Outcomes of task 2.3:

Empirical case study analysis emphasising the challenges in the very short-term, short-term and long-term electricity markets in Europe with high shares of RES-E penetration

Aurore Flament

Authors: Tiffany Chow, Ruben Verhaegen, Aurore Flament

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Context of the study

Shifts in environmental policy, economic conditions, and aging assets has led to major market changes in the past decade

- Energy-only market is facing its limits
- Influences the performance and outcomes from electricity markets
- Renewables playing larger and more influential role

In that context, the objectives of Market4RES Task 2.3 are to:

- Analyse market events and impacts in the very short-term, short-term and long-term European electricity markets with high shares of RES-E
- Understand successful electricity market design elements world-wide for managing a changing supply mix in increasingly harmonised markets

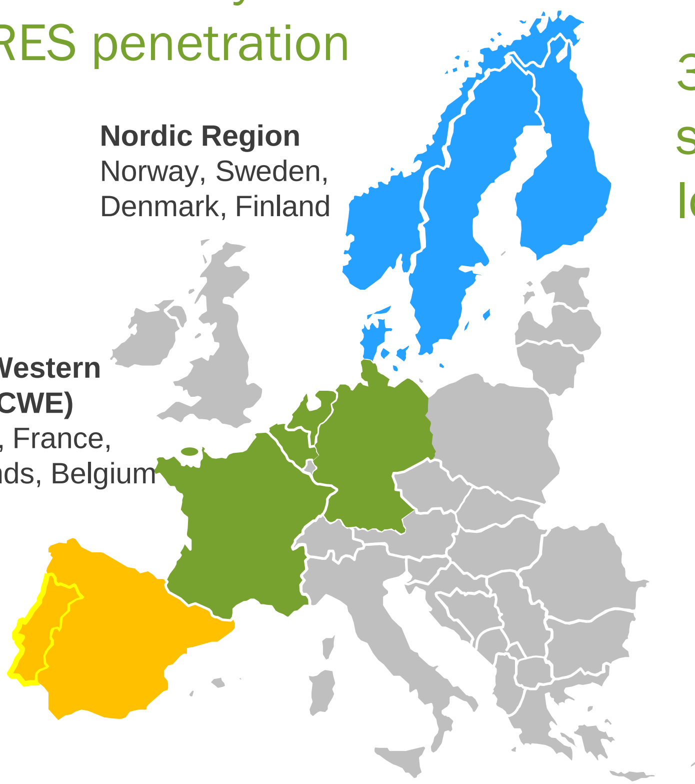
Relevance of task 2.3 in Market4RES:

- Supports the theoretical & regulatory discussions and analysis from WP2
- Basis for the analysis of potential (new) market designs in WP3-WP6

Agenda

Methodology used

1. Selection of countries* covering different market regions in the European electricity market with varying RES penetration



2. Gathering of historical data
   - Desk research
   - Involvement of partners

3. Empirical case study and sensitivity analysis of short-term and long-term markets
   - Analysis of particular events/scenarios such as market coupling, additional interconnectors, negative prices, etc.
   - Development of indicators

* Criteria applied: availability of data and consortium partners

Market RES

Agenda

METHODOLOGY

SHORT-TERM MARKET CASE STUDIES

LONG-TERM MARKET CASE STUDIES

CONCLUSION

INTERNATIONAL BEST PRACTICES

Short-term market case studies

Cases analysed accross the different regions:

Environmental policy: Increasing renewables uptake

C1. Falling electricity prices

C2. Negative short-term electricity prices

C3. RES-E curtailment

Economic efficiency: Market coupling and interconnections

C4. Price convergence

C5. Price volatility

C5. Interconnections

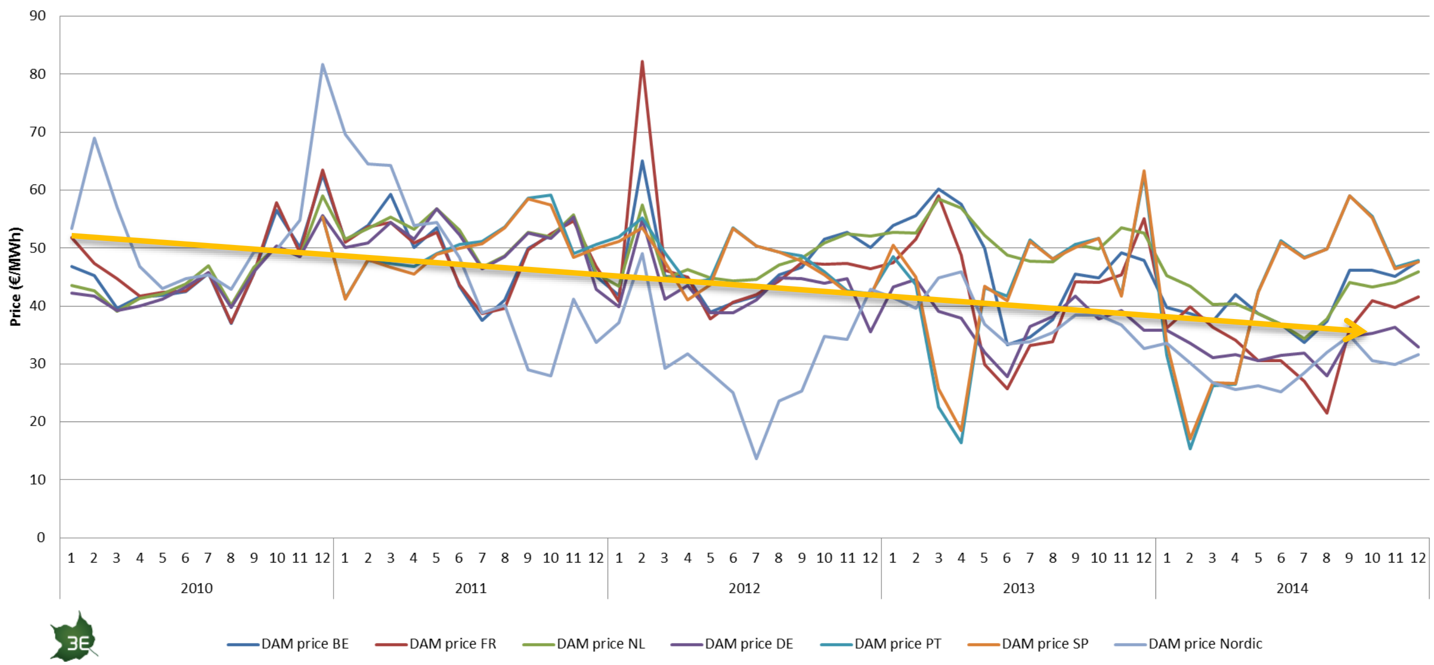
Security of supply: Conventional supply changes

C7. Nuclear shutdown

C1. Falling electricity prices

- There is a general trend towards **falling electricity prices** across countries.

