Programme Area: Carbon Capture and Storage

Project: NGCT2 Gas Capture

Title: ETI –Dispatch modelling for CCGT CCS plant

Abstract:

This project is a part of Next Gen 2 Technology Evaluation (Gas Capture) Project. The objective of this project was to understand the potential electricity system environment for CCGT with CCS and assess the impact of different technical characteristics on asset operating profiles and wider system dispatch.

Context:

The contribution of gas-fired power stations to the UK energy mix appears set to continue to grow rapidly over the next decade. Consequently, in 2012 the ETI launched this project with Inventys Thermal Technologies in collaboration with the Howden Group and Doosan Power Systems to accelerate the development of advanced carbon capture technologies for gas-fired power stations. It focussed on post combustion technologies and looked at designs to be used on new build plant or retrofitted onto combined cycle gas turbine power stations. The project delivered a small scale demonstrator prototype, laboratory work, and a technoeconomic assessment to confirm the projected benefits of the technologies for use on gas-fired power stations. Inventys is now working on initial large-scale applications for Enhanced Oil Recovery (EOR).

ETI – Dispatch modelling for CCGT CCS plant

Project summary – 12th April 2012

Date: 18 January 2017 Client: ETI

Contents

Key messages

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- Overall the impact of changing CCGT with CCS technical parameters on whole system CO_2 emissions and generation costs are small (however, there are some caveats in relation to the perfect foresight modelling)
- Changes in the market conditions such as interconnection and storage have a larger impact on system generation and the levels of flexibility provided by CCGT CCS plant.
- In the Base case, a CCGT CCS plant has an annual average load factor of ca 75%, indicating it is running baseload whenever it can but is providing downward flexibility in times of high wind generation.
- CCGT CCS plant require around 70-80 starts per year in the Base market environment. However, with storage at current levels or a higher cost of imports, the requirement can increase to around 130-140 starts per year.
- One caveat to note is that perfect foresight with a 3 day look ahead is used in the Plexos model, which could not be achieved in reality. This allows the model to optimise around wind and demand variations and may therefore underestimate the importance of flexibility parameters like ramp rates.

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Background & Key assumptions

Introduction – Context

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- This project is a part of Next Gen 2 Technology Evaluation (Gas Capture) Project.
- The objective of this project was to understand the potential electricity system environment for CCGT with CCS and assess the impact of different technical characteristics on asset operating profiles and wider system dispatch.
- The modelling was carried out by Redpoint Energy, supported by the ETIs ESME and CCS Teams (Chris Heaton, Rod Davies, Den Gammer)
- There was further supplementary work on levelised cost benchmarking by Foster Wheeler.
- The analysis supports the selection of technology support for investment by ETI.
- We have now reached the end of generic study.

Introduction – ESME & PLEXOS

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- ESME is the energy system model that was used as a starting point to determine the long term electricity supply mix and demand ensuring consistency with the likely evaluation from today's system.
- PLEXOS is a commercially available power market modelling tool. At its heart lies a dispatch 'engine' based on a detailed representation of market supply and demand fundamentals at a half hourly granularity.
- The supply mix is represented with the operating parameters of generating plant including costs parameters and operational constraints.
- We used the high level supply mix from ESME and added detailed operational parameters for each plant type in Plexos as well as hourly profiles of non-dispatchable generation technologies (eg wind).
- PLEXOS optimises storage injection and withdrawal endogenously on a half hourly basis.

Starting point

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- We started with 250 simulations from ESME Peak Energy WIP model for 2030, 2040 and 2050 with the following adjustments:
    - Biogas + CCS plant secondary product set to waste heat.
    - CCGT +/- CCS lifetimes set to 25 years.
    - Electricity availability and flexibility factors were revised.
    - Revised custom retirement profile of existing coal/nuclear/gas stock to match our Decarbonisation case.
    - Removed biomass availability from simulated parameters.
    - 2010 capacity mix was updated in line with Dukes data.
    - Imposed constraints on the amount of wind and nuclear build by 2030 in line with the Redpoint Decarbonisation scenario (October 2011).
    - Wind lifetimes – set offshore wind to 30 years and onshore wind to 25 years.
- We picked two simulations from the set of 250 to represent a High CCGT CCS and Low CCGT CCS case.
- After doing some initial work for the 2050 data, we focused the bulk of the analysis on 2030 since this is where CCGT CCS could start being deployed in significant volume and it is a supply mix with substantial intermittent capacity which increases the requirements for CCGT CCS plant to provide flexibility.

Adjustments made from starting point

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During the project we made a number of revisions to the dispatch model to improve the ability of the model to test the various CCGT CCS technical parameters.

- Optimisation horizon in Plexos model
  - We tested the impact of allowing the Plexos model to optimise 1, 3 or 7 days at a time. The length of the optimisation horizon has a particular impact on storage use as it changes the horizon over which storage injection and withdrawal can be optimised.
  - We chose a 3 day optimisation horizon as a compromise between operation of storage and the reality of plants ability to optimise.
- Hourly vs Half-Hourly optimisation
  - As we didn't observe a significant impact of varying ramp rates in the hourly model, we adjusted the model to be optimised at a half-hourly granularity.
- Capacity margin
  - Since the supply-demand balance from ESME led to quite high capacity margins and surplus flexible capacity in the system, we scaled up demand to achieve a de-rated annual peak capacity margin of around 10%.
- Storage and Interconnectors
  - Since storage and interconnectors are two key providers of flexibility in an electricity system, we ran a number of sensitivities to test the effect of changes to the following variables:
    - Increased cost of imports
    - Increased interconnector capacity
    - Current levels of storage only

Assumptions – Capacity mix

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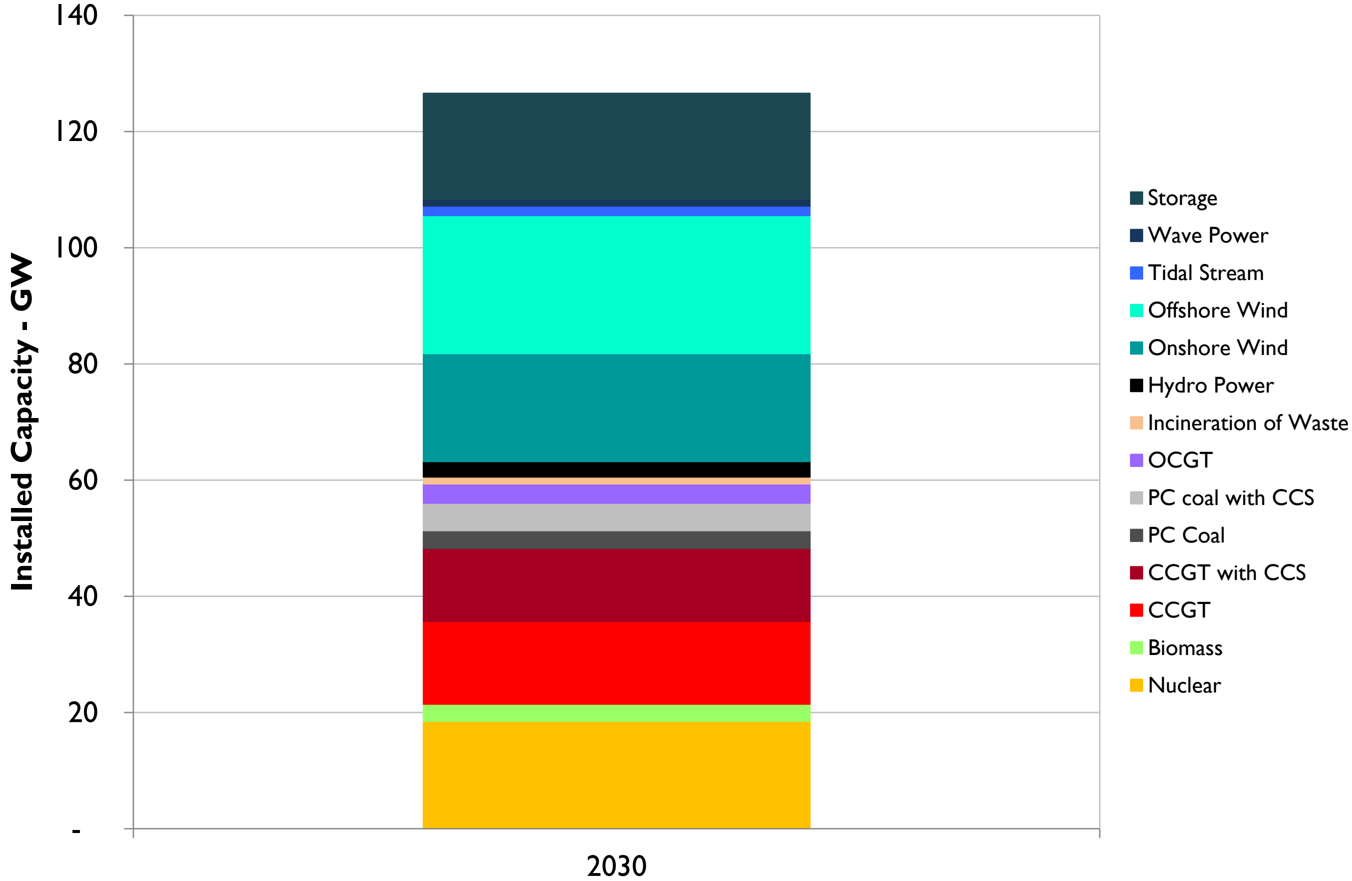
The capacity mix is the output of a single ESME simulation that was chosen based on high CCGT CCS deployment. Electricity demand was consequently adjusted up to create a more realistic capacity margin representation.



Sensitivities modelled

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- Base (High CCGT CCS scenario for 2030 from ESME with adjusted capacity margin)
- Sensitivities on improved CCGT CCS parameters
  - 1/2 Min On/Off Times
  - 1/2 Start Costs
  - 1.5x Ramp Rates
  - Flat Heat Rate Curve
  - Lower Minimum Stable Level
- Sensitivities on worsened CCGT CCS parameters
  - 1.5x Min On/Off Times
  - 1.5x Start Costs
  - 1/2 Ramp Rates
  - 3x Min On/Off Times
  - 3x Start Cost
  - 1/3 Ramp Rates
- Sensitivities on storage availability
  - Current Levels of Storage
  - Current Levels of Storage + 1.5x Min on/off times
  - Current Levels of Storage + 2x Min on/off times
  - Current Levels of Storage + 1.5x Start costs
  - Current Levels of Storage + 1/2 Ramp rates
- Sensitivities on interconnection
  - Current Levels of Storage + Increased Cost of Imports
  - Increased Cost of Imports
  - Increased Interconnection Capacity

Comparison of annual results

Generation of selected plant types

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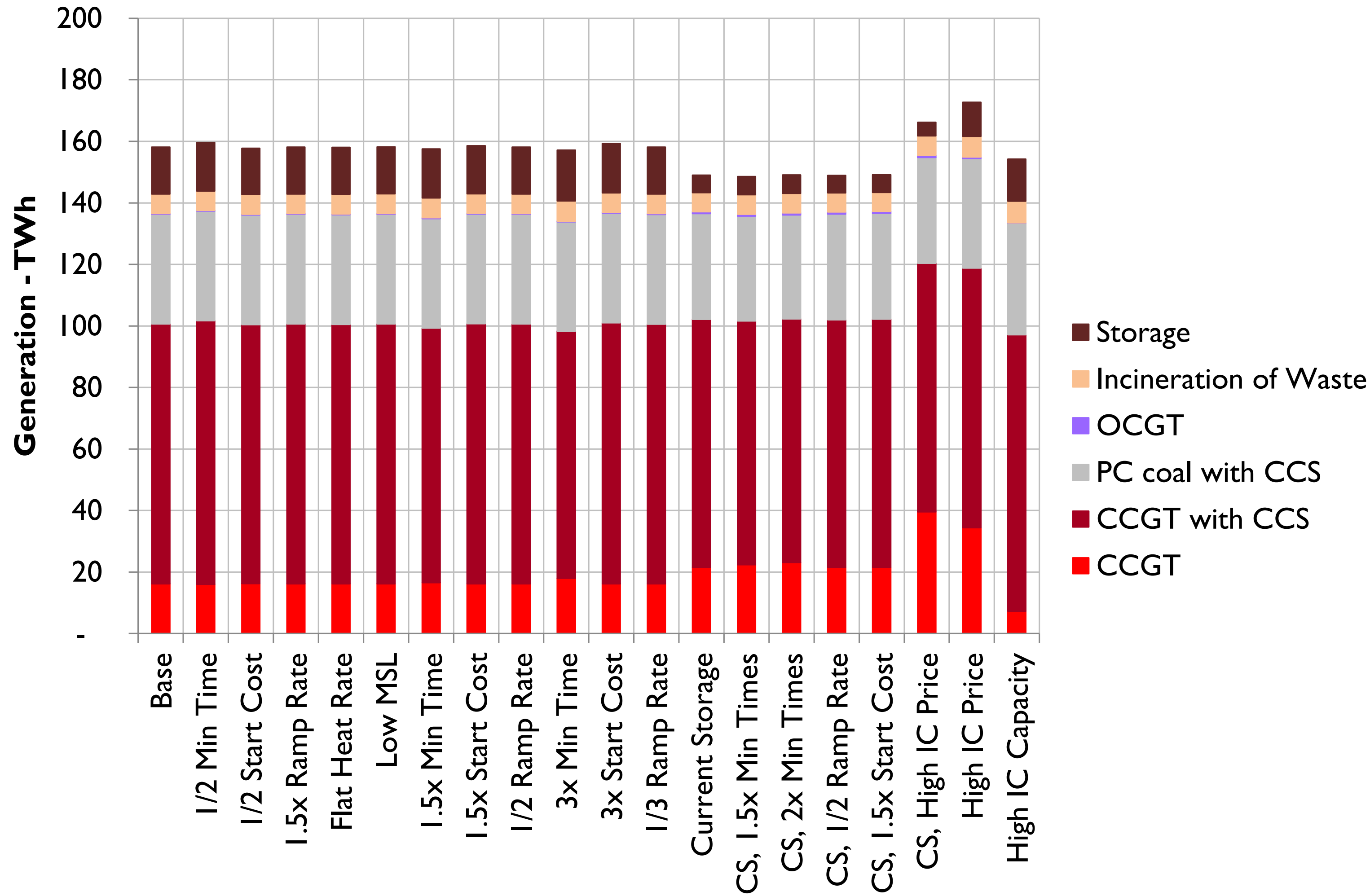

