PÖYRY

NETZ
ENTWICKLUNGS
PLAN STROM

NEP2015: OVERVIEW OF MARKET MODEL BID3

June 2015

v100

AGENDA

1. Introduction
2. Overview of BID3
3. BID3 key features
4. Screenshots

INTRODUCTION

NETZ ENTWICKLUNGS PLAN STROM

This pack gives an overview of the market model used in the NEP2015, BID3. It is not a comprehensive technical description, but an overview of the key principals and main features in the model

- The Grid Development Plan 2015 (NEP2015) deals with the expansion requirements of the German onshore energy transportation network and is based on the legal requirements as stipulated by the German Energy Management Act (Section 12a-d). The transmission system operators are planning, developing and building the grid of the future and the NEP2015 is used to show how power generation in Germany can successfully be restructured and renewable energy can be integrated within ten and twenty years.
- Following the ruling of the German Bundestag in August 2011, the transmission system operators have been tasked with compiling a plan for the development of the transmission network every year to allow for changing conditions in the energy industry. The result of all this work is the NEP2015.
- To carry out the NEP2015, simulations of the market and of the transmission network are required, and Pöyry was appointed to run the European market simulation of a series of scenarios for the NEP2015, using a bespoke market model called BID3.
- This document gives an overview of BID3 and expands upon the details laid out in the Grid Development Plan report.

BID3
Electricity Market Model

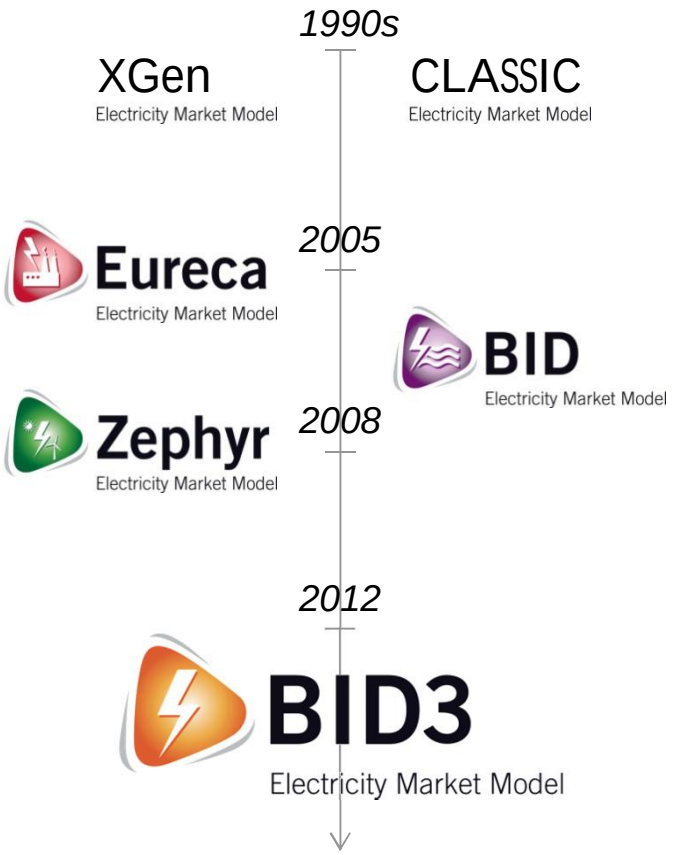
AGENDA

1. Introduction
2. Overview of BID3
3. BID3 key features
4. Screenshots

PÖYRY EXPERTISE IN POWER MARKET MODELLING

Pöyry has a long experience of market modelling, dating to the beginning of liberalisation

- Since the 1990s, Pöyry has been very active in following the latest computing technologies to improve its modelling and understanding of complex issues
- Early models (XGen and Classic) used simple merit-order stack based approaches
- Further developments led to Eureca, BID and Zephyr, using Linear Programming platforms
  - BID explored the interaction between the Nordics and the Continent
  - Zephyr explored the impact of intermittent renewables in thermal markets
- In 2012, Pöyry undertook a major redevelopment of its modelling platform, called BID3
  - merging expertise from all models, for unparalleled speed, quality and robustness
  - implementing a very user-friendly interface
- BID3 is continually upgraded to adapt to client demands



SUMMARY

BID3 Electricity Market Model

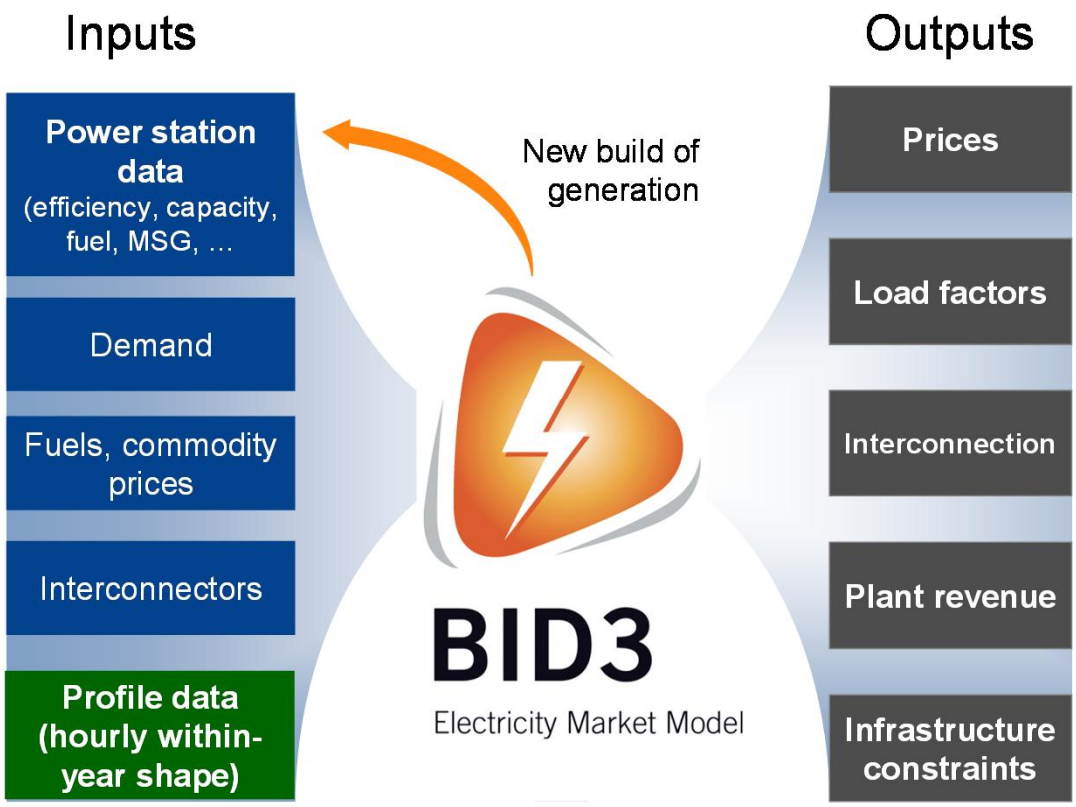
BID3 is the leading European electricity market simulation software – combining powerful simulations with user-friendliness

Detailed Mixed Integer market modelling	• BID3 is an optimisation which using either Linear or Mixed Integer Programming to minimise system costs
Extensive client base	• BID3 is already used by TSOs, energy companies and regulators, as well as extensively by Pöyry.
User-friendly	• Recently redesigned to be very user friendly, meaning that the training and implementation time is very low, and errors are avoided due to simplicity of use
High quality datasets underpin the analysis	• BID3 contains a database of all power stations in Europe, and all market relevant parameters (efficiency, transport costs, minimum generation levels etc.)
Detailed hydro, wind and solar modelling	• We use the model to underpin our extensive modelling work in 'intermittency' including detailed simulations of historical weather patterns, and sophisticated hydro modelling
Fast and powerful	• Designed to allow computing power to be focused where it is needed, and handles modelling all power stations in Europe (hourly) with ease.

BID3 – PÖYRY'S ELECTRICITY MARKET MODEL

BID3 projects physical operation (generator output, electricity flows, emissions) and economic behaviour (electricity prices, revenues)

Inputs and outputs of *BID3*



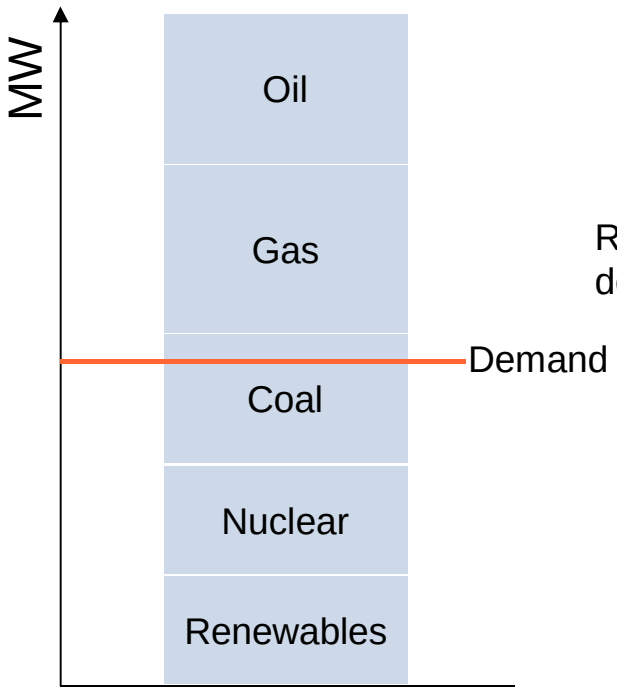
Basics of BID3

- BID3 is an optimisation which minimises the system cost in a year subject to constraints
- The model optimises all 8760 hours in the year
- Key features
  - Optimisation representing start-up, part-loading (no-load)
  - Minimum Stable Generation, minimum off times, minimum on time
  - Start-up cost and variable maintenance costs dependent on start temperature
  - Ramping
  - Reserve co-optimisation
  - Detailed CHP modelling
  - Hydro and pumped storage optimisation

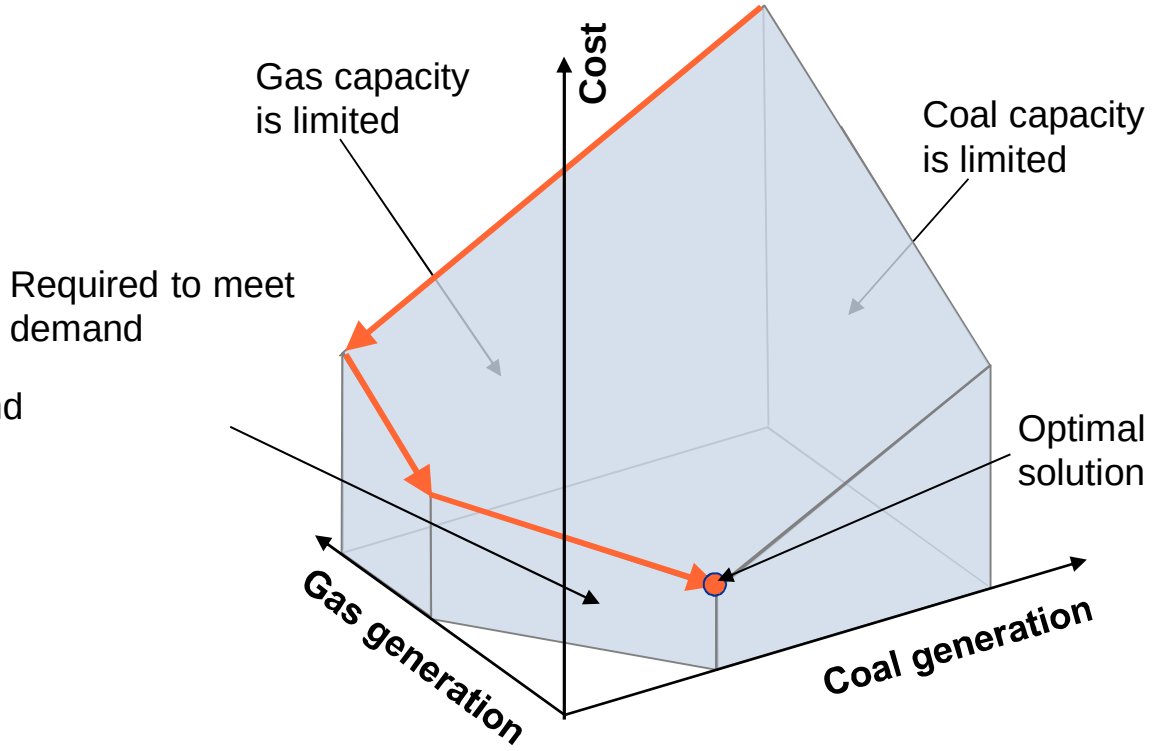
UNDERLYING PRINCIPLES: LINEAR OPTIMISATION STACK