Day-ahead price evolution by country since 2010



Sources: APX, Belpex, Elspot, EPEXspot, EXAA, OMIE

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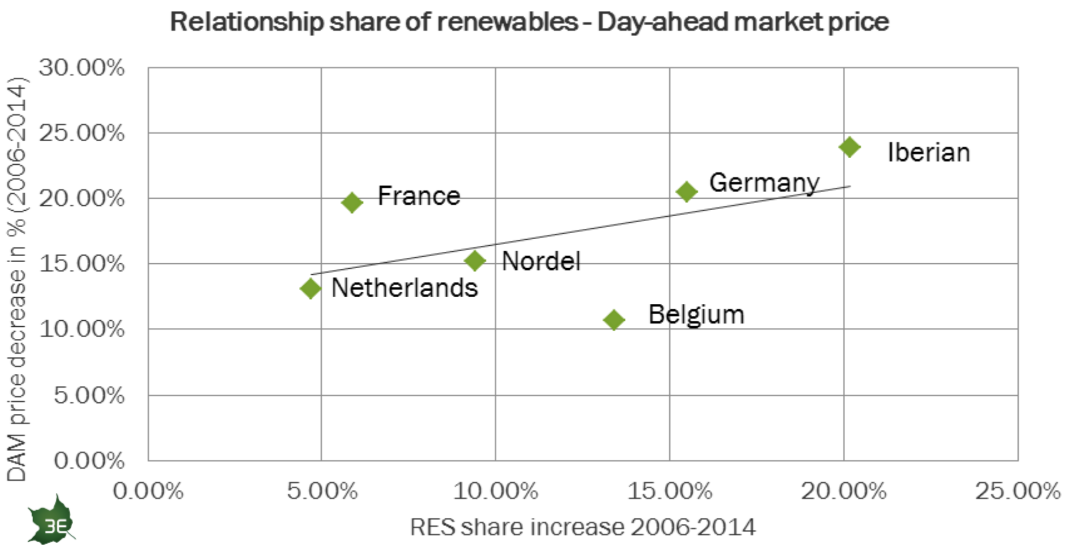
C1. Falling electricity prices, RES-E increases

- This can be attributed in part by a steady **increasing share of renewables**



- The phenomenon can be explained by the "**merit-order effect**"
  - Wind and solar generation can directly reduce the wholesale market price as zero variable cost energy contribution replaces expensive fossil-fuel electricity production.
  - When a certain injection of RES-E is predicted with an almost zero marginal cost, the supply curve is shifted away from conventional generation, lowering electricity prices

Sources: APX, Belpex, Elspot, EPEXspot, EXAA, OMIE, Entso-e

C2. Negative prices on the short-term markets

- In recent years, several European electricity market have seen their prices turn negative when high shares of inflexible generation hit a low demand.
- **System inflexibilities** can lead to periods with excess power, challenging the operation of the power system.
- Inflexibilities include:
    - Inappropriate incentive schemes for RES-E (more market oriented)
    - must run conditions of conventional power plants for system security reasons
    - conventional generation facing techno-economic limitations in output variations
- Negative power prices are expected to occur more frequently as a result

Analysis of negative prices across markets

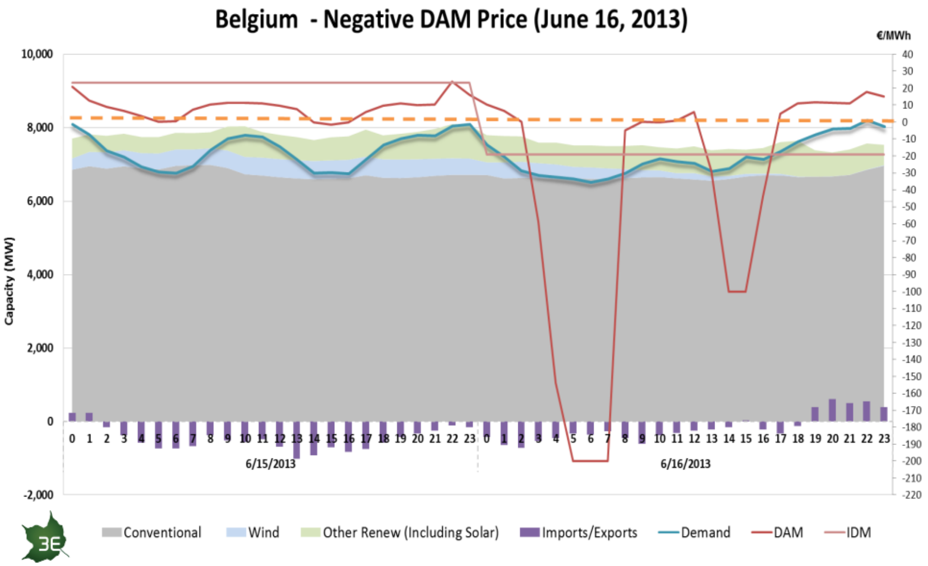
Period 2006-2014	Belgium	France	Germany	Netherlands	Nordic	Iberian
# hours of negative DAM prices	24	33	297	2	0	-
# hours of negative IDM prices	0	128	261	0	23	-
Lowest DAM value (€/MWh)	-200	-200	-500	-0.08	-37.65	-

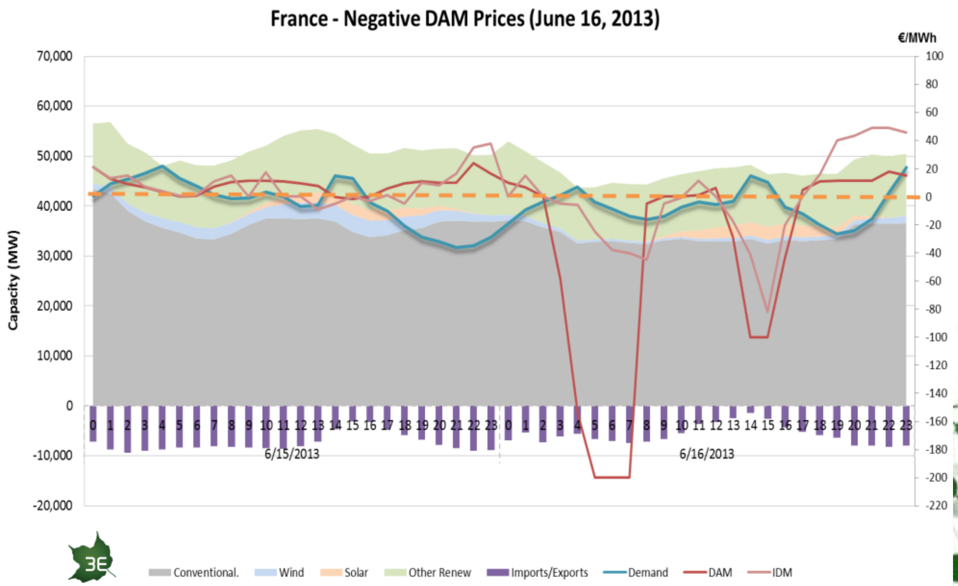
- The CWE region has witnessed several negative electricity price events on day-ahead and intra-day markets since 2012. Trend continues in 2013.

