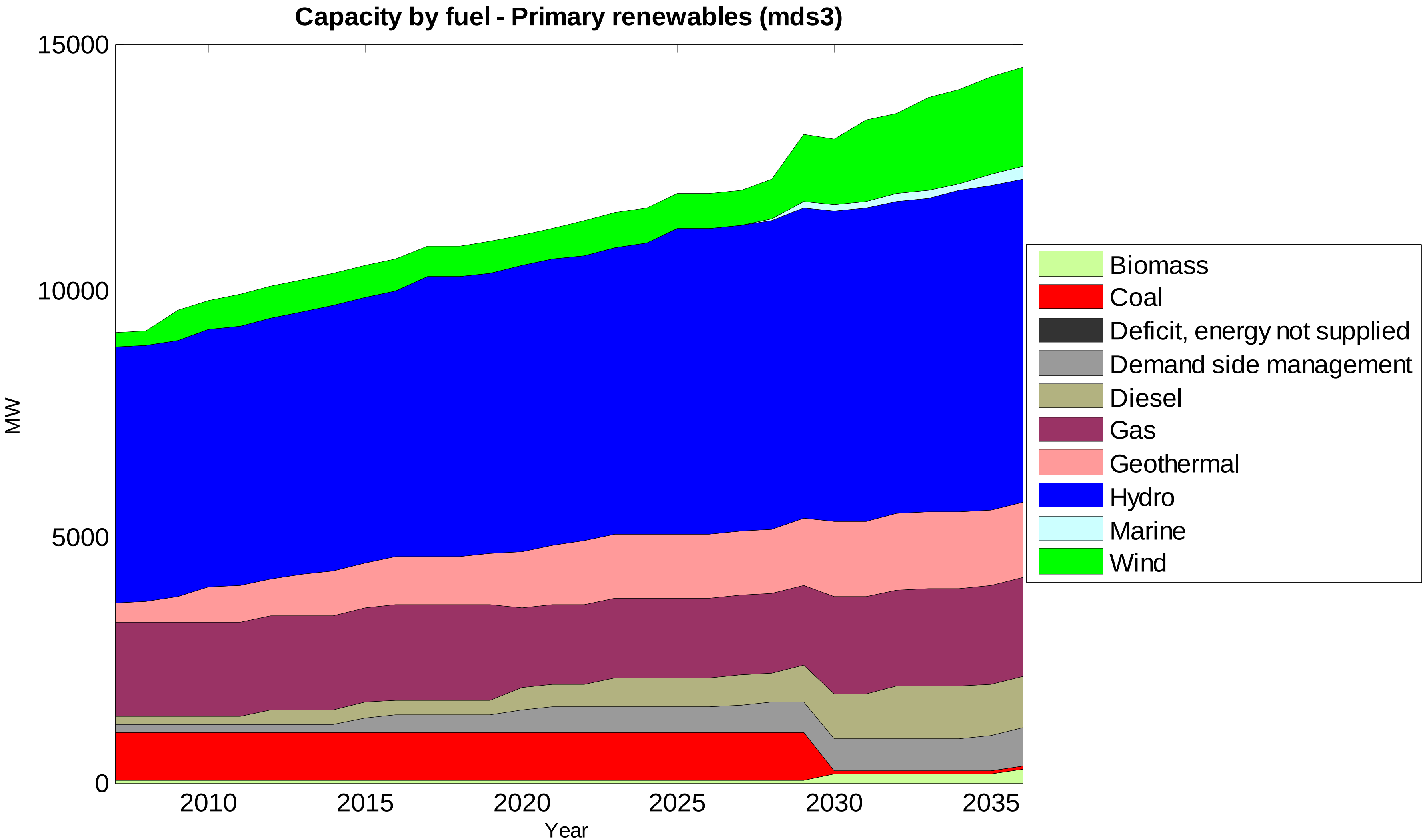
GEM outputs – capacity by fuel type