BID3 uses linear or mixed integer linear programming (MILP) to optimise the dispatch. This is similar to a merit order, but more accurate

Merit order



Linear optimisation (merit order adjusted for constraints)



Unlike a simple merit order stack, linear or MILP optimisation allows the inclusion of inter-temporal constraints (start-up costs, pumped storage, hydro etc.) and multiple zones

MODELLING PRINCIPLES – STEADY STATE COSTS

The cost of thermal plant operation is the largest contributor to the objective function

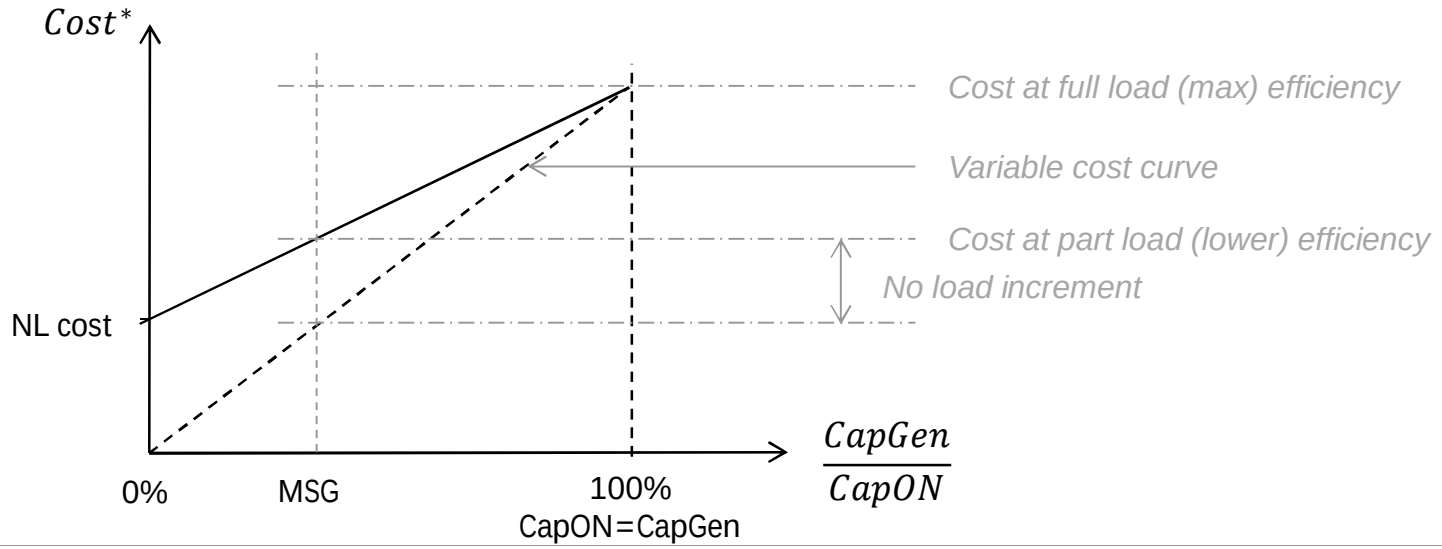
$$SteadyStateCosts = (\text{Variable cost} - \text{NLcost}) \times CapGen + \text{NLcost} \times CapON$$

CapON = the capacity turned on

CapGen = capacity generated ($CapGen \leq CapON$)

NLcost = the cost of having capacity turned on but not producing

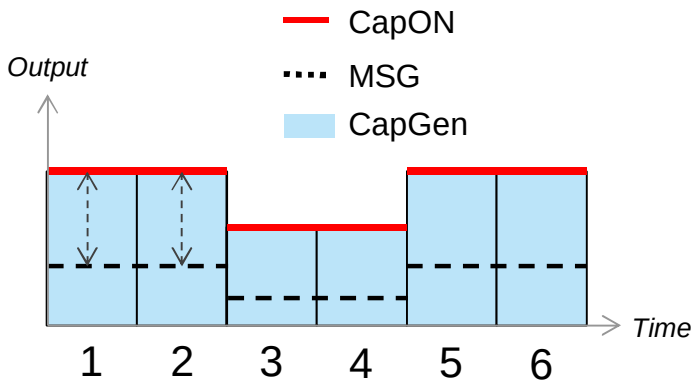
$$\text{Variable cost} = \frac{\text{FuelPrice} + \text{Transportation} + \text{CO2price} \times \text{Emissionfactor}}{\text{Efficiency}} + \text{VOWC}$$



MODELLING PRINCIPLES – DYNAMIC COSTS

The model also accounts for the costs incurred by starting or part-loading plant

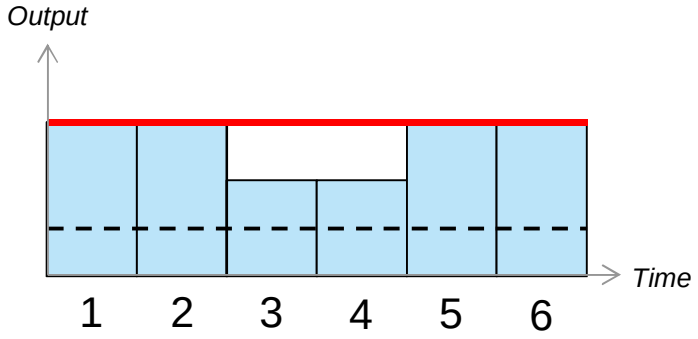
- There are two options for running: linear or mixed integer
- In the linear approximation of start-up costs, any % share of the plant can be considered ON
  - Massive runtime gain compared with full '1 or 0' mixed integer approach
  - Works very well in large systems



Incur start-up cost hour 5

- Depending on CapON, the Minimum Stable Generation (MSG, as % of CapON) determines the min level of CapGen

- The model chooses cheapest solution between start-up costs or part-load costs
  - Start-up costs when 'CapON' increases
  - Part load 'cost' when CapGen<CapON

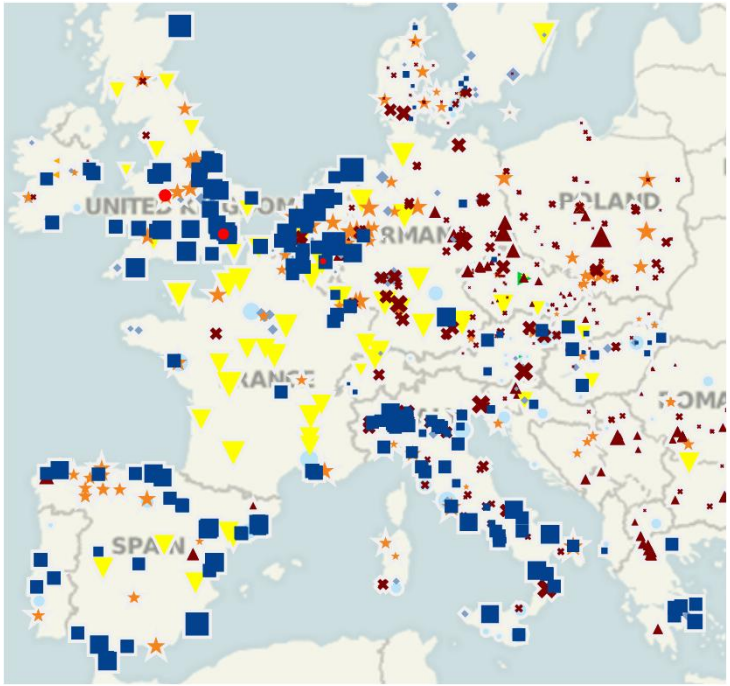


Incur part-load cost hour 3-4

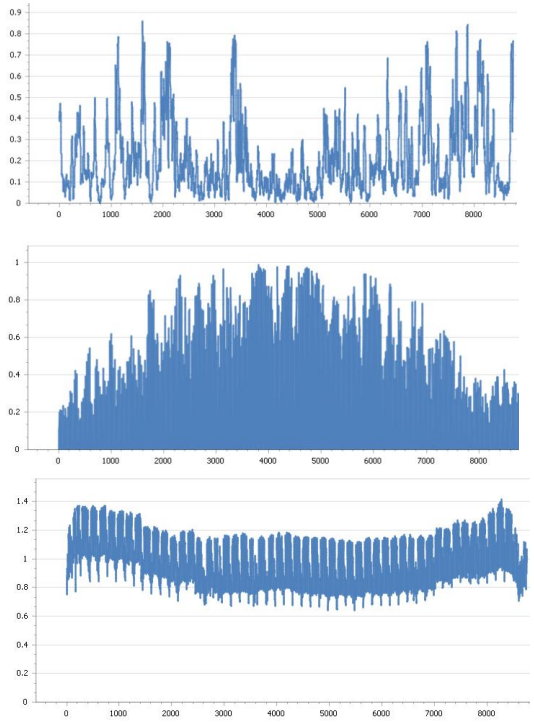
BID3 DATA

Data is available for Europe and selected countries worldwide. Databases provided come with a backcast, typically for two years, to ensure quality

