IEA-ETSAP
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Modelling ancillary markets in the Norwegian energy system

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Motivation

- Increased need for flexibility
  - Weather-dependent electricity generation
  - Electrification of end-use & power-to-X
- Forecast errors in supply and demand
- Long-term energy system models assume supply and demand are always met by energy market
  - ”Perfect foresight”
- Hypothesis
  - Perfect foresight underestimate need for flexible solutions
  - Including reserve markets in energy system models can improve insights on long-term flexibility needs

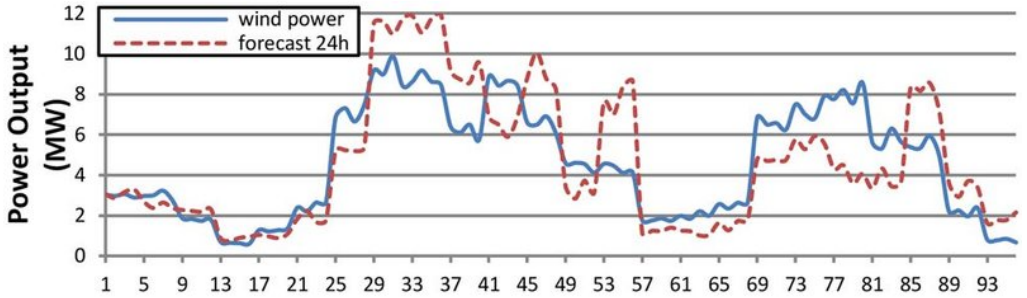
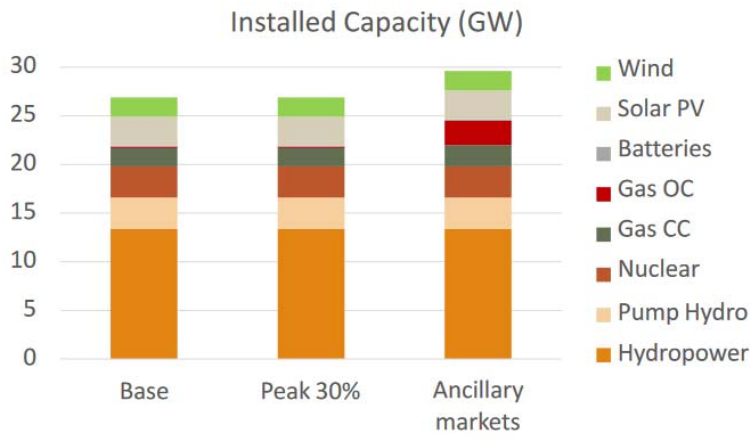


Illustration from Saint-Pierre, A. and P. Mancarella, Active Distribution System Management: A Dual-Horizon Scheduling Framework for DSO/TSO Interface Under Uncertainty. IEEE Transactions on Smart Grid, 2016. 8: p. 1-12.

Background

Energy Technology Systems Analysis Programme
TIMES Version 4.5 User Note



Enhancing the flexibility in TIMES: Introducing Ancillary Services Markets

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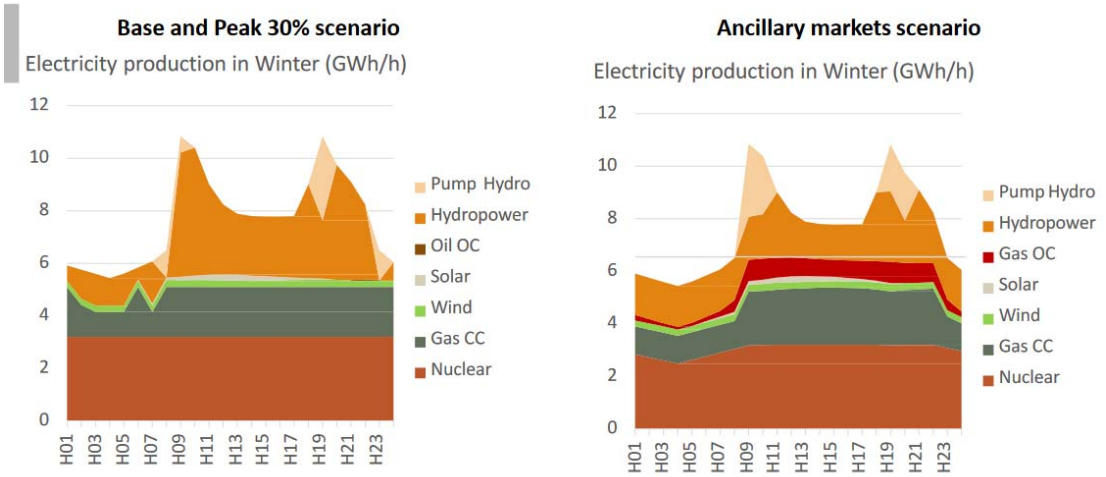