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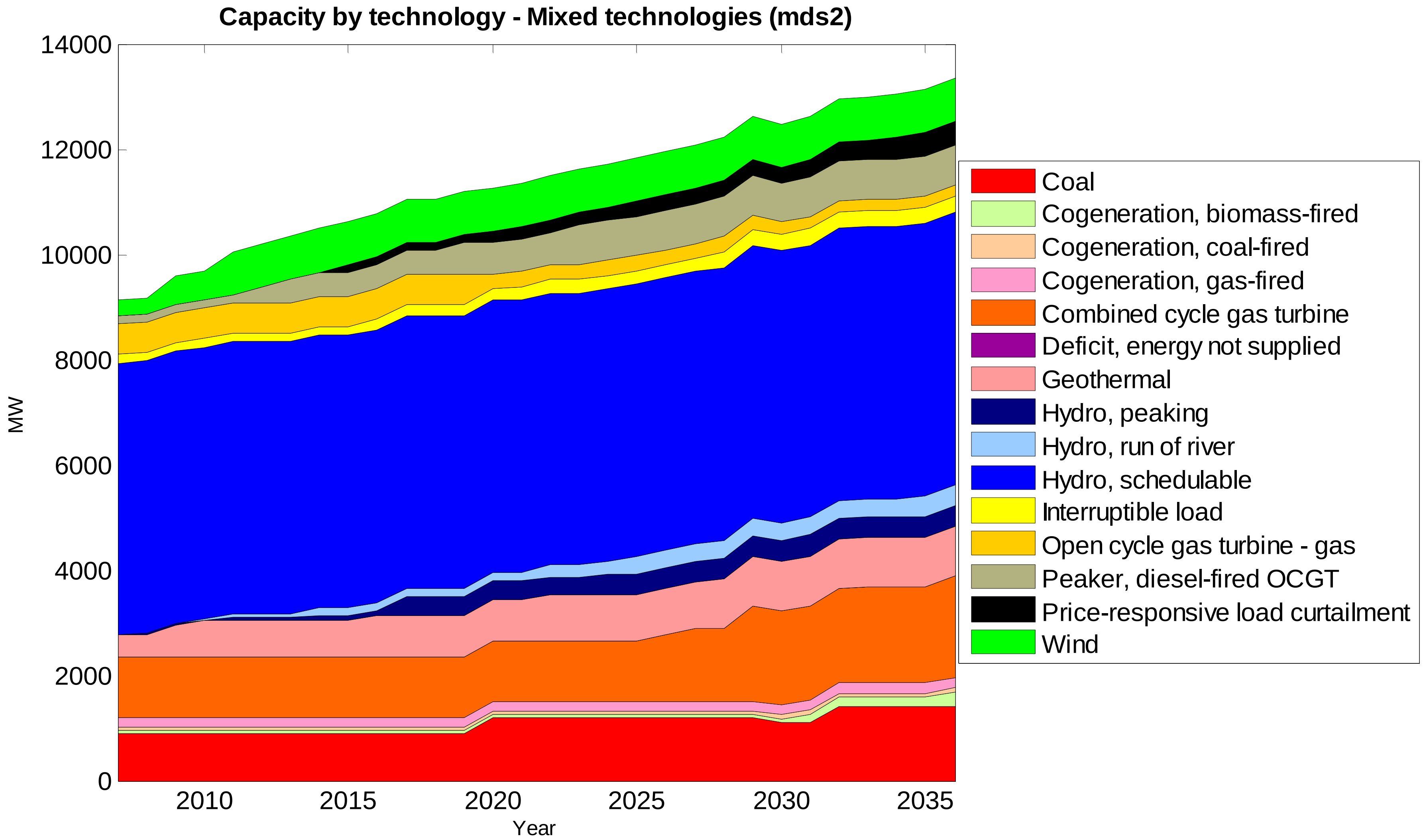
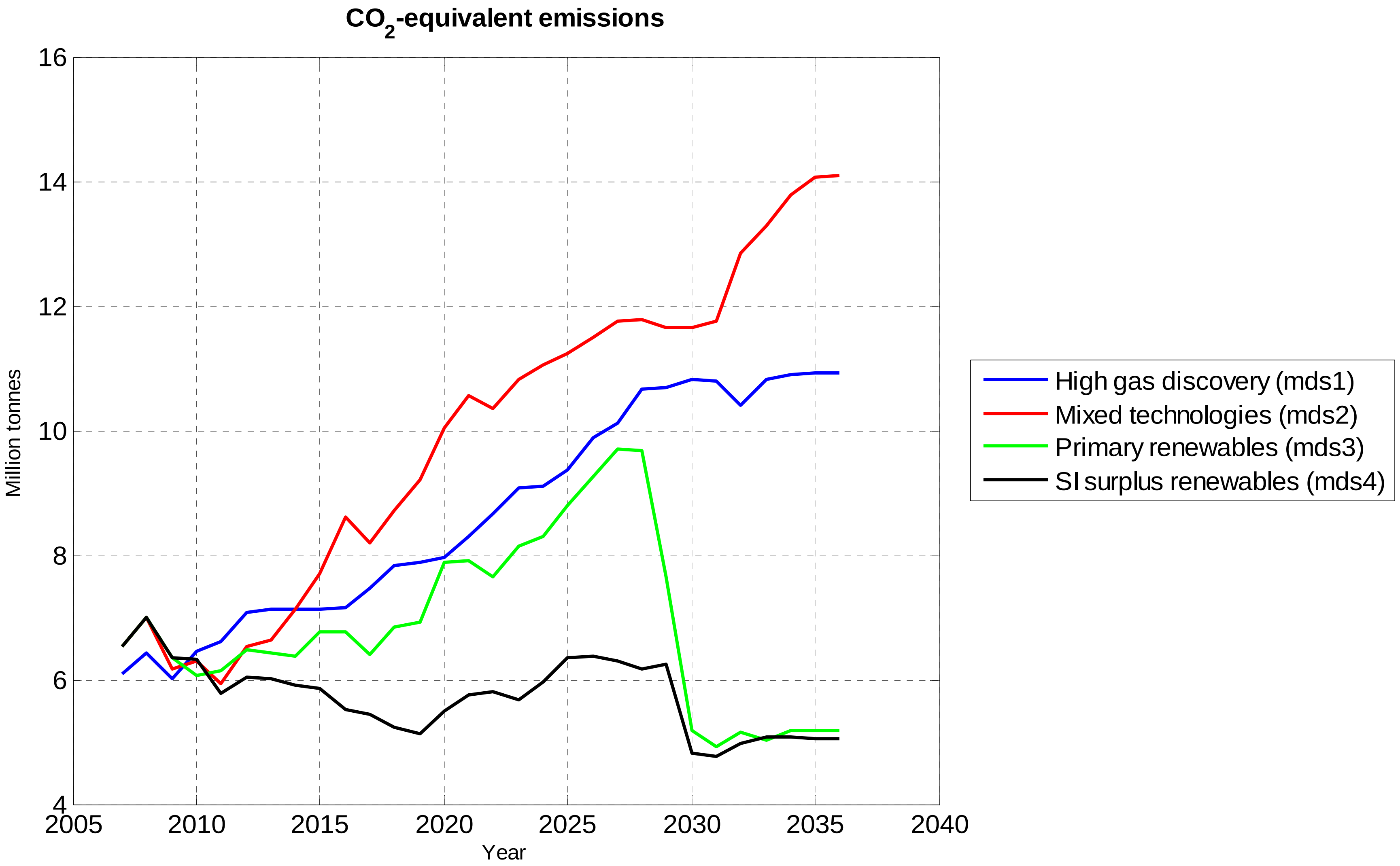