Power station data

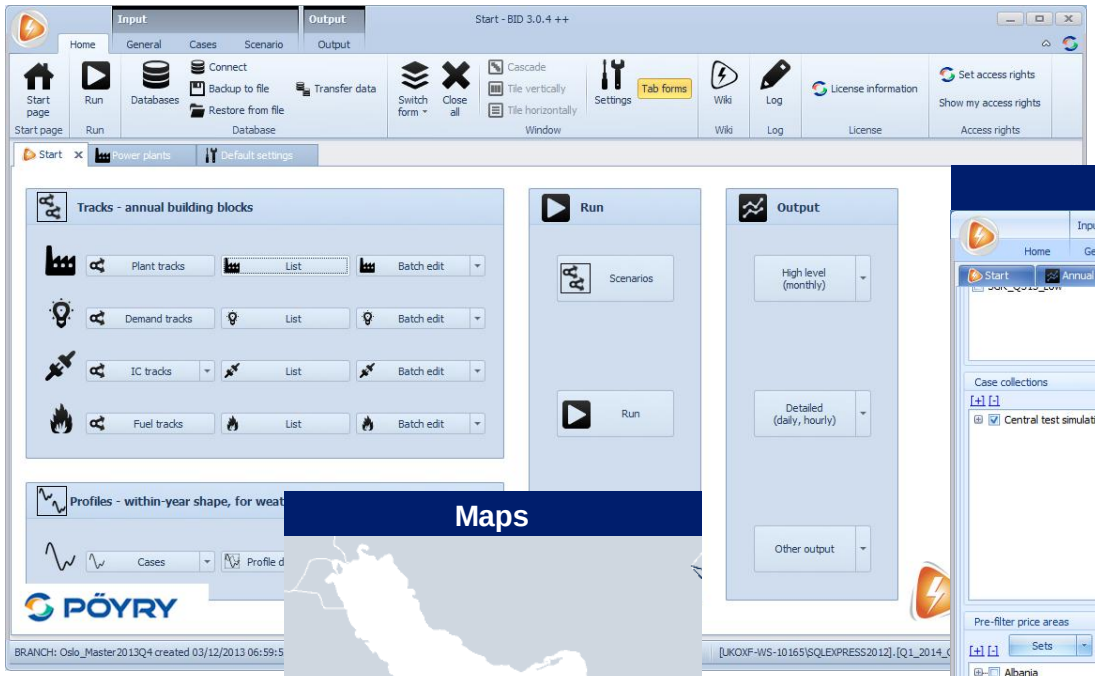


‘Profile’ data of hourly wind, solar and demand

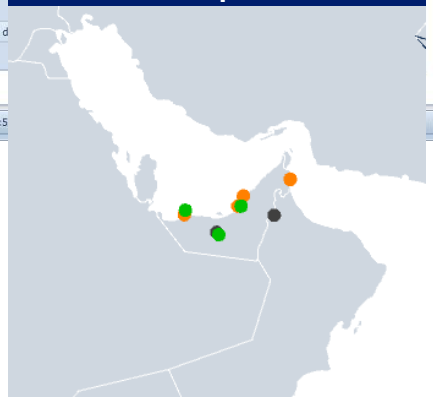


INTERFACE EXAMPLES

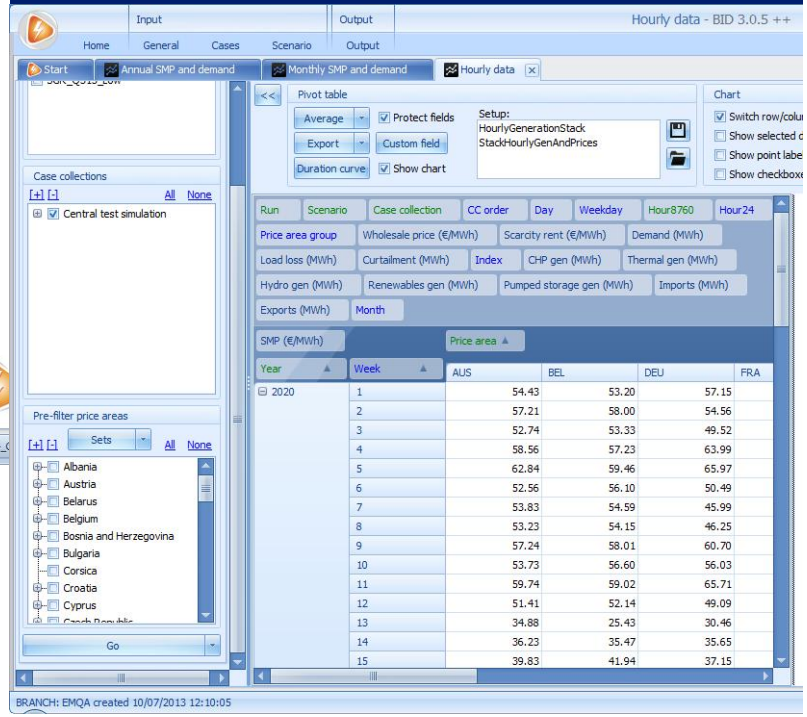
Start screen



Maps

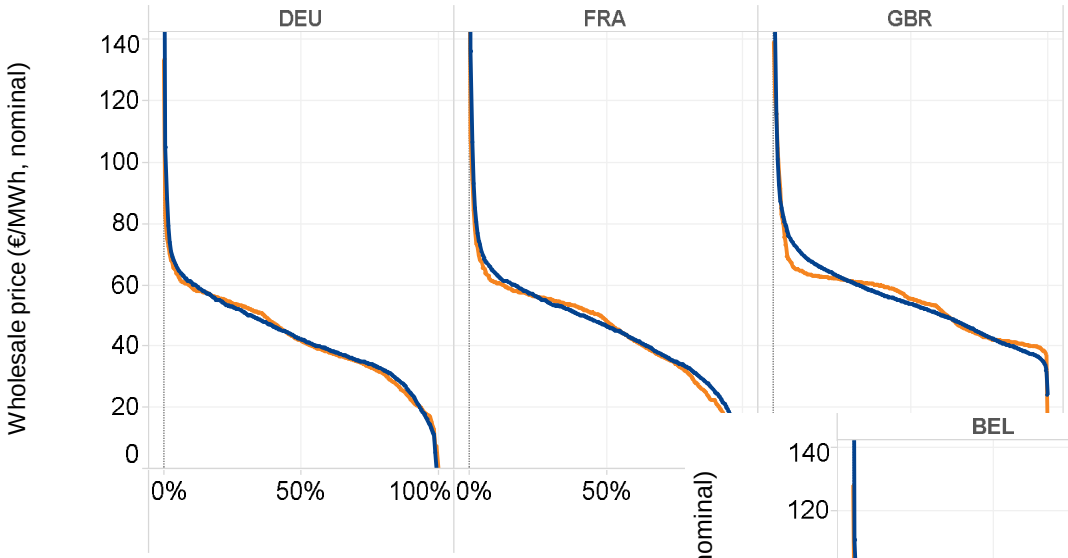


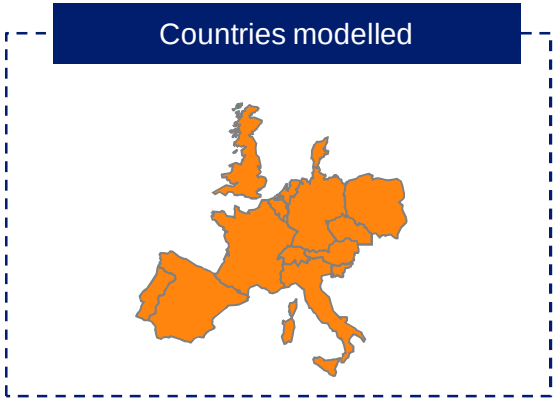
Flexible pivot tables/charts



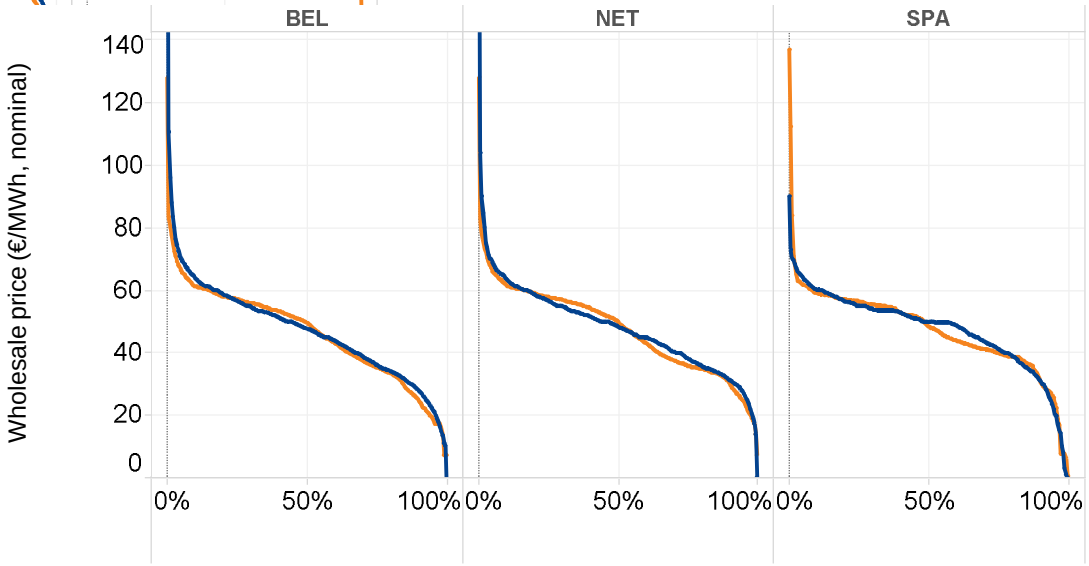
MODEL ACCURACY

Comparing historical prices against a 'backcast' of BID3 for 2012 shows that it produces accurate prices and a convincing price shape.





- Simulation used monthly average fuel prices, monthly average interconnector NTCs, monthly average plant availability and 2012 historical demand and weather patterns



LIST OF FEATURES

BID3 is simple and user-friendly, but has many advanced features

General features

- Modelling of 8760 hours per year
  - Across many weather/stochastic series for each 'future year' modelled
- Interface designed to allow an easy setup of sensitivities
- User-friendly, but detailed and powerful interface
  - Pivot-table/pivot-chart system, highly flexible,
  - Easy interaction with Excel
  - Several levels of outputs, from most aggregated to most detailed
- Investment analysis
  - Plant-by-plant profitability analysis
  - Capacity payment, need for other revenue streams
  - System indicators: costs, emissions, loss of load, capacity margin
- Mapping capabilities
  - Individual assets (power plants, interconnectors), and all results

Dispatch thermal plants

- Comprehensive set of plant dynamics
  - Start-up costs, dependent on plant temperature
  - Minimum stable generation
  - Minimum ON and OFF time
  - Start up ramp rates
- Advanced treatment of CHP plants
  - Hourly heat demand
  - Possibility of backup boiler
  - Electric generation limit as a function of heat demand
- Possibility of Mixed Integer Programming
  - Plants either ON or OFF, required for detailed dispatched patterns
- Many other features
  - Co-firing
  - Contractual/regulation limits on operations
  - Ambient profile temperature effect
  - …

Dispatch

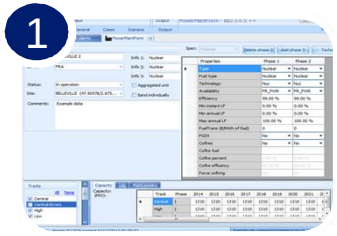
- Hourly renewables generation
  - Detailed analysis of satellite data, many historical weather patterns
- Optimisation of reservoir hydro using Stochastic Dynamic Programming
  - Dispatch under uncertainty of future inflows for the Nordics
  - Dispatch of reservoirs with annual constraints for the Continent
- Demand-side management
  - Load-shifting and smart grids
  - Electric vehicles, heating, power intensive industry, etc.
- Interconnectors
  - Flow-based allocation of interconnectors
  - Ramp rates on DC links
- Reserve holding within 'spot' simulation, with different products and timeframes
- ...

