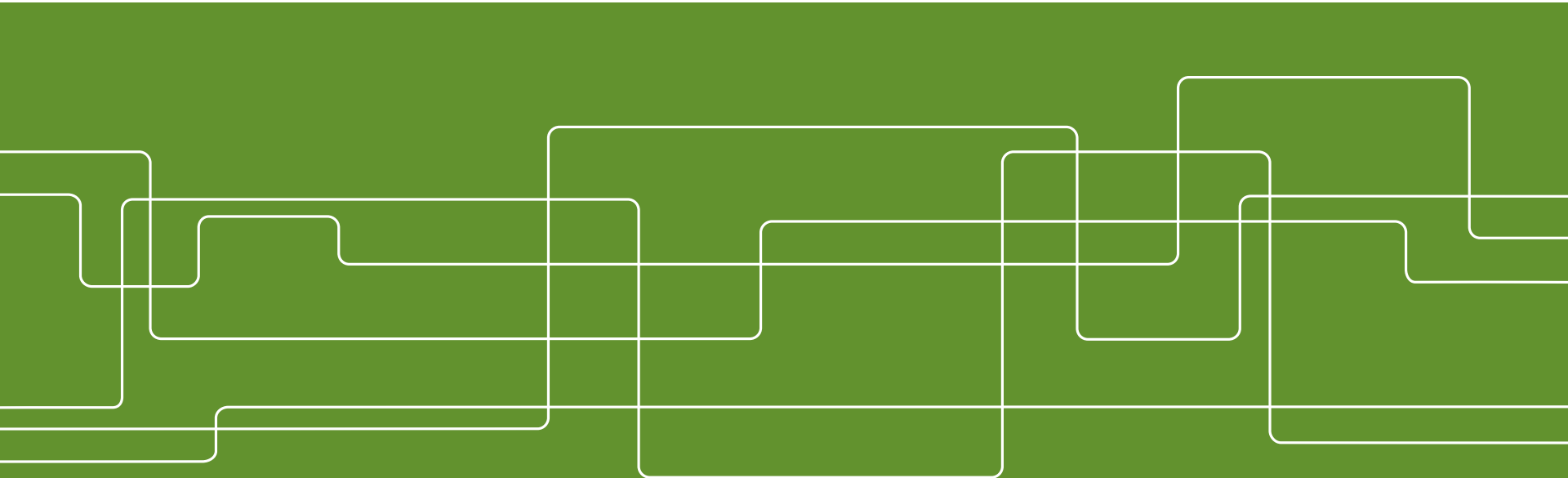




# Wind Power Research in Focus Göteborg, October 25, 2022

## The role of wind power in the future Swedish power system

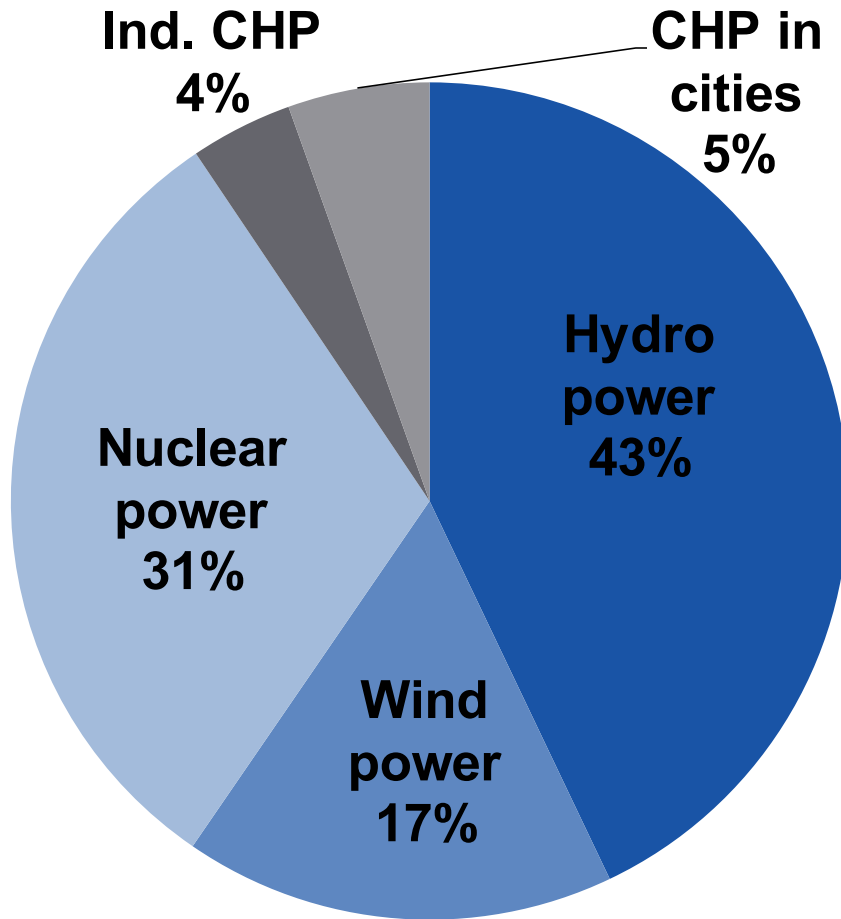
Lennart Söder  
Professor Electric Power Systems, KTH





# Swedish power production year 2021

## Total: 166 TWh, export: 25 TWh

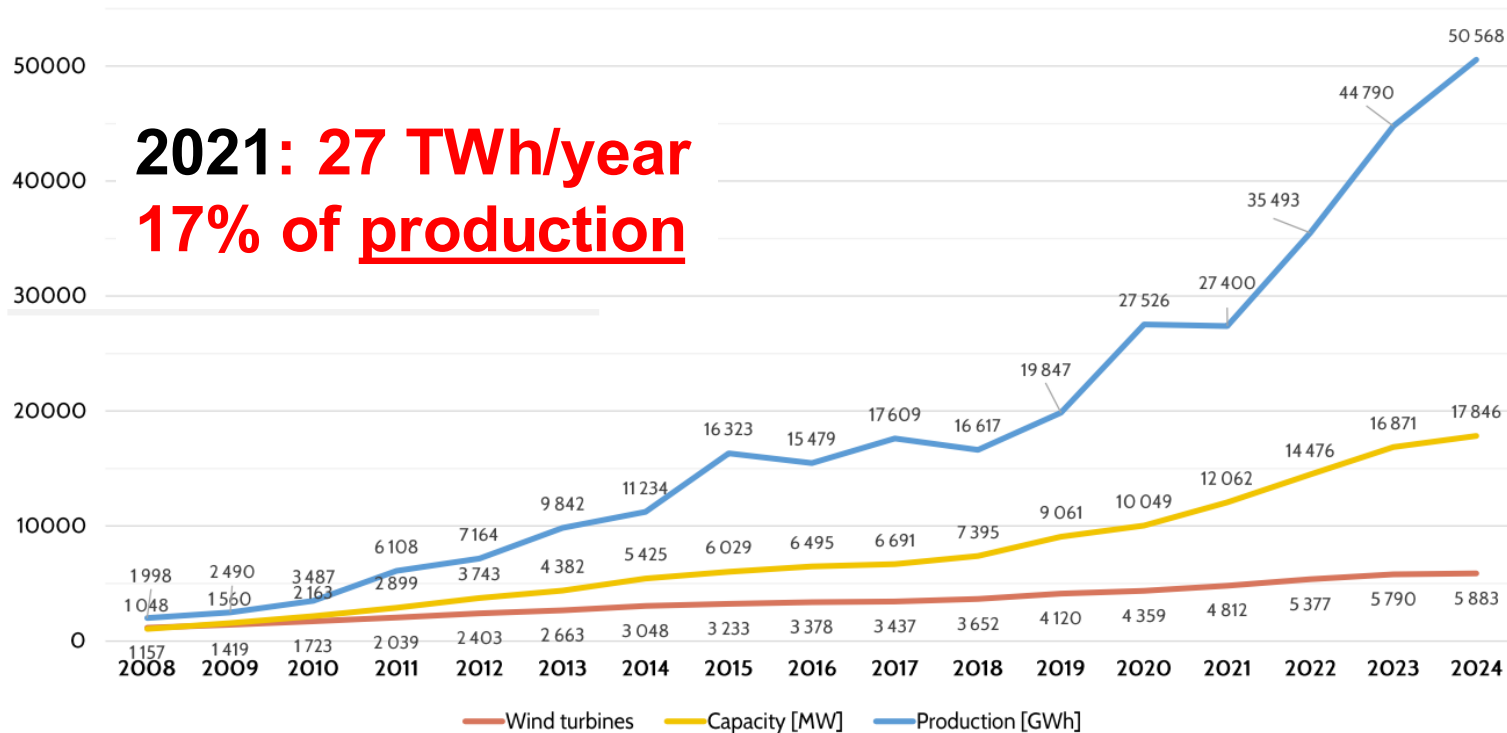




# Swedish wind power **forecast to 2024**

From June 2022 (based on investment decisions)