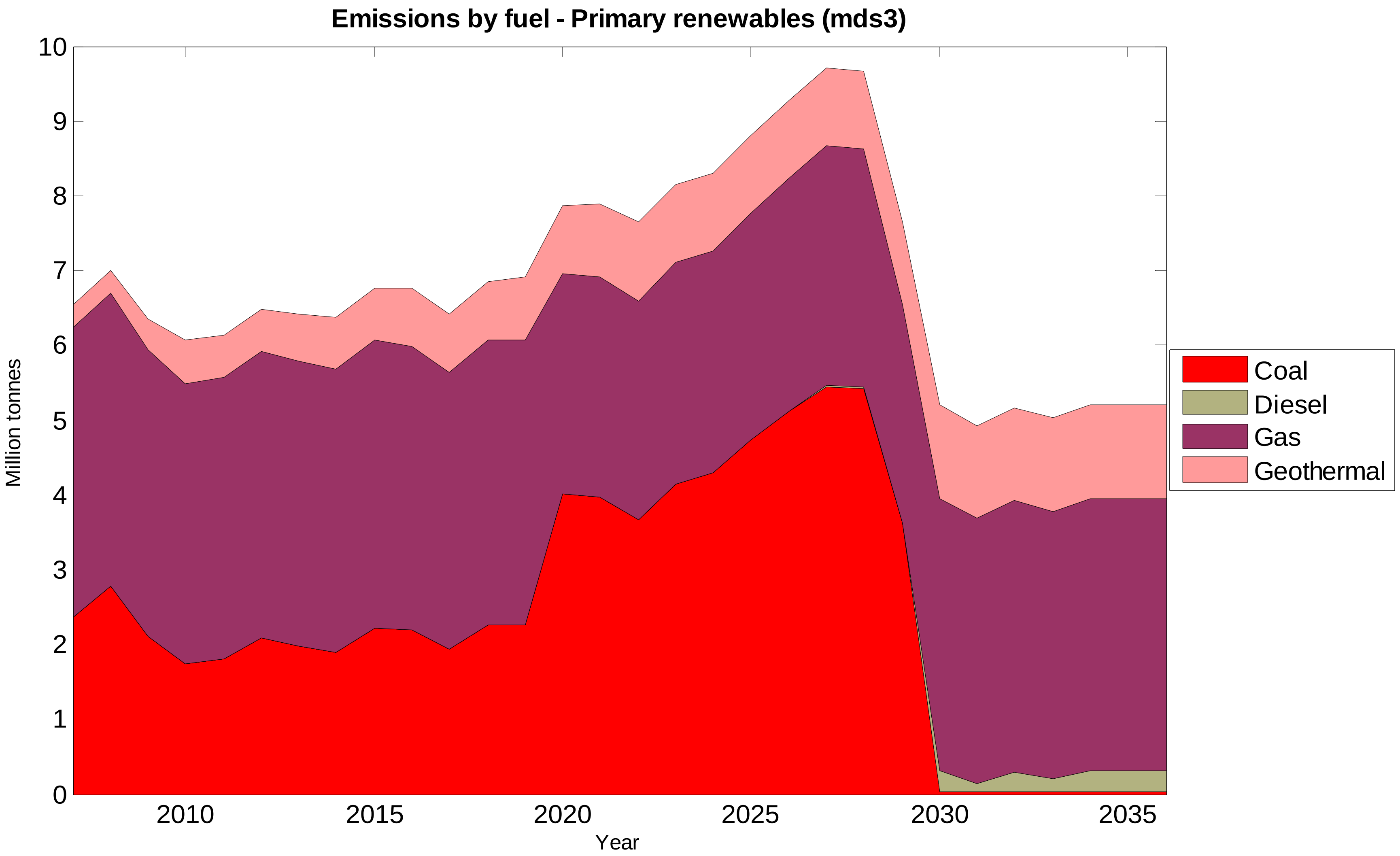
GEM outputs – capacity by technology type