Sources: APX, Belpex, Elspot, EPEXspot, OMIE

C2. Negative prices , a multi-country example

- During weekend of June 15-16 2013, the market saw negative prices across multiple countries
- Belgium, Germany and France faced a regional **low** industrial and residential **consumption** on Sunday, on mild weather, and **abundant inflexible generation** driven by wind, PV, hydro and nuclear.





Belgian and French day-ahead prices hit a low of ~200 €/MWh.

Sources: Belpex, Elia, Epexspot, RTE, Entso-e

Market RES

C3. RES-E curtailment

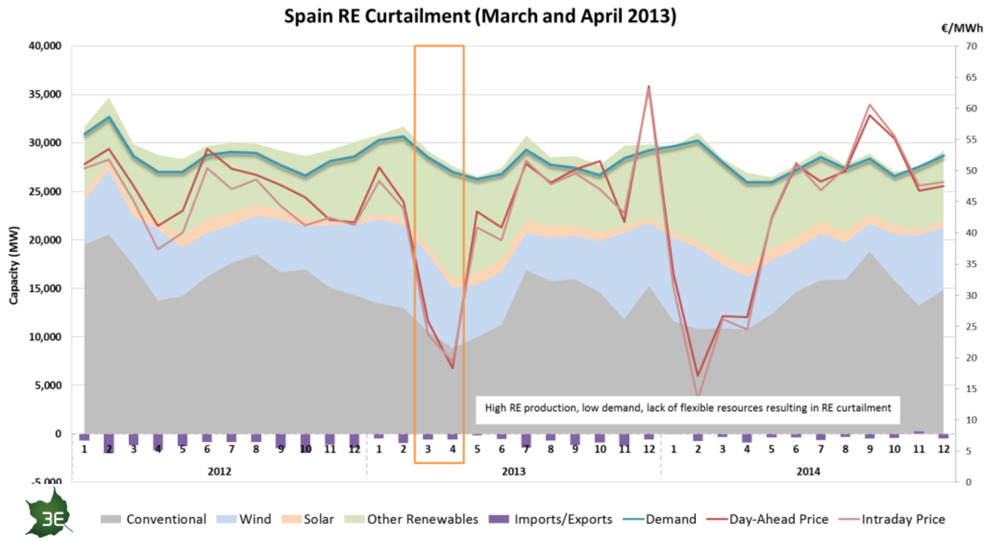
- "Curtailment" is an option that some system operators employ **to deal with overabundance** of electricity production on the system. Electricity producers can be shutdown for periods of time to balance the grid.
- High RES-E generation coupled with low demand can create a need to curtail renewable capacity.
- Table shows that Denmark, Portugal and Spain have **maximum production levels that far exceed minimum consumption levels**, indicating that generators in these countries are at a greater risk for curtailment

	Wind				
	Capacity (GW)	Max. production level (TWh)	Min. Consumption level (TWh)	Penetration (%)	
				mean	max
Denmark	4.2	10.3	5.15	30	200
Portugal	4.2	10	7.86	20.4	127.3
Spain	22.4	48.5	38.3	18.2	126.6
Germany	30.9	46	47.8	8.5	96.3
Belgium	1.3	2.9	13.8	3.4	21

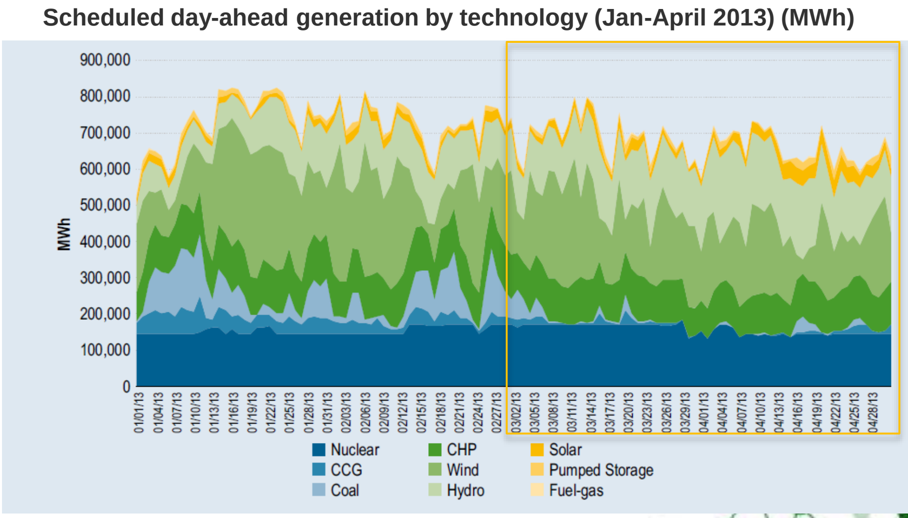
Sources: adapted from KU Leuven Energy Institute

C3. RES-E curtailment, an example

- Spain makes extensive use of curtailment due to its **high wind production**, **limited interconnection** to neighboring markets constraining ability to sell excess power, **must-run conditions** of some non-RES units, and **low demand levels** at off-peak times
- Excess generation has already been observed in the DAM when the prices equaled zero and generation exceeded day-ahead demand.
- For example, graph below shows the lack of (scheduled day-ahead) flexible resources in March and April 2013, resulting in curtailment of renewable producers