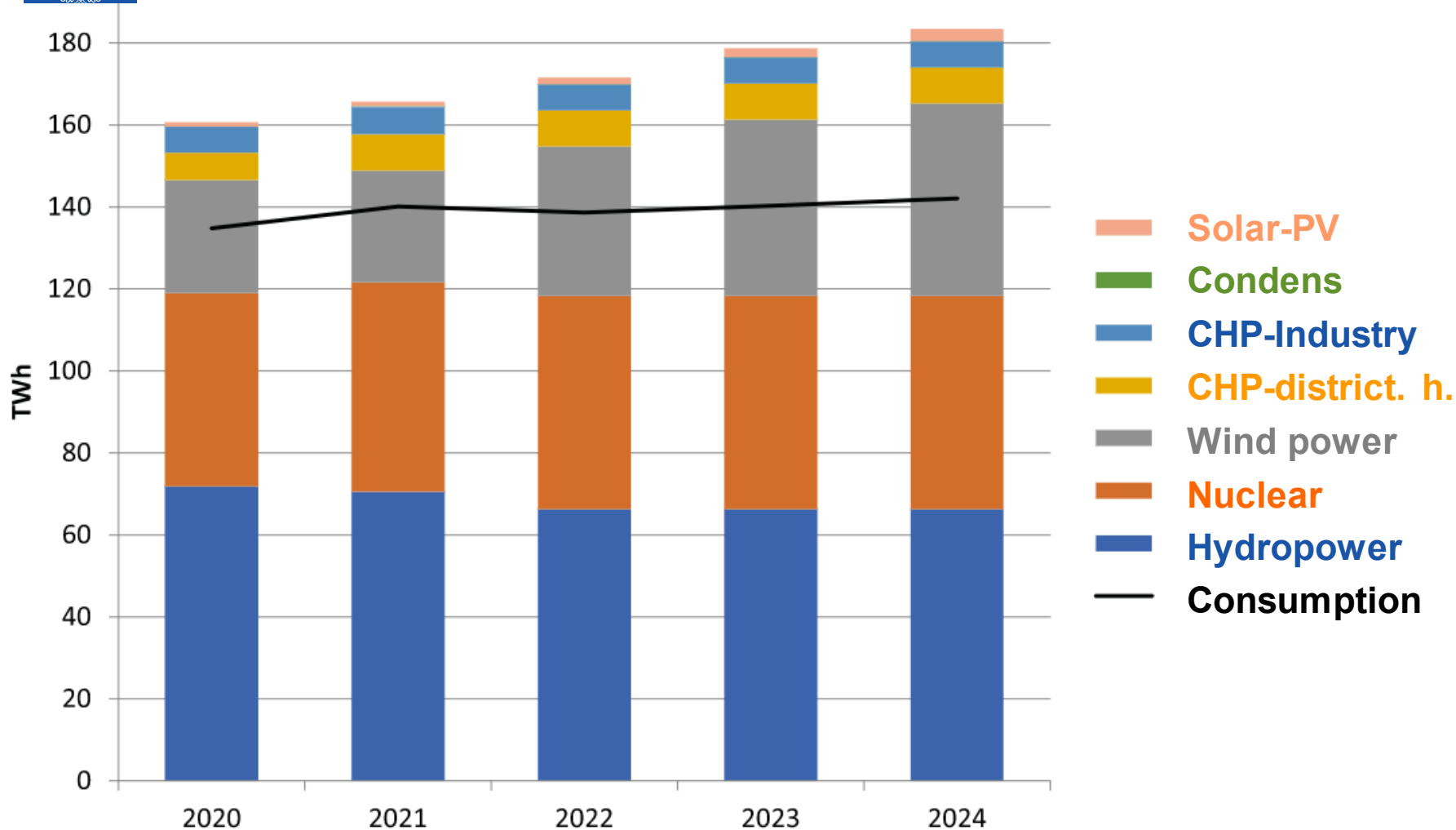
## Short term forecast, 2022-06-30



**51 TWh**



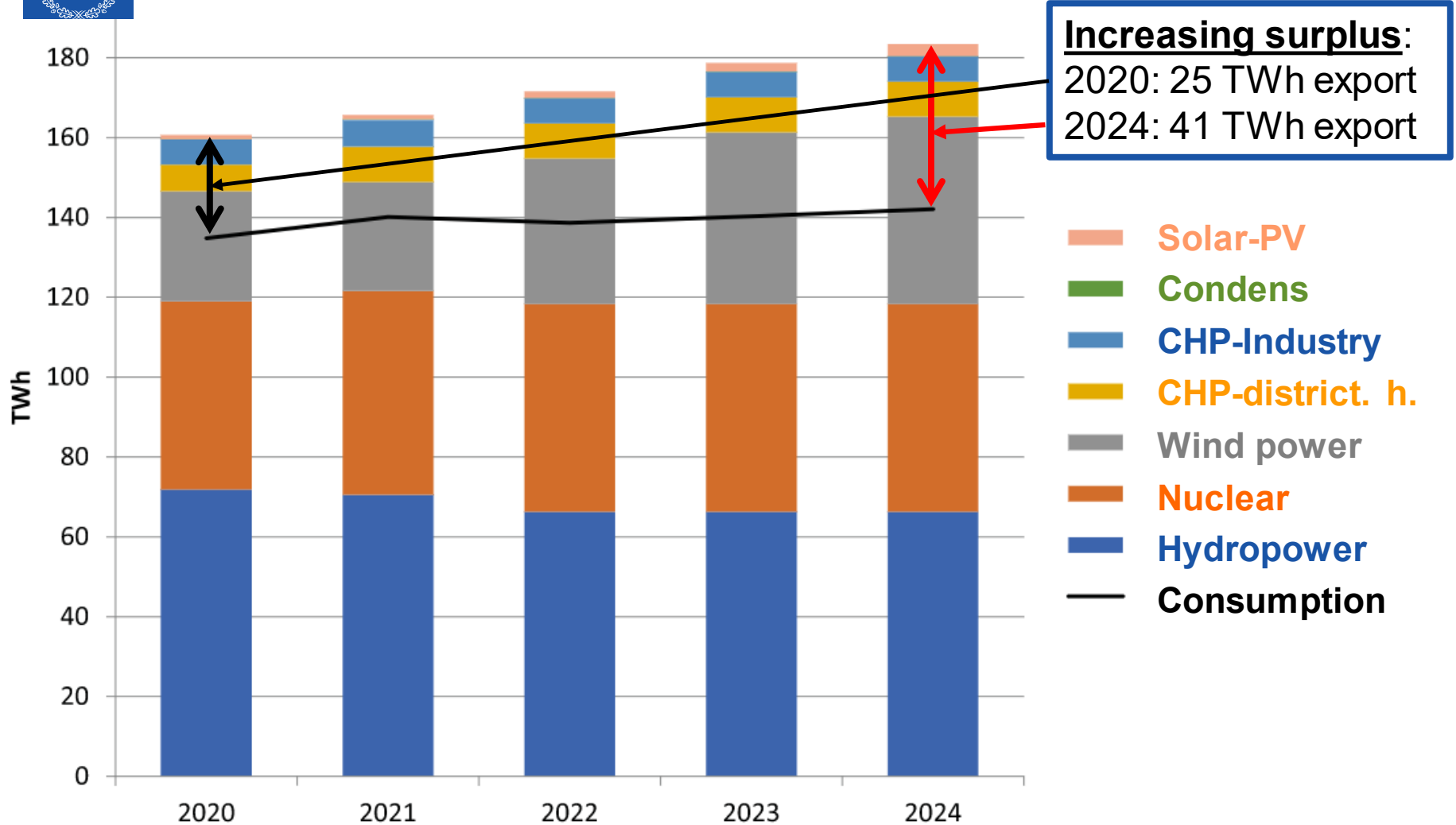
# Forecast from Energimyndigheten, March- 2022



<https://www.energimyndigheten.se/nyhetsarkiv/2022/ny-prognos-kraftig-okning-av-vindkraft-solel-och-elexport-till-2024/>



# Forecast from Energimyndigheten, March- 2022



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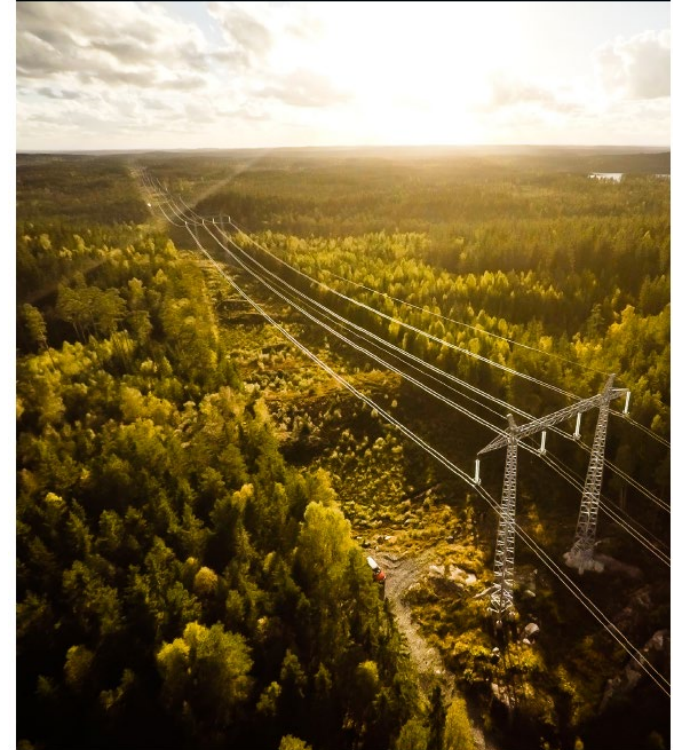
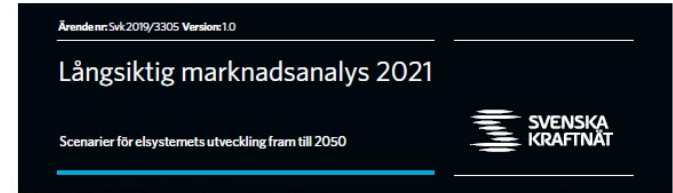
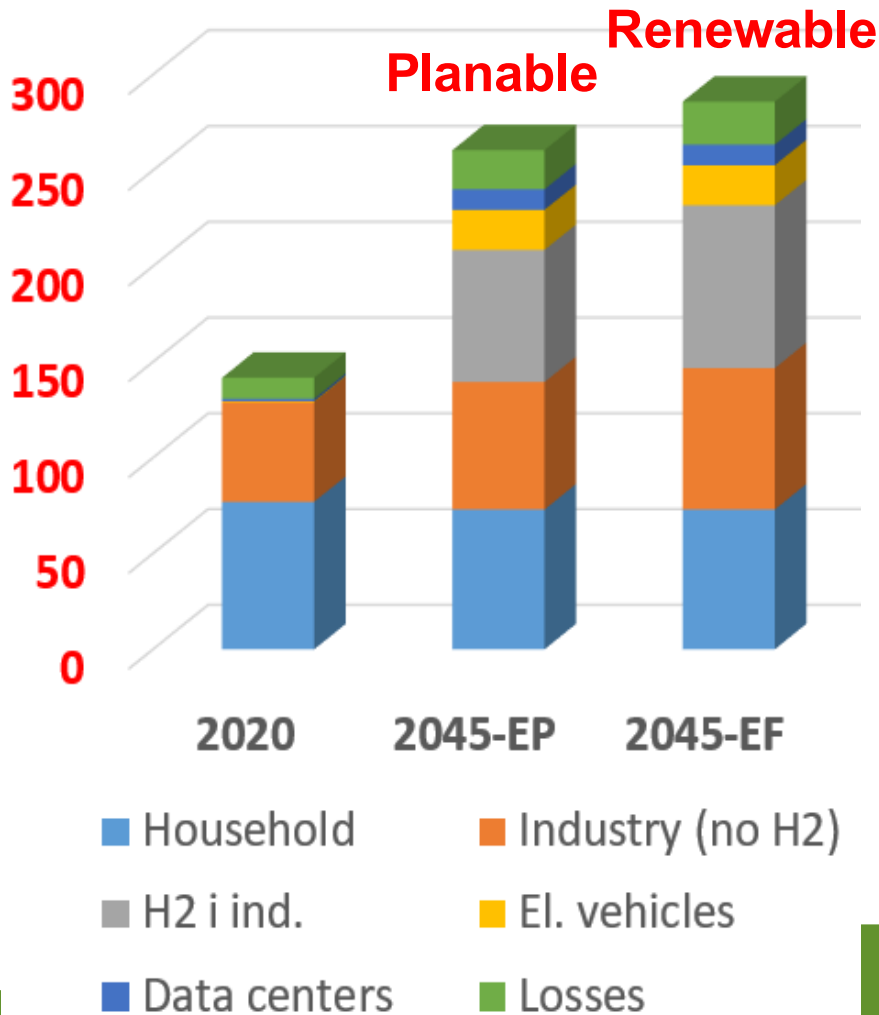


# Two studied scenarios for the future

## Electrification

”Long Term market analysis”,  
from May 2021

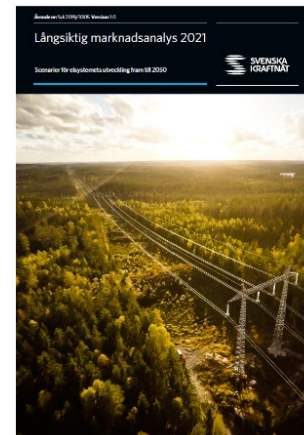
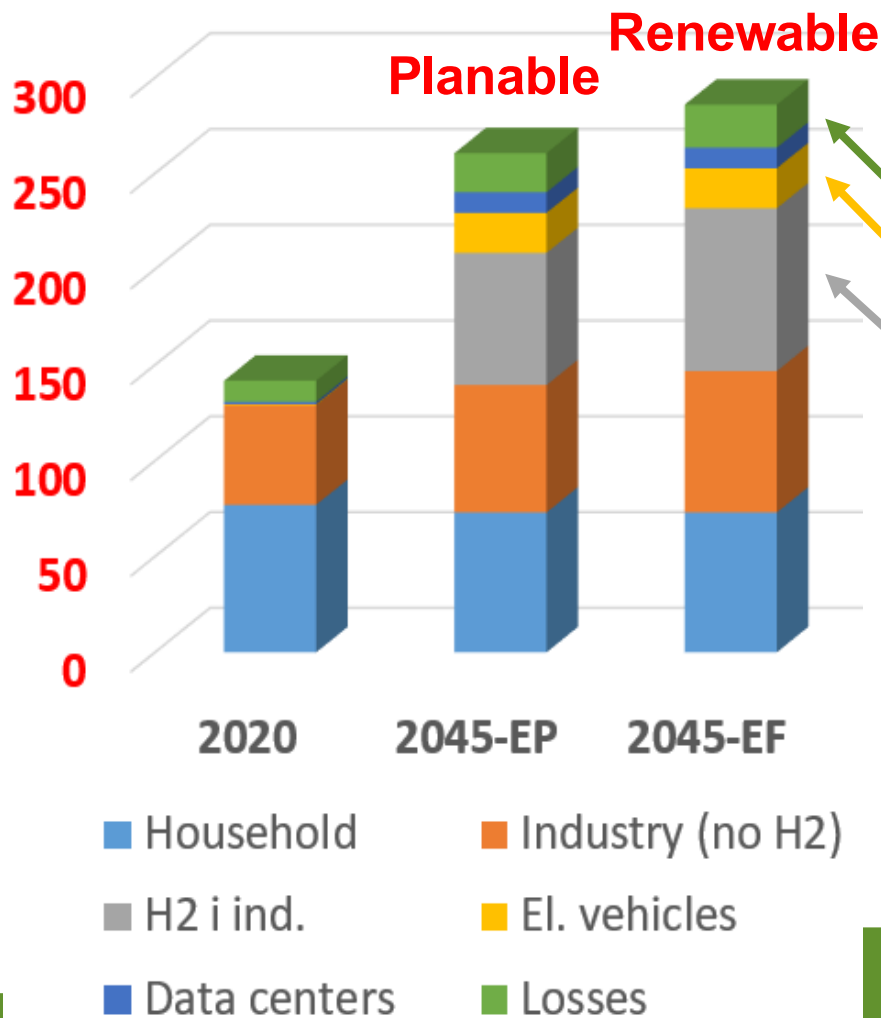
### Consumption assumption