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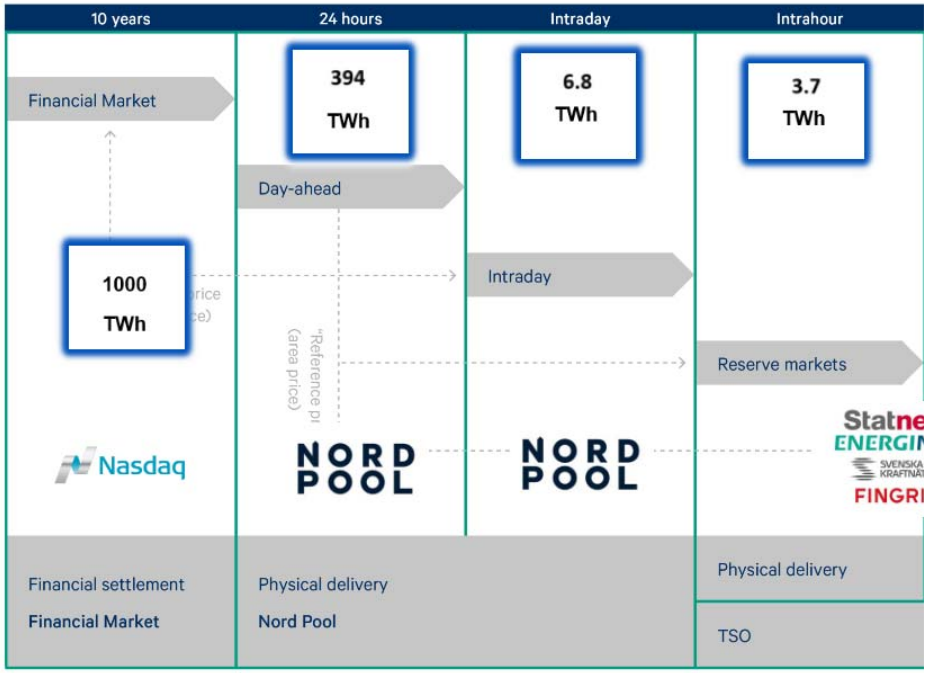
Norwegian power market



1. **Primary control reserves (5-30 s): 1400 MW**
   Frequency Containment Reserve (FCR)

2. **Secondary control reserves (2 min): 400 MW**
   Automatic Frequency Restoration Reserve (aFRR)

3. **Tertiary control reserves (15 min) : 1700 MW**
   Manual Frequency Restoration Reserve (mFRR)
   Dimensioning incidents: 1200 MW
   Bottlenecks etc.: 500 MW
   Expected to increase 50% in 2025

- Reserves corresponds to 14% of peak electricity demand of 2021

Norwegian energy system

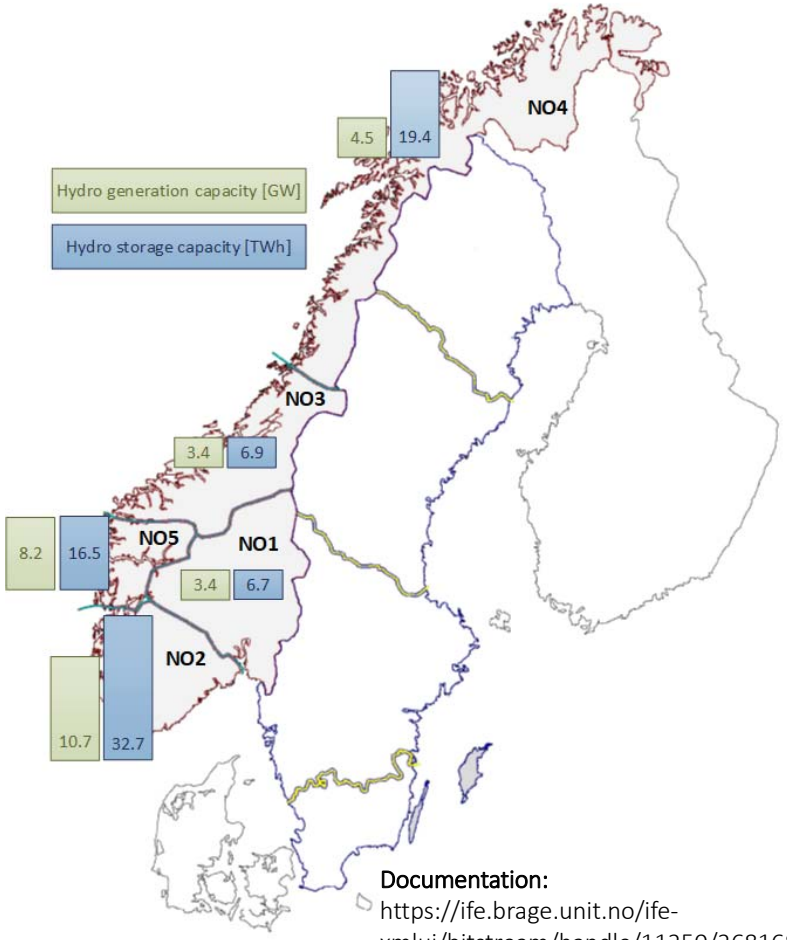

Photo by Martin Adams on Unsplash


Photo by Jason Baldkeye on Unsplash

- Electricity generation mainly based on hydropower
  - 90% 2021
  - Large water reservoirs: NO & SE: 50% of European capacity
- Cold climate → High demand for space heating
- Historically electricity has been inexpensive
  - Energy-intensive industry
  - Electricity based heating system
- Large potential for onshore and offshore wind power

IFE-TIMES-Norway

- Continuously updated and improved
  - Recent updates on transport, end-use flexibility & offshore wind power
- Model strength
  - Captures interplay between sectors, technologies, energy carriers and emissions
  - Detailed on end-use; buildings, industry and transport
- Model specification
  - Five regions according to spot price market
  - Model horizon: 2018- 2050 (2060)
  - Time slices (base version): 96 = 4 seasons x 24 h
  - Electricity trade between Norwegian regions & SE, DK, NL, DE & UK
  - Hydrogen trade within Norway



Documentation:
https://ife.brage.unit.no/ife-xmlui/bitstream/handle/11250/2681685/IFE+2020+Documentation+of+IFE-TIMES+v1+%28ID+45458%29.pdf?sequence=1

Reserve market modelling

- Reservation of capacity but not activation
- Reserves can either be downward or upward
- Documentation:

- https://iea-etsap.org/projects/TIMES-BS-Documentation.pdf
- https://www.youtube.com/watch?v=kxUZvJkPbO8
- https://ieaetsap.org/webinar/BS_Webinar_Presentation.pdf

Steps of implementation:

1. Overview of reserve market
2. Implementation in VEDA
   - Exogeneous demand for reserves
   - Endogenous demand for reserves based on forecast errors
   - A combination
- Evaluating results

Recommend to calibrate cplex.opt

- https://www.youtube.com/watch?v=423dhngBwvY&feature=youtu.be

Model input - Reserves

~TFM_INS									
Attribute	**Cset_CN**	**Other_Indexes**	**Year**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	
|: Deterministic Exogenous Reserve Demand									
BS_DEMDET	FCR+	EXOGEN	2020	366	388	280	194	172	1400 MW
BS_DEMDET	FCR-	EXOGEN	2020	366	388	280	194	172	
BS_DEMDET	aFRR+	EXOGEN	2020	105	111	80	55	49	400 MW
BS_DEMDET	aFRR-	EXOGEN	2020	105	111	80	55	49	
BS_DEMDET	mFRR+	EXOGEN	2020	445	471	340	235	209	1700 MW
BS_DEMDET	mFRR-	EXOGEN	2020	445	471	340	235	209	
BS_DEMDET	mFRR+	EXOGEN	2025	667	706	510	353	314	2550 MW
BS_DEMDET	mFRR-	EXOGEN	2025	667	706	510	353	314	

- FCR: Primary 5- 30 seconds, aFRR: Secondary 2 min, mFRR: Tertiary: 15 min

- Assumptions
  - Same reserve demand for positive and negative reserve for all types
  - Distribution key between regions corresponds to demand distribution
  - National transmission capacity can be used to trade reserves

Model input - Reserve provision

- Today hydropower provides all primary and secondary reserves. For tertiary, also large energy-intensive industries contribute.
- Anticipated more future end-use participation

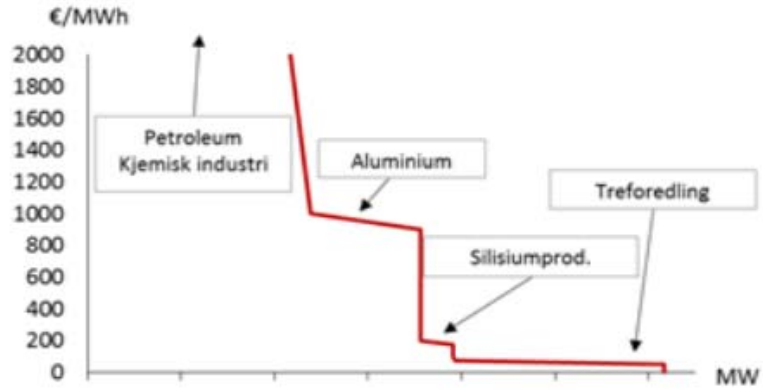
Assumed possible participation options:

Primary (FCR)
- Regulated hydropower

Secondary (aFRR)
- Regulated hydropower
- 10% of international electricity trade cap
- Data centers* (only downwards)
- PEM hydrogen production*
- Electric boilers*
- Energy intensive industry* (only downwards)

* From 2025

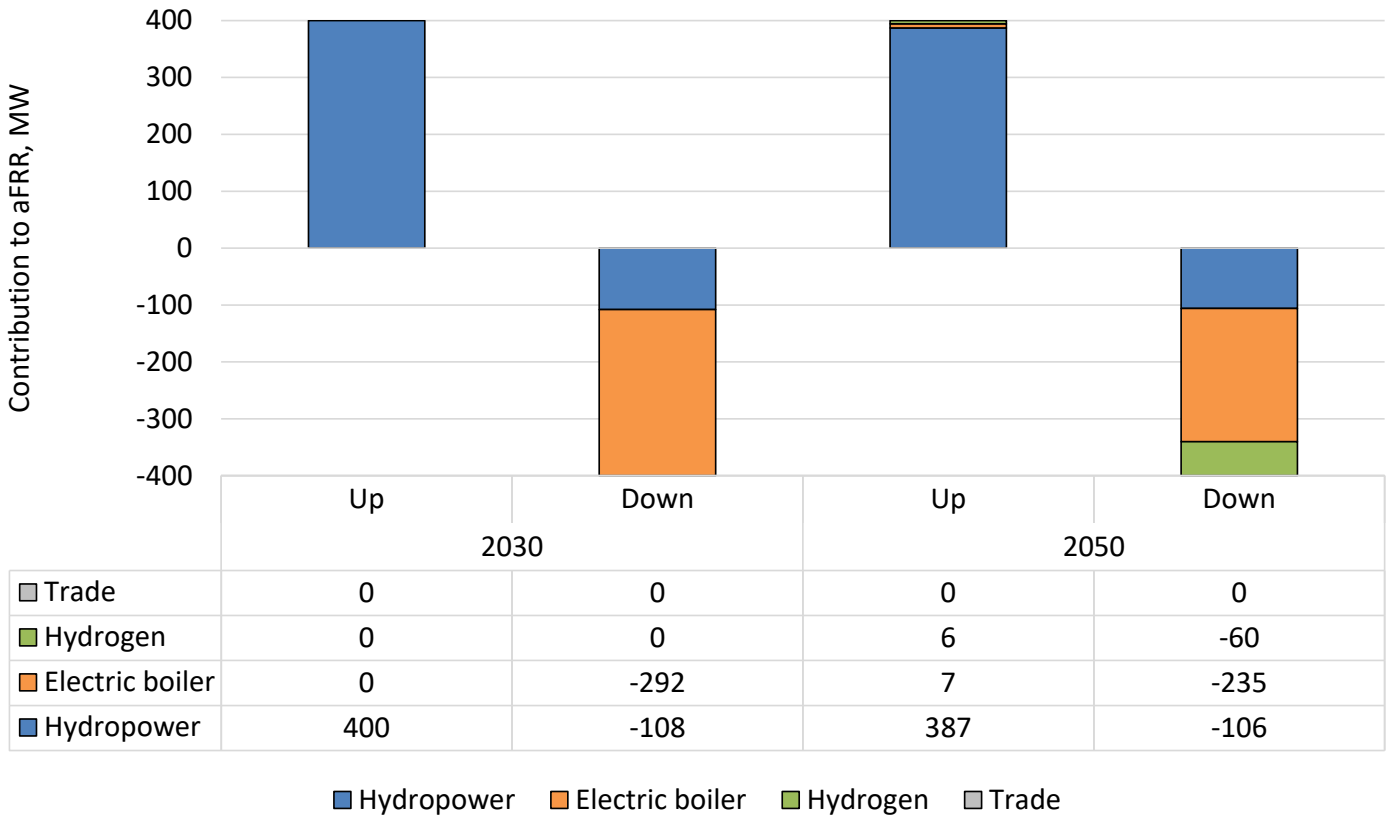
Tertiary (mFRR) = aFRR +
- Stationary batteries
- Flexible electric heating of hot water
- To do: Flexible EV charging + +