% difference in generation vs Base case

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% generation change vs Base	1/2 Min Time	1.5x Min Time	1.5x Start Cost	3x Min Time	3x Start Cost	Current Storage	CS, 1.5x Min Times	CS, High IC Price	High IC Price	High IC Capacity
CCGT	-1%	2%	0%	11%	0%	33%	38%	145%	112%	-55%
CCGT with CCS	1%	-2%	0%	-5%	0%	-5%	-6%	-4%	0%	6%
PC coal with CCS	0%	0%	0%	-1%	0%	-3%	-4%	-4%	0%	2%
OCGT	0%	1%	1%	1%	1%	138%	160%	150%	80%	-77%
Incineration of Waste	-2%	2%	0%	3%	0%	-3%	-1%	0%	6%	10%
Storage	4%	4%	2%	8%	6%	-62%	-61%	-71%	-28%	-10%

*CS = Current Storage

**IC = Interconnector Import

Average annual load factor

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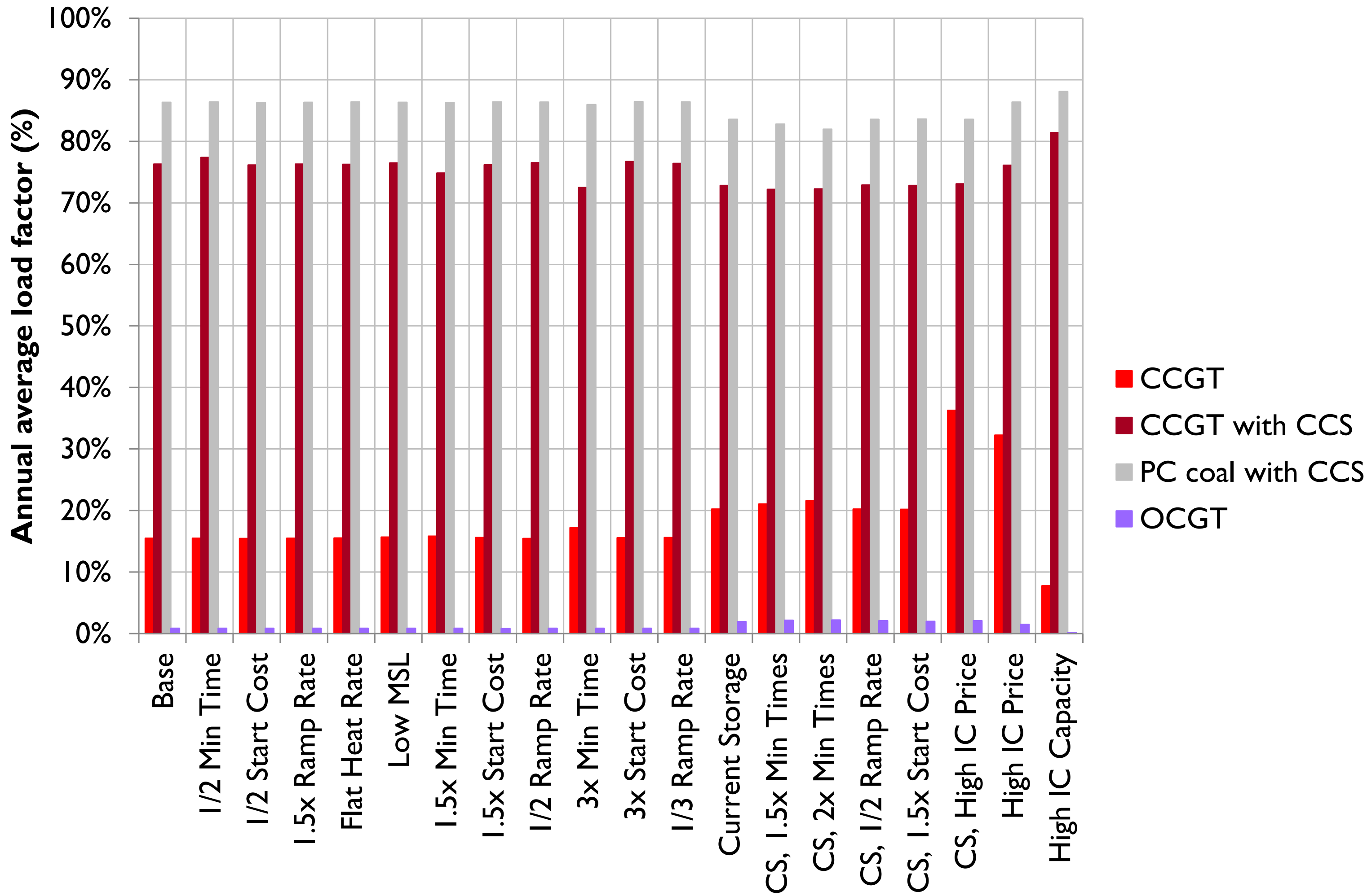

Average number of starts per year

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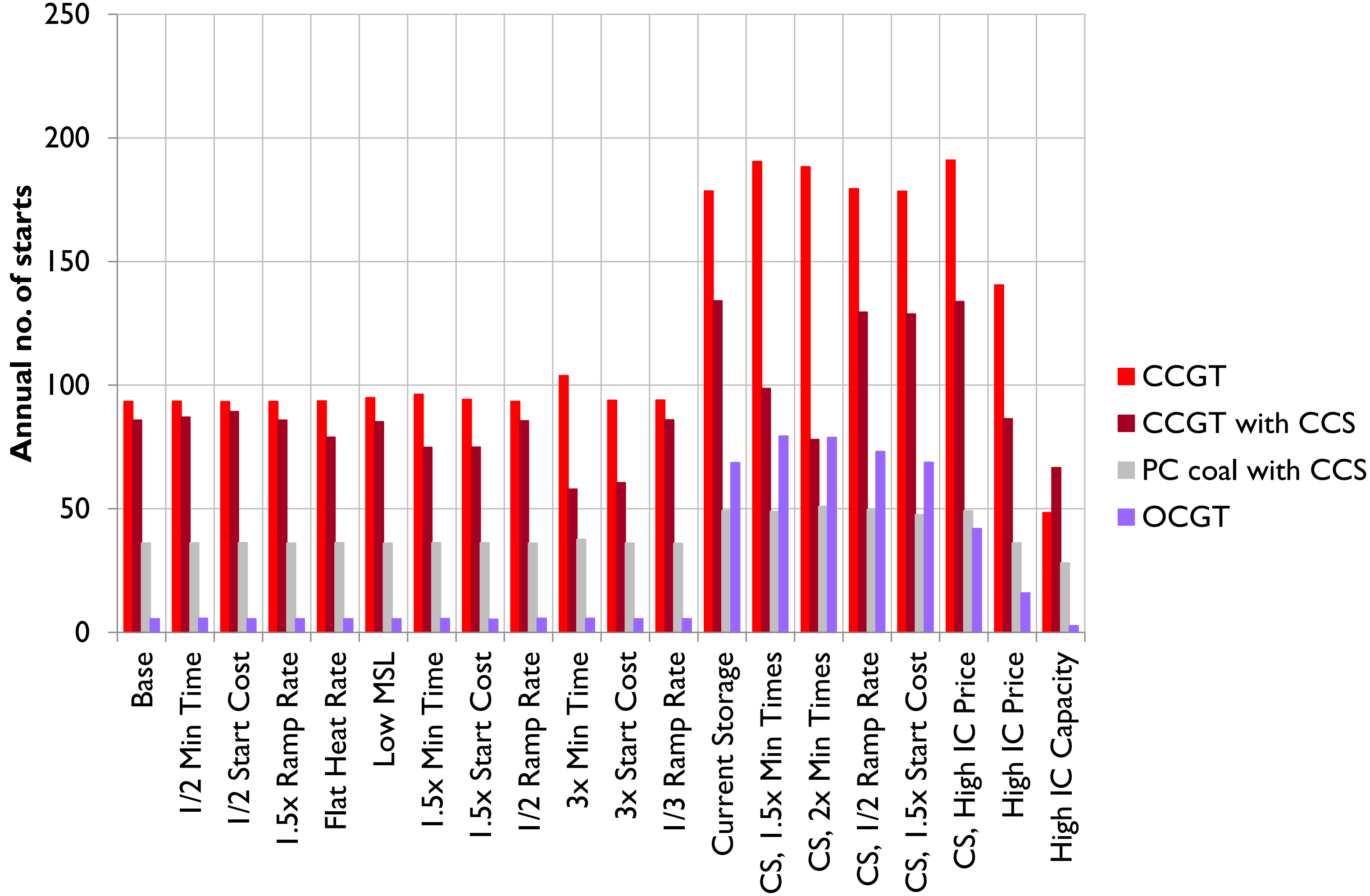
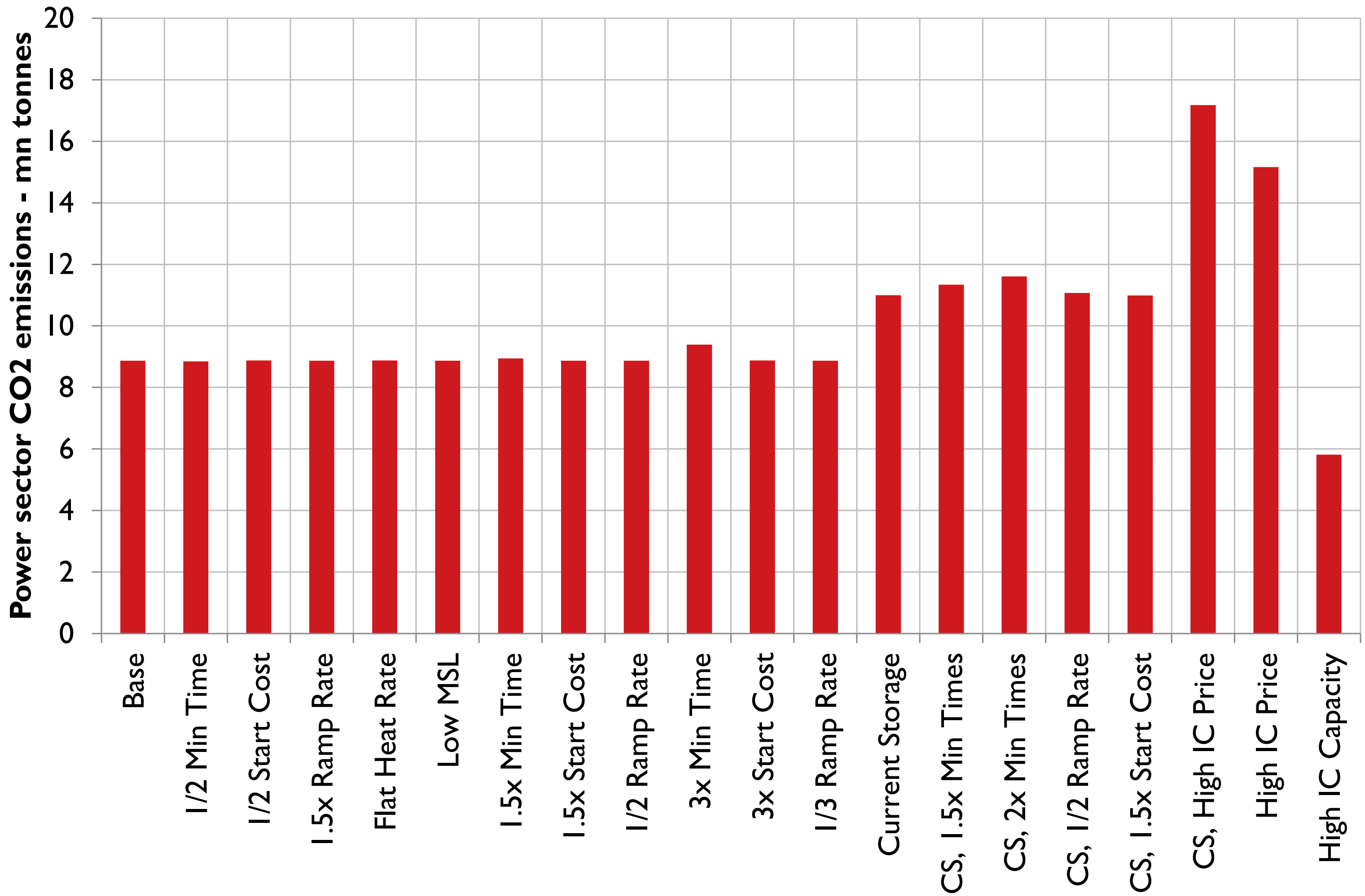