GEM outputs – CO_2-equivalent emissions



GEM outputs – emissions by fuel type



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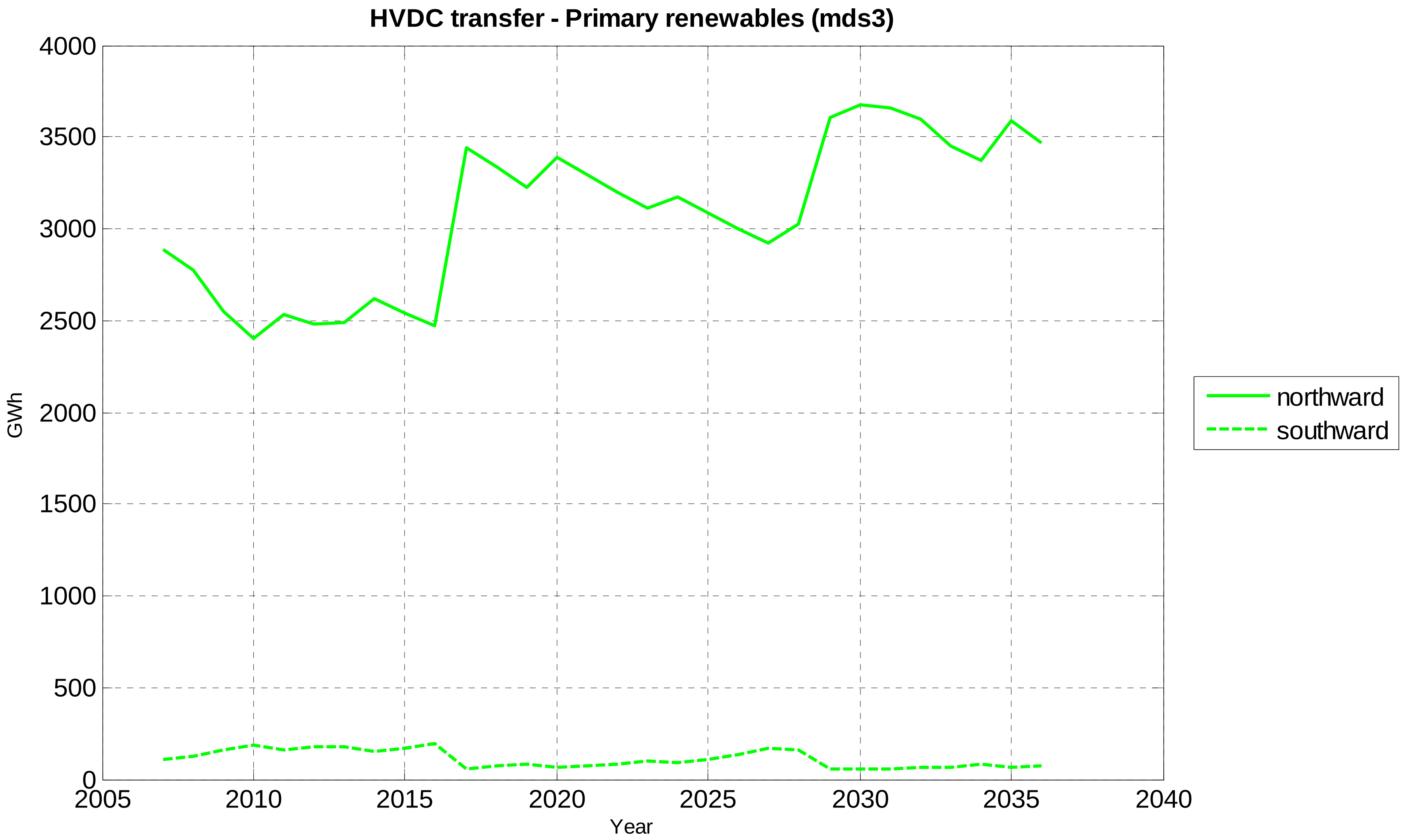
GEM outputs – HVDC transfer



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What next?

- Validation against similar models
- Finish preparing documentation and user manual
- Endogenise transmission investment, i.e. co-optimise with generation investment
- 19 regions with interregional transmission (currently 2 nodes)
- Monthly, 5-block load duration curve (currently quarterly 4-block LDC)
- Rethink HVDC/Tx pricing
- Hydro storage with intertemporal management of hydro resource
  - Perhaps some simple rules to mimic water valuation, but no intention to implement a stochastic treatment of inflow uncertainty

Further information

http://www.electricitycommission.govt.nz/opdev/modelling/gem/index.html

or email gem@electricitycommission.govt.nz