Cost of being without electricity for one hour (Home et al., 2020).

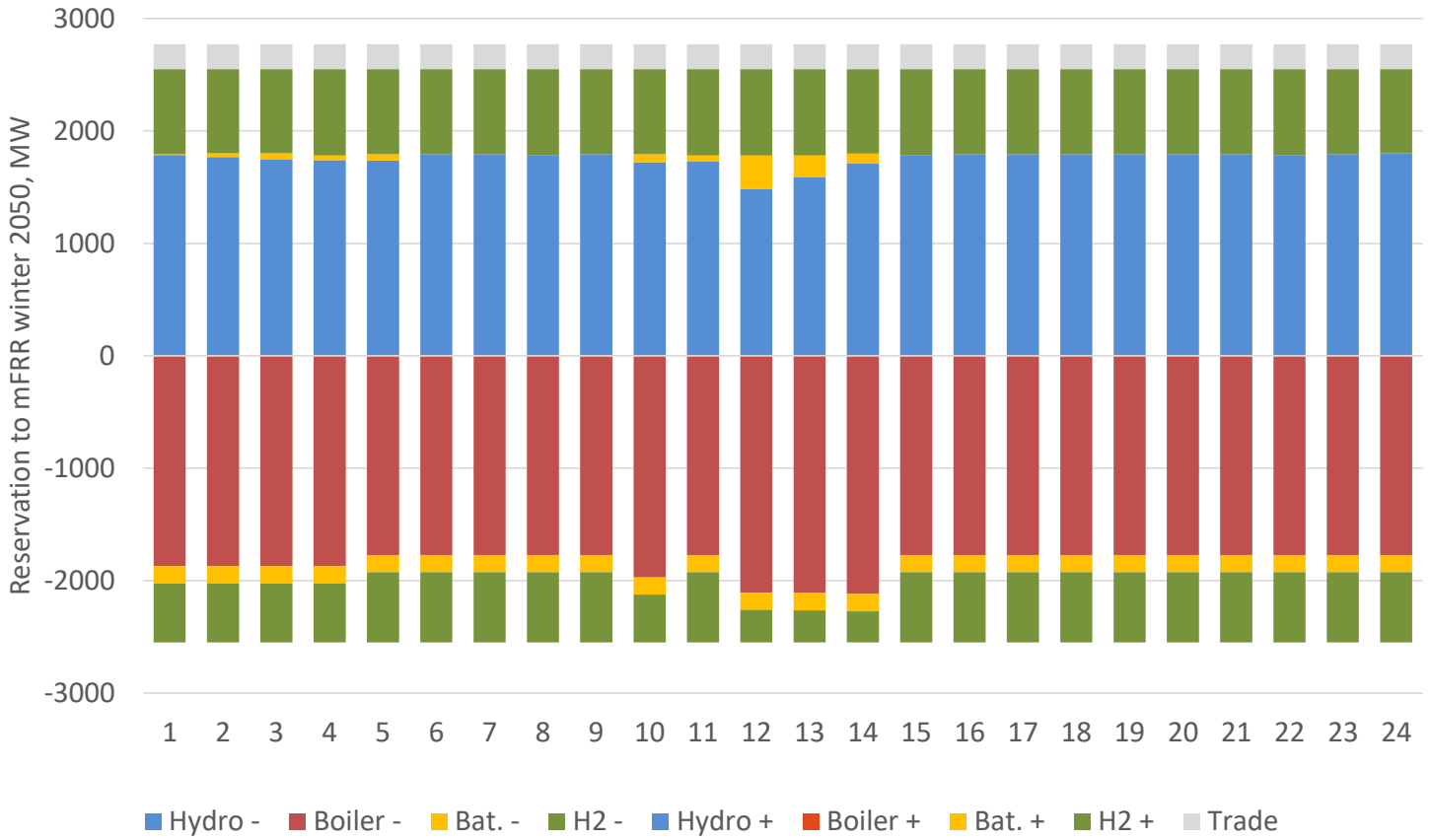
Costs for the provision of reserves from industry	Euro/MW	kNOK2016/MW
Aluminium	900	8.97
Metals	900	8.97
Wood and Paper	50	0.50