Sources: OMIE, Entso-e



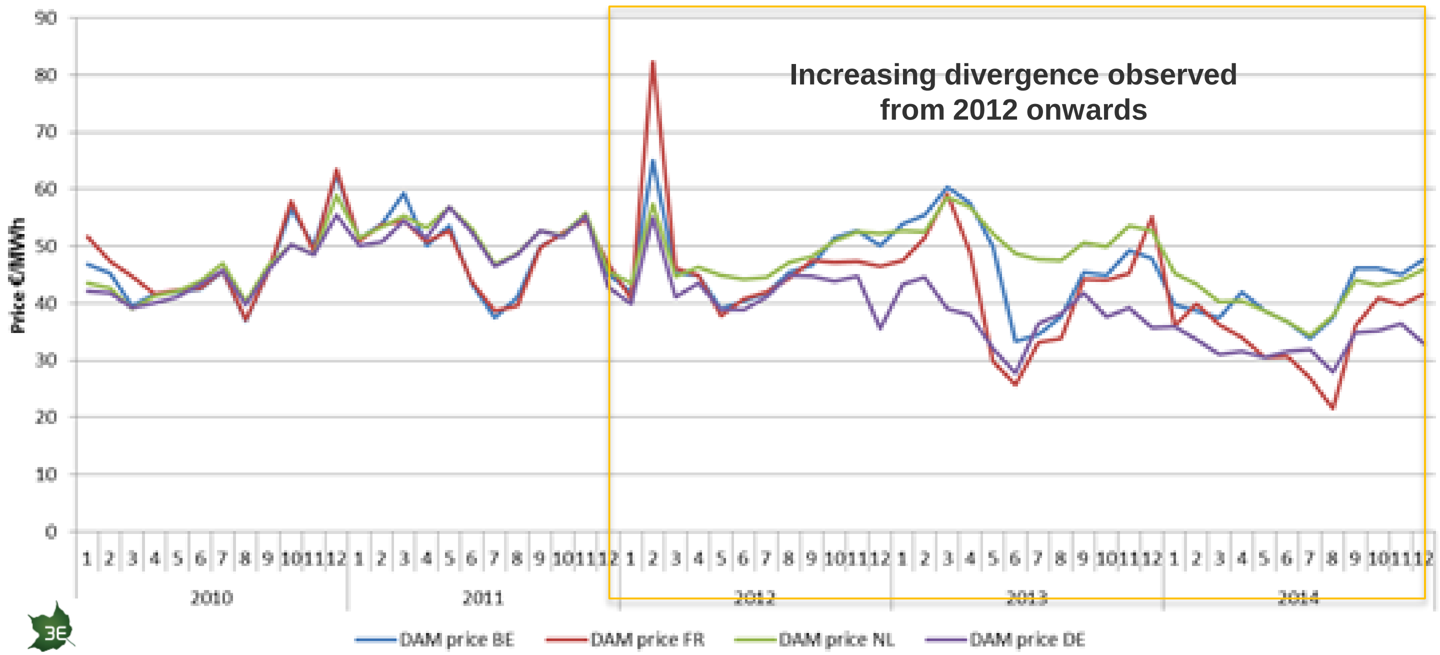
Sources:CNMC

Market RES

C4. CWE market coupling , price divergence?

- CWE market coupling in 2010.
- Initial price convergence, but significant **decrease of price convergence** in late 2012. CREG hypothesises - this is due to:
  - 2,000 MW (two Belgian nuclear plants) unavailable between August 2012 and June 2013
  - Insufficient interconnections between four countries
  - Difference between fuel costs (coal relative to gas prices)

Analysis of Price Convergence (2010-2014)



Sources: APX, Belpex, Elspot, EPEXspot, EXAA, OMIE
NB: SWE in Spain - Spot prices continue to increase after mkt coupling + price volatility

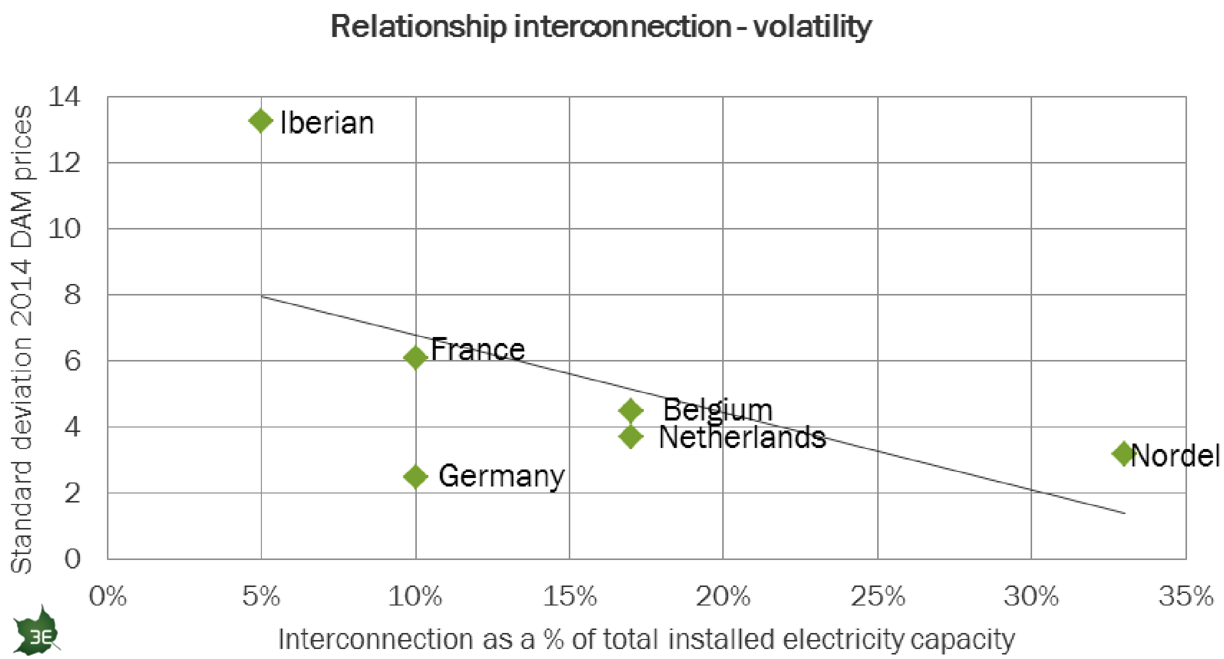
C5. Price volatility

- Price **volatility increased** in all the countries during the period 2012-2014 compared to 2010-2011 except for the Nordic countries where the volatility decreased.
- In the Nordic markets, short-term variations in the price of electricity have lowered, as the share of easily regulated hydropower has increased. However, through market integration and growing share of variable renewable electricity generation, the price volatility may increase in the Nordic markets.