CO2 emissions



Total system generation costs

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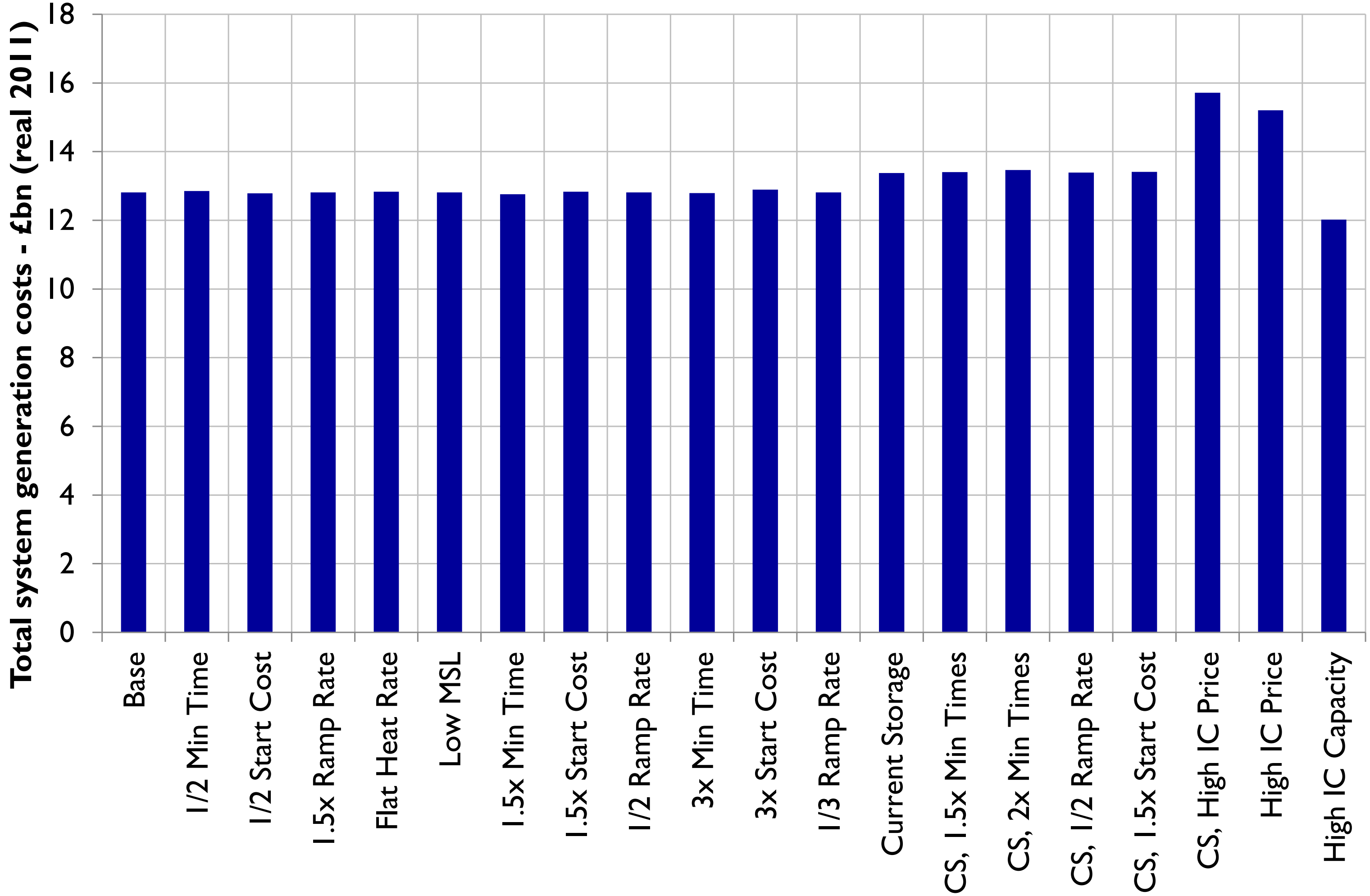

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Half Hourly Generation profiles

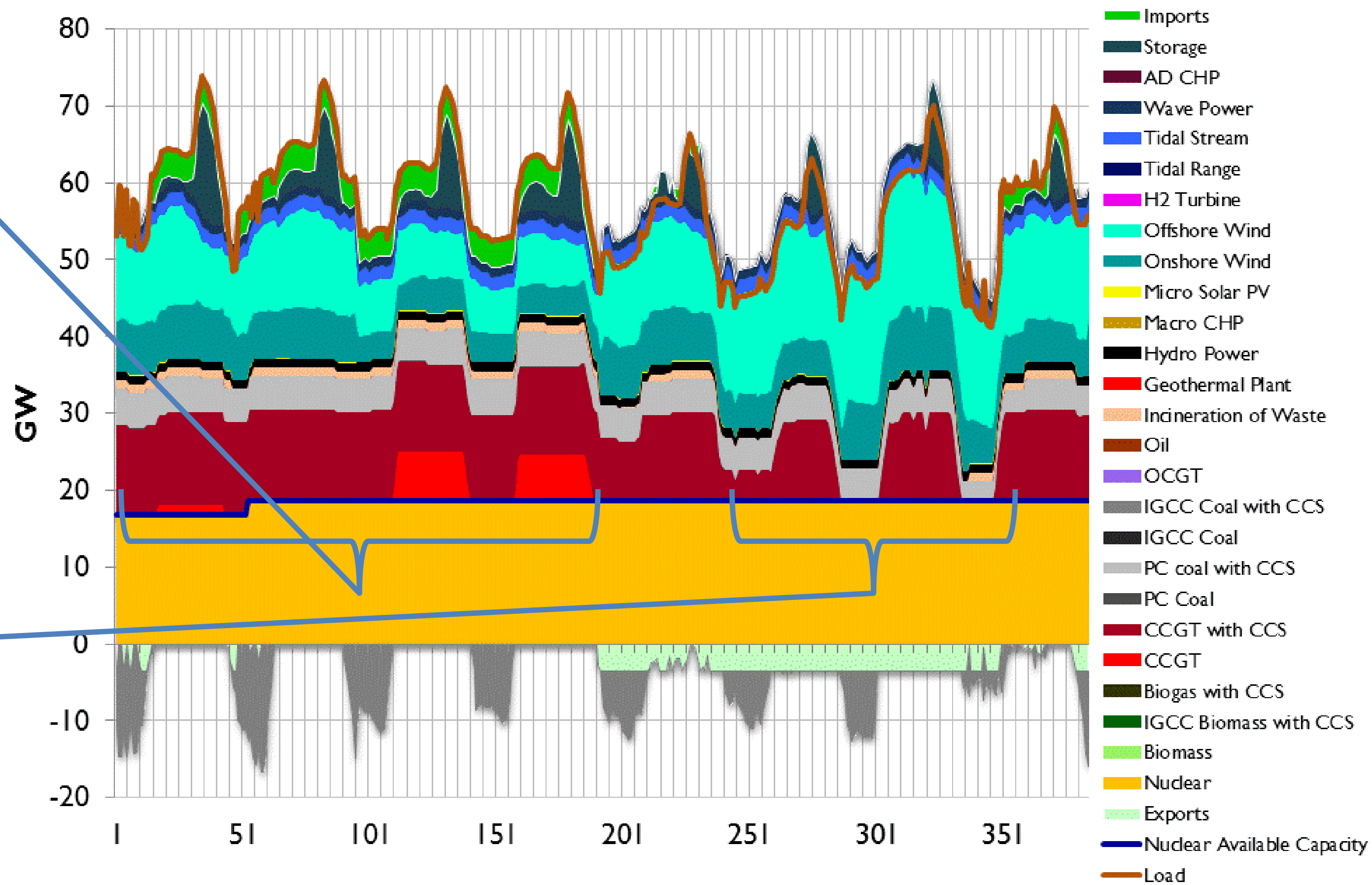
Base

The chart below shows the half hourly generation for the week commencing 6th Jan 2030 in the High scenario.

In high demand periods CCGT with CCS runs near baseload. CCGT provides upwards flexibility

In periods with high wind supply CCGT with CCS provides downwards flexibility.

Storage provides peak flexibility throughout



Sensitivities on improved CCGT CCS parameters

Half Min On/Off Times for CCGT CCS

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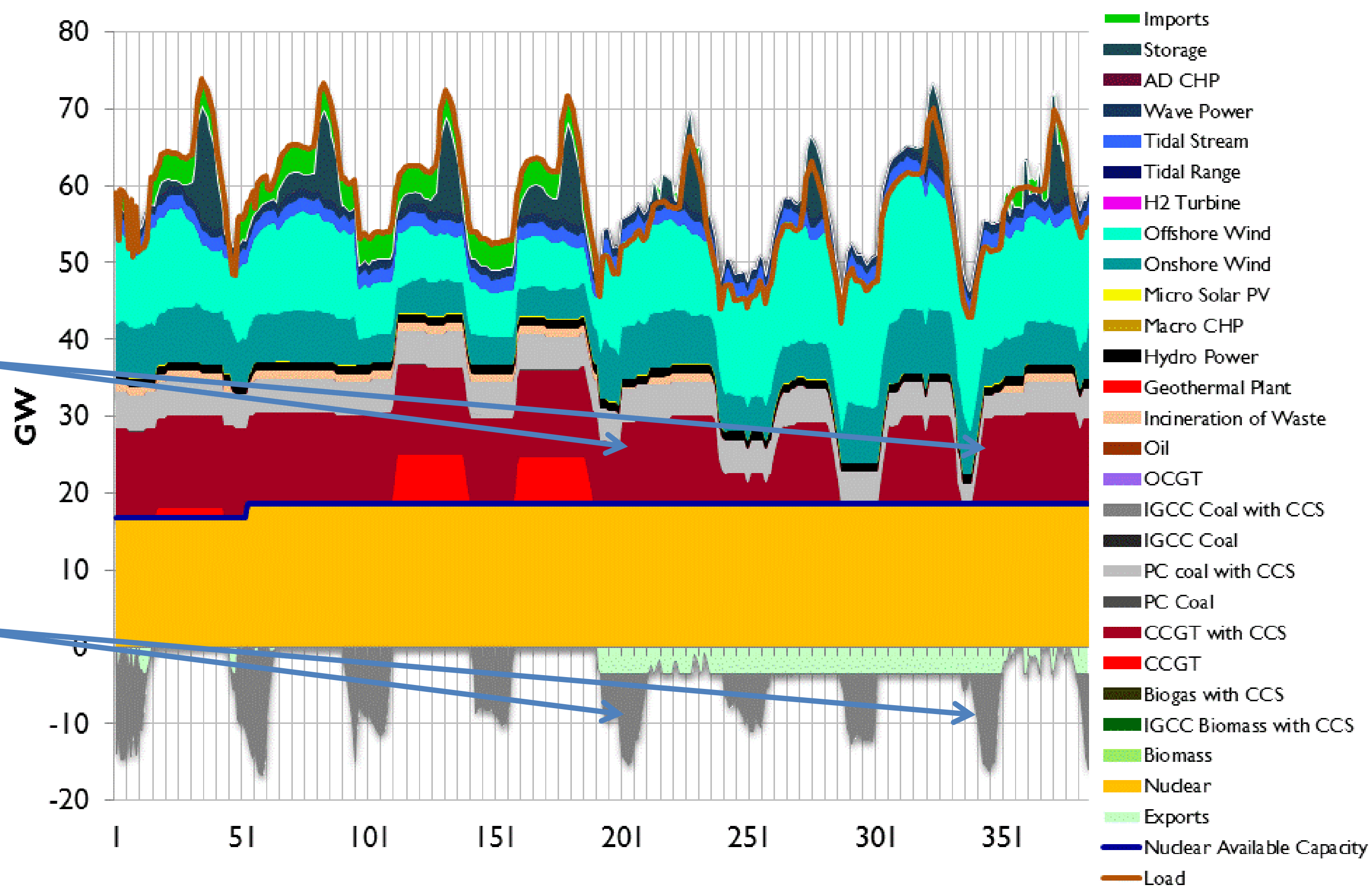
CCGT with CCS ramping up earlier

Increased utilisation of storage and exports



Half Start Costs for CCGT CCS

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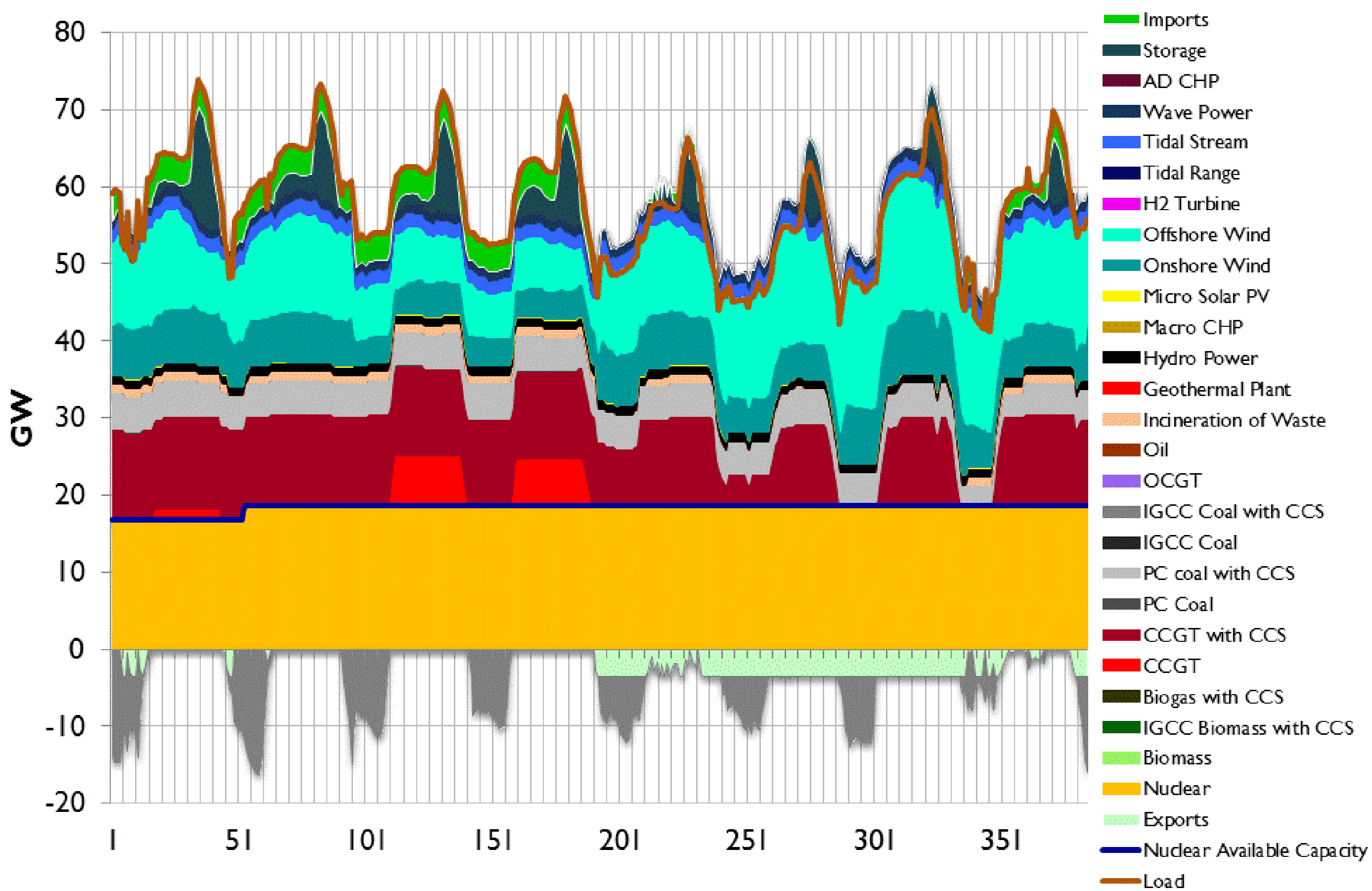
Small increase in downward flexibility in off peak periods provided by CCGT with CCS