Results: Reserve contribution secondary (aFRR) 2050

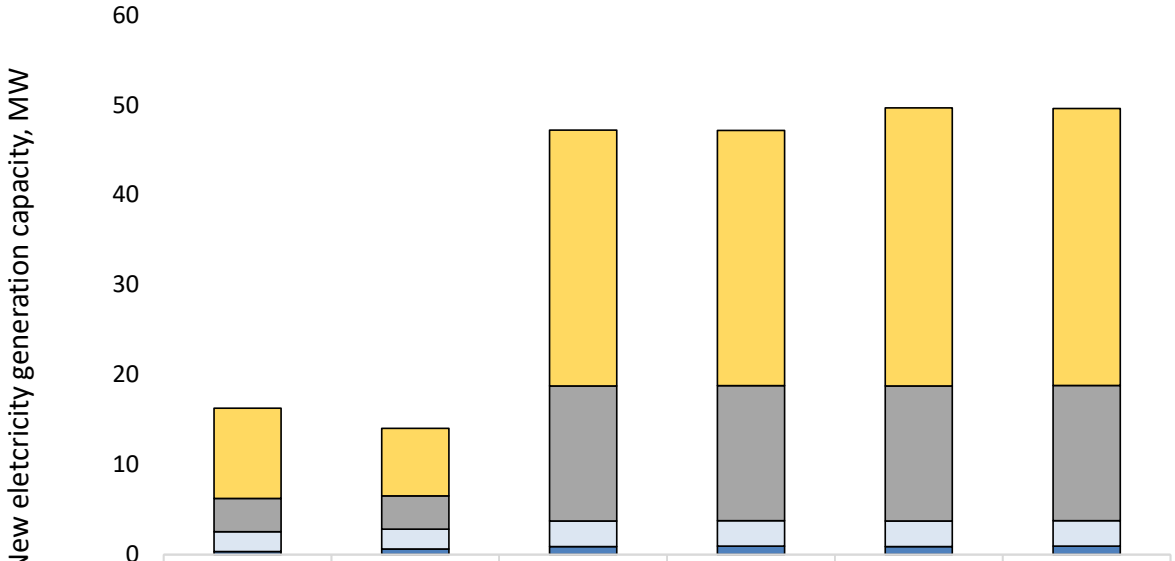


	2030 Up	2030 Down	2050 Up	2050 Down
Trade	0	0	0	0
Hydrogen	0	0	6	-60
Electric boiler	0	-292	7	-235
Hydropower	400	-108	387	-106

Result: Contribution to tertiary (mFRR) winter 2050



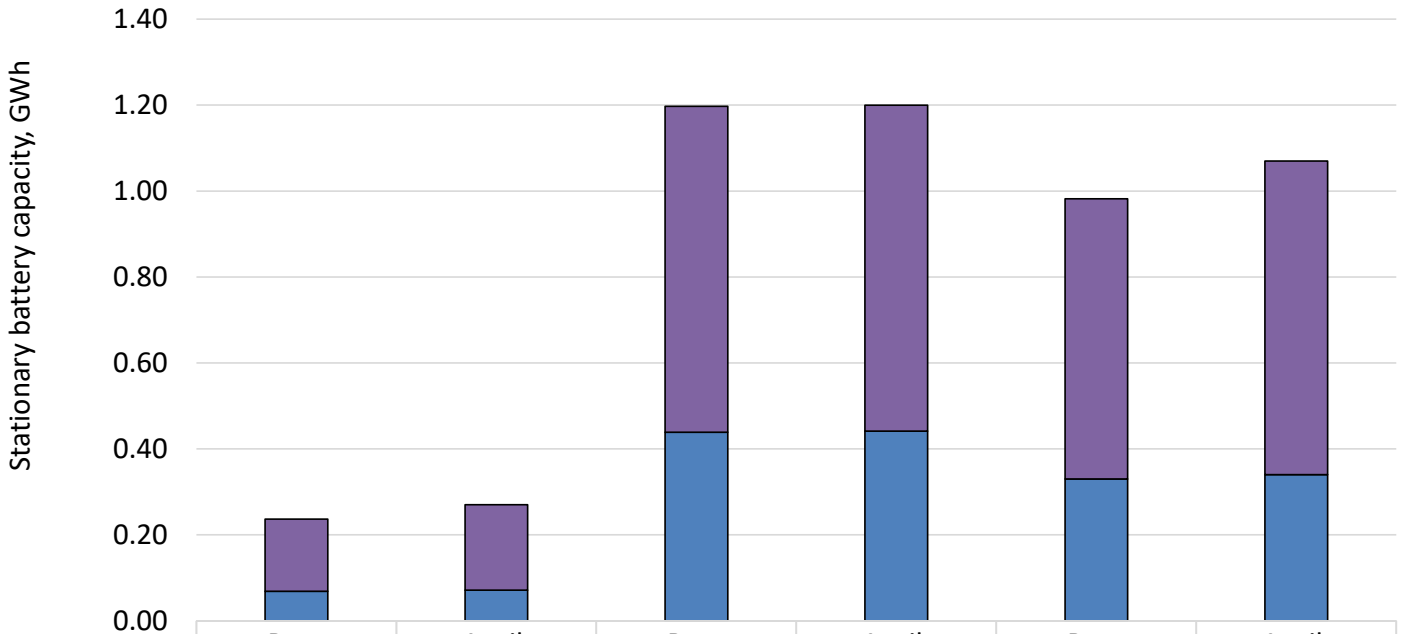
Reserve markets give marginally more regulated hydropower and lower solar PV