AGENDA

1. Introduction
2. Overview of BID3
3. BID3 key features
4. Screenshots

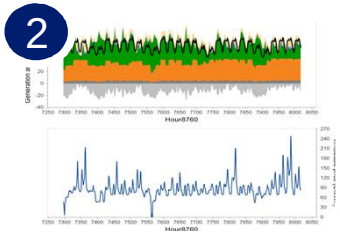
KEY FEATURES OF BID3

1



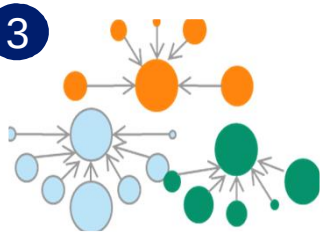
Detailed power station database

2



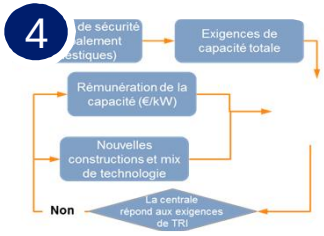
High quality auditing of data

3



Different modules for increased accuracy

4

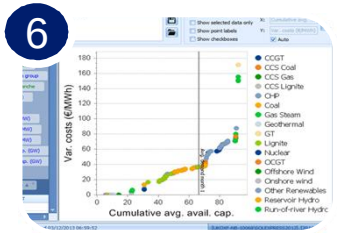


Energy-only and energy + capacity markets

5

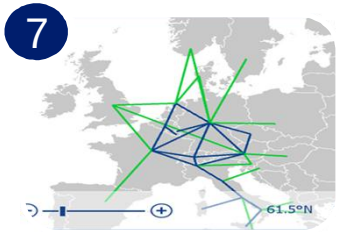
Sophisticated hydro modelling

6



Supply curves

7

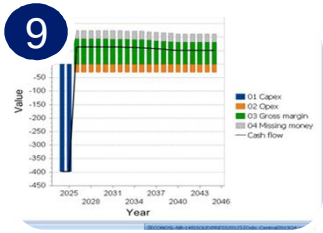


Interconnector optimisation

8

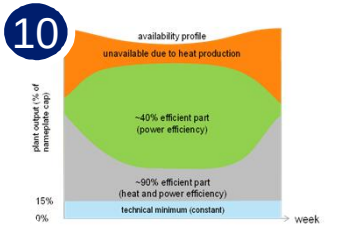
BID3 building blocks

9



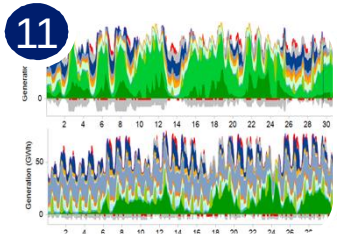
Investment and retiral auditing tools

10



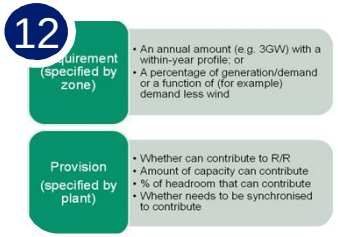
Detailed CHP modelling

11



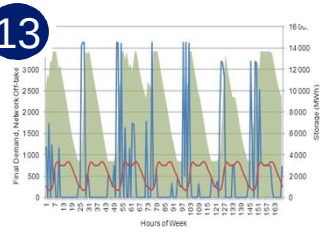
Solar and wind modelling

12



Reserve and response

13

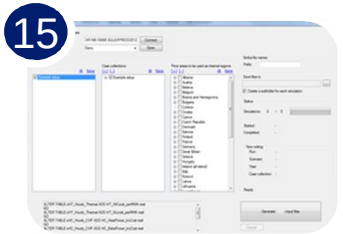


Demand-side management

14

Linear and Mixed Integer modelling

15

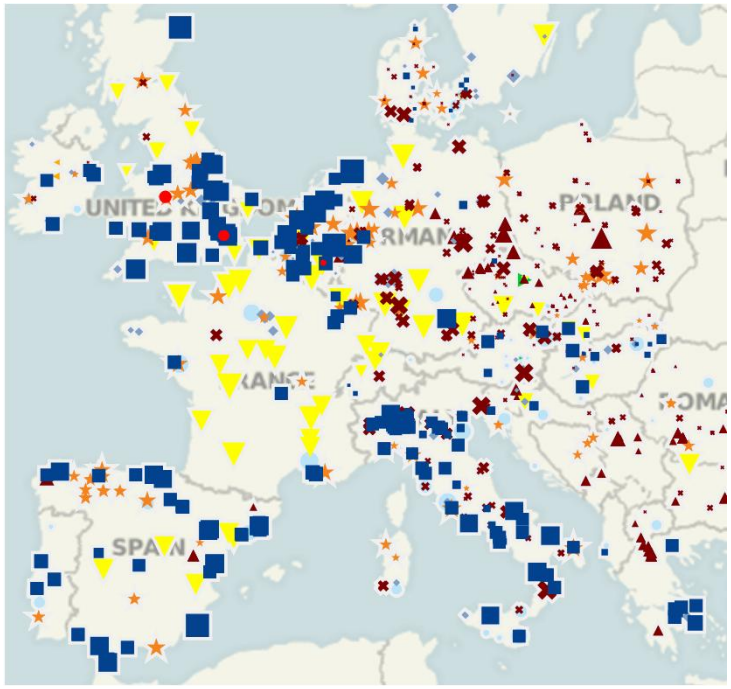


Load flow model integration

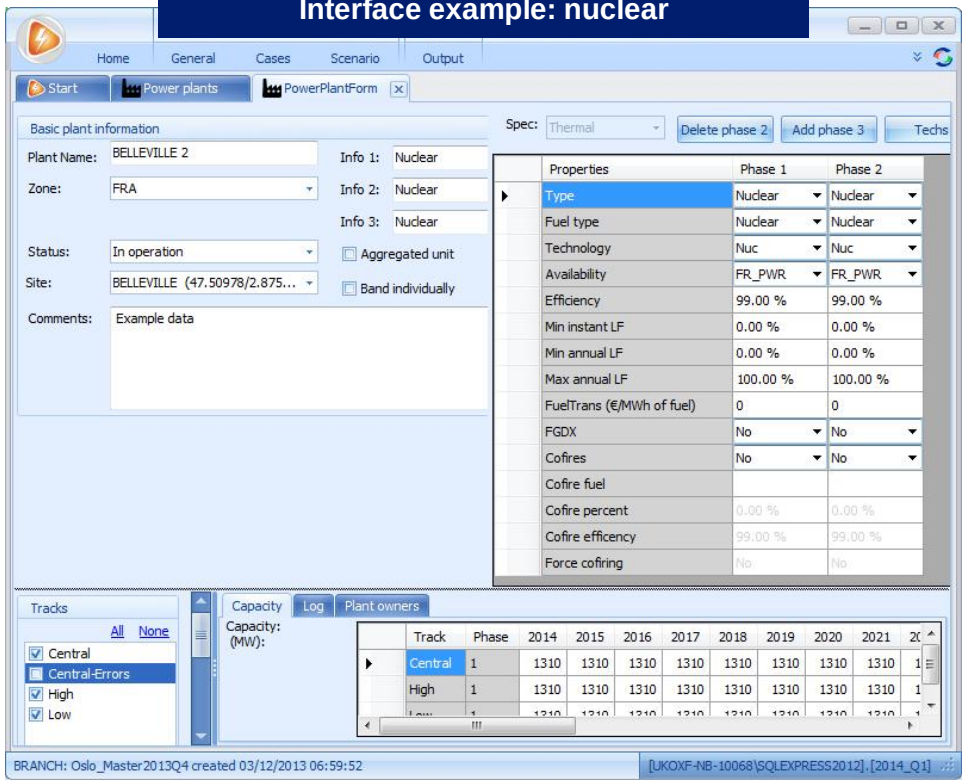
1 DETAILED POWER STATION DATABASE

Different categories of plant exist (hydro, pumped storage, thermal, renewable and CHP) with detailed parameters for each type. Different phases can be used for shifts in technology (e.g. change in efficiency, change of fuel)

All European power stations



Interface example: nuclear

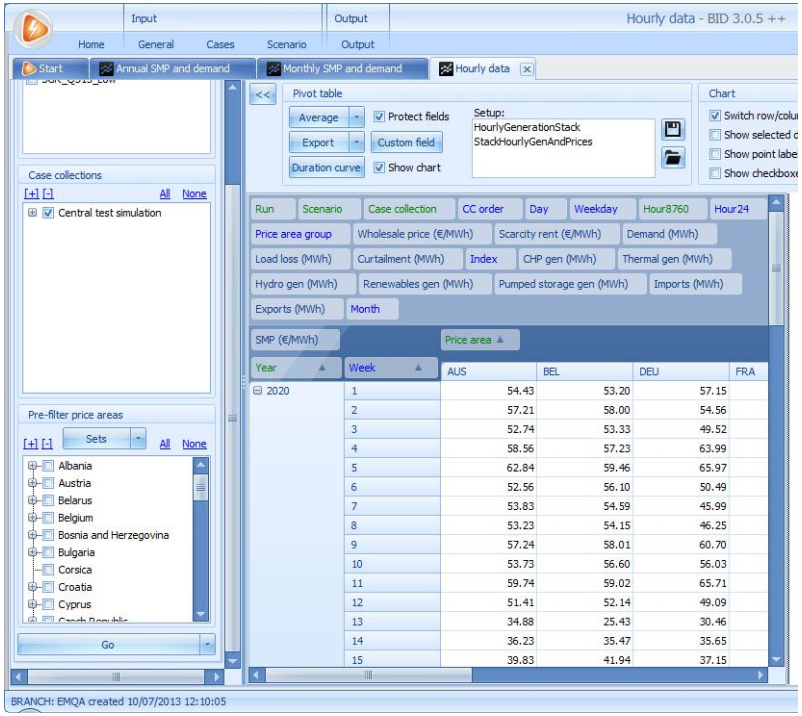


- BID3 datasets hold data on all power stations in Europe, including detailed technical parameters

2 HIGH QUALITY AUDITING OF DATA

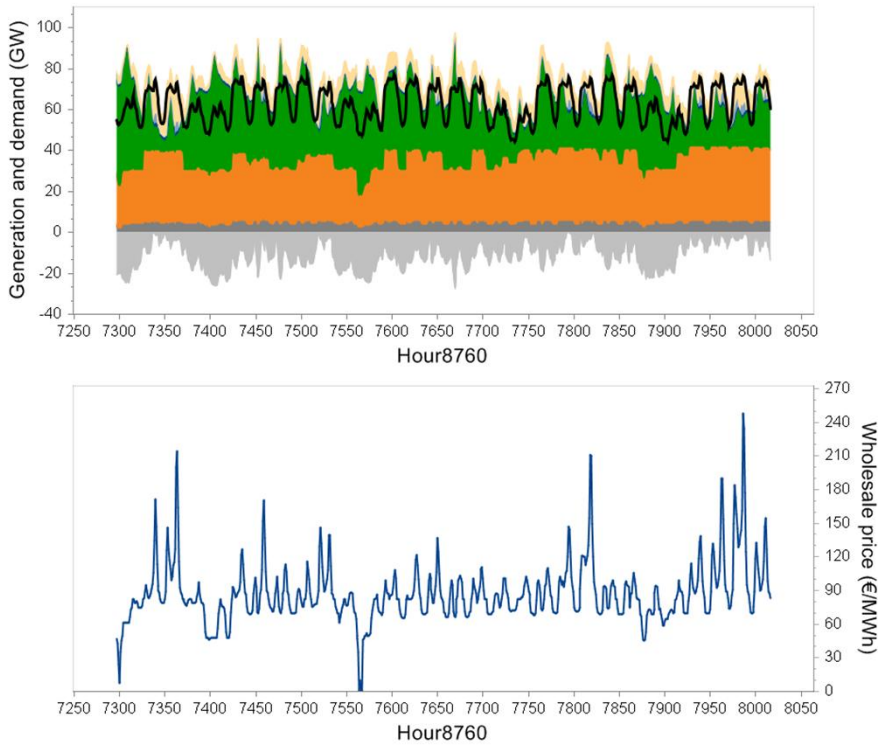
BID3 uses the latest visual environment to allow pivoting and charting of data, quickly and flexibly, allowing increased quality of results

Any outputs can be pivoted instantly understand data



- Standard set-ups can be saved and instantly restored
- Pivot grid allows duration curves
- Custom fields can be specified for bespoke calculations

Any data can be visualised quickly and flexibly, and graphs customised to corporate colours/fonts

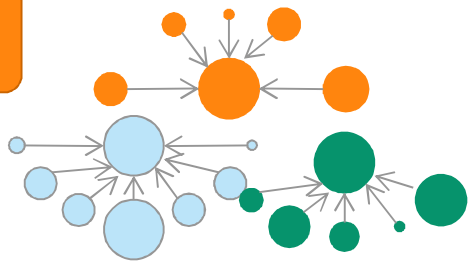


3 DIFFERENT MODULES FOR INCREASED ACCURACY

The heart of BID3 is in four main modules

1 Banding module

Groups plants into bands based on similar characteristics (e.g. efficiency)



2 Capacity margin module

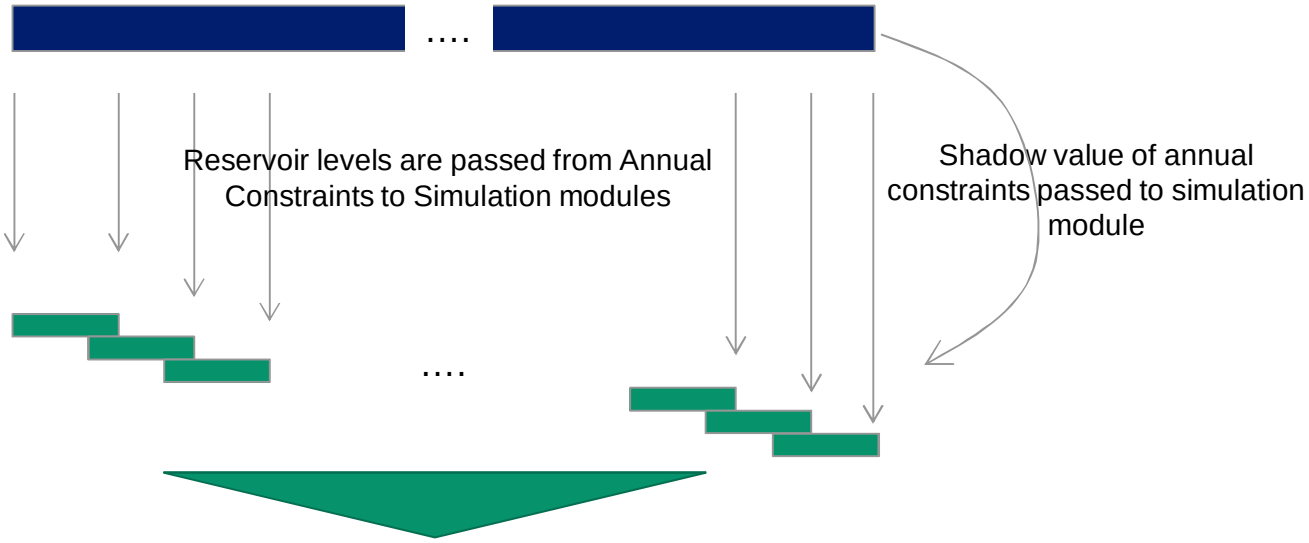
Calculates hourly system margin (tightness) for scarcity rent

3 Annual constraints module

Whole year simulation, lower resolution, for hydro and take-or-pay/must run conditions