1.5x Ramp Rates for CCGT CCS

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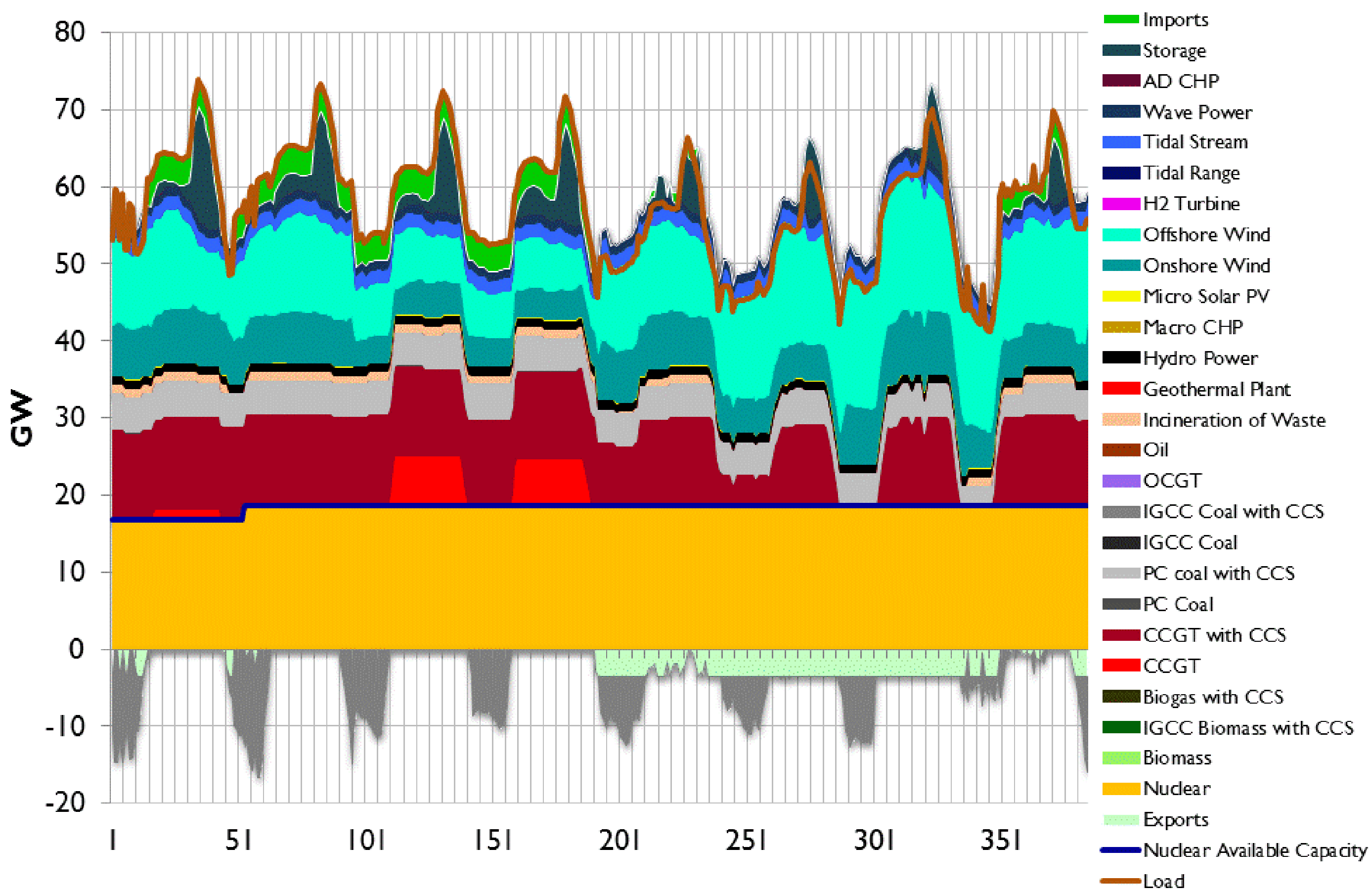
No change in CCGT CCS operation due to increasing ramp rate from 6 MW/min to 9 MW/min



Flat Heat Rate Curve for CCGT CCS

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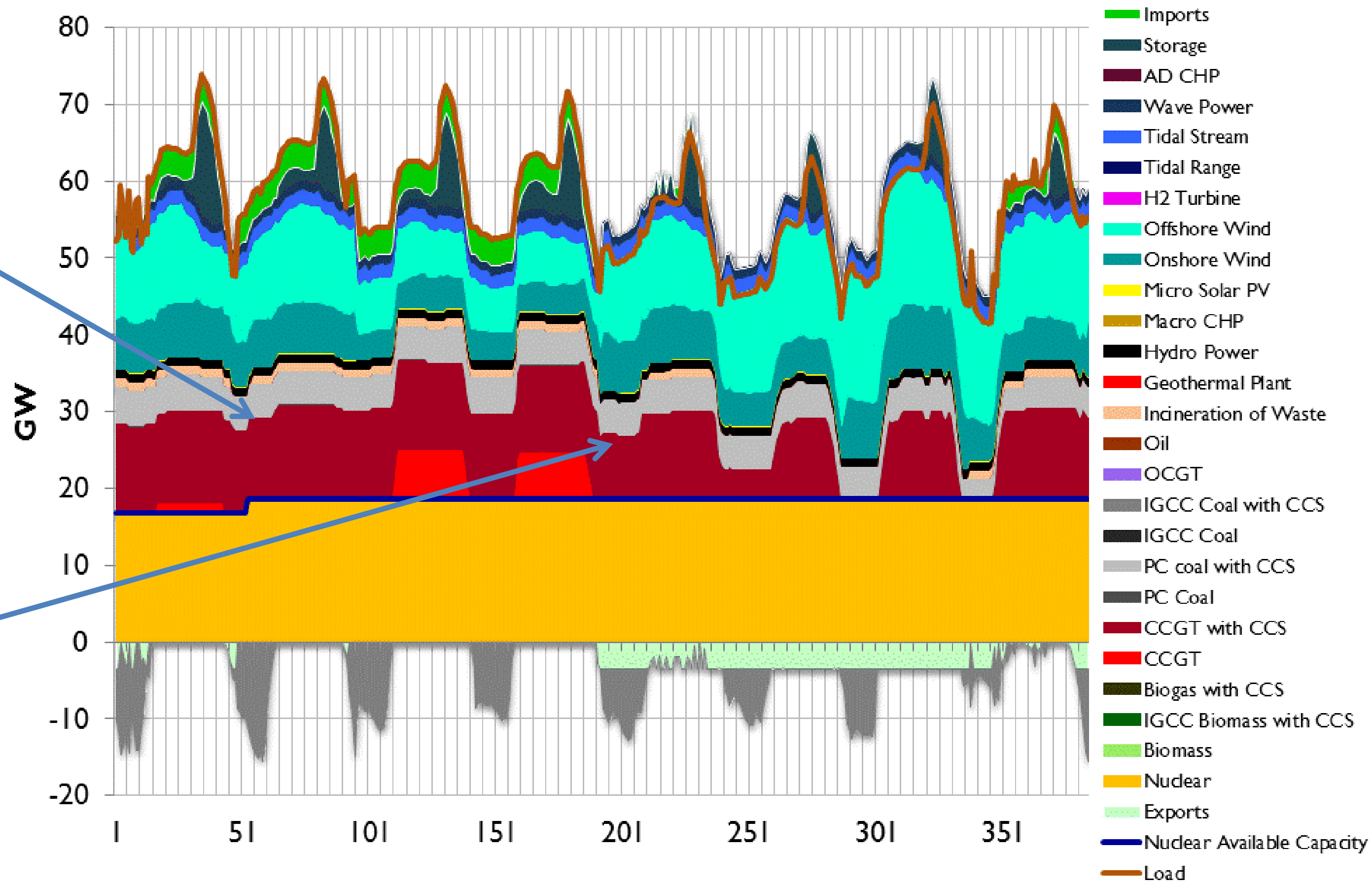
Additional downward flexibility from CCGT with CCS in some periods

Slight increase in level of CCGT CCS operation in some periods



Lower MSL for CCGT CCS

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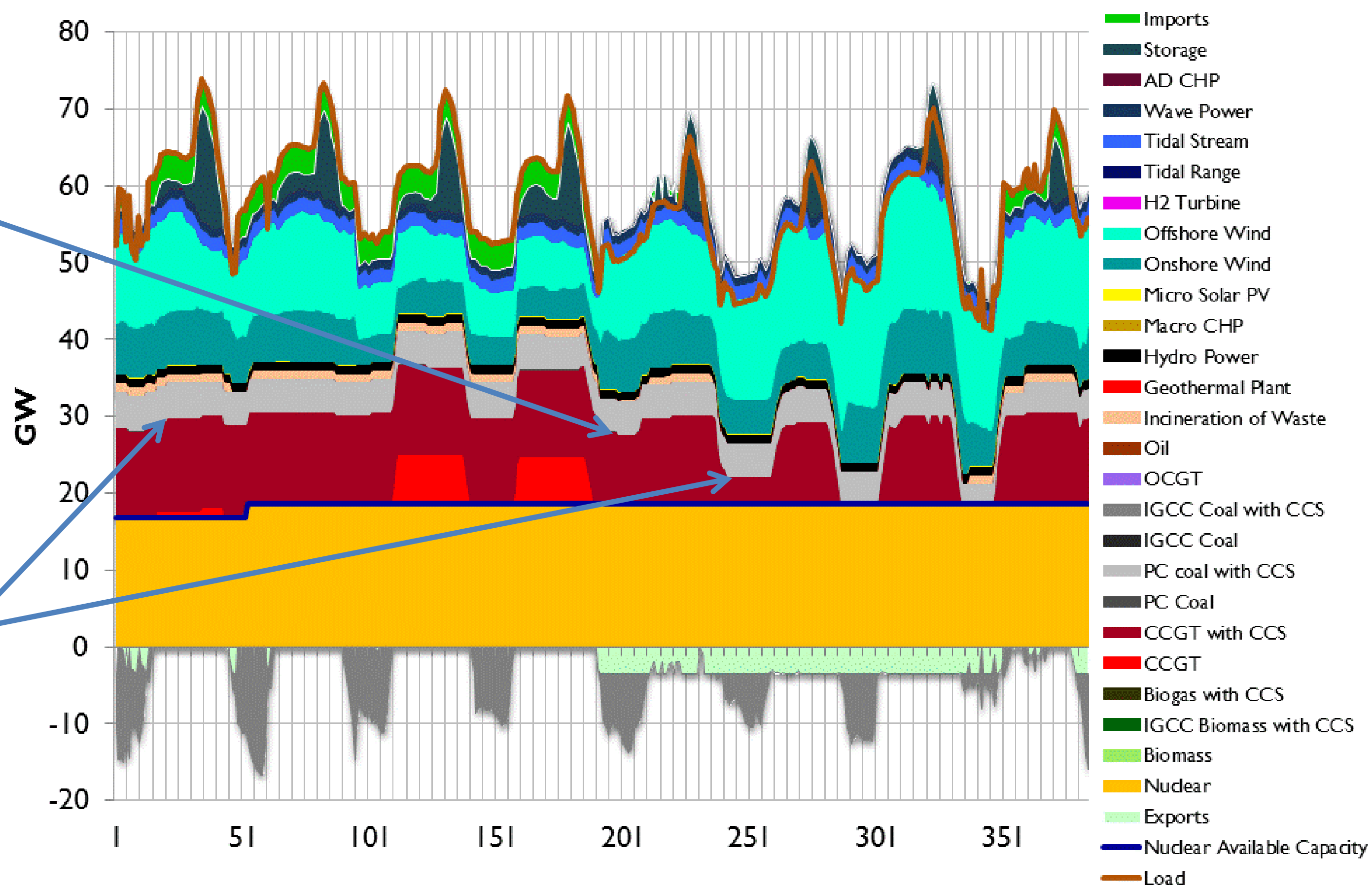
Higher level of CCGT CCS operation and more storage in one of the off peak periods