DAM price volatility (StdDev/mean)	Belgium	France	Germany	Netherlands	Nordic	Iberian
Period 2010-2011 (%)	14.3	13.3	11.6	11.6	26.1	9.3
Period 2012-2014 (%)	16.7	25.9	15.2	12.4	21.5	23.5

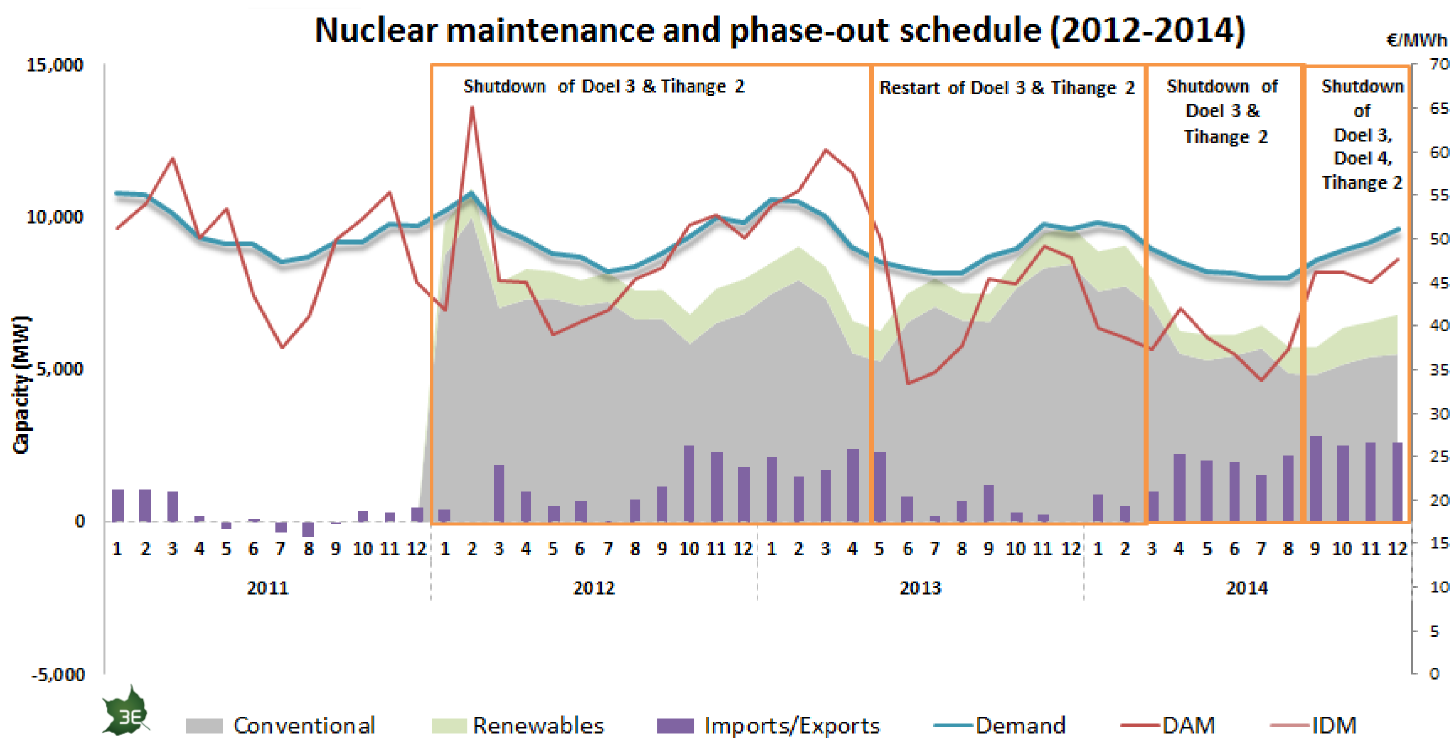
C6. Interconnection capacity and price stability

- Interconnections are key for promoting **price stability** during high production periods.
- The Nordic market has high RES-E share but low price variability because of its relatively high interconnection capacity
- Spain and Portugal in contrast has high price volatility, due to high RES-E production but relatively low interconnection capacity to export excess production.



C7. Nuclear shutdown - Belgium since 2012

- Building **interconnection** capacity also key to ensuring security of domestic supply and stable price levels during low production periods.
- During nuclear shutdown period in Belgium: price volatility and increased import needs



Sources: World Nuclear Association, Belpex, Elia

Agenda

METHODOLOGY

SHORT-TERM MARKET CASE STUDIES

LONG-TERM MARKET CASE STUDIES

CONCLUSION

INTERNATIONAL BEST PRACTICES

Market RES

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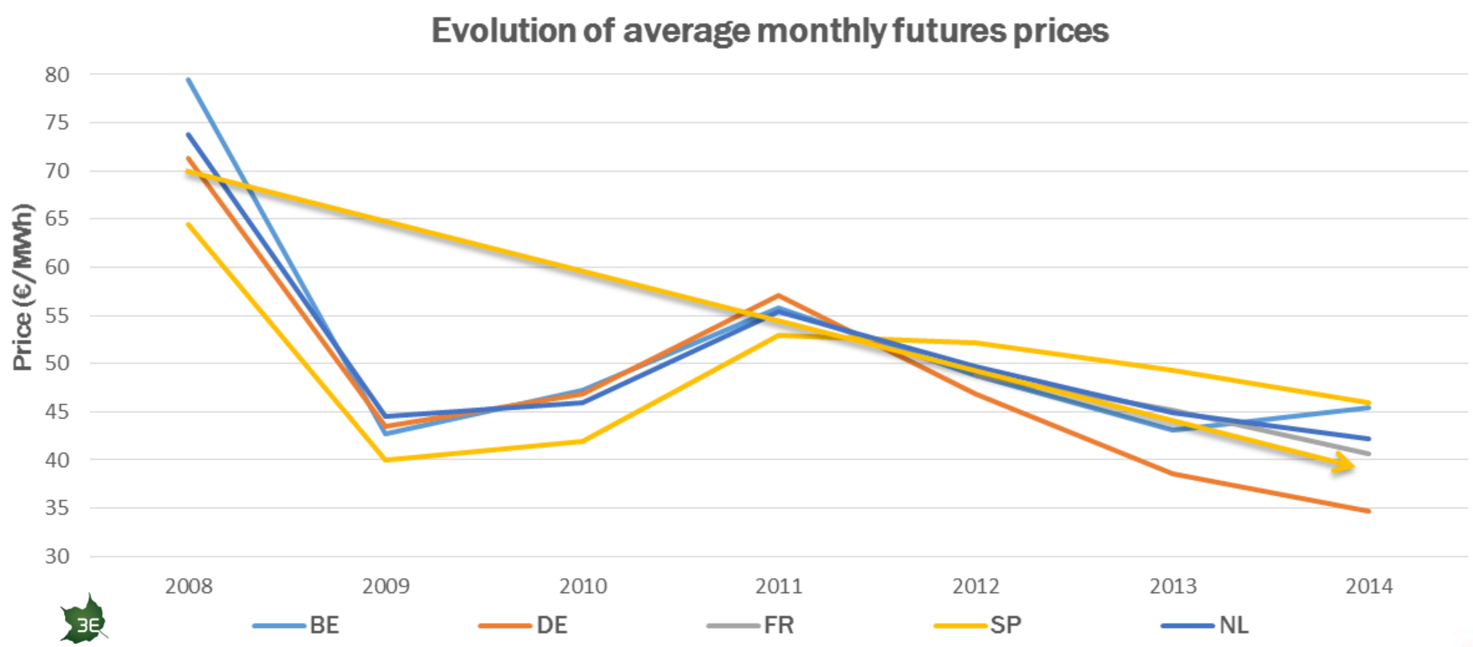
C4. Nuclear shutdown