4 Simulation module

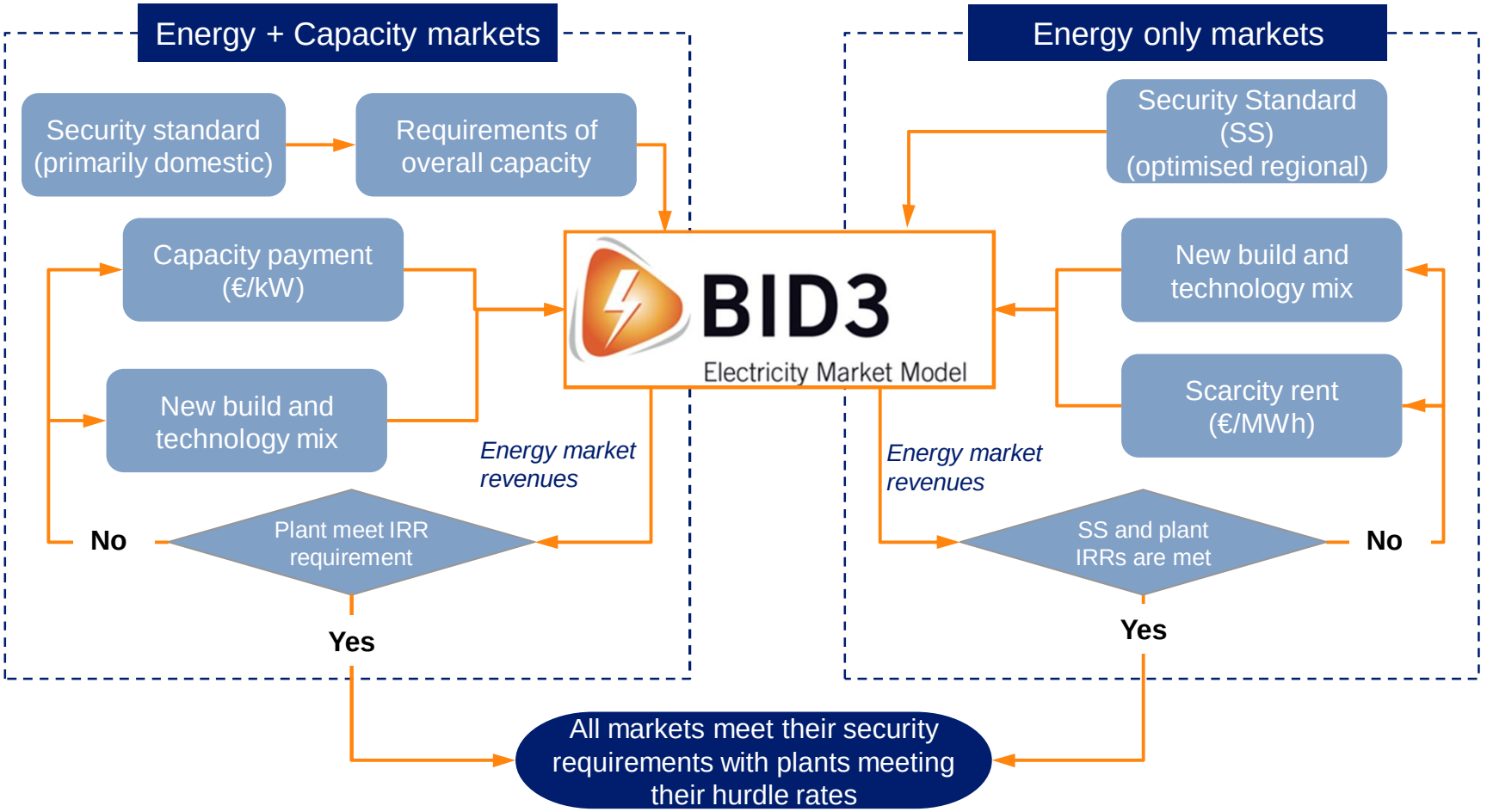
Detailed simulation, with full treatment of plant dynamics



Hourly prices and plant dispatch

4 ENERGY-ONLY AND ENERGY+CAPACITY MARKET MODELLING

Pöyry's BID3 electricity modelling takes into account the complex interactions between countries having different electricity market designs

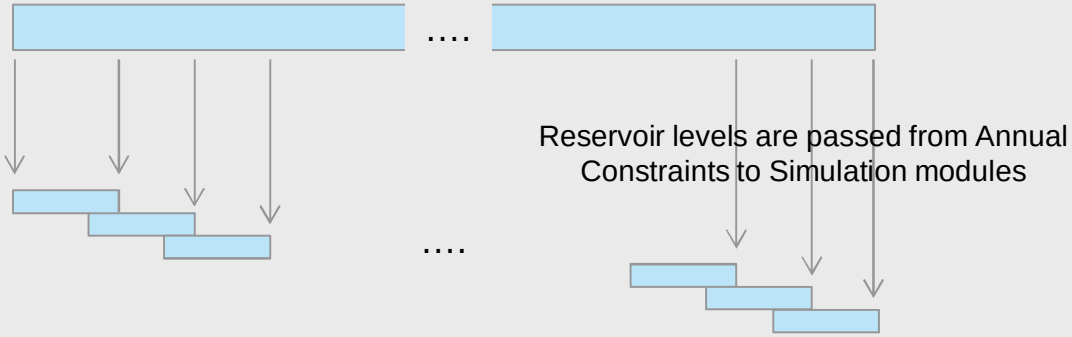


5 HYDRO MODELLING

BID3 has a sophisticated approach to hydro modelling, ensuring that hydro is accurately represented

Annual constraints module
(whole year simulation, lower resolution)

Simulation module
(weekly simulation, higher resolution)

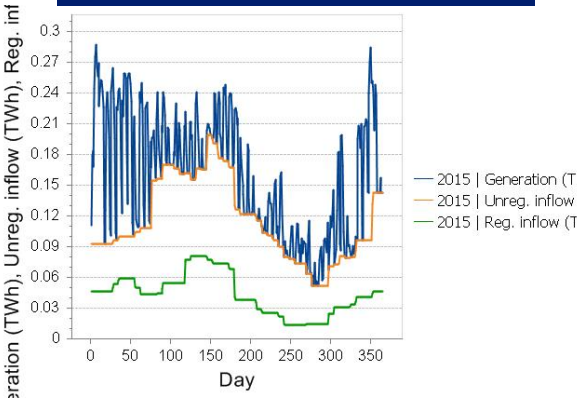


- Reservoir hydro is first scheduled at a weekly level in the *Annual Constraints Module*, subsequently the main model optimises the hydro use or pumping (alongside all other powerstations within individual week (*Simulation Module)*

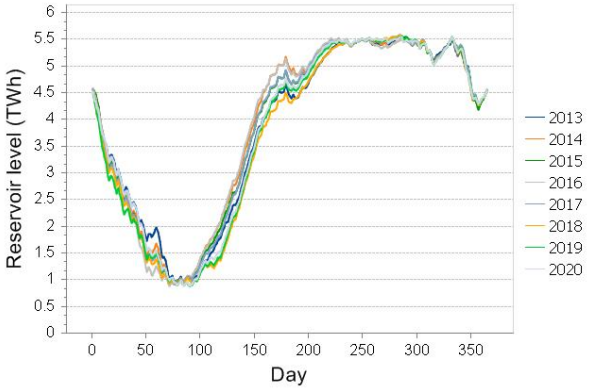
- Run-of-River is not directly optimised and is based on the historical inflow profiles (weekly/monthly profile input to the model, as available).

- Operation of pumped storage is considered separately and its operation is also optimised within the model

Inflows and generation



Reservoir levels



6 SUPPLY/DEMAND CURVES

Supply/demand curves can be generated quickly and easily, allowing instant understanding of price formation

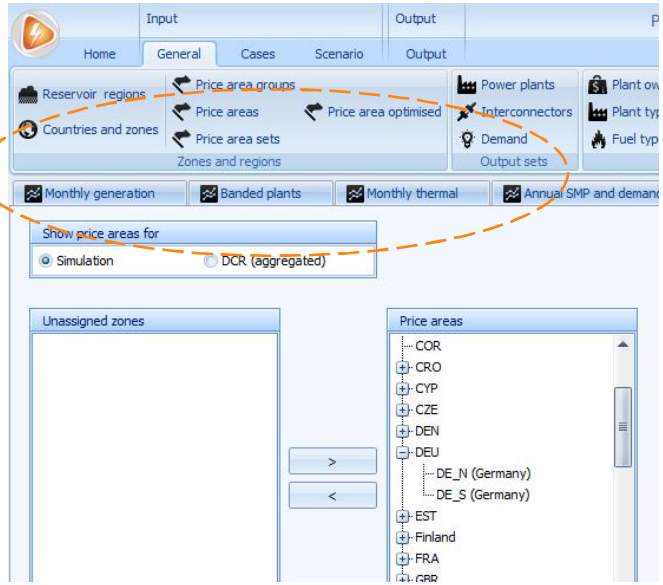
Supply curve by type

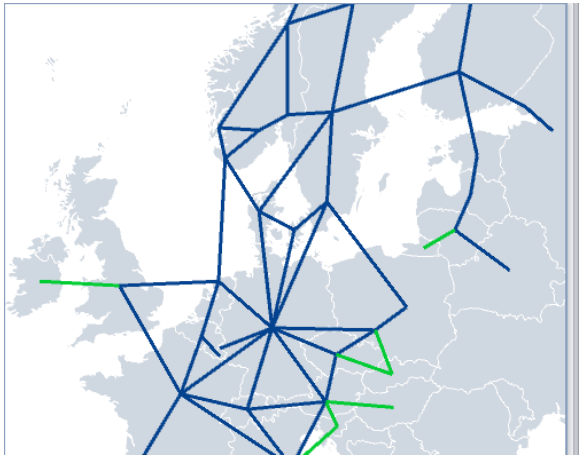
Supply curve comparing Jan and June

- The interface can generate supply/demand curves at a monthly resolution, for any number of price areas simultaneously
- The supply curve can be plotted down to the individual plant

7 INTERCONNECTION MODELLING USING NTCS

The model optimises flows between any specification of pricing areas. In addition, the user can choose between fixing flows or optimising





- Zones (e.g. Norway NNO) level of resolution of all of the input data
- Price areas (e.g. Norway NNO + NFI = Norway NO4)
  - transmission constraints ignored within group of zones
  - only one price created per price area, lower run time
- Country? irrelevant for the model, practical for filtering data

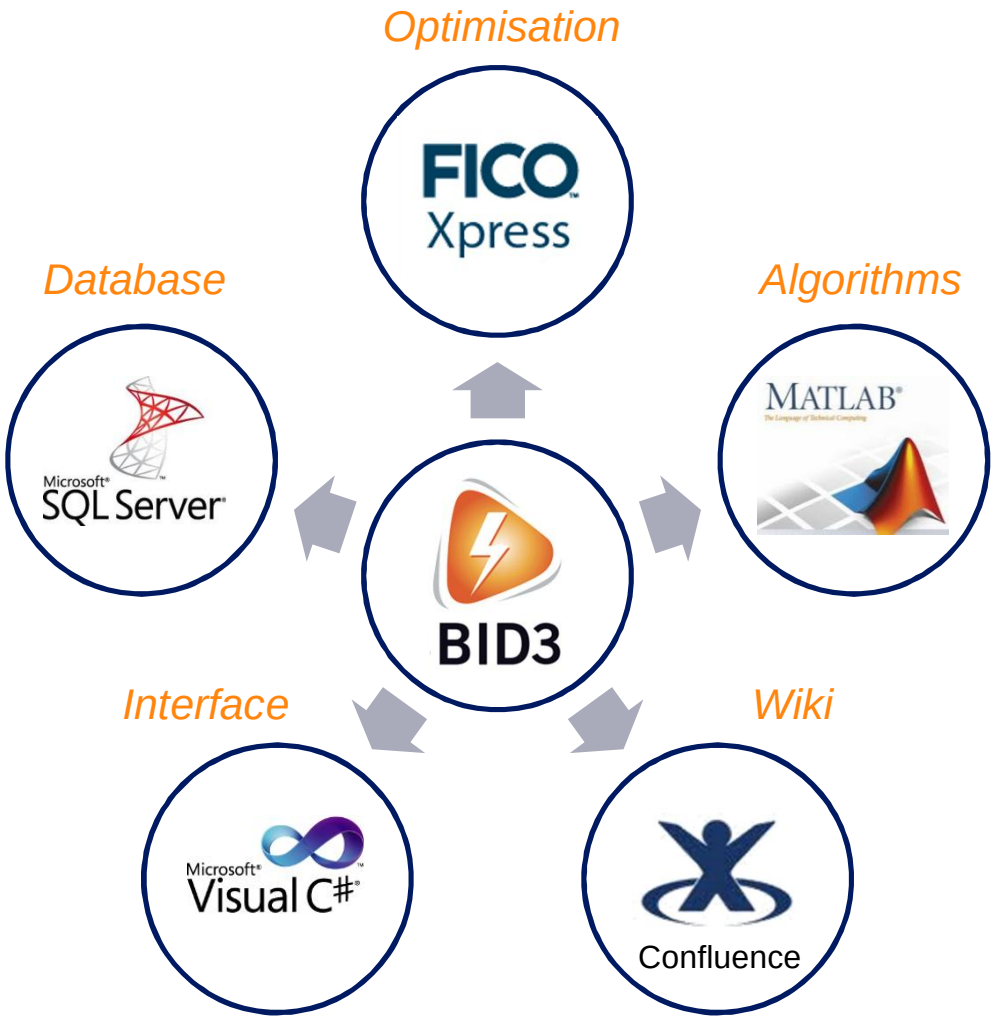
- By fixing flows, it is possible to dramatically reduce the size of the area being modelled, and hence speed up the run time
- BID3 allows two options for reducing the size of the modelled area:

1. Fixed flows based on a profile. This involves specifying an annual value and a profile. BID3 will then 'lock' a certain amount of interconnector flow
2. Fixed flows based on a previous run. This allows you to do (say) an overnight run with a large area (e.g. all Europe), but then use that run as the basis for fixed flows for a smaller area

8 BID3 BUILDING BLOCKS

BID3 uses professional software, with a flexible and modular structure

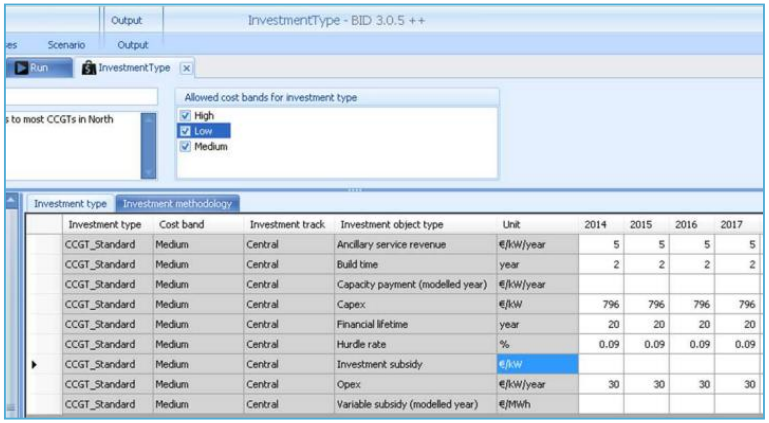
- BID3 uses the most powerful technologies
  - *Xpress* optimisation software, for power market simulation
  - *Matlab* for optimisation of hydro reservoir under uncertainty
  - *SQLserver* for robust storing of data
- BID3 is designed for the maximum ease of use
  - User-friendly interface developed in professional language *C#*
  - Structure is designed for powerful, yet easily set-up analysis
  - Input, output and processing all encompassed into the same interface
  - Dynamic documentation in *wiki* format



9 AUDIT OF INVESTMENT AND RETIRAL

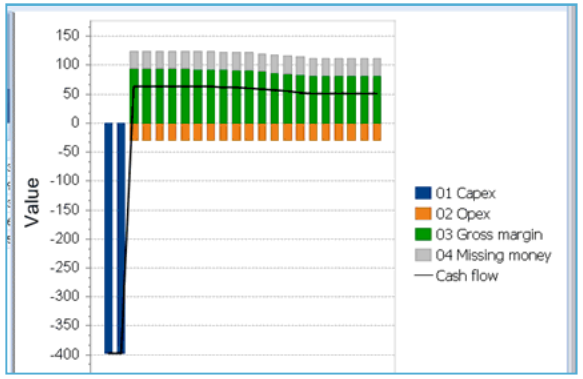
BID3 calculates cashflows for any future investment, along with key metrics such as IRRs and shortfall against fixed costs.

Specify plant parameters, such as build time, capex, opex, hurdle rates, direct subsidies, capacity payments and ancillary service revenues



Investment type	Cost band	Investment track	Investment object type	Unit	2014	2015	2016	2017
CCGT_Standard	Medium	Central	Ancillary service revenue	€/kW/year	5	5	5	5
CCGT_Standard	Medium	Central	Build time	year	2	2	2	2
CCGT_Standard	Medium	Central	Capacity payment (modelled year)	€/kW/year				
CCGT_Standard	Medium	Central	Capex	€/kW	796	796	796	796
CCGT_Standard	Medium	Central	Financial lifetime	year	20	20	20	20
CCGT_Standard	Medium	Central	Hurdle rate	%	0.09	0.09	0.09	0.09
CCGT_Standard	Medium	Central	Investment subsidy	€/kW				
CCGT_Standard	Medium	Central	Opex	€/kW/year	30	30	30	30
CCGT_Standard	Medium	Central	Variable subsidy (modelled year)	€/MWh				

Cashflow calculation and visualisation



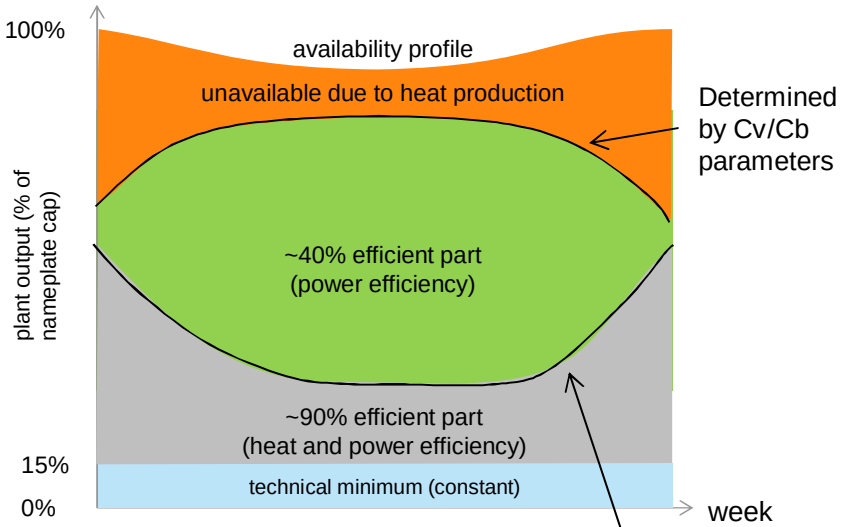
IRR calculations

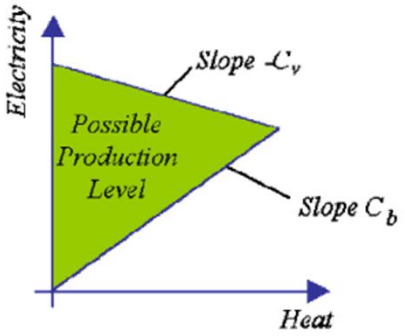
Audit investment module allows internally consistent scenarios to be rapidly built

10 DETAILED CHP MODELLING

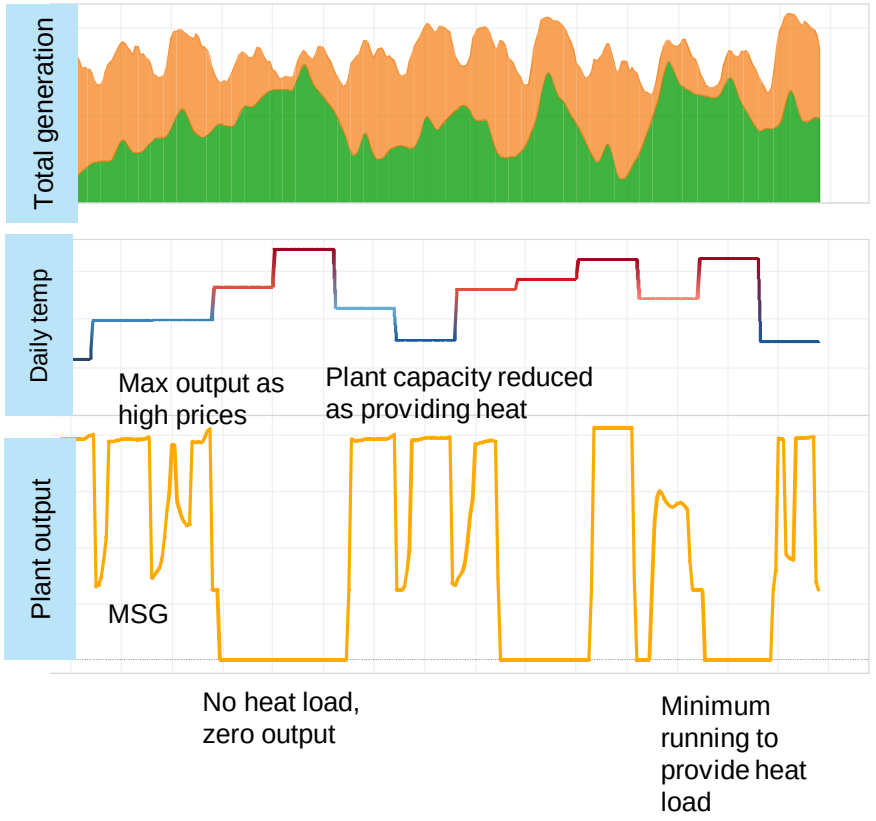
BID3 allows sophisticated specification of CHP, including capturing the heat load, varing efficiencies, backpressure or extraction types and backup boilers

CHP parameters





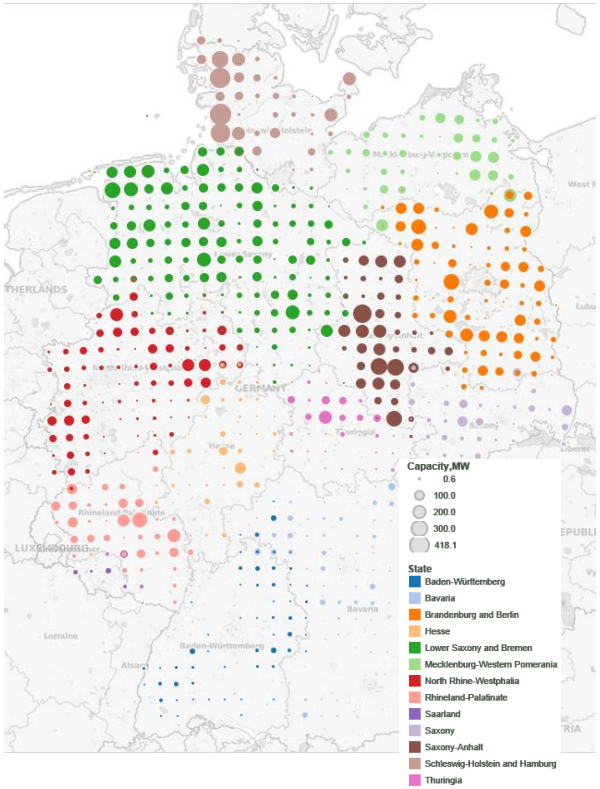
Example for a CCGT with heat load



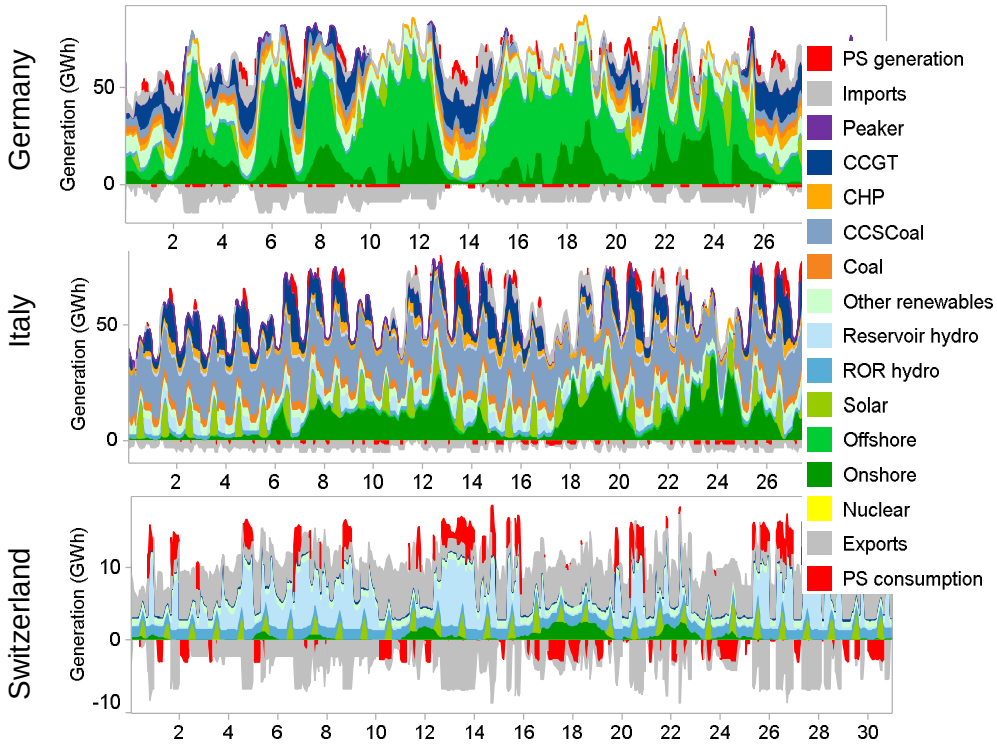
11 MODELLING OF INTERMITTENT GENERATION

By modelling consistent historical weather patterns, BID3 accurately examines the impact of wind and solar on dispatch and prices