# Two studied scenarios for the future Electrification

## Consumption assumption



Increased consumption 2020-2045-EF: 144 TWh

- Part of losses
- 21 TWh: vehicles
- 85 TWh: hydrogen

→ **79% of increase**  
is hydrogen or  
vehicles, → **flexible**  
**consumption**



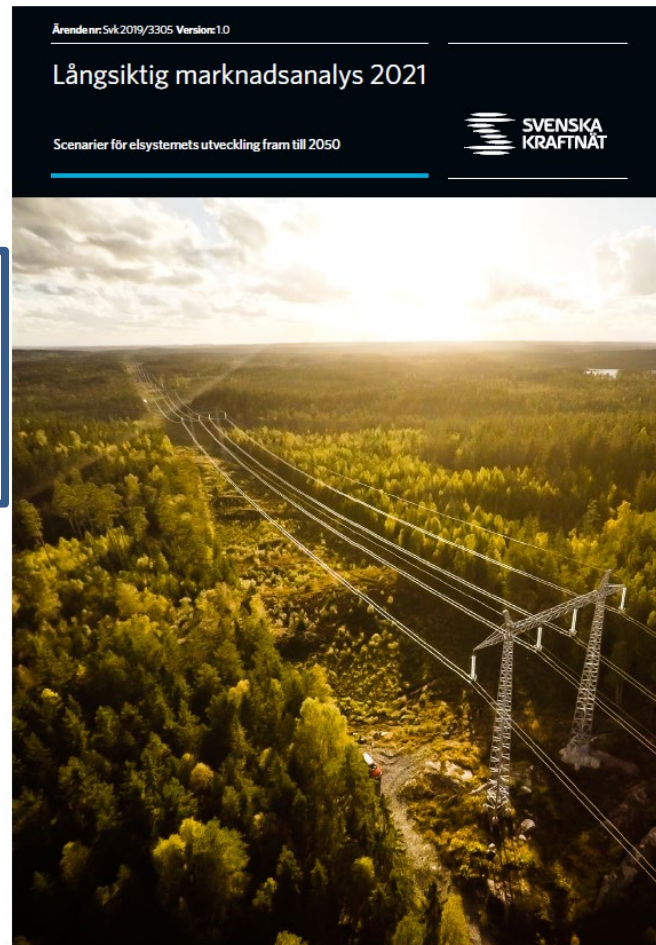
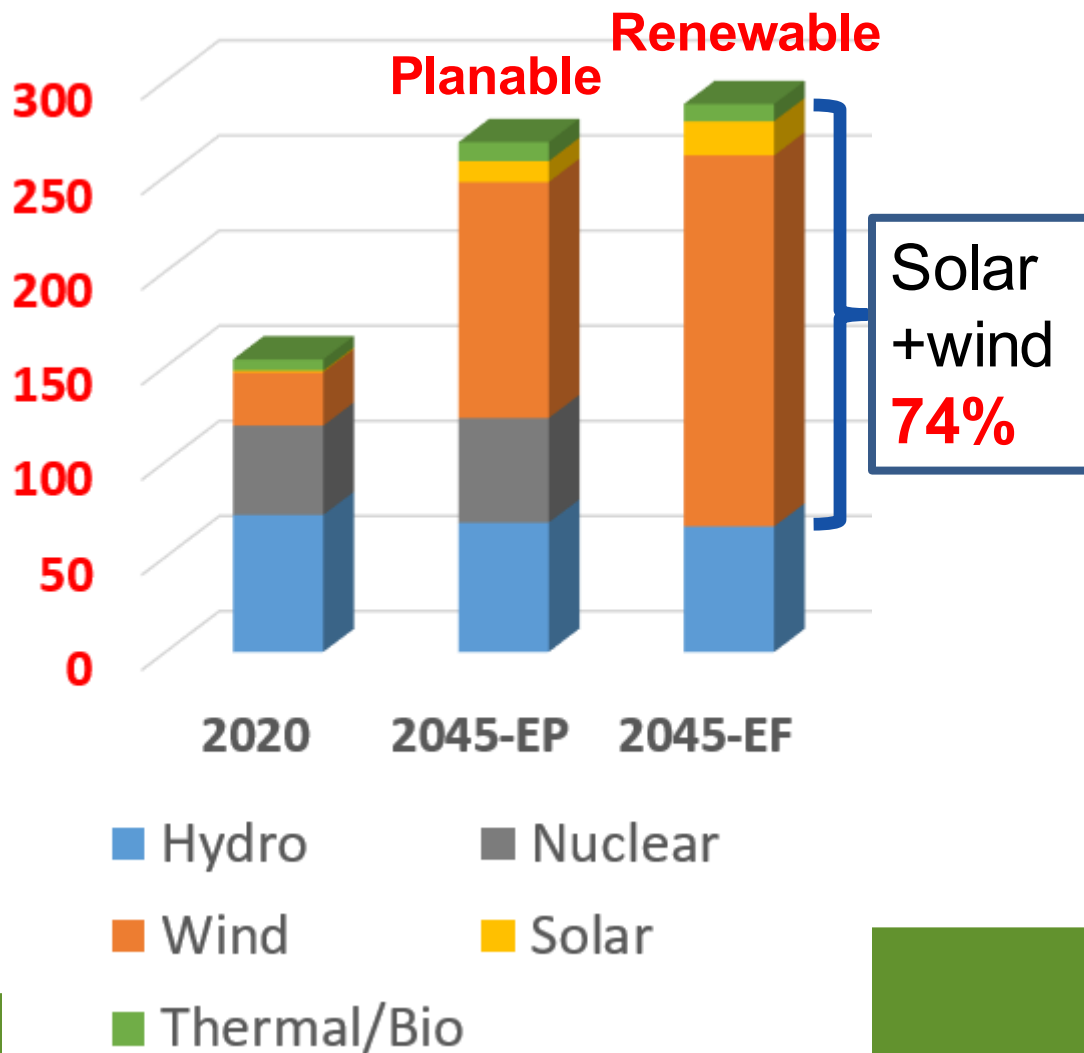


# Two studied scenarios for the future

## Electrification

”Long Term market analysis”,  
from May 2021

### Production results/assumption



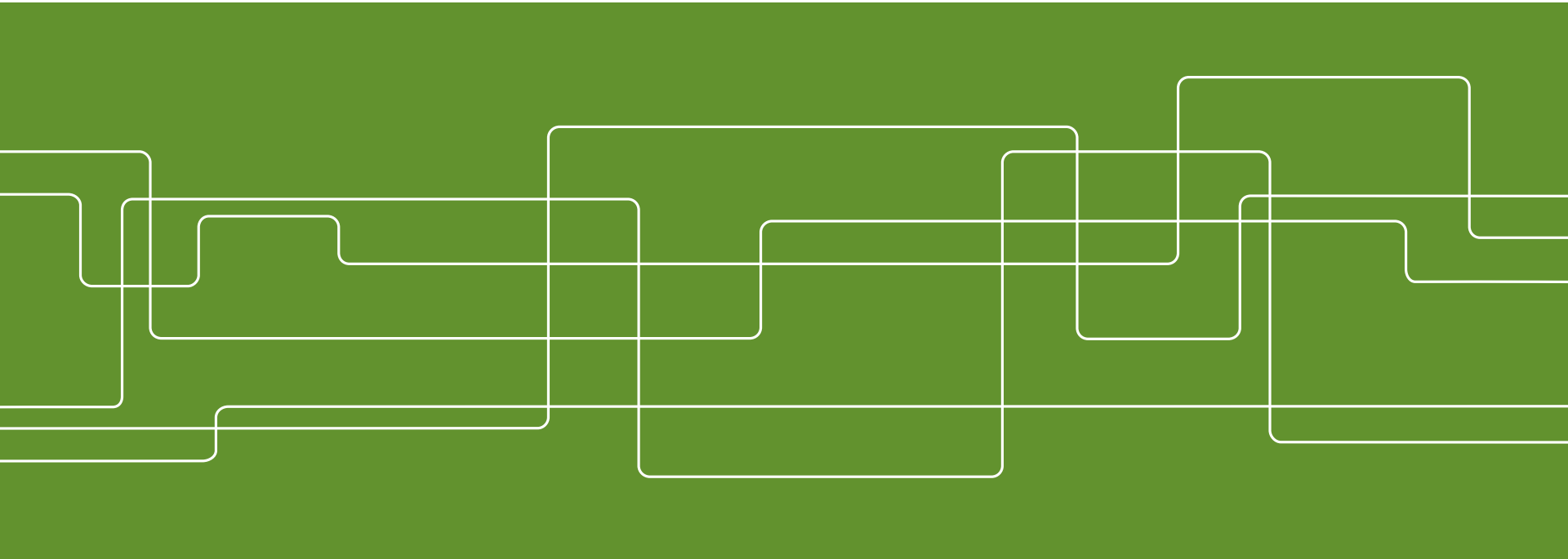




# Proposals from new Swedish Government

## SD – M – KD – L

**Tidö agreement**





# On wind power

## Vindkraft (page 16)

Vindkraft har en viktig plats i energimixen, men ska byggas på konkurrensneutrala villkor och med hänsyn tagen till miljö och lokala intressen. All ny elproduktion som stärker kraftsystemet, och som bidrar till en snabb expansion av kraftsystemet, behövs. Planen att låta elnätsskollektivet subventionera den havsbaserade vindkraftens elnätsanslutningar stoppas. Principen att den som ansluter till elnätet ska stå för de kostnader anslutningen orsakar ska upprätthållas även till havs. Pågående uppdrag till Havs- och vattenmyndigheten att utreda frågor om exklusivitet för anläggande av vindkraftsparker behöver breddas till Svenska kraftnät (då den som får exklusiv rätt till ett område också behöver binda upp sig på något sätt för de investeringar de beställer av Svenska kraftnät). Utgångspunkten ska vara att alla produktionsslag bär sina egna kostnader. På samma gång får utredningen Stärkta incitament för utbyggd vindkraft Dir. 2022:27 ett tilläggsuppdrag att tydligt föreslå hur verksamhetsutövarna ska ersätta kommunerna vid vindkraftsutbyggnad.

Tidöavtalet:  
**Överenskommelse  
för Sverige**





# On wind power in Tidö-avtalet - 1



- **Wind power** has an important place in the energy mix, but **must be built on competitively neutral terms and with consideration for the environment and local interests.**
- **All new electricity production that strengthens the power system, and that contributes to a rapid expansion of the power system, is needed.**
- The **plan** to have the electricity grid collective subsidize the **offshore wind power grid connections is stopped.**
- The principle that whoever connects to the electricity grid must **bear the costs caused by the connection** must **also be maintained at sea.**



## On wind power in Tidö-avtalet - 2



- Ongoing assignment to the Maritime and Water Authority to investigate issues of exclusivity for the construction of wind farms needs to be broadened to Svenska kraftnät (since the person who gets exclusive rights to an area also needs to bind himself in some way for the investments they order from Svenska kraftnät).
- The starting point must be that **all types of production bear their own costs**. At the same time, the investigation Strengthened incentives for expanded wind power Dir. 2022:27 an additional task to clearly propose how the operators should **compensate the municipalities** in wind power expansion.