Lower level of CCGT CCS operation in some off peak periods



Sensitivities on worsened CCGT CCS parameters

1.5x Min On/Off Times for CCGT CCS

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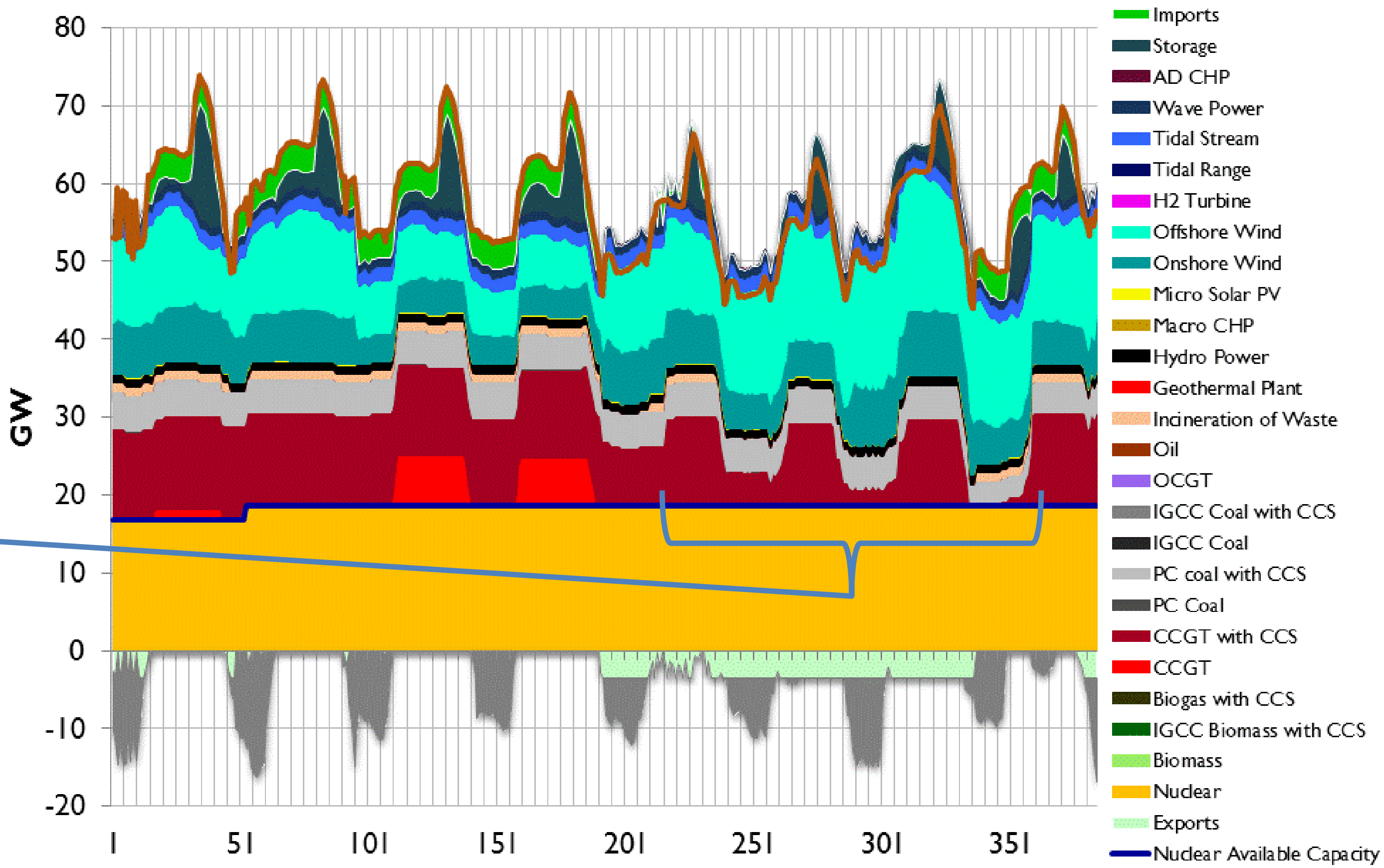
Reduced flexibility of CCGT with CCS operation during low demand periods



1.5x Start Costs for CCGT CCS

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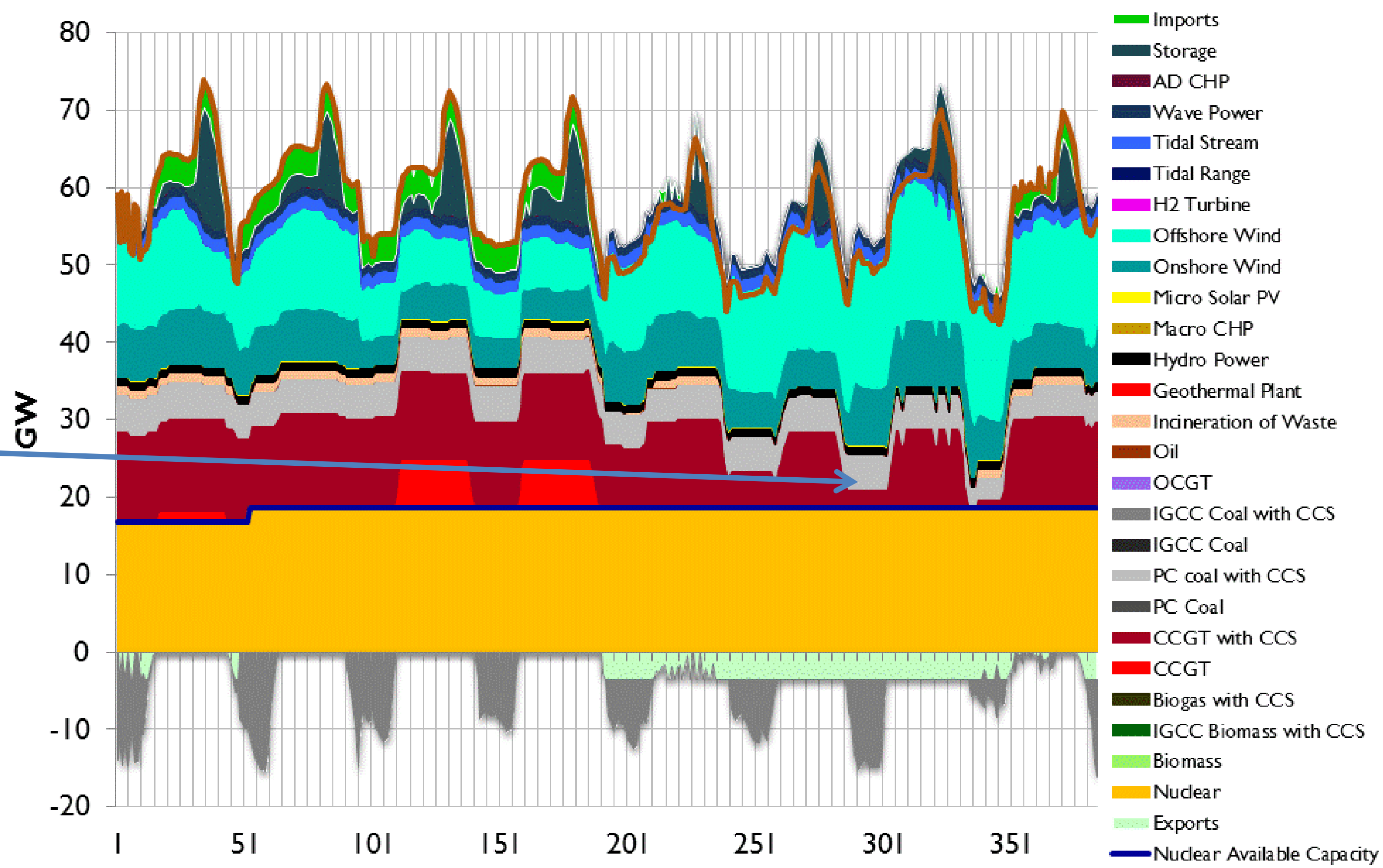
CCGT with CCS continued operation during low demand period



Half Ramp Rates for CCGT CCS

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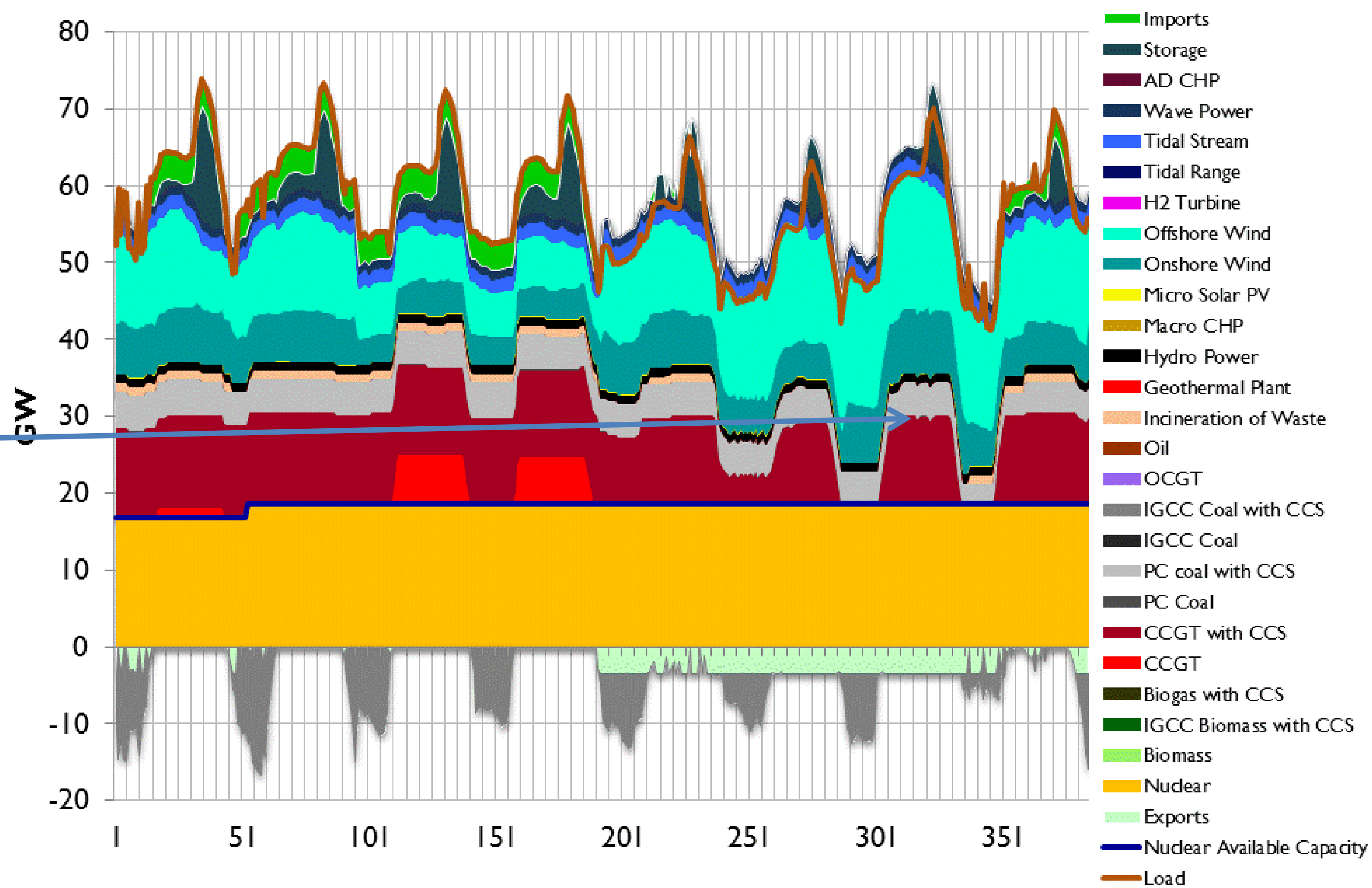
Small reduction in flexibility of CCGT CCS operation due to decreasing ramp rate from 6 MW/min to 3 MW/min



3x Min On/Off Times for CCGT CCS

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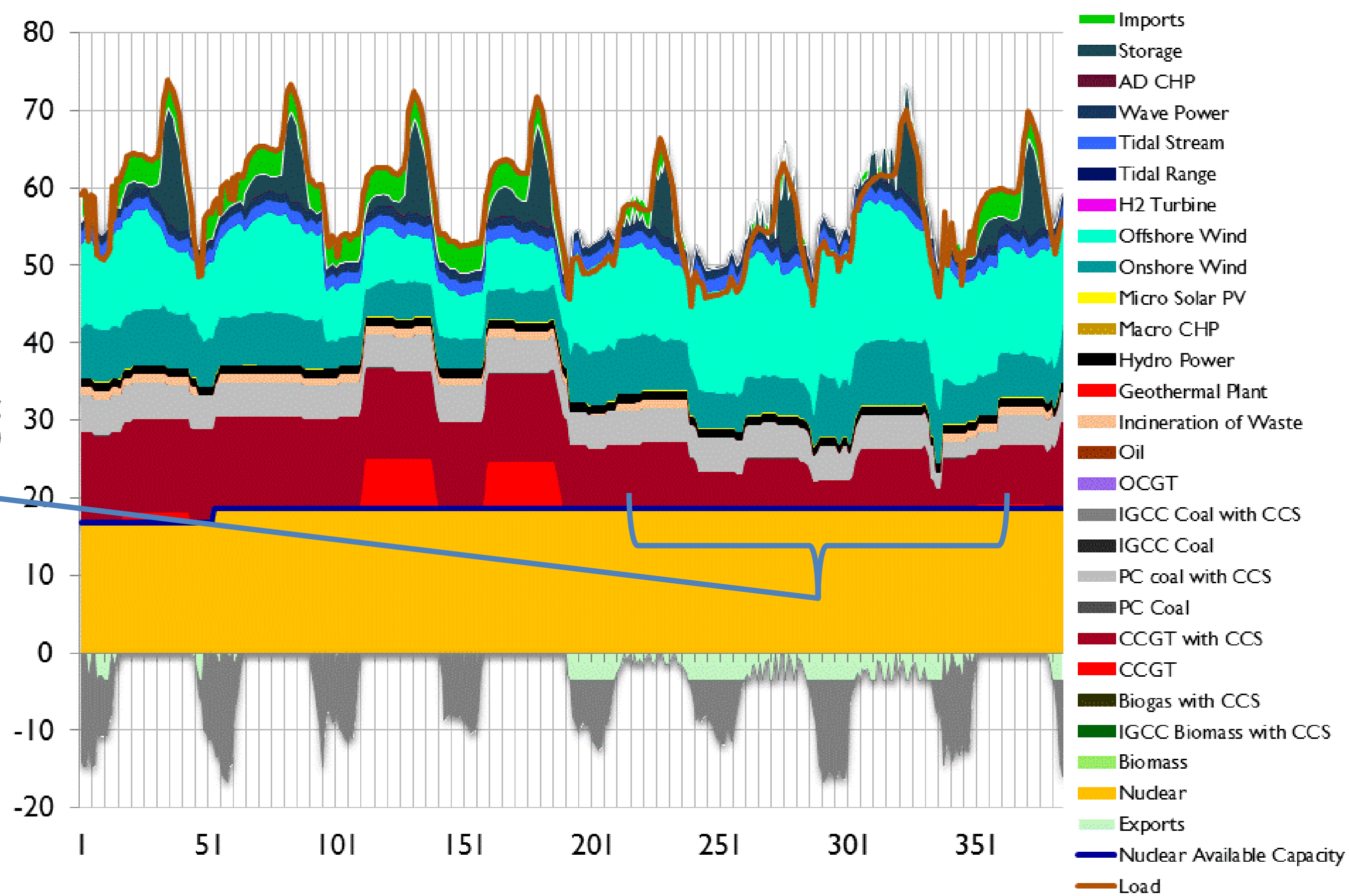
Reduced flexibility of CCGT with CCS operation