Detailed database of wind farm locations used



A snapshot of the system



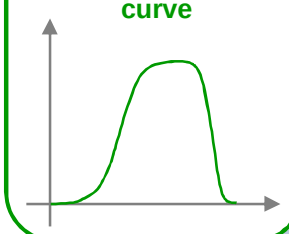
11 MODELLING OF INTERMITTENT GENERATION

BID3 uses highly detailed wind and solar data to accurately simulation historical weather patterns

Future wind capacity

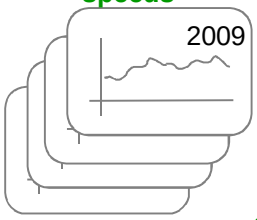
Future wind capacity based on country totals and probable future locations

Aggregated power curve



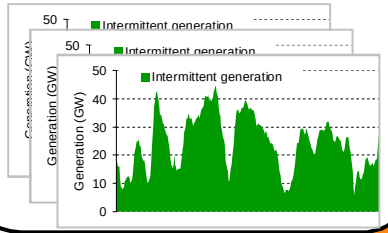
Two aggregated power curves used – one for offshore and one for onshore

Historical wind speeds

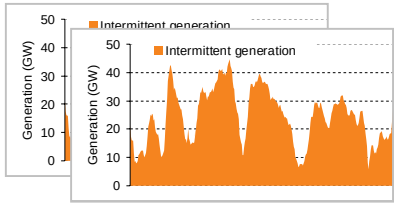


Historical wind speeds at hourly resolution for '000s of locations

Wind generation profiles



Solar generation profiles

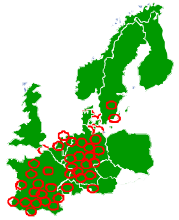


BID3

Electricity Market Model

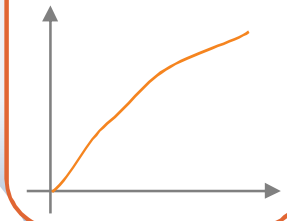
Future solar capacity based on country totals and probable future locations

Future solar capacity



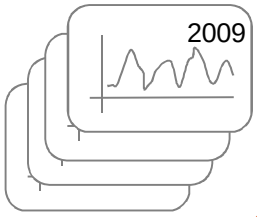
Conversion to MWh accounting for seasonal temperatures and losses

Conversion to MWh



Historical solar irradiation data at hourly resolution for '000s of points across Europe

Historical radiation



12 RESERVE AND RESPONSE

BID3 models the holding (not the activation) of any type of reserve/response (primary to tertiary ancillary services)

Generic specification of reserve/response

Requirement (specified by zone)

- An annual amount (e.g. 3GW) with a within-year profile; or
- A percentage of generation/demand or a function of (for example) demand less wind

Provision (specified by plant)

- Whether can contribute to R/R
- Amount of capacity can contribute
- % of headroom that can contribute
- Whether needs to be synchronised to contribute

- BID3 allows the specification of any number of types of reserve/response, although typically three are used – primary, secondary or tertiary
- BID3 requires the specification of both the requirement (the need for reserve/response) and the provision (what is providing the reserve/response).

13 DEMAND SIDE MANAGEMENT

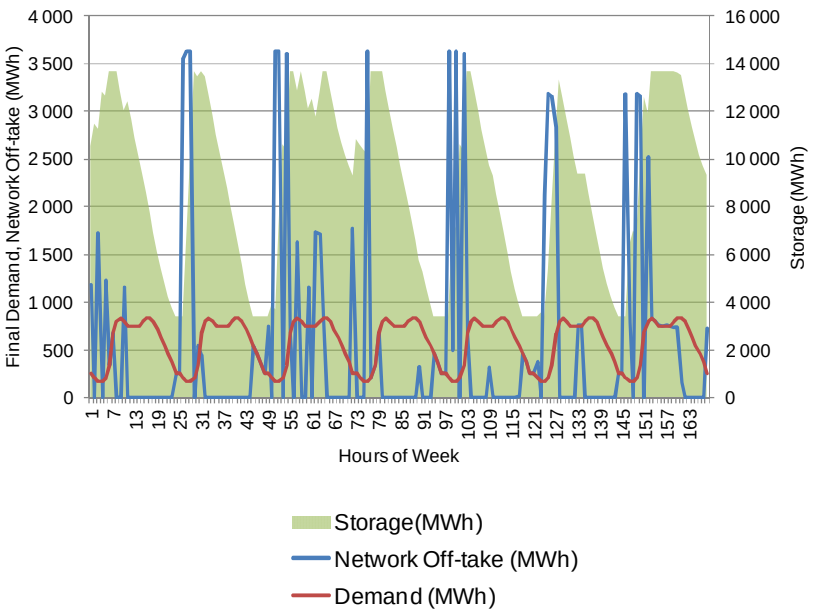
BID3 allows any type of demand side management (such as Electric Vehicles or flexible heat) to be modelled by specifying a number of generic parameters.

Screenshot of BID3

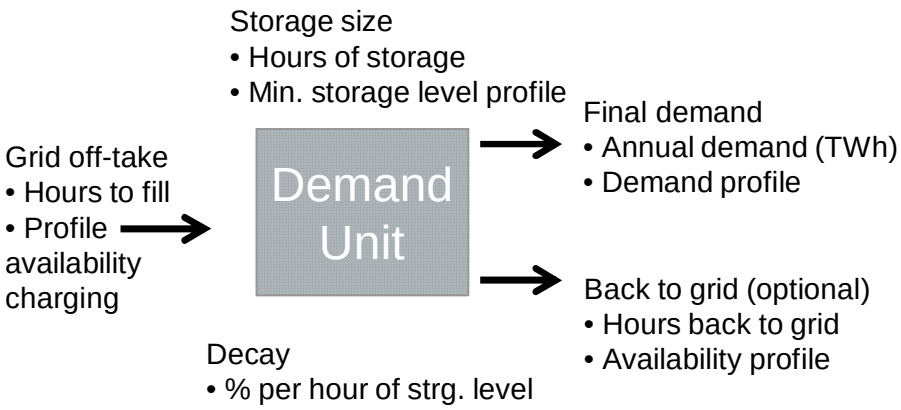
Start | Hourly demand flexibility | Demand groups | Run

	demGrpID	Demand group	Is flexible	Hours of storage	Hours to fill	Avail. profile def. filling	Decay rate	Minimum storage level profile def.	Back to grid
	1	All	☐	3		Not set		Not set	☑
	5	EV_backToGrid	☑	24	6	Flat	0	Flat - 0.25	☑
	2	EV_LeafHomeCharge	☑	24	3	EV - charging availability	0	Flat - 0.25	☐
▶	3	EV_LeafQuickCharge	☑	24	1	EV - charging availability	0	Flat - 0.25	☐
	4	HEAT	☑	24	10	Flat	0.01	Flat - 0.25	☐

Example for Electric Vehicles



Generic specification of DSM



14 LINEAR AND MIXED INTEGER MODELLING

For each scenario, Poyry runs three simulations using BID3, increasing the resolution of the run to hone in on Germany

Pan Europe
Pan-European model run covering the entire ENTSO-E region. Linear programming (relaxed MIP) version used, with simplified intertemporal dynamics and some grouping of power plants.
Main output is border flows (between countries) for the Germany Plus run

Germany-Plus
A linear programme (relaxed MIP) run of BID3 with full intertemporal dynamics, including temperature dependent starts, reserve co-optimisation, with some grouping of plant

Main output is border flows between Germany and neighbours for use in Germany-only run

Germany-Only
Maximum resolution run using Mixed Integer programming and full dynamics.
All plant in Germany modelled individually (i.e. no grouping)

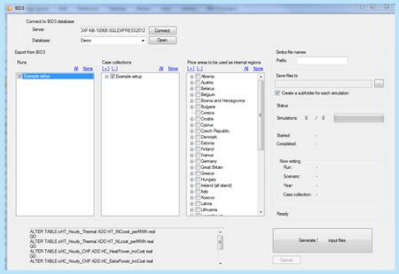
15 INTEGRATION OF BID3 WITH LOAD FLOW MODELS

BID3 has been integrated to allow a smooth transfer of data to the load flow model, Integral

BID3
Electricity Market Model

- Hourly generation for each plant
- Flows between countries
- Merit order (short-run marginal cost)

BID3/load flow model interface



- Takes BID3 data and writes appropriate csv files in required form for the DC LF model