	2030 Base	2030 Ancil.	2040 Base	2040 Ancil.	2050 Base	2050 Ancil.
Solar power	10.0	7.5	28.5	28.4	30.9	30.8
Wind power	3.7	3.7	15.0	15.0	15.0	15.0
Run-of-river hydro	2.2	2.2	2.8	2.8	2.8	2.8
Regulated hydro	0.3	0.6	0.9	0.9	0.9	0.9

Figure: New electricity generation capacity after 2020

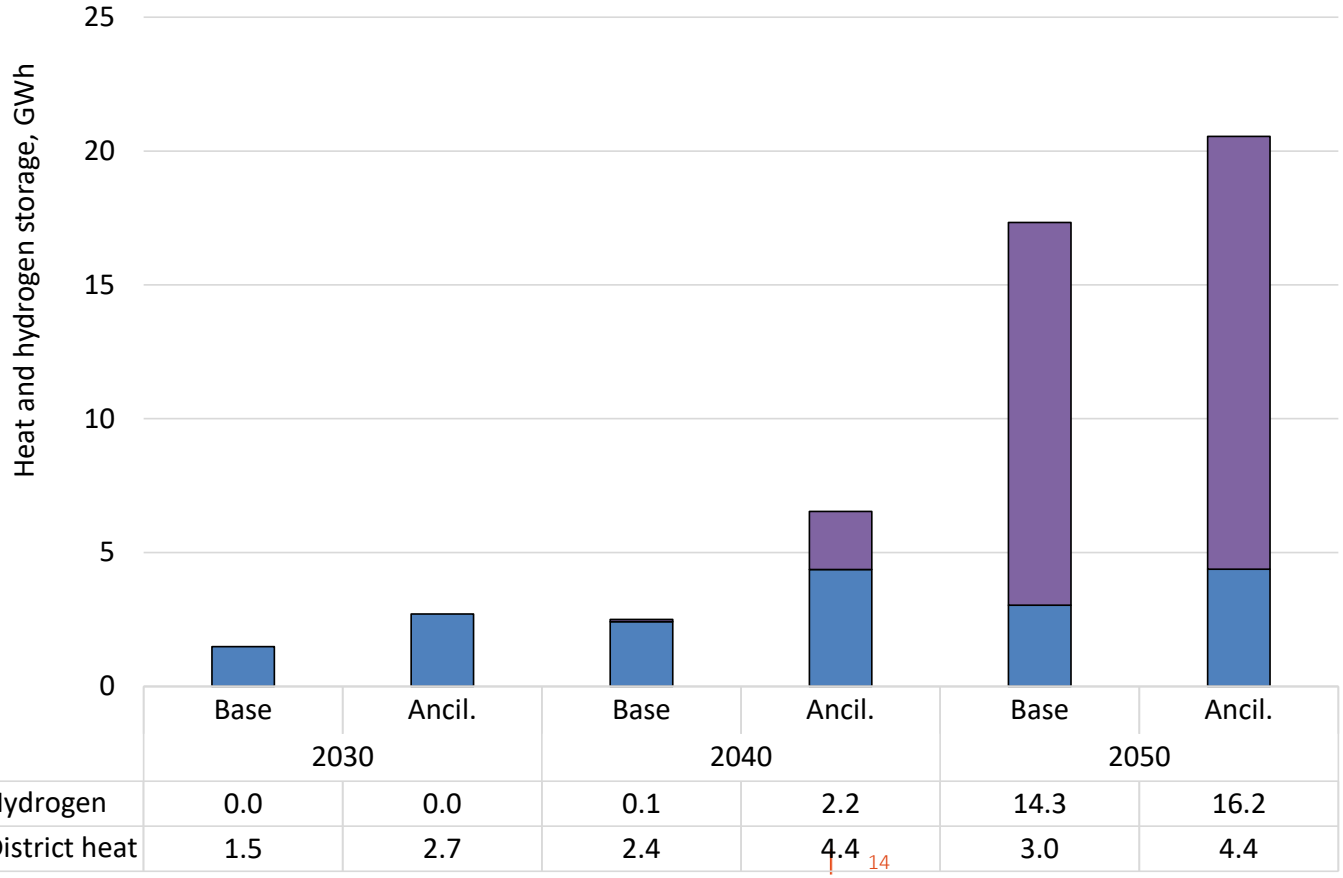
Reserve markets marginally increase battery capacity



	Base 2030	Ancil. 2030	Base 2040	Ancil. 2040	Base 2050	Ancil. 2050
Residential	0.17	0.20	0.76	0.76	0.65	0.73
Commercial	0.07	0.07	0.44	0.44	0.33	0.34

Figure: New battery capacity after 2020

Reserve markets increase hydrogen and district heat storage



	2030 Base	2030 Ancil.	2040 Base	2040 Ancil.	2050 Base	2050 Ancil.
Hydrogen	0.0	0.0	0.1	2.2	14.3	16.2
District heat	1.5	2.7	2.4	4.4	3.0	4.4