3x Start Costs for CCGT CCS

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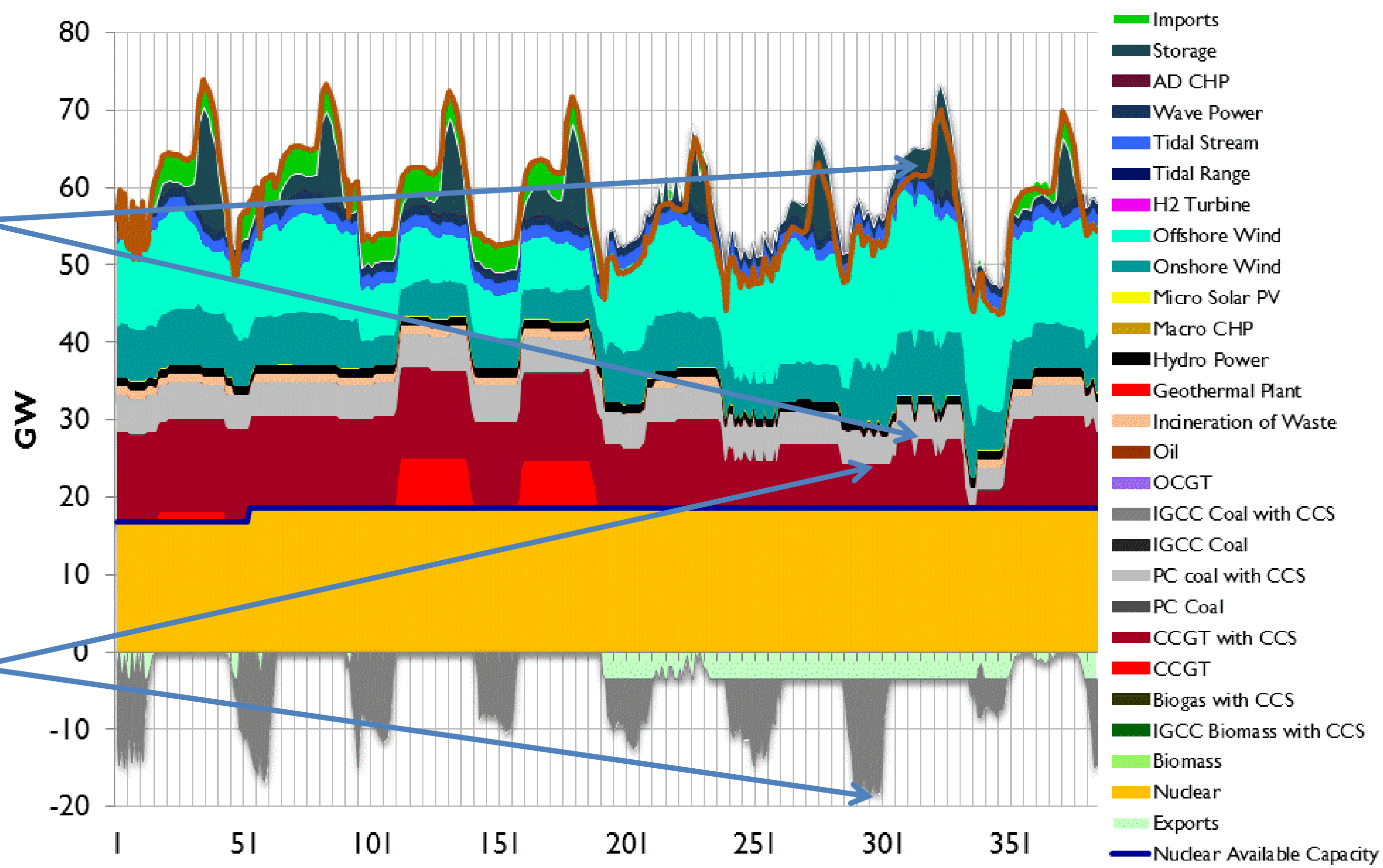
Less upward flexibility of CCGT with CCS operation and increased storage some peak period

Less downward flexibility of CCGT with CCS operation and increased pumped load in some off peak period



1/3 Ramp Rates for CCGT CCS

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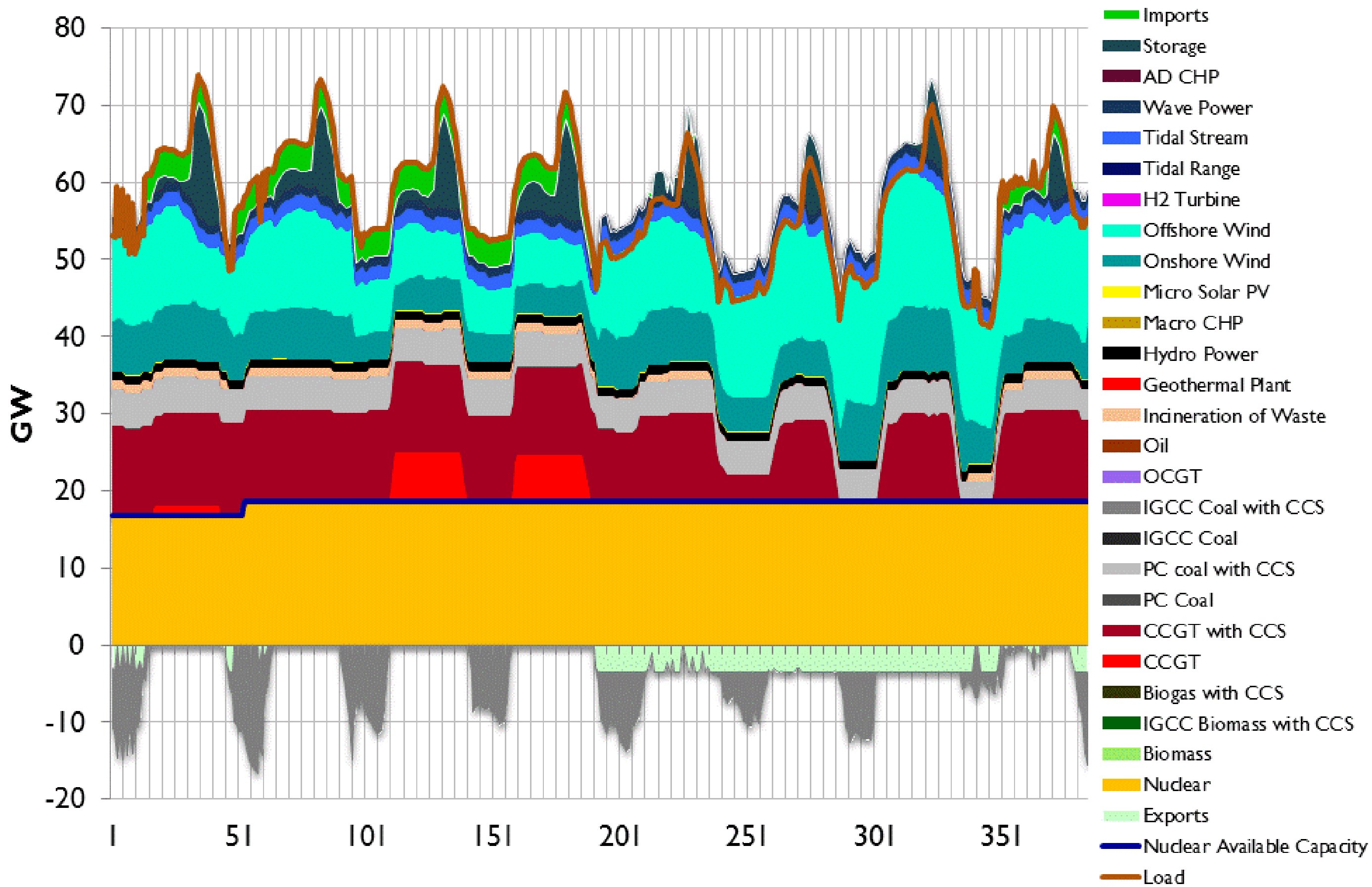
Small differences in CCGT with CCS operation due to decreasing ramp rate from 3 MW/min to 2 MW/min



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Sensitivities on storage availability

Current Levels of Storage

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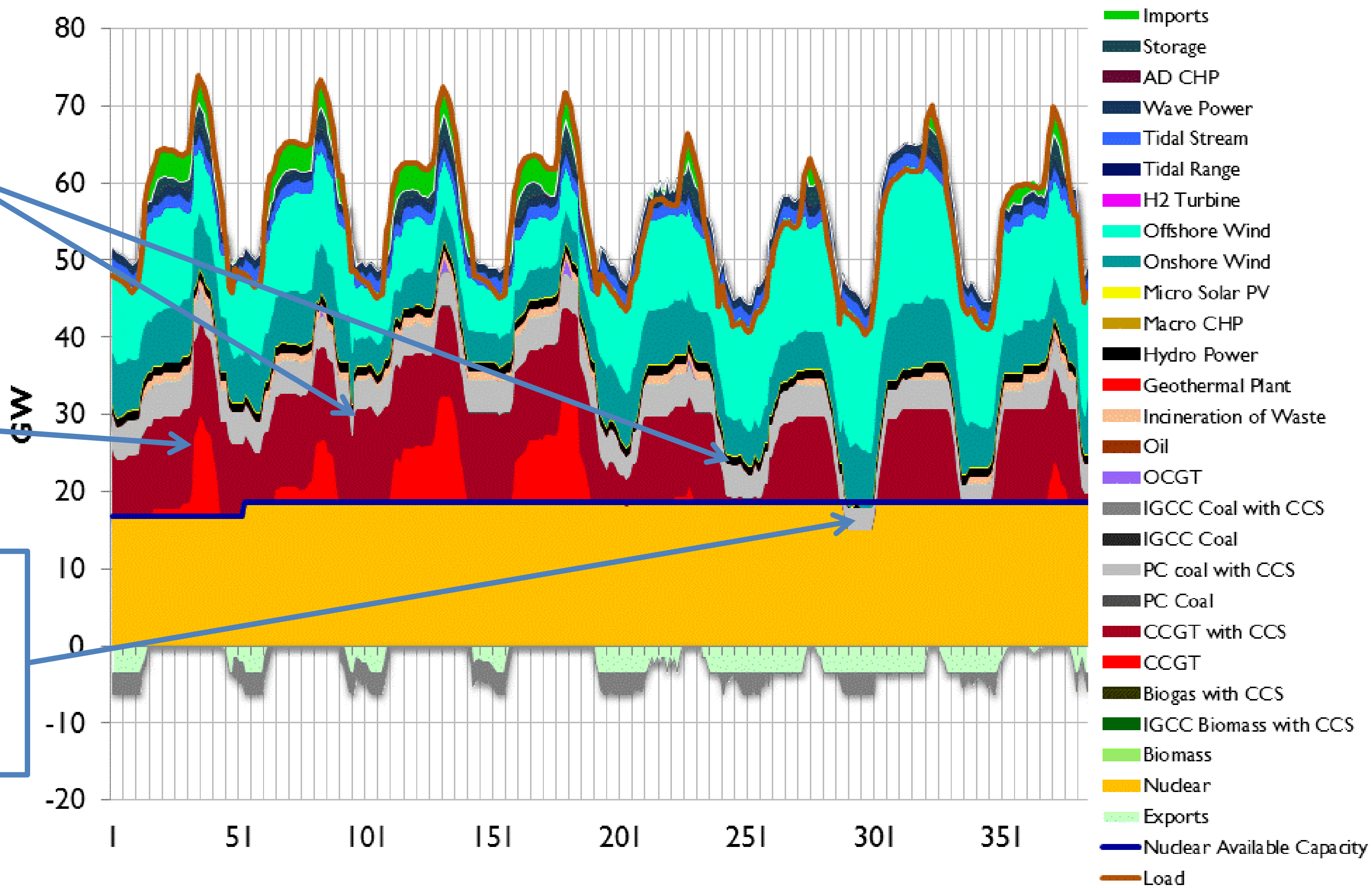
CCGT with CCS provides downward flexibility in off peak