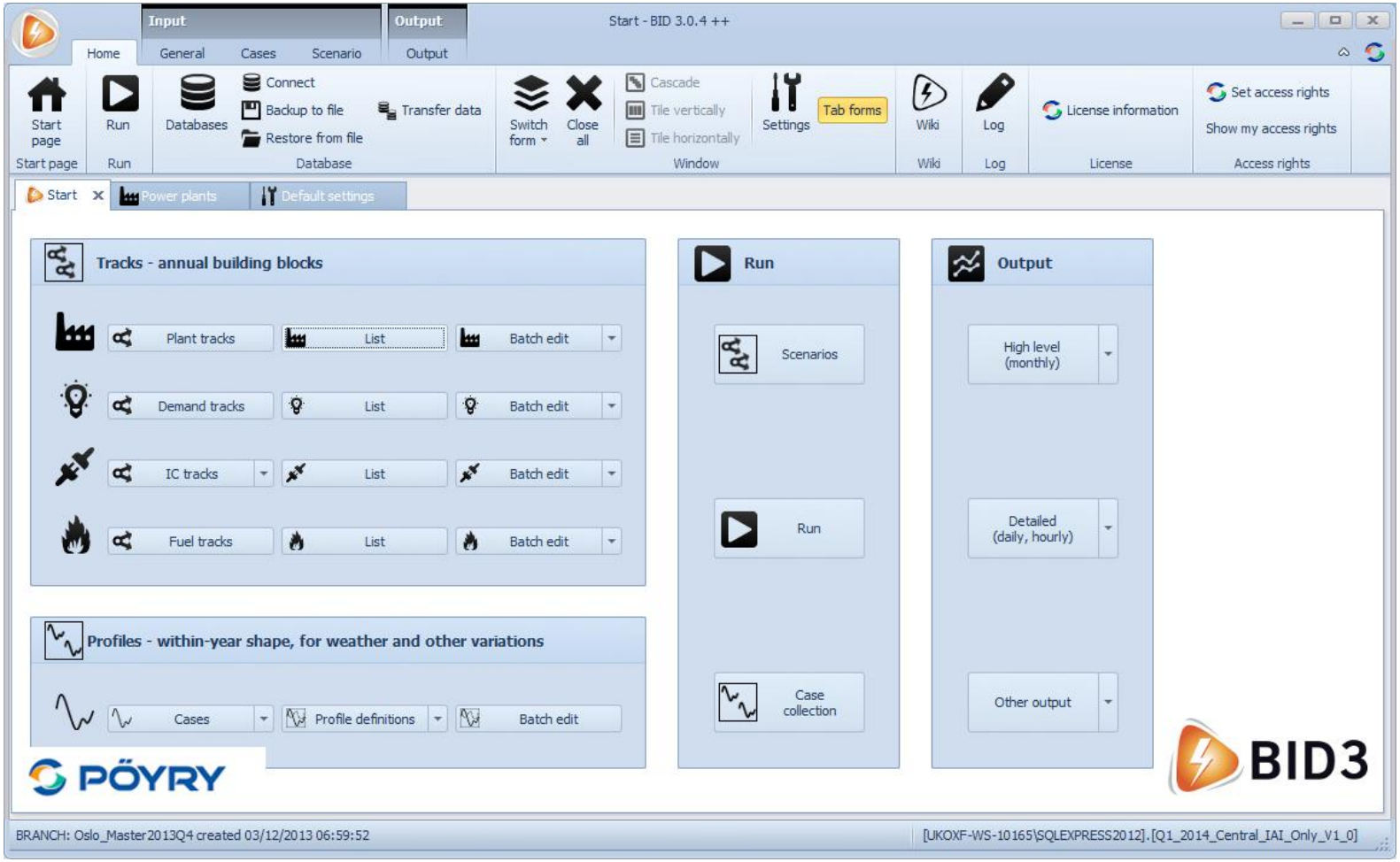
Integral

TRANSNET BW
50hertz
TenneT Taking power further
amprion

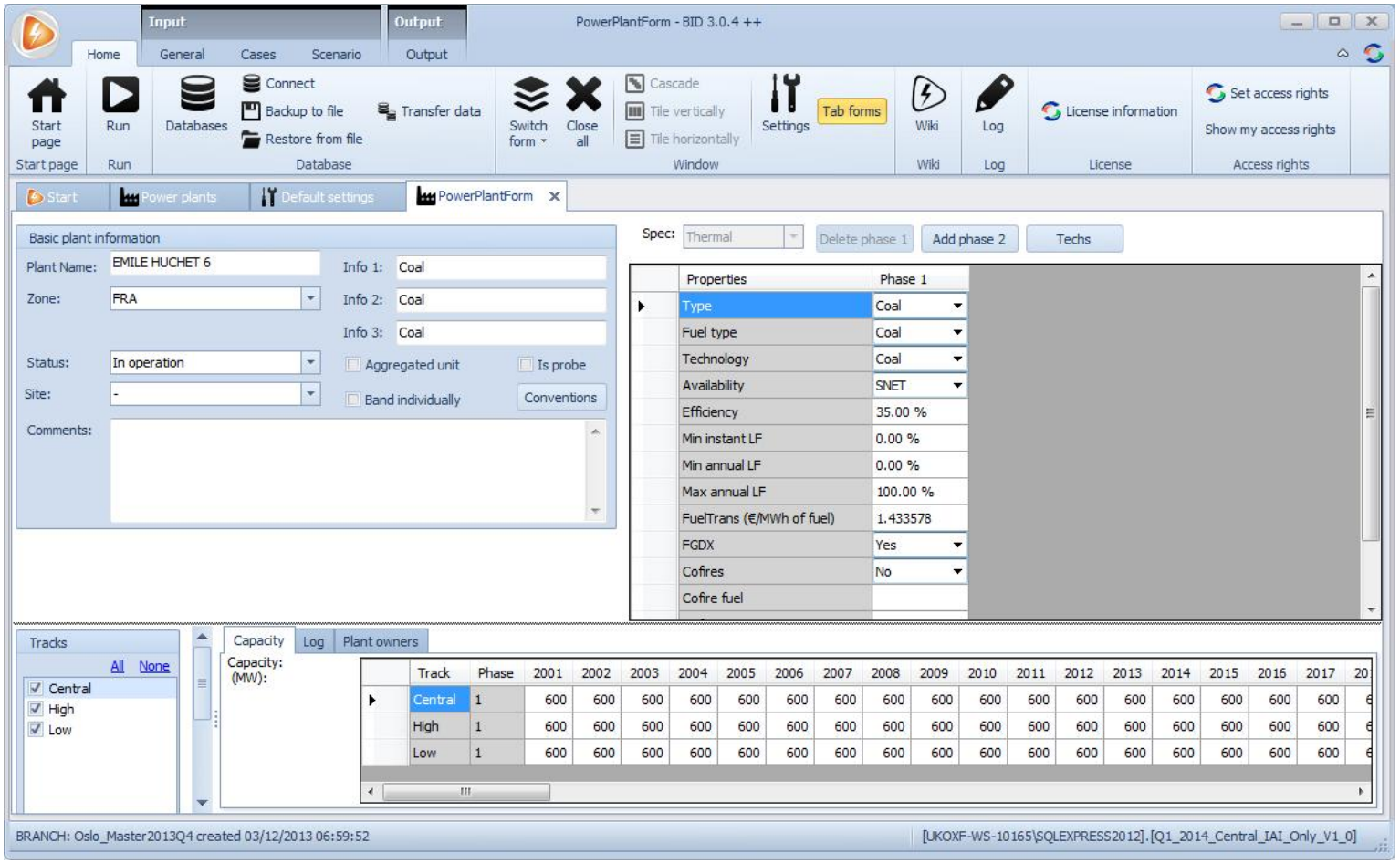
AGENDA

1. Introduction
2. Overview of BID3
3. BID3 key features
4. Screenshots

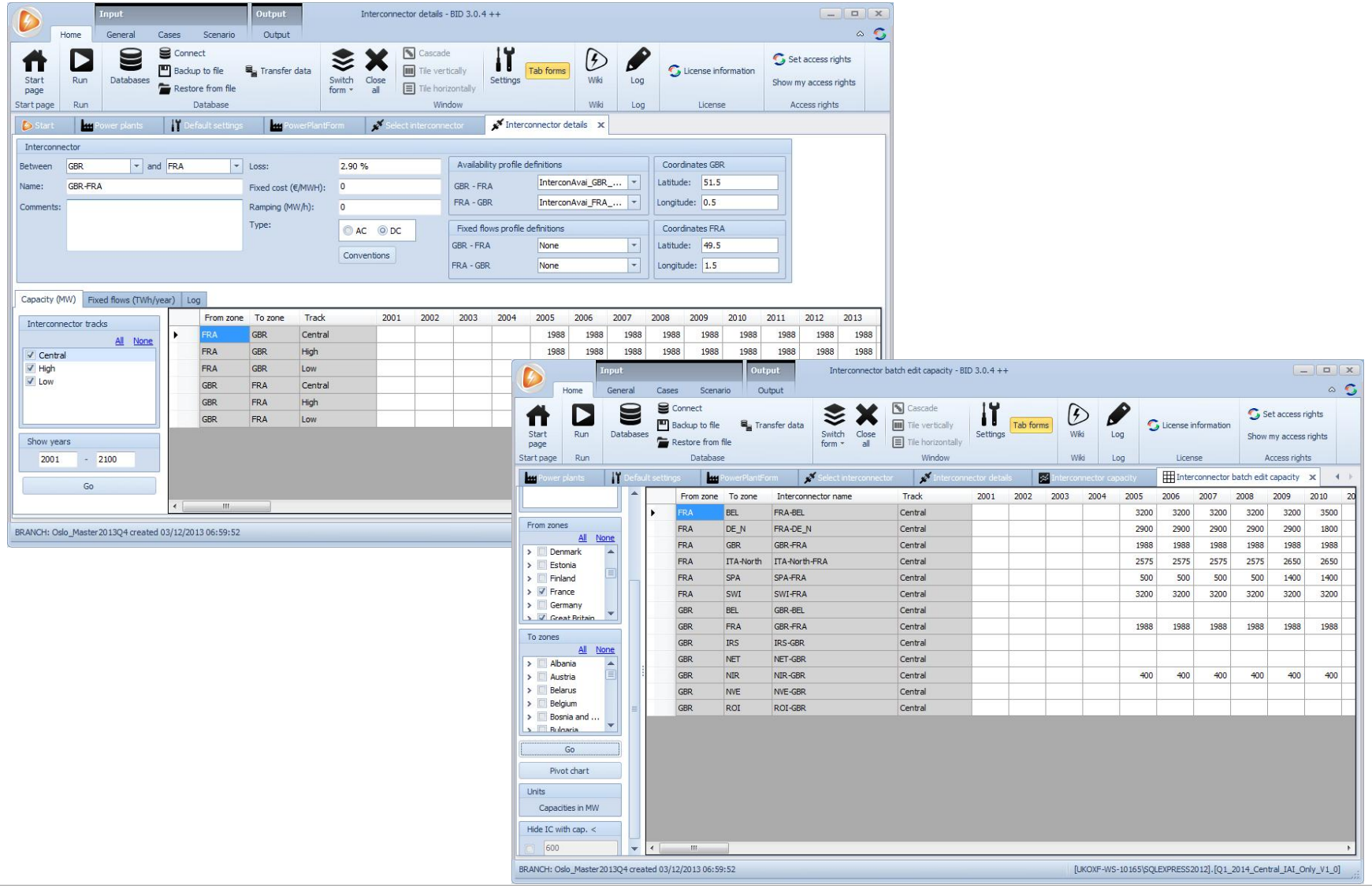
INTERFACE EXAMPLES – START SCREEN



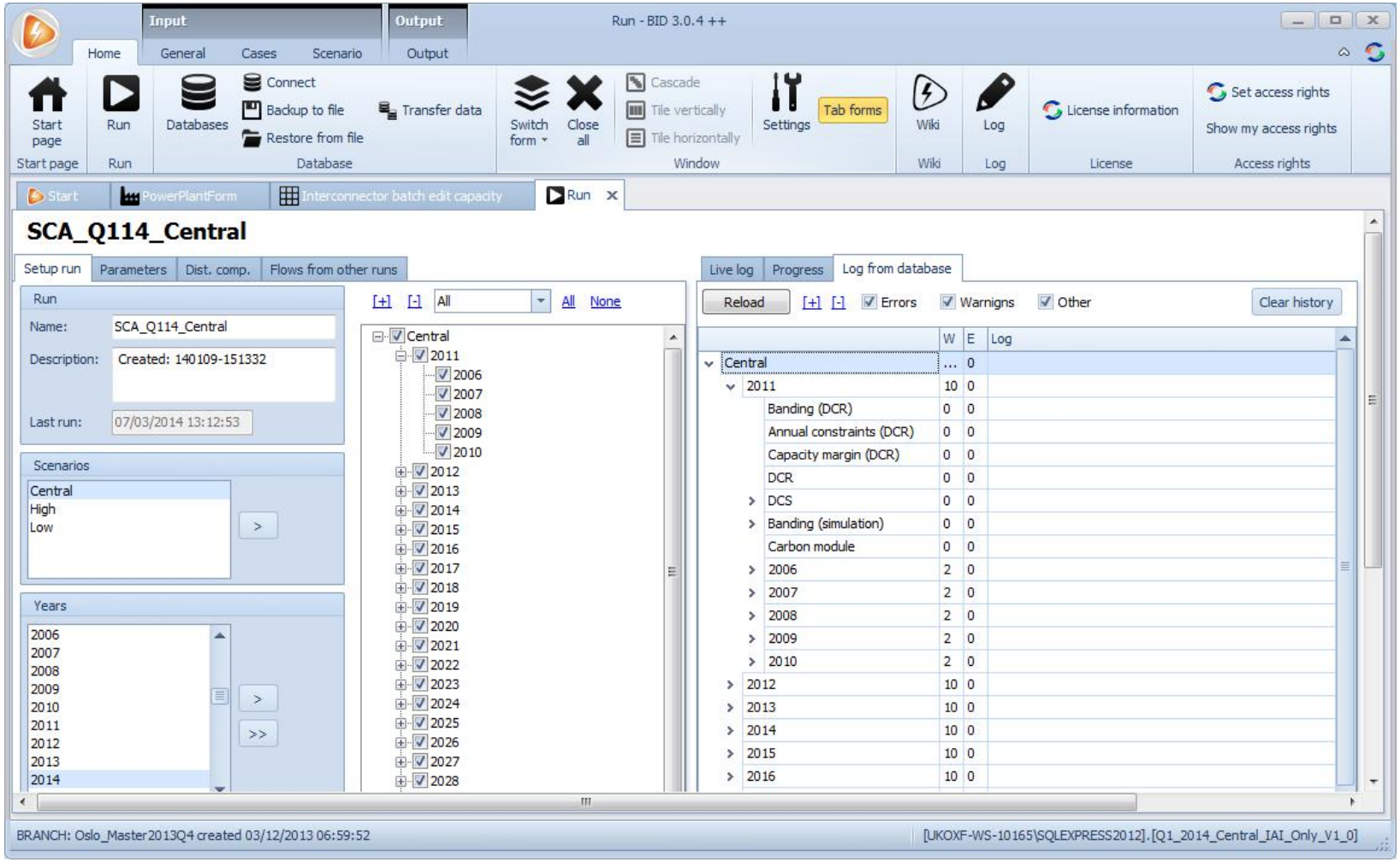
INTERFACE EXAMPLE – PLANT DETAILS



INTERFACE EXAMPLE – EDITING INTERCONNECTION



INTERFACE EXAMPLE – RUN SCREEN



The leading advisor to the world's capital and resource intensive industries. Clients choose us for the sharpness of our insight, deep industry expertise and proven track record – because results count.

Pöyry Management Consulting