# On wind power

## Nya regler för elmarknaden (sid 13)

En ny utredning om elmarknadens utformning tillsätts med uppdrag att ta fram förslag som syftar till att samtliga kraftslag ha likvärdiga spelregler samt en ordning där stödtjänster som krävs för ett välfungerande elsystem prissätts och där de kraftslag som bidrar med sådana stödtjänster också ersätts för detta, i första hand genom ersättning från de producenter som inte kan bistå med samma stödtjänster.

Elmarknadsdirektivet ska få en korrekt implementering i svensk rätt, där ansvarsfördelning mellan elsystemets aktörer tydliggörs. Angående slutkundsmarknaden bör anvisningsavtalen tas bort.

Tidöavtalet:

## Överenskommelse för Sverige





## On wind power in Tidö-avtalet - 3

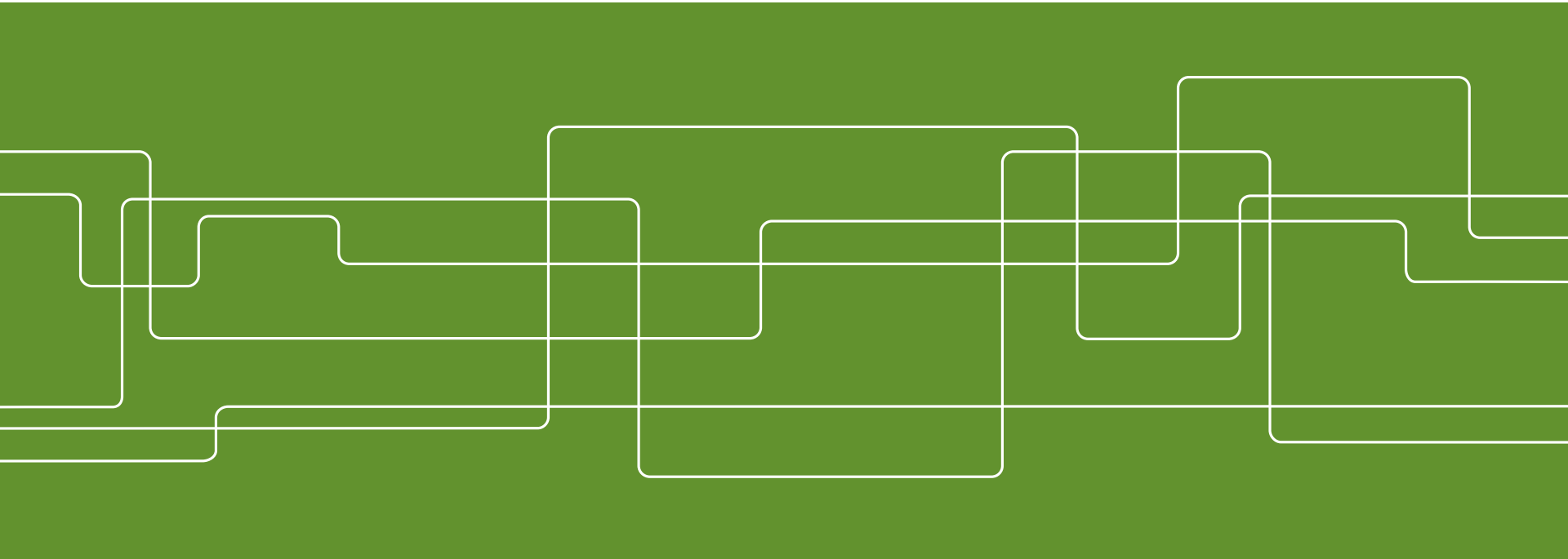


- A new investigation into the design of the electricity market is added with the task of developing proposals aimed at ensuring that **all power types have equal rules of the game** as well as a system where **support services required for a well-functioning electricity system are priced and where the power types that contribute with such support services are also compensated for this**, in the first instance hand through **compensation from the producers who cannot assist with the same support services**.
- The electricity market directive must be properly implemented in Swedish law, where the division of responsibilities between the actors of the electricity system is made clear. Regarding the end-customer market, referral agreements should be removed.



# Concerning costs of balancing

**Possible cost changes caused by  
Tidö-avtalet**







# Concerning **system services** i.e. continuous balancing

## Current System Services at Svenska Kraftnät:

<b><u>FFR</u></b> : Fast frequency reserve	Automatically activated service that handles the initial rapid and deep (transient) frequency deviations that can occur in the case of low-level rotational energy errors in the Nordic power system.
<b><u>FCR-N</u></b> : Frequency Containment Reserve - Normal	Automatically activated services that stabilizes the frequency in case of small changes in consumption or production.
<b><u>FCR-D up</u></b> : Frequency Containment Reserve - Disturbance	Automatically activated service that stabilizes the frequency in the event of a disturbance (production outage)
<b><u>FCR-D down</u></b> : Frequency Containment Reserve - Disturbance	Automatically activated service that stabilizes the frequency in the event of a disturbance (consumption outage)
<b><u>aFRR</u></b> : automatic Frequency Restoration Reserve)	Automatically activated service which restore the frequency to 50 Hz.
<b><u>mFRR</u></b> : manual Frequency Restoration Reserve	Manual service which relieves the automatic services and restore the frequency to 50 Hz.



# Concerning **system services** i.e. continuous balancing

- The aim of these "**system services**" is to keep the continuous balance between production and consumption.
- These are today financed by the **balance responsible parties**, in reality the ones who **sells electricity** to final consumers or **purchases electricity** from producers. These are economically responsible for the deviation between real and forecasted production/consumption.

SvK: has "**Fees for balance responsible parties**". New 22-11-16

Volume fee: 0,850 EUR/MWh  $\approx$  **0.85 öre/kWh**

Imbalance fee: 1,150 EUR/MWh  $\approx$  **1.15 öre/kWh**

Weekly fee: 30 EUR/week:  $\approx$  **300 SEK/week**

Peak load reserve fee: 0,330 EUR/MWh  $\approx$  **0.33 öre/kWh**



# Concerning **system services** i.e. continuous balancing

- Imbalances = Deviation from forecast (e.g. wind power / demand)
- Balance responsible pays the one who "cleared" the imbalance + an imbalance fee (**punishment to incentivize good forecasts**)
- Nov 2021 – Jun 2022: Total obalans (konsumtion och produktion): 12.5 TWh →  $12.5 \cdot 10^6 \cdot 1.15 = 14$  Meuro: Per year:  $12/8 \cdot 14 \rightarrow$  **216 MSEK/y**

SvK: has "**Fees for balance responsible parties**". New 22-11-16

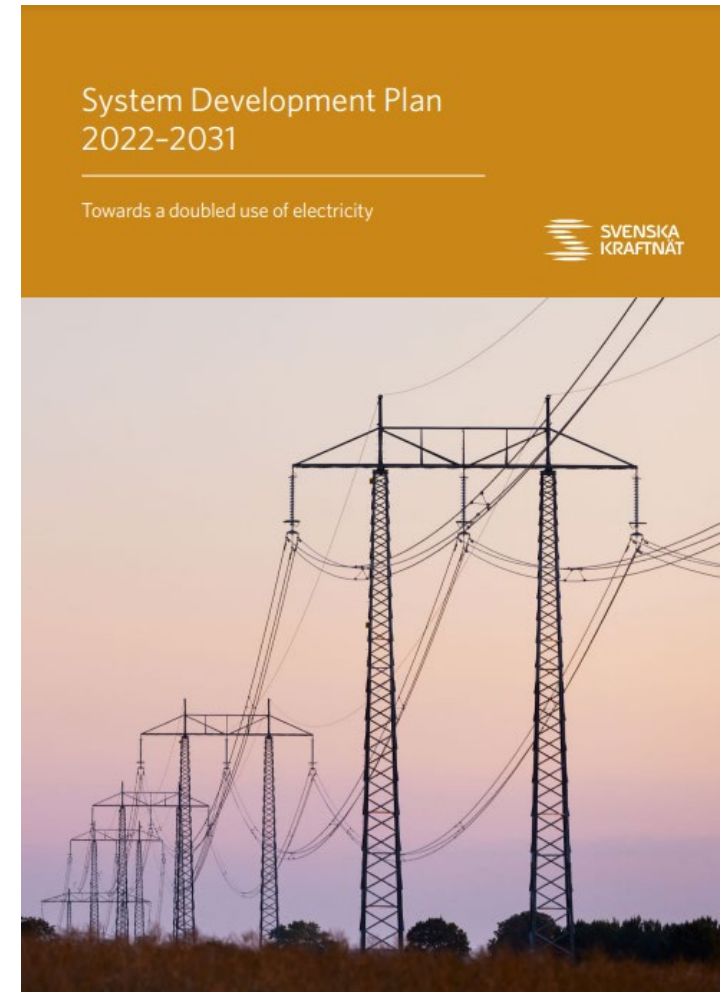
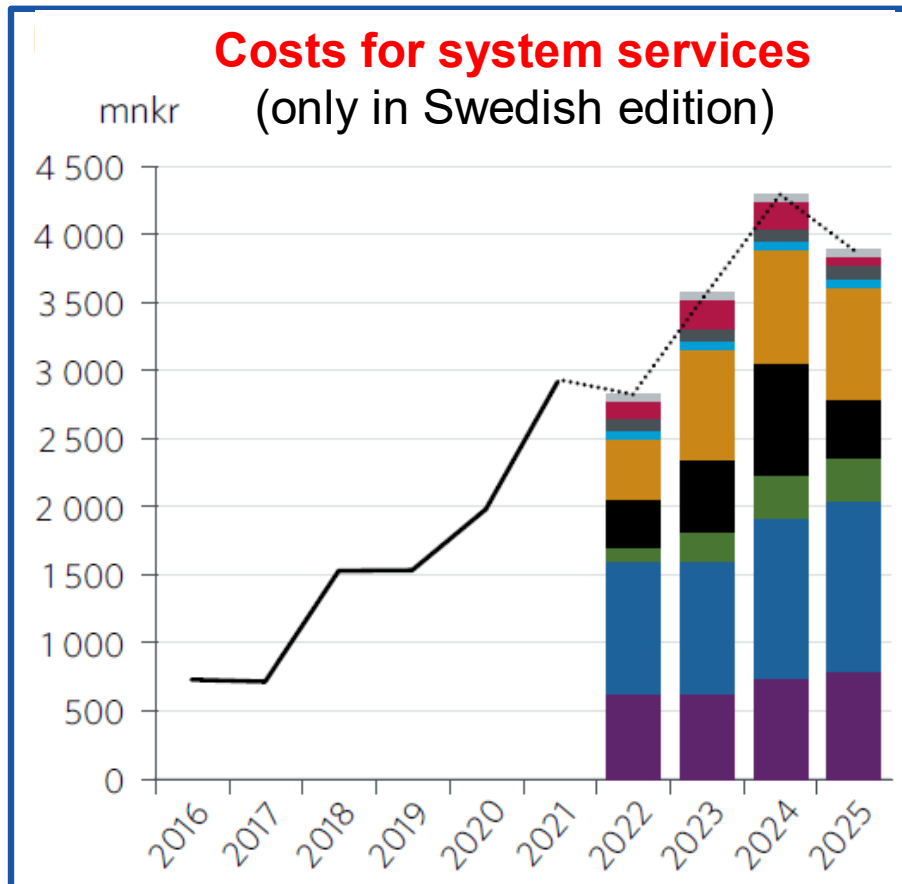
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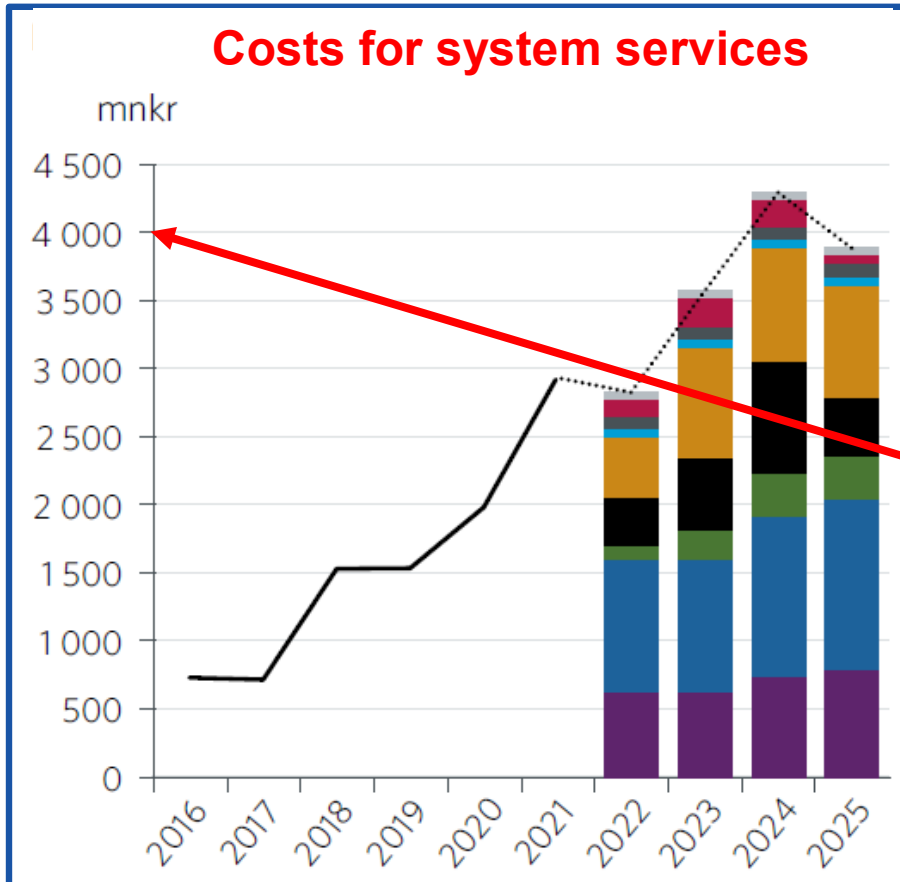
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Peak load reserve fee: 0,330 EUR/MWh  $\approx$  **0.33 öre/kWh**