Upwards flexibility from CCGT

Nuclear plant provide downward flexibility by moving to MSL



Current Levels of Storage + 1.5x Min On/Off Times

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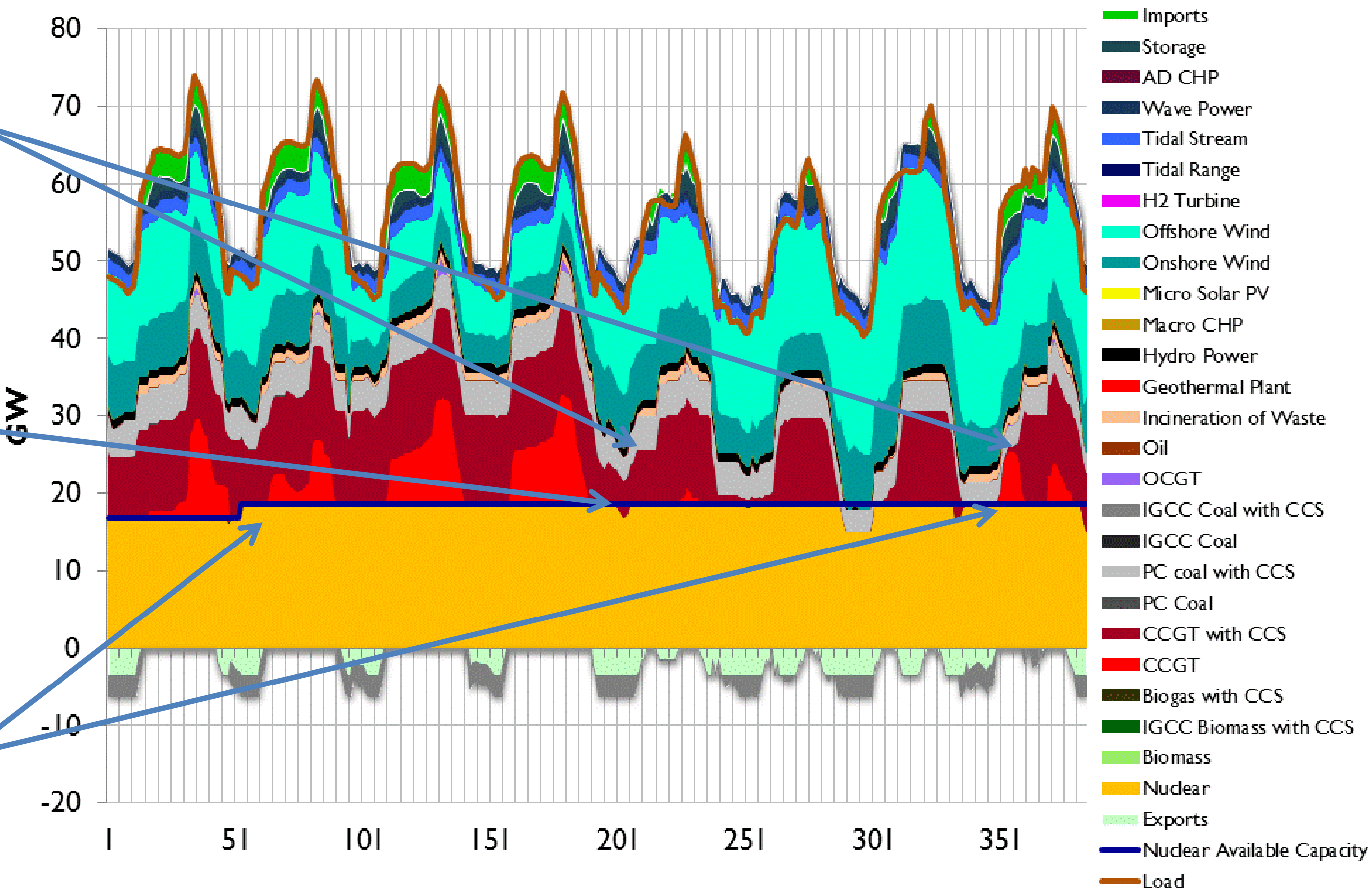
CCGT with CCS ramps up later

Downward flexibility from nuclear

Increasing upward flexibility from CCGT



Current Levels of Storage + 2x Min On/Off Times

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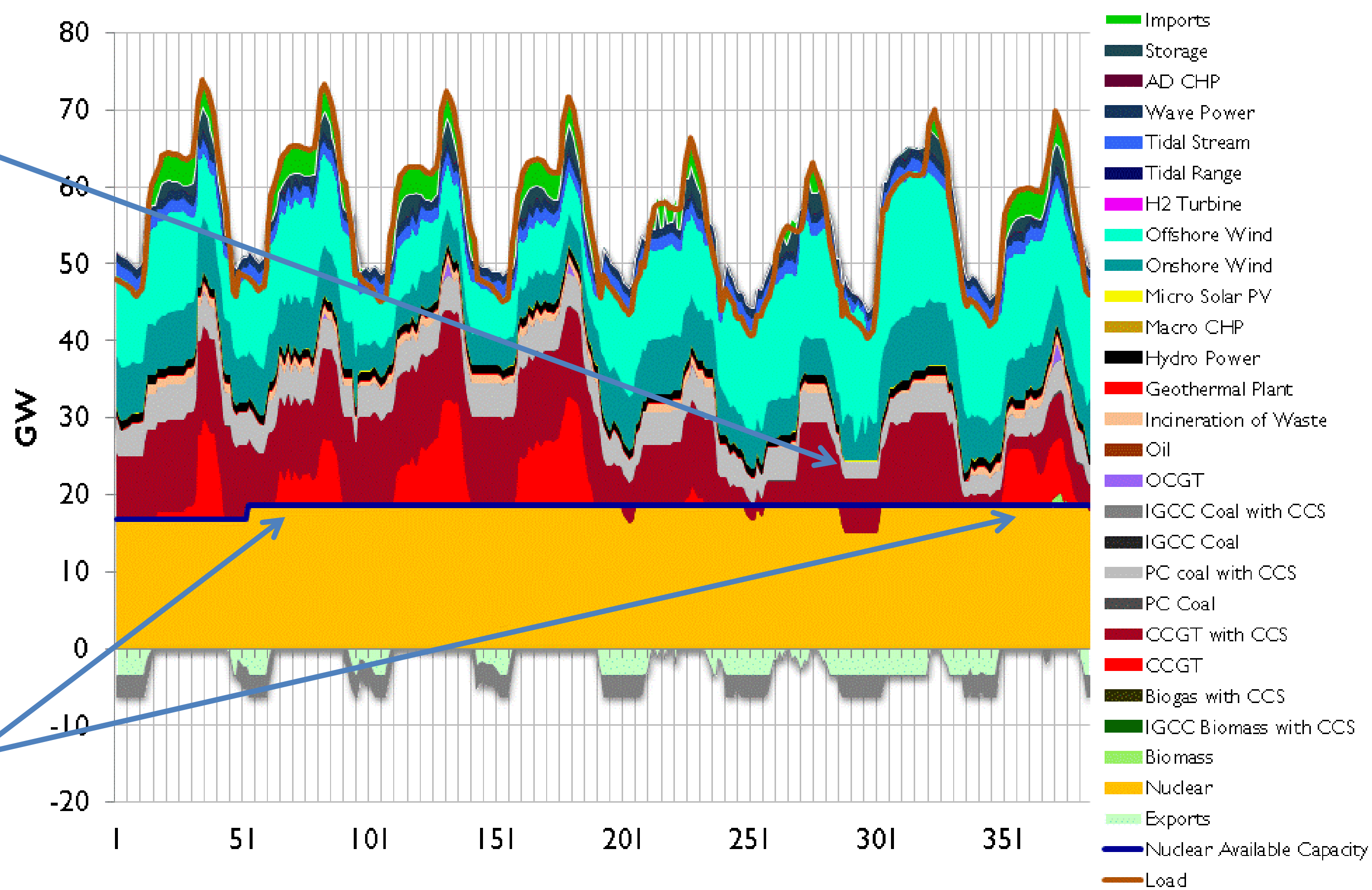
CCGT with CCS remains on over off peak periods

Some biomass plant operating in peak periods

Increasing upward flexibility from CCGT



Current Levels of Storage + 1.5x Start Costs

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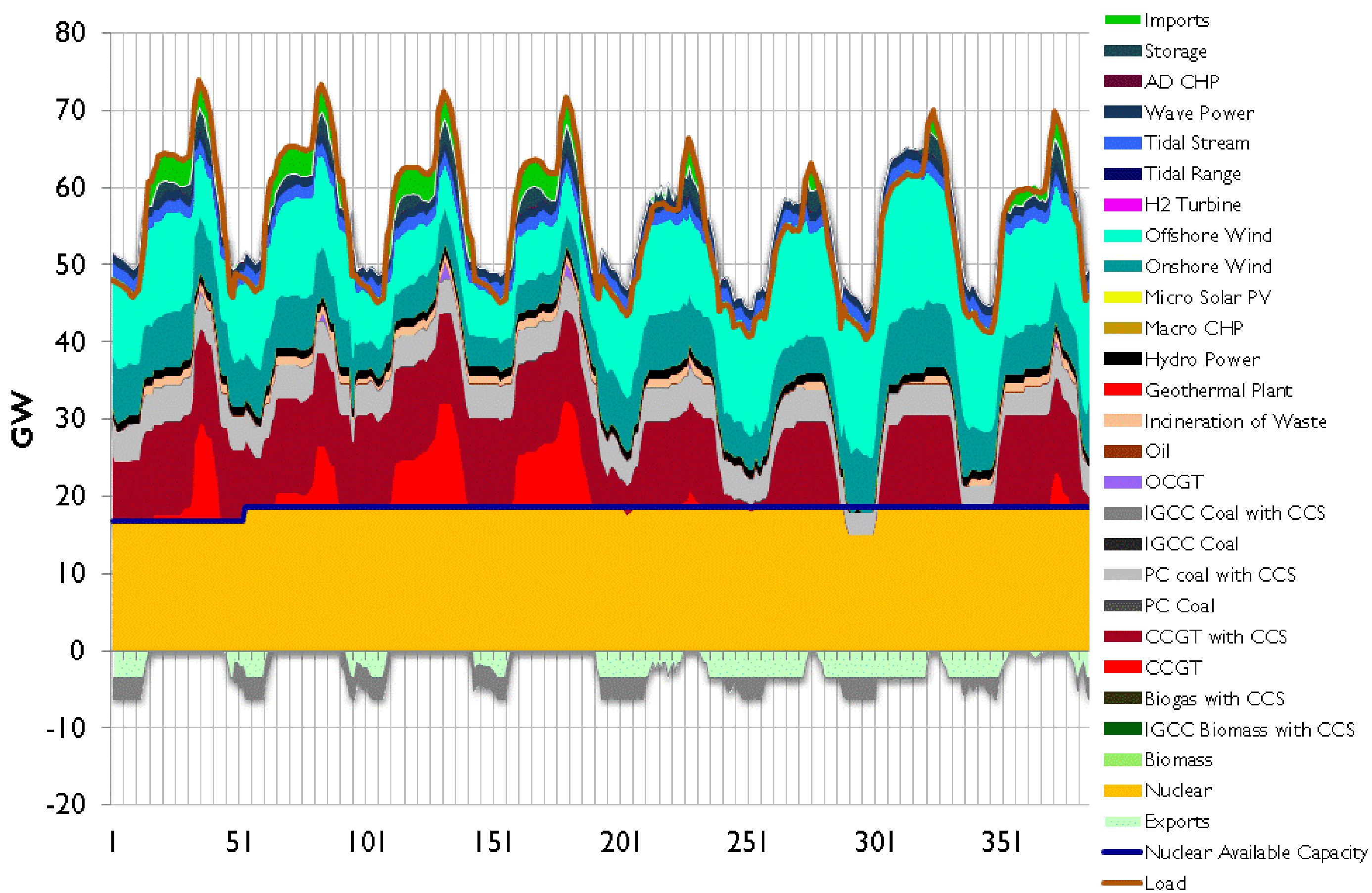

Current Levels of Storage + 1/2 Ramp Rates

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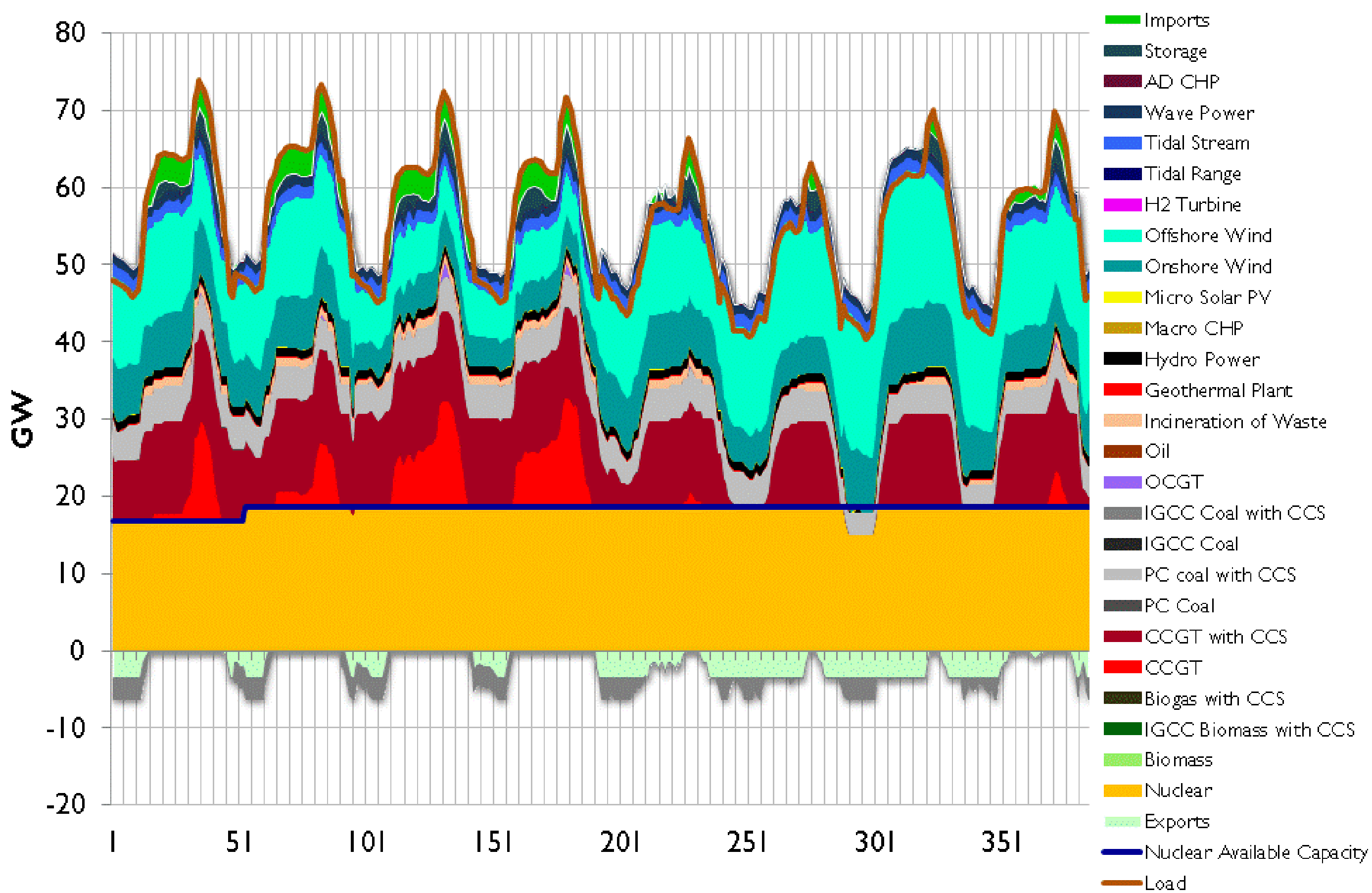