Figure: New storage capacity after 2020

Reserve markets influence hydrogen investments & operation

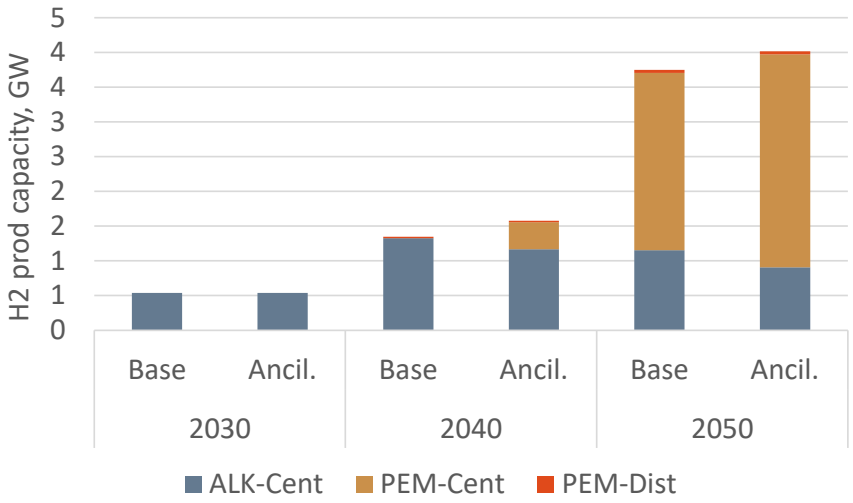
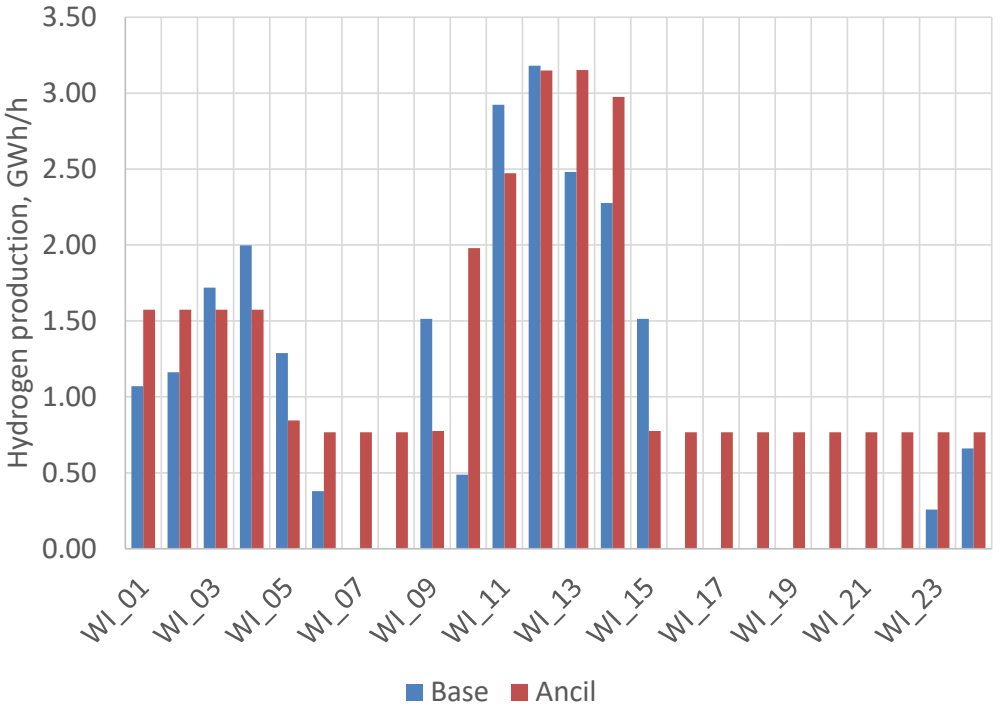
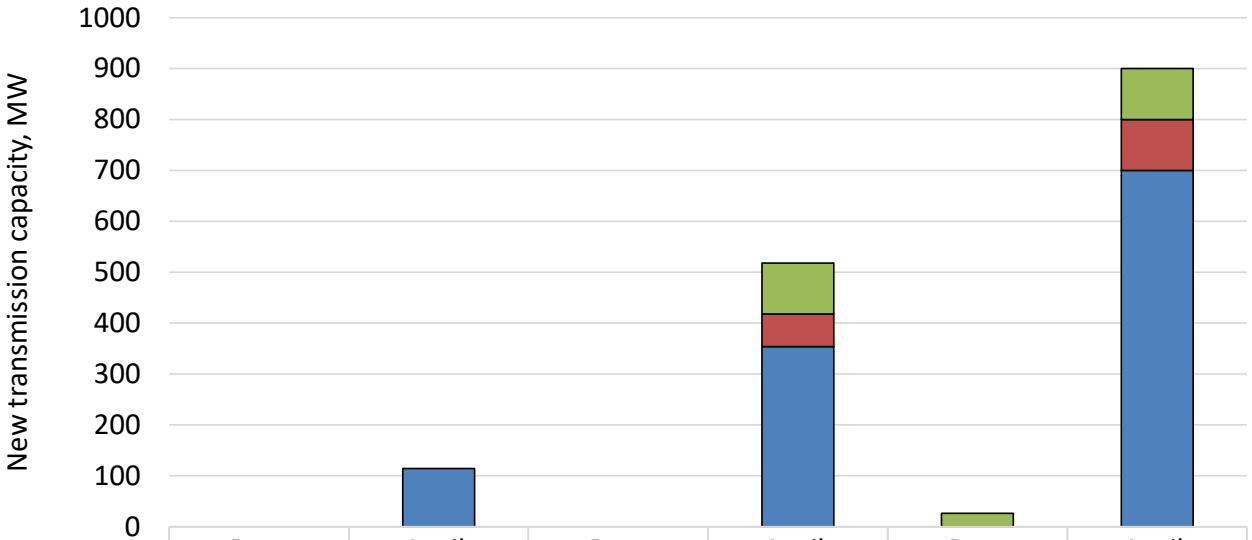