C5. Failure of generation capacities

C1. Falling futures electricity prices and relationship with the RES-E share (2008-2014)

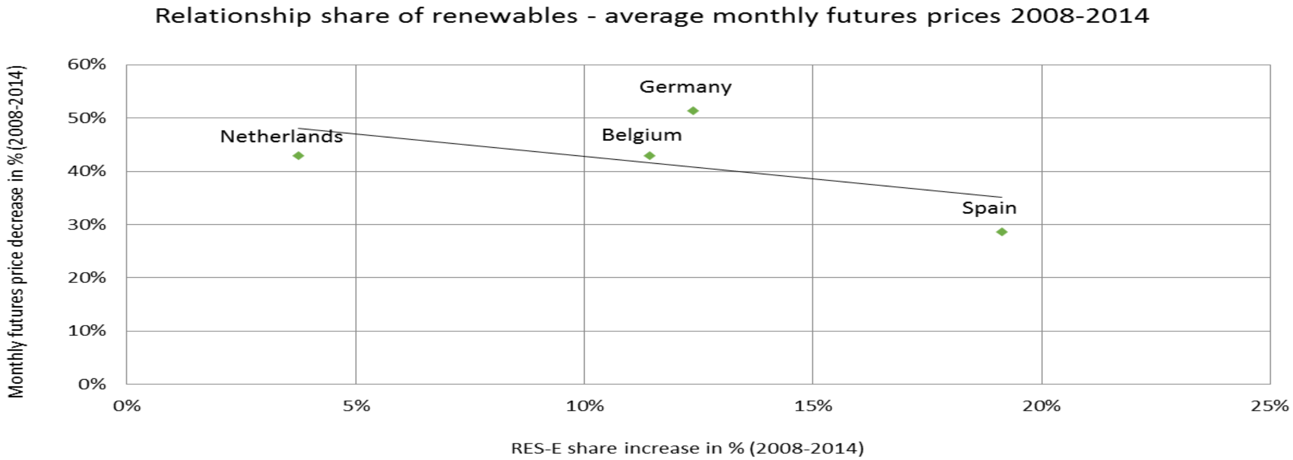
- RES-E share is increasing and average **monthly/yearly** futures prices are decreasing in all countries



Sources: ICE, EEX, OMIE

Market RES

C1. Falling futures electricity prices and relationship with the RES-E share (2008-2014)



- **Germany** has the **lowest prices** and **Spain** has the **highest prices**

Evolution 2008 - 2014	Type of RES-E share	Increase of RES-E share	Interconnection capacity 2014	Support od RES-E	Average monthly futures price decrease
Germany	Steady	12.37%	10%	Stable	51%
Spain	Irregular	19.14%	5%	Suspension support in 2012 and 2013	29%

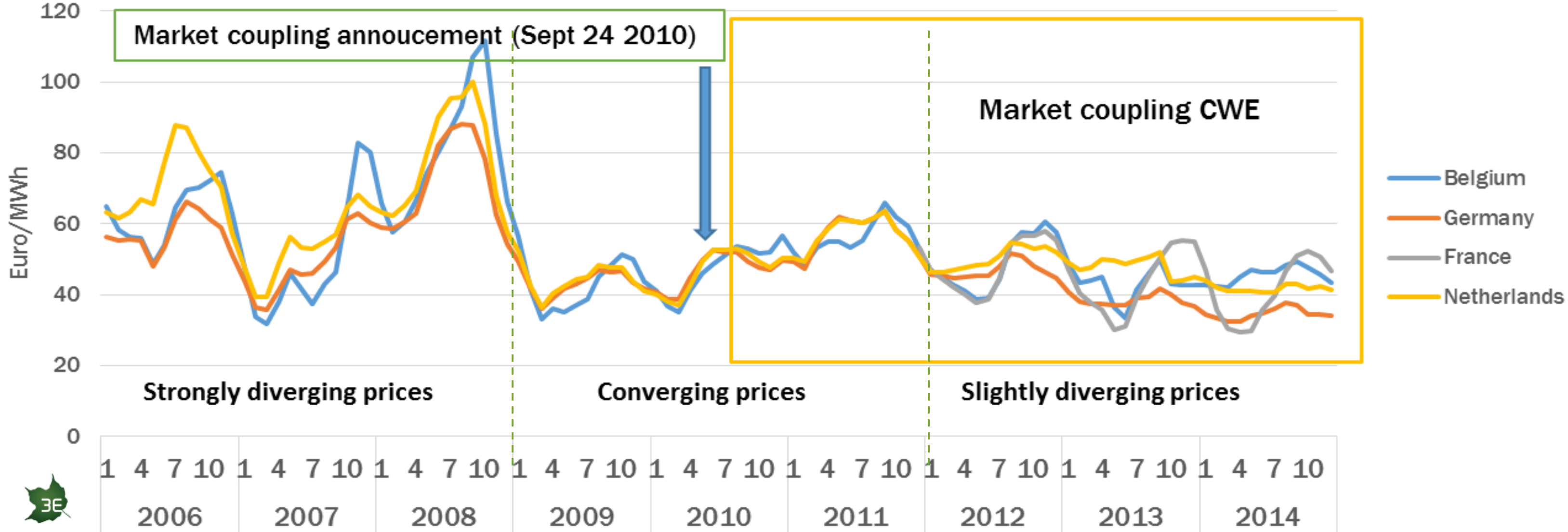
Different factors determine degree of price decrease

* France: only data is available for the period 2012-2014

Market RES

C2. The impact of the CWE market coupling (2010) on price convergence and volatility

- **Average monthly futures prices** have never **diverged** as during 2006-2008 after 2010



- **Average monthly futures price volatility** is decreasing after market coupling in 2010*