# Concerning **system services** i.e. continuous balancing



# Concerning **system services** i.e. continuous balancing



Assume 4000 MSEK/year:

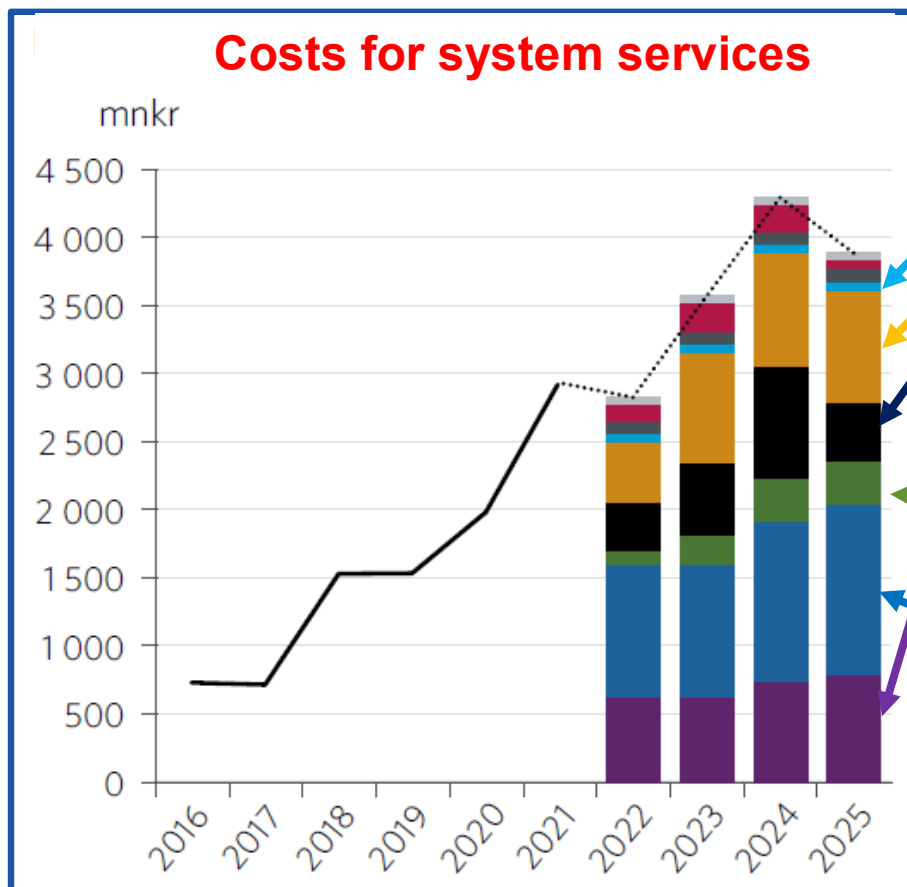
- Assume power consumption 150 TWh/year:

→  $4/150 = \underline{\underline{2.7 \text{ öre/kWh}}}$

(10 SEK/EUR)

→ 2.7 EUR/MWh

# Concerning **system services** i.e. continuous balancing



**FFR**: Low inertia

**mFRR+aFRR+FCR-N**:

Variation of wind power + consumption + change in other production

**FCR-D down**: Outage in large HVDC export

**FCR-D up**: Outage of large production (or HVDC import), e.g. nuclear power



# Concerning system services i.e. continuous balancing

## System services developed from wind power, solar power and EVs.

**Vindparken som ska frekvensreglera**

- Namn:** Häjsberget och Södra Länsmansberget.
- Plats:** 8 kilometer sydväst om Sunne.
- Ägare:** Värmlandsvind (som i sin tur ägs av Tekniska verken och Växjö Energi).
- Togs i drift:** 2020.
- Antal vindkraftverk:** 13 stycken (nio på Häjsberget och fyra på Södra Länsmansberget).
- Effekt per vindkraftverk:** 4,1 MW.
- Modell:** Siemens Gamesa DD-142.
- Beräknad årsproduktion av el:** 180 GWh (13,8 GWh/verk).
- Totalhöjd:** 200 meter.
- Rotordiameter:** 142 meter.

KÄLLA: TEKNISKA VERKEN

**Så stöttar vindkraft elnätet**

Vindkraft i Sverige har hittills varit reglerat tekniskt och ekonomiskt. Men nu öppnas för första gången upp för att tillgodosena behovet av systemtjänster i ett elnät som blir allt mer förnybart. Detta innebär att vindkraftverken ska kunna bidra till att stabilisera elnätet och förhindra frekvensfall. Detta görs genom att vindkraftverken utrustas med avancerade styrningar som kan reagera snabbt på förändringar i elproduktionen och efterfrågan. Detta innebär att vindkraftverken kan fungera som vridmoment och frekvensreglerare i elnätet. Detta är ett viktigt steg mot ett mer flexibelt och stabilt elnät.

**Vindparken som ska frekvensreglera**

- Namn:** Häjsberget och Södra Länsmansberget.
- Plats:** 8 kilometer sydväst om Sunne.
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- Rotordiameter:** 142 meter.

KÄLLA: TEKNISKA VERKEN

**Pilotparken i Småland**

- Solceller** med en installerad effekt om 10 MW som väntas ge 10 GWh per år.
- Ultrakondensatorer** med en installerad effekt om 4 MW.
- Batterisystem** med litiumjärnfosfatceller om 0,5 MWh och 0,5 MW.
- Stödtjänster** som ska levereras: FFR, FCR-D Upp och FCR-D Ned.
- Projektet heter formellt **Demonstration av stödtjänster från smarta solelparker för framtidens energisystem.**
- Projektet har en total budget av 38,7 miljoner kronor.
- Energimyndigheten** bidrar med 14,4 miljoner kronor.
- Projekttiden löper från 2022 till slutet av 2025.

**Pilotparken visar vägen för 20 GW solceller**

En pilotpark för solceller i Småland ska bli en pilotpark för att testa hur smarta stödtjänster med batterier, ultrakondensatorer och solceller fungerar i ett elnät. Detta är ett viktigt steg mot ett mer flexibelt och stabilt elnät.

**Solceller med en installerad effekt om 10 MW** som väntas ge 10 GWh per år.

**Ultrakondensatorer** med en installerad effekt om 4 MW.

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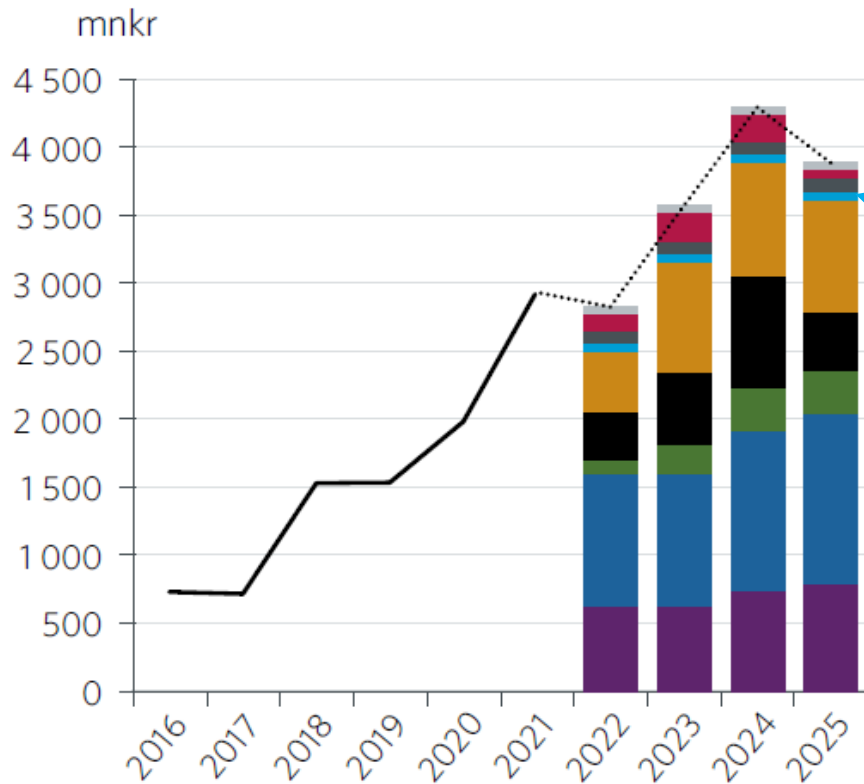
# Concerning **system services** i.e. continuous balancing

Two important system services are today (2022) not paid:

- **System inertia (synchronous machines or grid-forming converters)**
- **Voltage support (reactive power)**

# Concerning **system services** i.e. continuous balancing

## Costs for system services



## About: inertia - 1

Small economic issue:

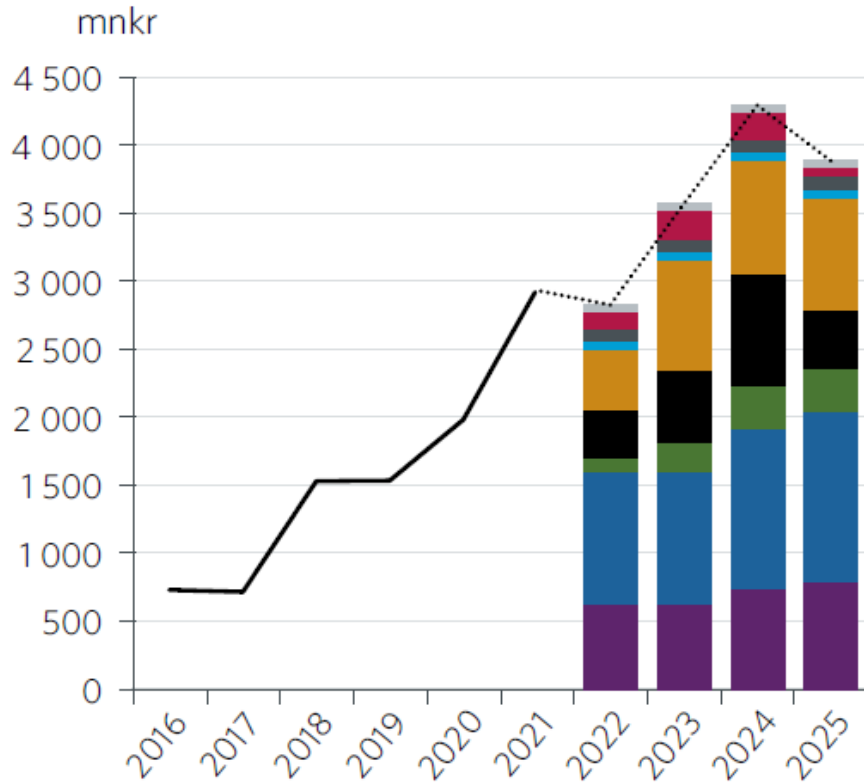
FFR compensates today at "low inertia"

However, an important issue!