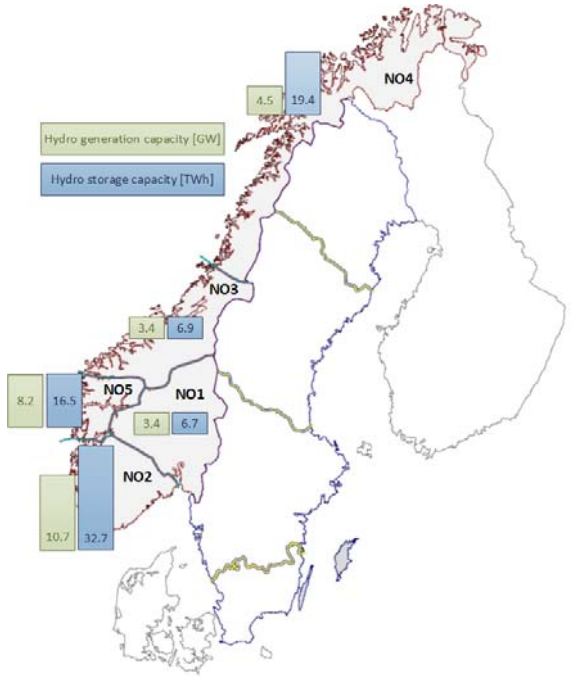
Figure: Production from PEM-Cent. Winter 2050



Reserve markets highly impact new national transmission capacity



	2030		2040		2050	
	Base	Ancil.	Base	Ancil.	Base	Ancil.
NO3-NO5	0.0	0.0	0.0	100.0	26.5	100.0
NO1-NO3	0.0	0.0	0.0	64.0	0.0	100.0
NO1-NO2	0	114	0	354	0	700



Summary and conclusions

- Hypothesis: Impact of reserve market is lower for Norway with flexible hydropower than other countries
- Explicit modelling of ancillary services:
  1. Decrease cost-competitiveness of solar power
  2. Increase cost-competitiveness:
     - Flexible hydropower
     - Stationary batteries
     - Hydrogen storage
     - District heat production & storage
     - National transmission expansion
- Further work: Power market input, Partly endogenous reserves, Flexible EV charging

We welcome cooperation with ETSAP partners on ancillary services

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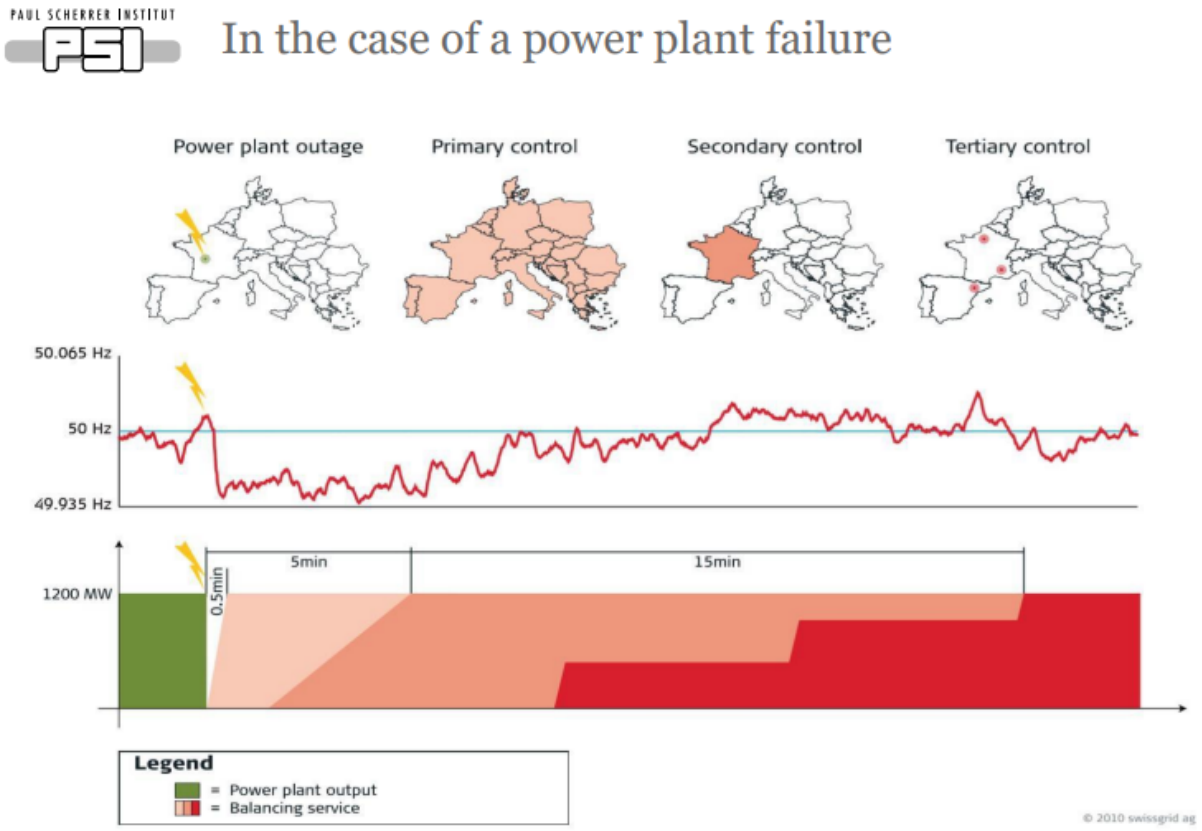
Reserve market



- Several ways to model ancillary services, e.g.
  - define demand for primary, secondary, tertiary resources in MW per spot price region.
  - Endogenously define demand for balancing services by indicating forecast errors.

- From: https://iea-etsap.org/webinar/BS_Webinar_Presentation.pdf