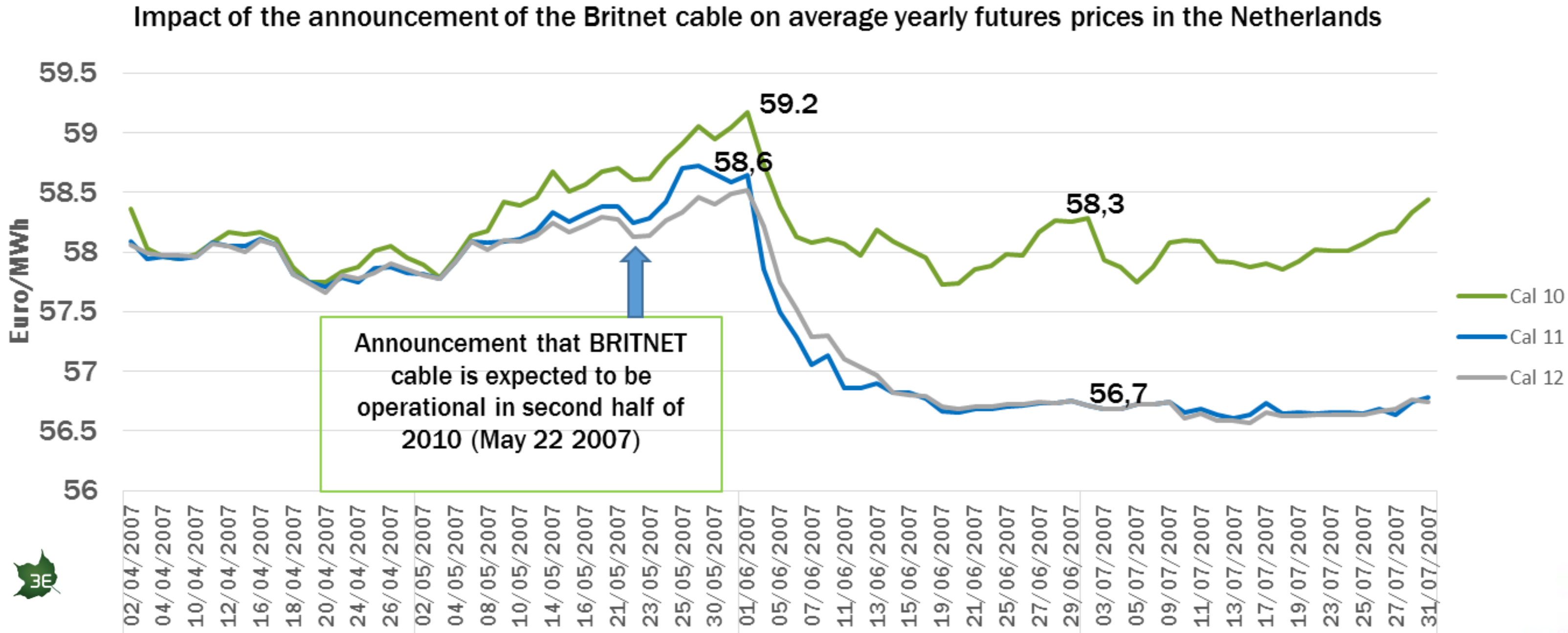
Monthly futures price volatility before and after market coupling (StdDev/Mean)	Belgium	Germany	France	Spain	Netherlands
Period 2008-2010	35.6	27.6	N/A	24.5	32.2
Period 2011-2014	15.0	20.7	59.5	8.3	12.9

Sources: ICE, EEX, OMIE

* France: only data is available for the period 2012-2014

C3. The impact of interconnection capacity and average export volumes on futures prices

- Announcement of **Britnet** cable (1000 MW) expected to be in use in second half/2010: **May 2007**
- **Clear price decreases** for years 2011 and 2012



- **France** and **Germany** have high interconnection capacities (10%) and the highest average export volumes/year ➡ **2 countries with the lowest futures prices**

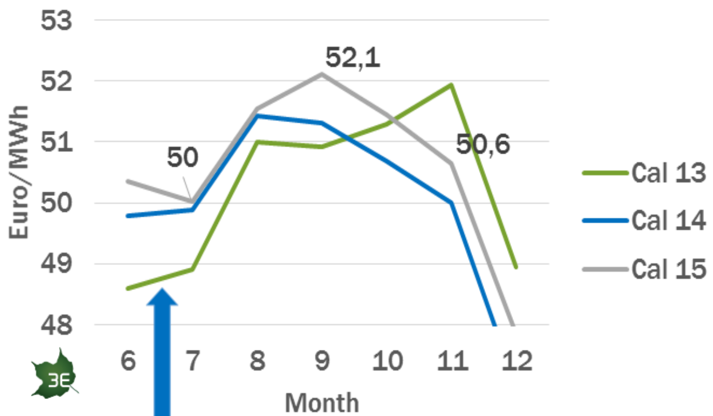
Sources: ICE

Market RES

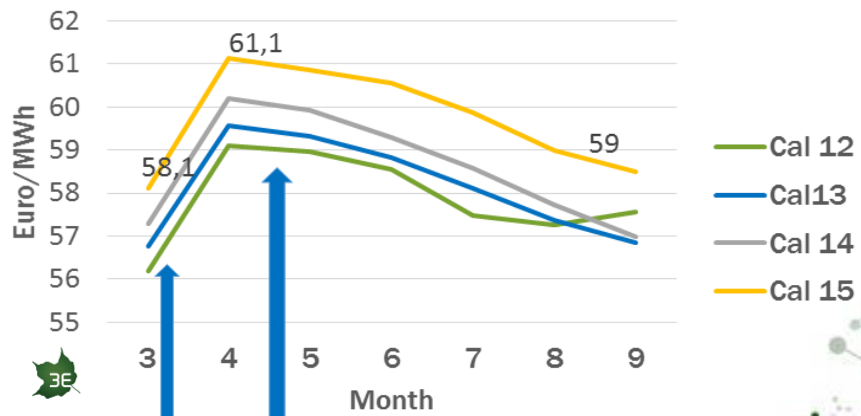
C4. The impact of the annoucement of nuclear shutdowns in Belgium and Germany

- Analysis of **yearly futures prices** because events far away in the future
- **Belgium**: partial phase-out by 2015, **Germany**: entire phase-out by 2022 (impact of the Energiewende)
- Announcements of a shutdown have a **price-increasing effect** that is **higher** if shutdown is less far away
- **Price-increasing effect** only present for a **few months**

The impact of the annoucement of the shutdown of Doel 1&2 by 2015 in **Belgium** (July 2012)



The impact of the annoucement of the nuclear phase-out by 2022 in **Germany** (May 2011)



Government confirms shutdown of Doel 1&2 by 2015 (July 4 2012)

Germany shuts down 8 nuclear plants (March 15 2011)