Can be obtained from nuclear, hydro, CHP, some consumers, gas turbines, or grid-forming converters with margins.

# Concerning **system services** i.e. continuous balancing

## Costs for system services



## On: inertia - 2

**Inertia is needed:**

- **At fast, large, outages in, e.g. large nuclear stations or HVDC import/export.**
- **”Polluters pay” then means that they should pay for it.**



# Concerning **system services** i.e. continuous balancing

## On voltage control (reactive power)

- **Yes, a very important issue!**
- **Is today kept by nuclear power, wind power, hydro power, CHP, substations and in Germany with solar power.**
- **Many sources for this supply.**



# On wind power in Tidö-avtalet - 3



- A new investigation into the design of the electricity market is added with a set of developing proposals aimed at ensuring that **all power types have rules of the game** as well as a system where **support services required for a well-functioning electricity system are priced and where the power types that contribute with such support services are also compensated for this**, in the first instance hand through **compensation from the producers who cannot assist with the same support services**.

## Lennarts comments

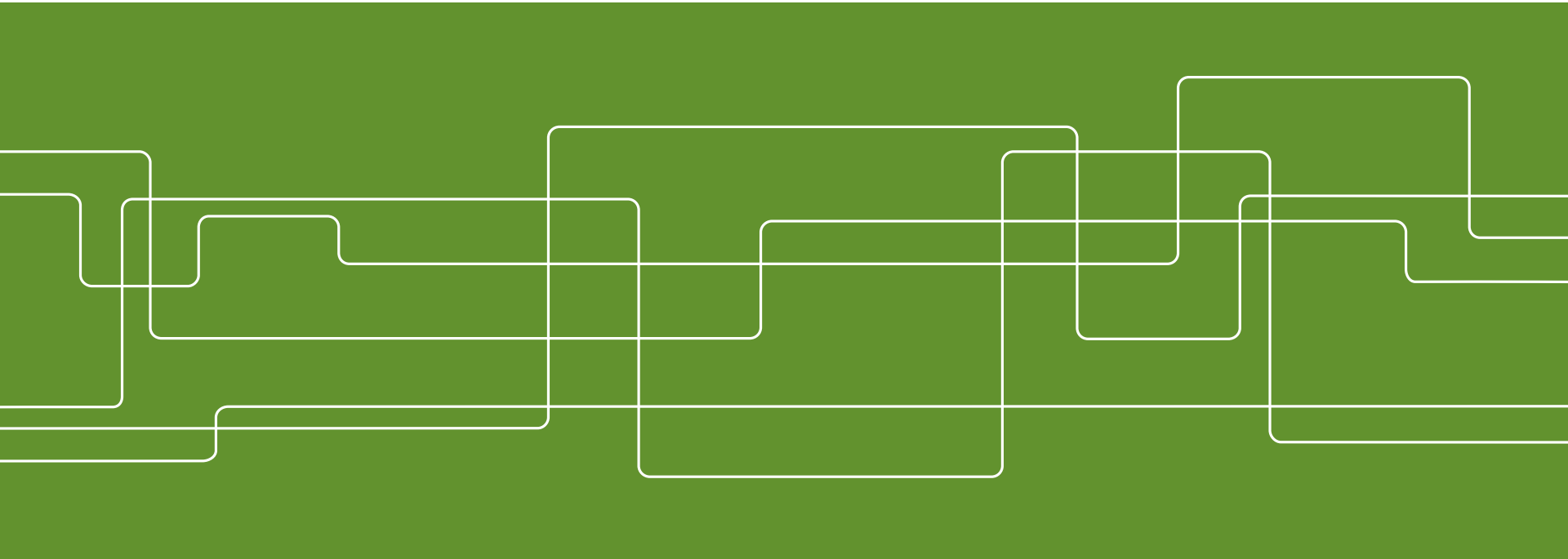
- This is what the aim of Svenska Kraftnät has always been, i.e., a cost neutral system. However, it cannot be too complicated.
- Very close to “fair” already now. Possible changes will have an impact on part of öre/kWh. Unclear in which direction
- Not trivial to change since we are a part of the Nordic system.
- But if the government will “subsidize nuclear” (i.e. not “fair treatment”), then they have a (rather small) tool here. (today < 1 öre/kWh).



# Proposals from new Swedish Government

## SD – M – KD – L

**Tidö - agreement - 2**





# On demand + nuclear power

## Förutsättningar för investeringar i ny kärnkraft (page 12)

Förutsättningarna för investeringar i kärnkraft ska stärkas genom särskilda statliga kreditgarantier uppgående till 400 miljarder kronor, med mer generösa villkor än dagens system. Avgränsningarna i dagens system med gröna kreditgarantier behöver ses över så att kreditgarantierna kan användas även för nybyggnation av kärnkraft.

## Styrning av myndigheter, statliga verk samt ny forskningsinriktning

Vattenfall bör omedelbart påbörja planeringen av ny kärnkraft vid Ringhals och andra lämpliga platser.

## Nytt energipolitiskt mål

Planeringen för ökad elanvändning bör utgå från ett nu prognosticerat elbehov på minst 300 terawattimmar 2045.

Tidöavtalet:

# Överenskommelse för Sverige







# On demand + nuclear power

**(page 9)**

Energipolitikens mål är att Sverige går från hotande elunderskott till ett överflöd på fossilfri el. Svensk internationell konkurrenskraft bygger på god tillgång till prisvärd energi.

## Regeringsförklaringen

18 oktober 2022



Regeringen



# On demand + nuclear power

## Management of authorities, government works and new research direction

Vattenfall should **immediately start planning new nuclear power** at Ringhals and other suitable locations.

## New energy policy goal

The planning for increased electricity use should be based on a currently forecasted **electricity demand of at least 300 terawatt** hours in 2045.

Tidöavtalet:  
**Överenskommelse  
för Sverige**



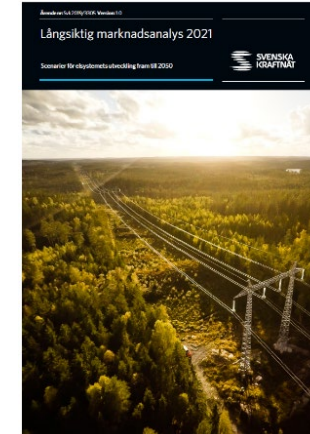
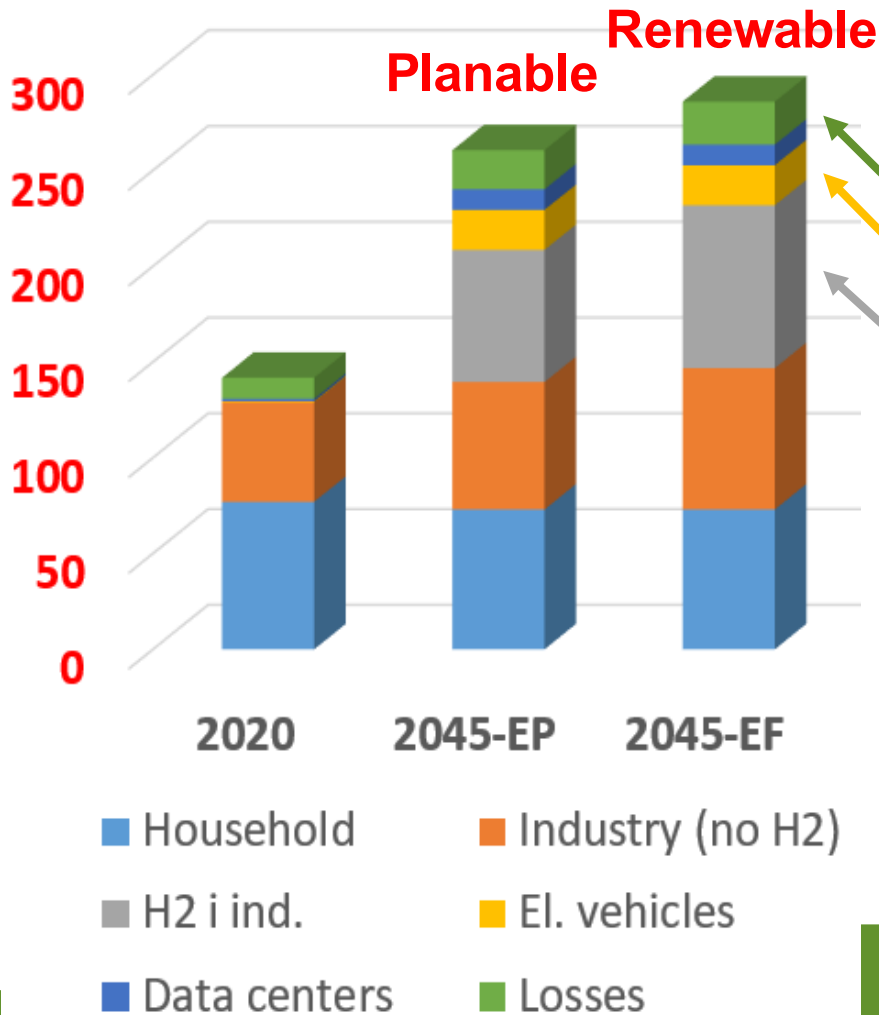
The energy policy's goal is for Sweden to move from a threatening electricity deficit to one abundance of fossil-free electricity. **Swedish international competitiveness is based on good access to affordable energy.**