Sensitivities on interconnection

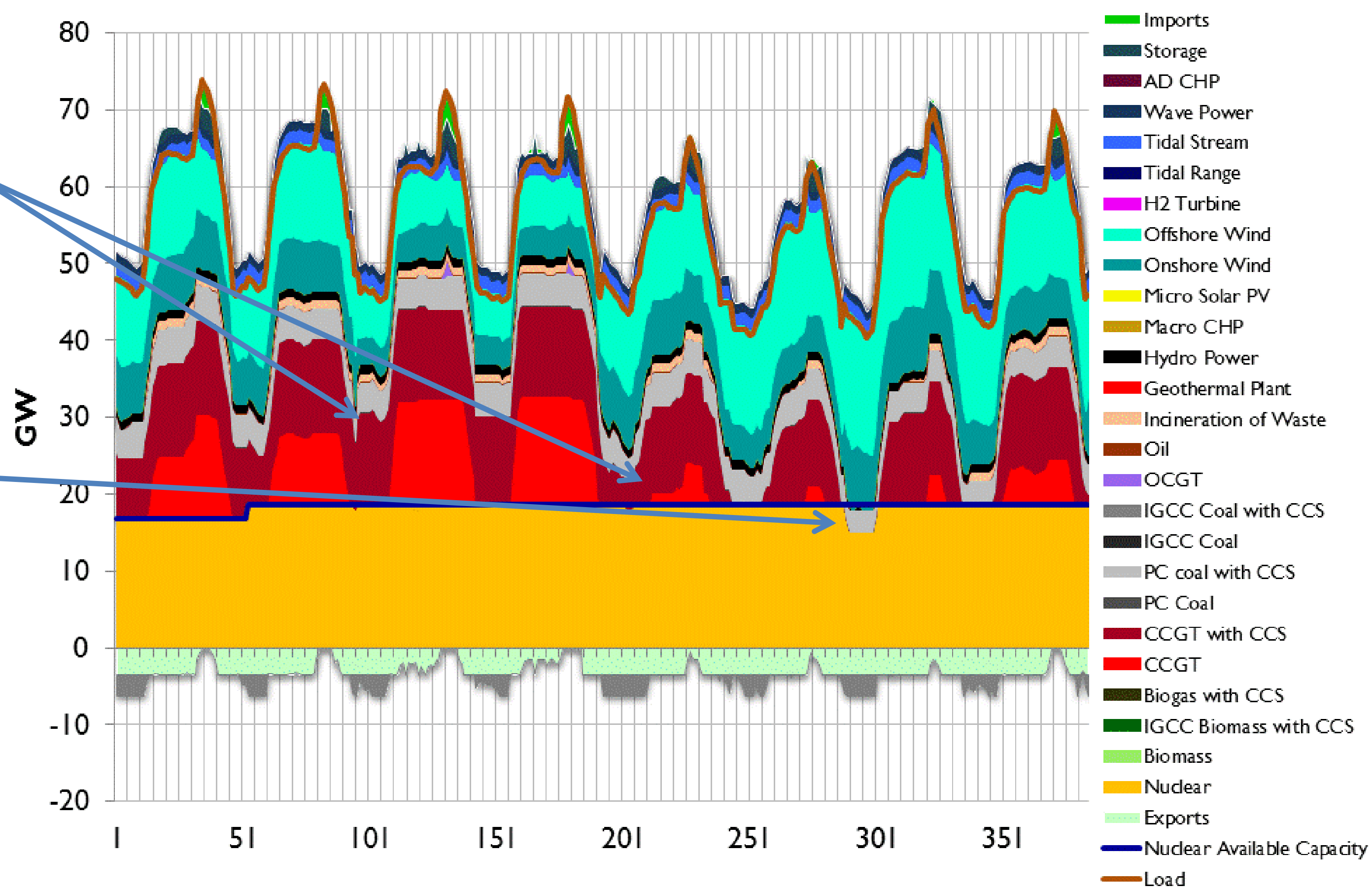
Current Levels of Storage + Increased Cost of Imports

REDPOINT

CCGT with CCS provides downward flexibility in off peak

Downward flexibility in off peak periods provided by nuclear

Increasing upward flexibility from CCGT



Increased Cost of Imports

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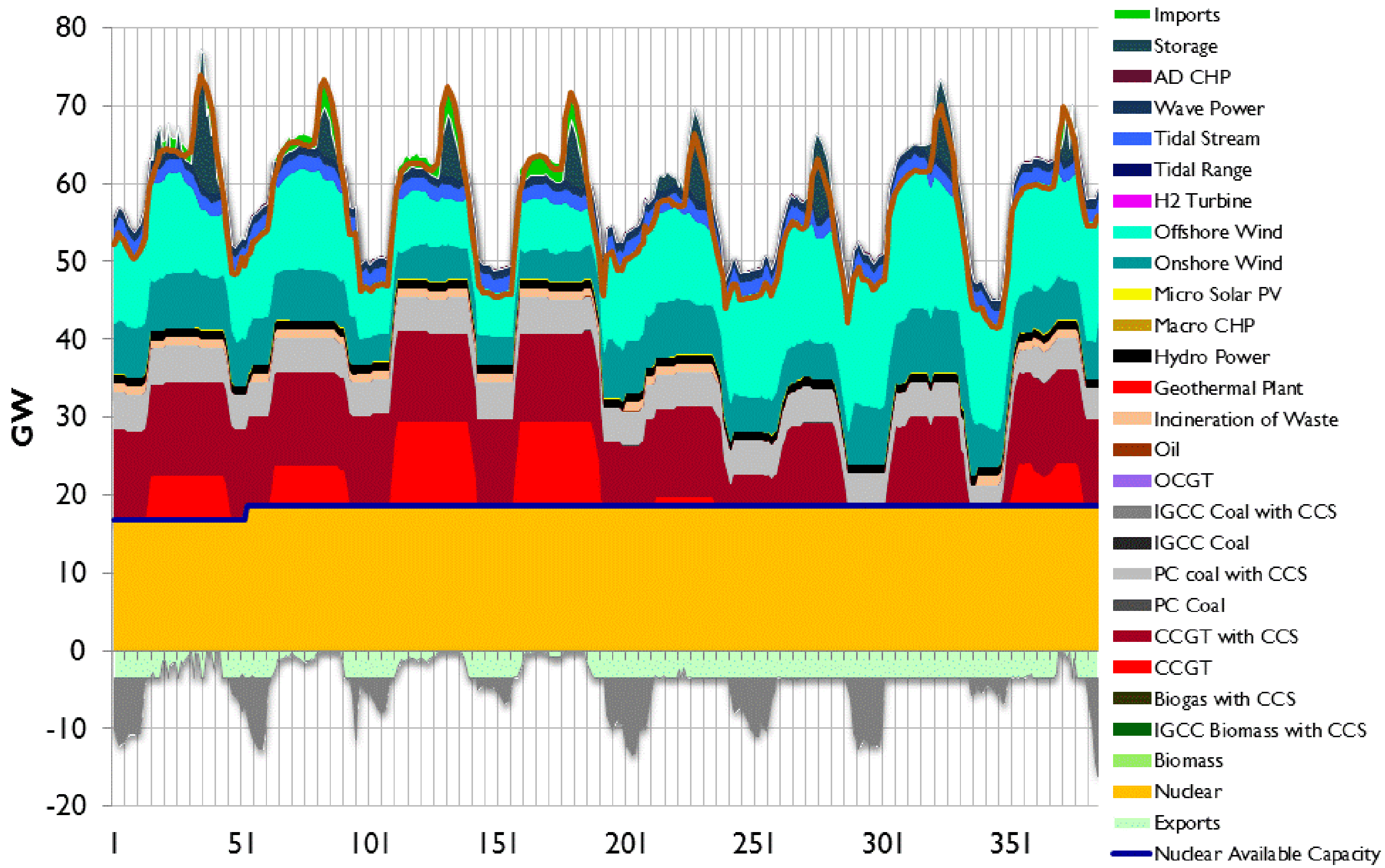
The chart below shows the half hourly generation for the week commencing 6th Jan 2030 in the High scenario.

Exports increase and storage decrease in off peak periods

Generation to balance increased exports, reduced imports and less storage in peak periods is meet by CCGT



Increased Interconnection Capacity

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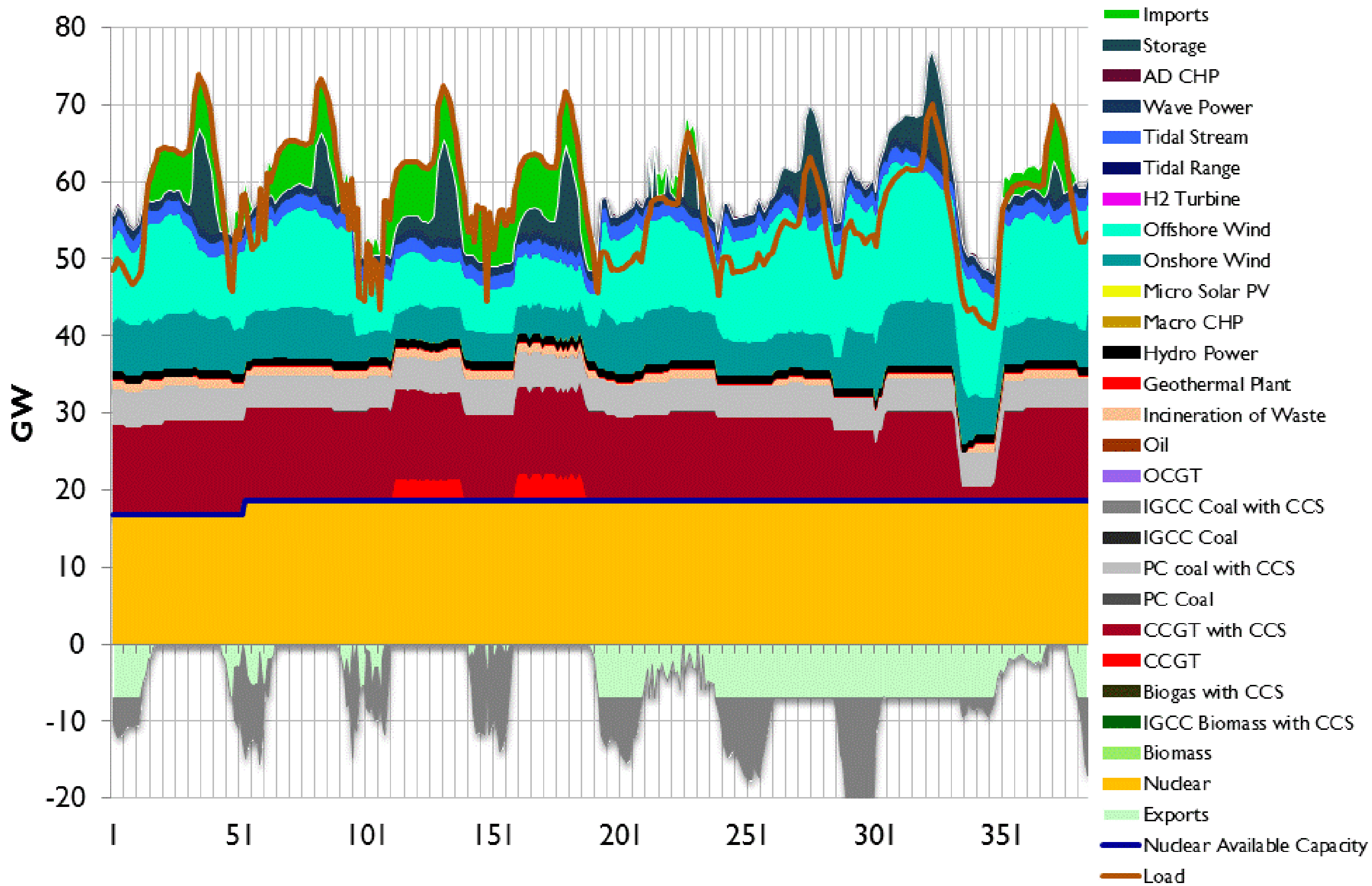
The chart below shows the half hourly generation for the week commencing 6th Jan 2030 in the High scenario.

Imports provide increase upwards flexibility in peak periods, displacing some of the generation from CCGT

Increased exports provides downwards flexibility, CCGT with CCS has a flatter generation profile



Conclusions

Conclusions – CCGT CCS technical parameters

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- Overall the impact of changing CCGT with CCS technical parameters on whole system CO_2 emissions and generation costs are small
- CO_2 emissions under each sensitivity vary from the base case by less than +/-1% except where the min up and min down time is tripled. This sensitivity results in a 6% increase in CO_2 emissions from the base case.
- Generation costs under each sensitivity vary from the base case by less than +/-1%.
- Changes in the market conditions such as interconnection and storage have a larger impact on the system generation and the flexibility provided by CCGT CCS plant.
- In the Base case, a CCGT CCS plant has an annual average load factor of ca 75%, indicating it is running baseload whenever it can but is providing downward flexibility in times of high wind generation.
- CCGT CCS plant require around 70-80 starts per year in the Base market environment. However, with storage at current levels or a higher cost of imports, the requirement can increase to around 130-140 starts per year.
- One caveat to note is that perfect foresight with a 3 day look ahead is used in the Plexos model, which could not be achieved in reality. This allows the model to optimise around wind and demand variations and may therefore underestimate the importance of flexibility parameters like ramp rates.

Improving the model

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During the workshops we have discussed a number of ways that could improve the modelling further. These include:

- Modelling more start fuel consumption & potentially hot/warm/cold starts and the costs & emissions associated with those.
- Adding variable CO2 transportation and storage costs for CCS plant. This could potentially affect the short run competition between CCGT CCS and Coal CCS plant.
- Assessing options for modelling imperfect foresight.
  - Run the model, freeze the generation position and re-run with different demand and wind profile
  - Run Plexos in unconstrained mode and then fix the baseload generation in the next run with a shorter optimisation horizon
  - Non-anticipativity functionality in Plexos