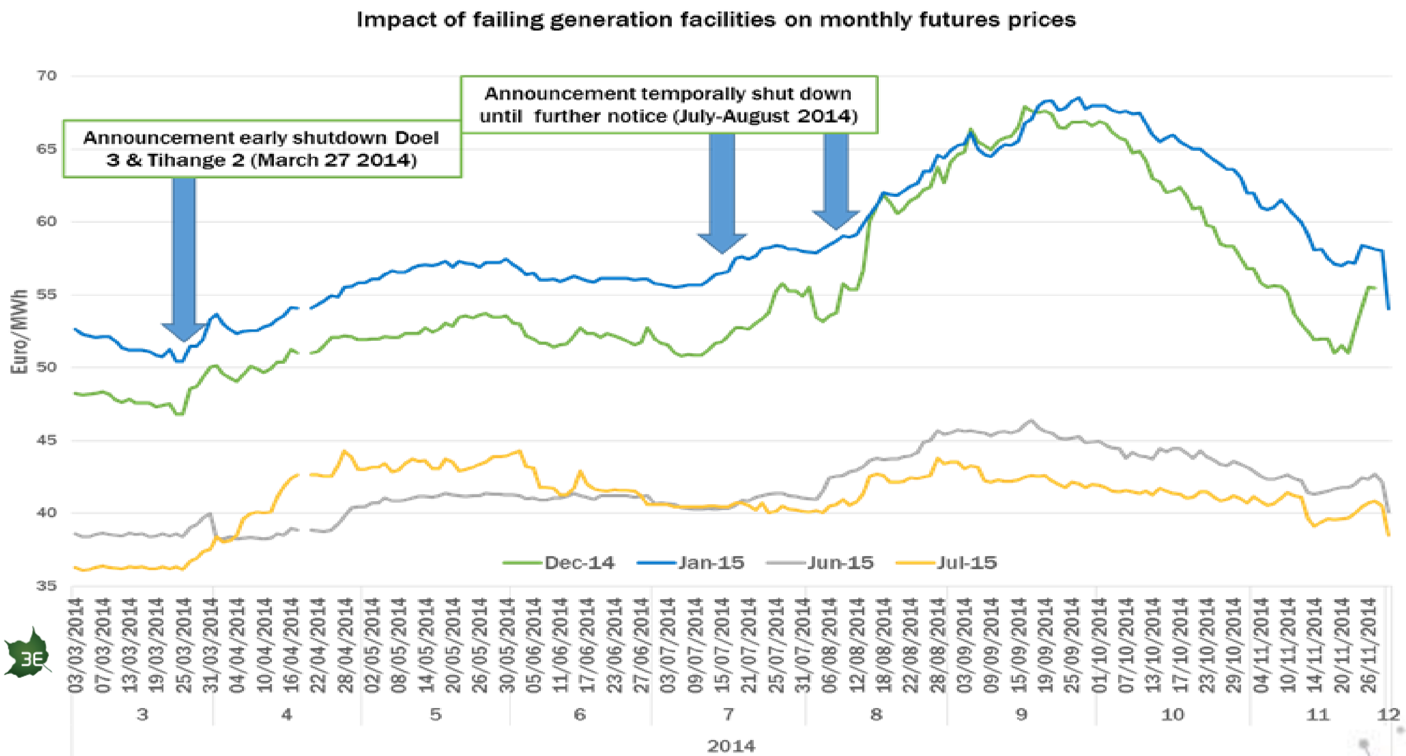
Germany announces nuclear phase-out by 2022 (May 30 2011)

Sources: ICE

Market RES

C5. Impact on monthly futures prices when generation facilities fail - BE

- March 2014: high risk for radiation for Doel 3 & Tihange 2 → Early outage
- July-August 2014: Nuclear plants stay shut down until further notice
- **Price difference for winter is rising from 10-15 euro/MWh to 15-20 euro/MWh**



Sources: ICE

Market RES

Agenda

METHODOLOGY

SHORT-TERM MARKET CASE STUDIES

LONG-TERM MARKET CASE STUDIES

CONCLUSION

INTERNATIONAL BEST PRACTICES

Conclusions

- With an increasing amount of RES-E penetration:
  - average spot and futures prices tend to fall*
  - More and more occurrences of negative prices* on the spot markets
  - Needs for RES-E curtailment*

- The impacts on monthly futures are higher than impacts on yearly futures

- Solutions:
  - More **transparent** Energy market
  - Building new **interconnections** helps controlling volatility and increases efficiency of the market
  - There is a clear need for building more **flexibility**

*NB: it is a combination of factors that is responsible for these market trends

Market RES

Conclusions

- To respond reliably and rapidly to sudden changes in demand and supply, the following are needed:
  - Cope with **intermittency**:
    - Enforce smart policies: RES-E need incentives to decrease intermittency
    - Improve RES-E availability forecasts (availability better predicted, need for expensive back-up capacity reduced)
    - Decrease the lead-time for forecasts through intraday markets
    - Average the RES-E output over larger areas
  - Increase **flexibility**:
    - Regional integration (merge balancing areas, share flexible generation assets, share back-up reserves, etc.)
    - Have stand-by capacity that can ramp up rapidly
    - Intraday and balancing markets that make full use of the flexibility of transmission system and the different generation technologies: Increase the lead time available to pursue system adjustments, make it possible to reschedule power flows btw countries more often, etc.

Agenda

METHODOLOGY

SHORT-TERM MARKET CASE STUDIES

LONG-TERM MARKET CASE STUDIES

CONCLUSION

INTERNATIONAL BEST PRACTICES

Market RES

International Market Designs: best practices

Environmental policy

US: Incorporation of <u>improved generation forecasting</u> of intermittent sources closer to real-time: ISOs use a centralized day-ahead wind power forecast in the reliability unit commitment model

MISO: <u>"Dispatchable intermittent resources"</u> program, which allows wind plants to bid into the real-time market and update those bids based on sub- hourly forecasts.

CAISO: "<u>Participating Intermittent Resource Program</u>" allowing individual wind facilities to self-schedule according to shared forecasting technologies

Australia: <u>sub-hourly (5 min.) dispatch intervals</u> to reduce the need for ramping and improve forecast accuracy.

Economical efficiency

US: <u>Nodal pricing/ LMP</u>: prices differ btw locations according to grid congestion and generators are incentivized to adapt their production in order to minimize congestion

PJM, Texas, California: generators can submit <u>complex bids</u> that reflect start-up costs, ramping constraints and energy costs

PJM: <u>Pool type trading system</u> - ISO calculates close to real-time an optimal dispatch based on firm schedules and flexible bids provided by market participants on the IDM clearing platforms.
It ensures high liquidity for short-term optimization of the system.

Security of Supply

California: Power generators have to <u>bid a portion of their most flexible capacity</u> into the market at all times; <u>"Flexible Ramping Product":</u> Generators paid to remain "off" during low-ramp periods

Brazil: <u>capacity auctions</u> with long-term contracts to allow for hedging investment risks

Australia: <u>Scarcity pricing</u> to ensure sufficient cost recovery for generators and maintain sufficient planning reserve margins.

India: <u>Unscheduled Interchange" Mechanism:</u> price curve linked to frequency = financial incentives to maintain grid frequency.

Ontario: <u>Comprehensive asset life management program</u> of nuclear plants

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CONTACT

Market4RES@sintef.no

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