Regeringsförklaringen  
18 oktober 2022



# Two studied scenarios for the future Electrification

## Consumption assumption



Increased consumption 2020-2045-EF: 144 TWh

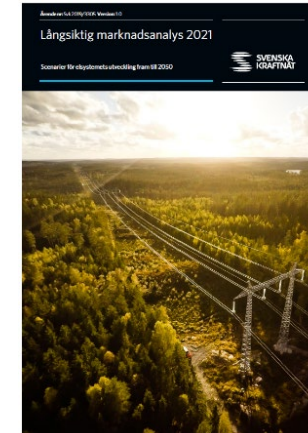
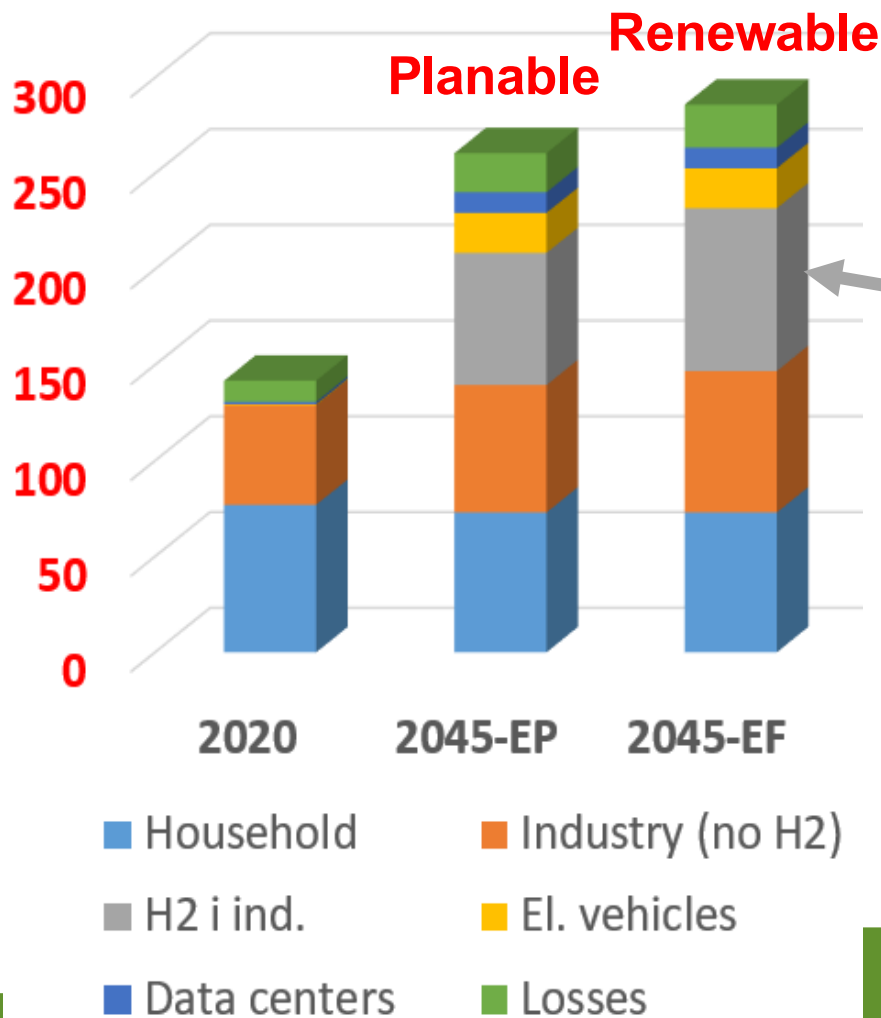
- Part of losses
- 21 TWh: vehicles
- 85 TWh: hydrogen

→ **79% of increase**  
is hydrogen or  
vehicles, → **flexible**  
**consumption**



# Two studied scenarios for the future Electrification

## Consumption assumption



**85 TWh yearly  
consumption from  
electrolyzers/hydrogen**

**These industries have  
to get cheap electricity  
to be internationally  
competitive**

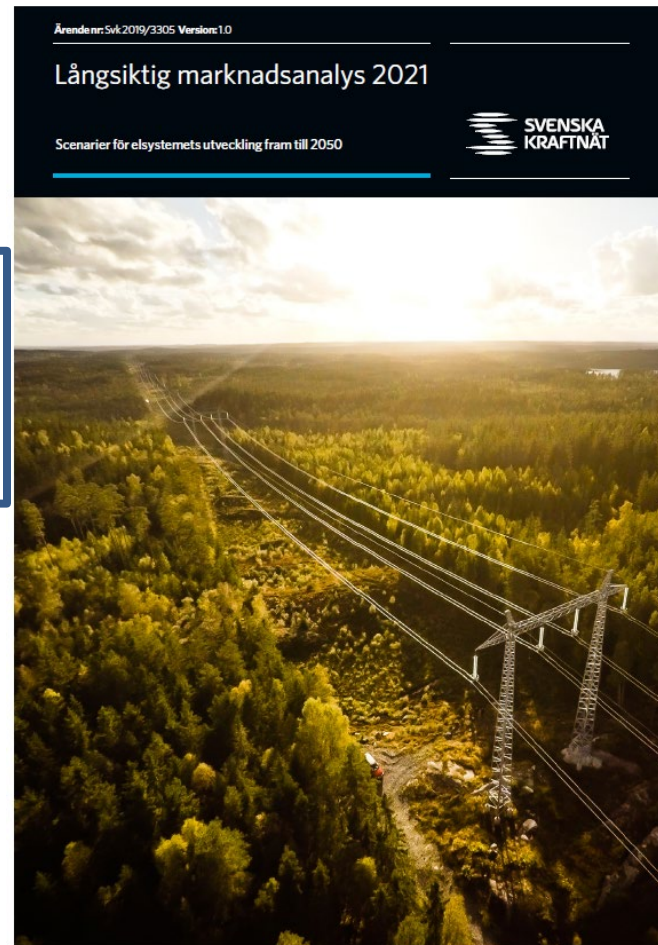
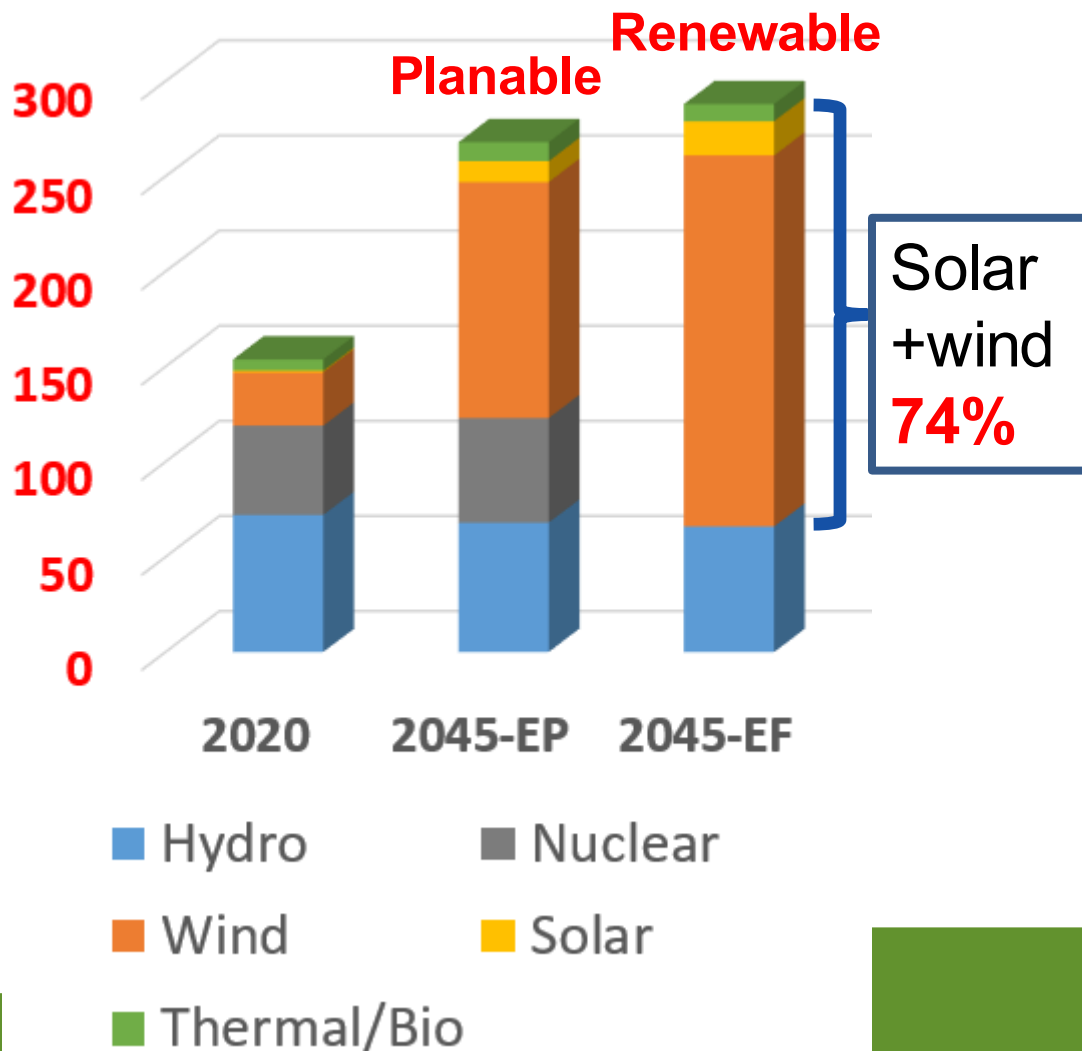


# Two studied scenarios for the future

## Electrification

”Long Term market analysis”,  
from May 2021

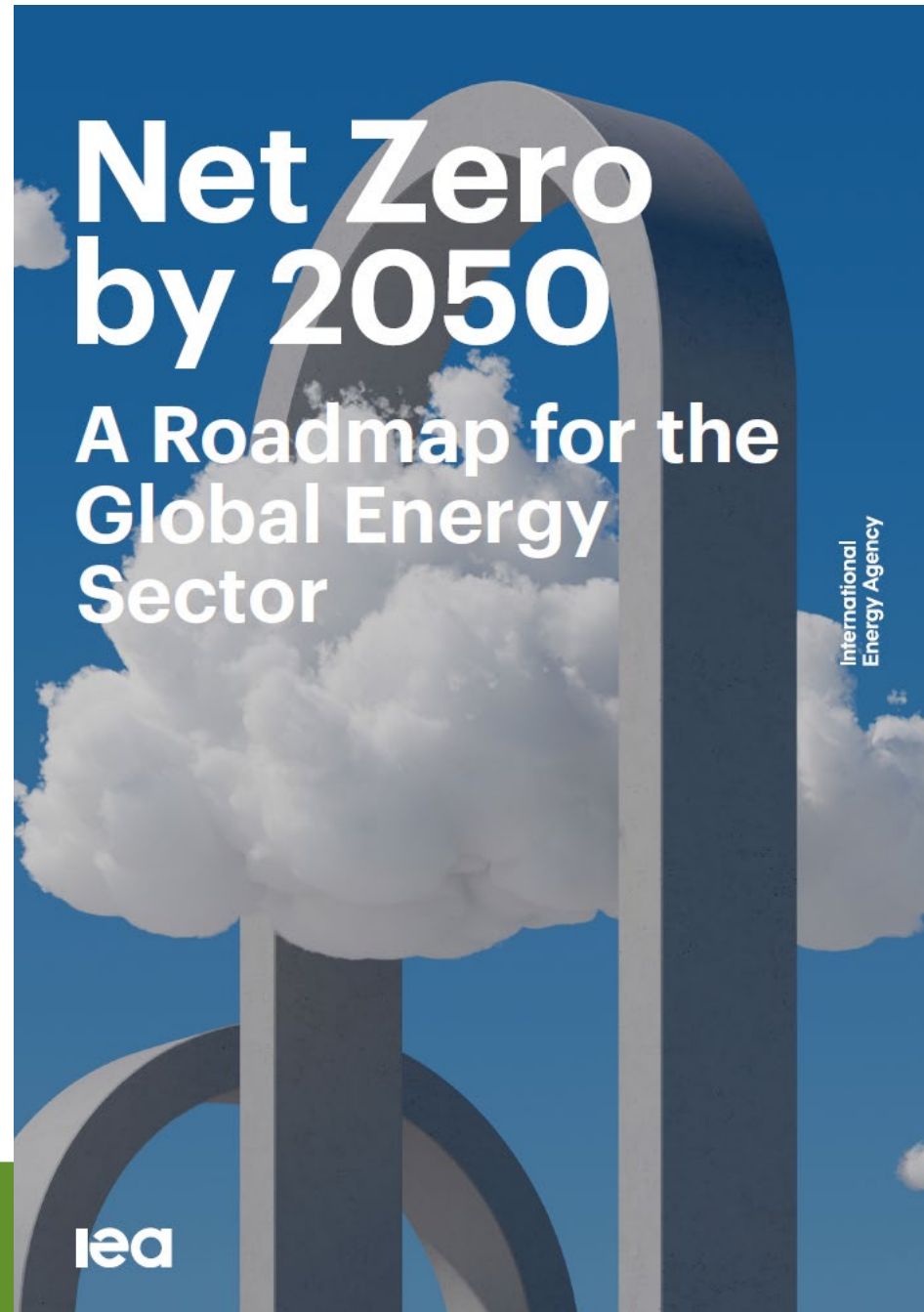
### Production results/assumption



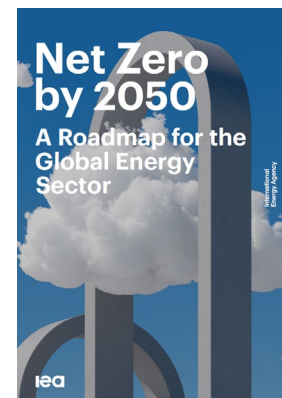


# Report from IEA – International Energy Agency

May 2021



# Assumed cost development: p 201



**Table B.1** ▶ Electricity generation technology costs by selected region in the NZE

	Financing rate (%)	Capital costs (\$/kW)			Capacity factor (%)			Fuel, CO <sub>2</sub> and O&M (\$/MWh)			LCOE (\$/MWh)		
		All	2020	2030	2050	2020	2030	2050	2020	2030	2050	2020	2030
<b>European Union</b>													
Nuclear	8.0	6 600	5 100	4 500	75	75	70	35	35	35	150	120	115
Coal	8.0	2 000	2 000	2 000	20	<i>n.a.</i>	<i>n.a.</i>	120	205	275	250	<i>n.a.</i>	<i>n.a.</i>
Gas CCGT	8.0	1 000	1 000	1 000	40	20	<i>n.a.</i>	65	95	120	100	150	<i>n.a.</i>
Solar PV	3.2	790	460	340	13	14	14	10	10	10	55	35	25
Wind onshore	3.2	1 540	1 420	1 300	29	30	31	15	15	15	55	45	40
Wind offshore	4.0	3 600	2 020	1 420	51	56	59	15	10	5	75	40	25





## About new nuclear power

### Cheapest bid from a UK auction on nuclear:



- The UK Government and EDF Group have reached commercial agreement on the key terms of a proposed investment contract for the Hinkley Point C nuclear power station in Somerset.(2013).
- The key terms include a “Strike Price” of £89.50 /MWh fully indexed to the Consumer Price Index for 35 years which will be increased with inflation.
- <https://www.gov.uk/government/news/initial-agreement-reached-on-new-nuclear-power-station-at-hinkley>





# About new nuclear power



Cheapest bid from a UK

**Now** (October-2022)

106.12 £/MWh = **1.33 kr/kWh**.

<https://www.lowcarboncontracts.uk/cfds/hinkley-point-c>

- The UK government has reached a proposed investment contract for the Hinkley Point C nuclear power station in Somerset.(2013).
- The key terms include a “Strike Price” of **£89.50 /MWh** fully indexed to the Consumer Price Index for 35 years which will be increased with inflation.
- <https://www.gov.uk/government/news/initial-agreement-reached-on-new-nuclear-power-station-at-hinkley>



# Off-shore wind power in UK

## Contracts for Difference (CfD) Allocation Round 4: results (accessible webpage)

Published 7 July 2022

In UK there are auctions for renewable power production where the actors provide bids for which fixed price they need to build their power plant.

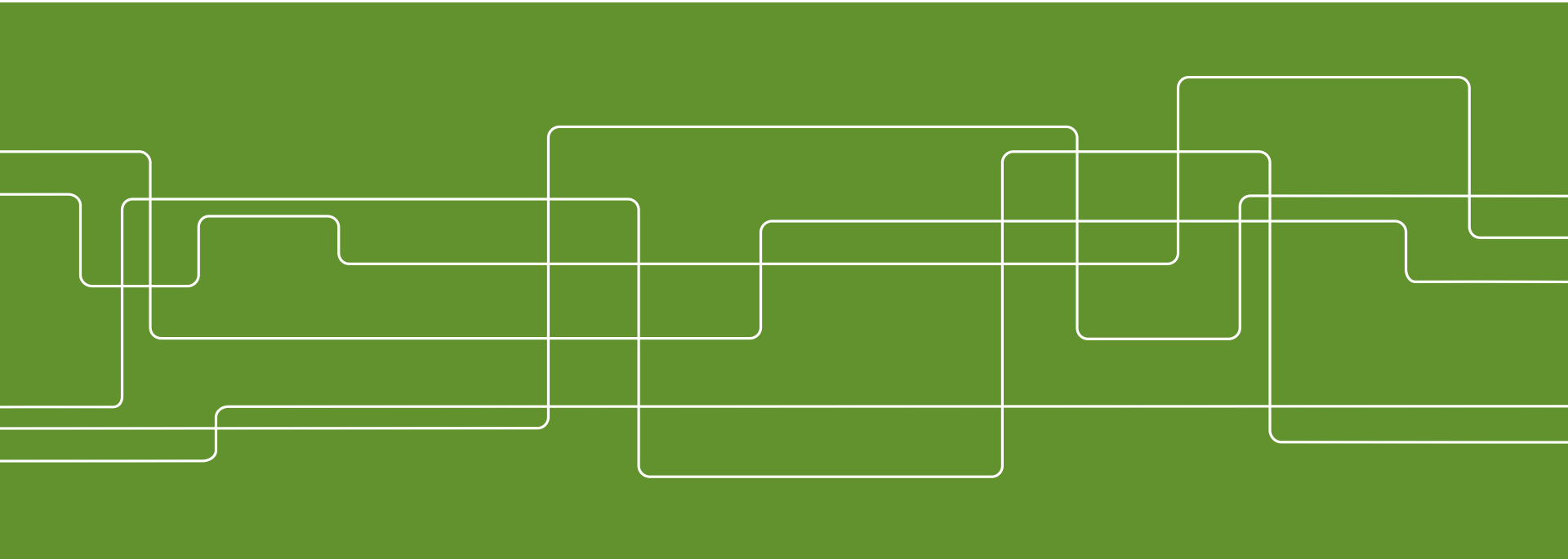
Project Name	Region	Applicant	Technology Type	Size (MW)	Strike Price (£/MWh)
Inch Cape Phase 1	Scotland	INCH CAPE OFFSHORE LIMITED	Offshore Wind	1080.00	37.35
EA3, Phase 1	England	EAST ANGLIA THREE LIMITED	Offshore Wind	1372.34	37.35
Norfolk Boreas (Phase 1)	England	NORFOLK BOREAS LIMITED	Offshore Wind	1396.00	37.35
Hornsea Project Three Offshore Wind Farm	England	ORSTED HORNSEA PROJECT THREE (UK) LIMITED	Offshore Wind	2852.00	37.35
Moray West Offshore Wind Farm	Scotland	MORAY OFFSHORE WINDFARM (WEST) LIMITED	Offshore Wind	294.00	37.35

**37.35 £/MWh**  
**≈ 47 öre/kWh**

A UK offshore wind farm **pays for** the majority of **the offshore grid** investment, **and a proportion of the onshore grid** determined by the UK's regulated charging arrangements.



# The role of hydrogen production as a flexible demand in the Swedish future power system



# Presentation from Vattenfall at a hydrogen online seminar: December 11, 2020 (translated)

## Making steel without coal

**HYBRIT**  
▶▶ FOSSIL-FREE STEEL

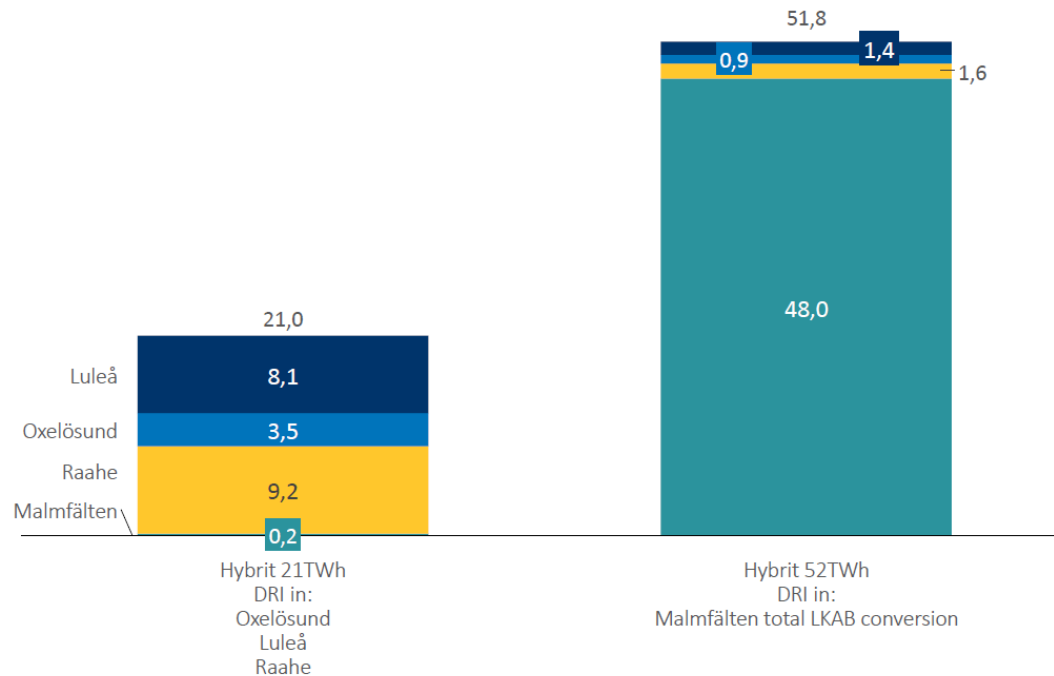
### HYBRIT – Power system integration and flexibility

Tobias Rehnholm



# Presentation from Vattenfall at a hydrogen online seminar: December 11, 2020 (translated)

## Scenario analysis and market interaction



### Flexibilitetsantaganden

#### Hybrit 21TWh

- 180% elektrolyserkapacitet
- 7 dagars vätgaslager

#### Hybrit 52TWh

- 180% elektrolyserkapacitet
- 14 dagars vätgaslager

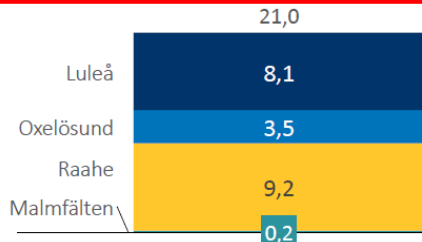
Elkonsumtion är kompenserad med 100% vind

# Presentation from Vattenfall at a hydrogen online seminar: December 11, 2020 (translated)

## Hybrit-large:

- 52 TWh/year
- Assume 80% for hydrogen
- → Mean: 4700 MW
- 180% → **Peak: 8500 MW**
- **14 days storage**

## market interaction



### Flexibilitetsantaganden

- Hybrit 21TWh
- 180% elektrolyserkapacitet
  - 7 dagars vätgaslager

- Hybrit 52TWh
- 180% elektrolyserkapacitet
  - 14 dagars vätgaslager

Elkonsumtion är kompenserad med 100% vind

## Hybrit-large:

- Power consumption **compensated with 100% wind**

# Slide from LKAB concerning forecasted/ planned / assumed increase of hydrogen use.

## Electricity need and hydrogen production





# Wind Power Research in Focus Göteborg, October 25, 2022

## The role of wind power in the future Swedish power system

### Conclusions:

- Wind power expansion is essential for a low cost fossil free expansion of the Swedish power system.





# Wind Power Research in Focus

## Göteborg, October 25, 2022

### The role of wind power in the future Swedish power system

#### Conclusions:

- Wind power expansion is essential for a low cost fossil free expansion of the Swedish power system.
- The new Swedish Governments set-up of off-shore wind farms should pay for their grid + their discussions on "new nuclear power" will delay the expansion.



# Wind Power Research in Focus

## Göteborg, October 25, 2022

### The role of wind power in the future Swedish power system

#### Conclusions:

- Wind power expansion is essential for a low cost fossil free expansion of the Swedish power system.
- The new Swedish Governments set-up of off-shore wind farms should pay for their grid + their discussions on "new nuclear power" will delay the expansion.
- The continuous power system balancing is essential and new technologies has a large potential.