WHEN TRUST MATTERS

Framtidens elsystem och energiomställningen

Med sikte på 2050

Ambra Sannino, Power Systems Planning, Northern Europe

18 April 2023

About myself – Ambra Sannino

M.Sc. Electrical Engineering, 1997
Ph.D. Power Systems, 2000

2001-2004: Post-doc > Assistant Professor > Associate Professor

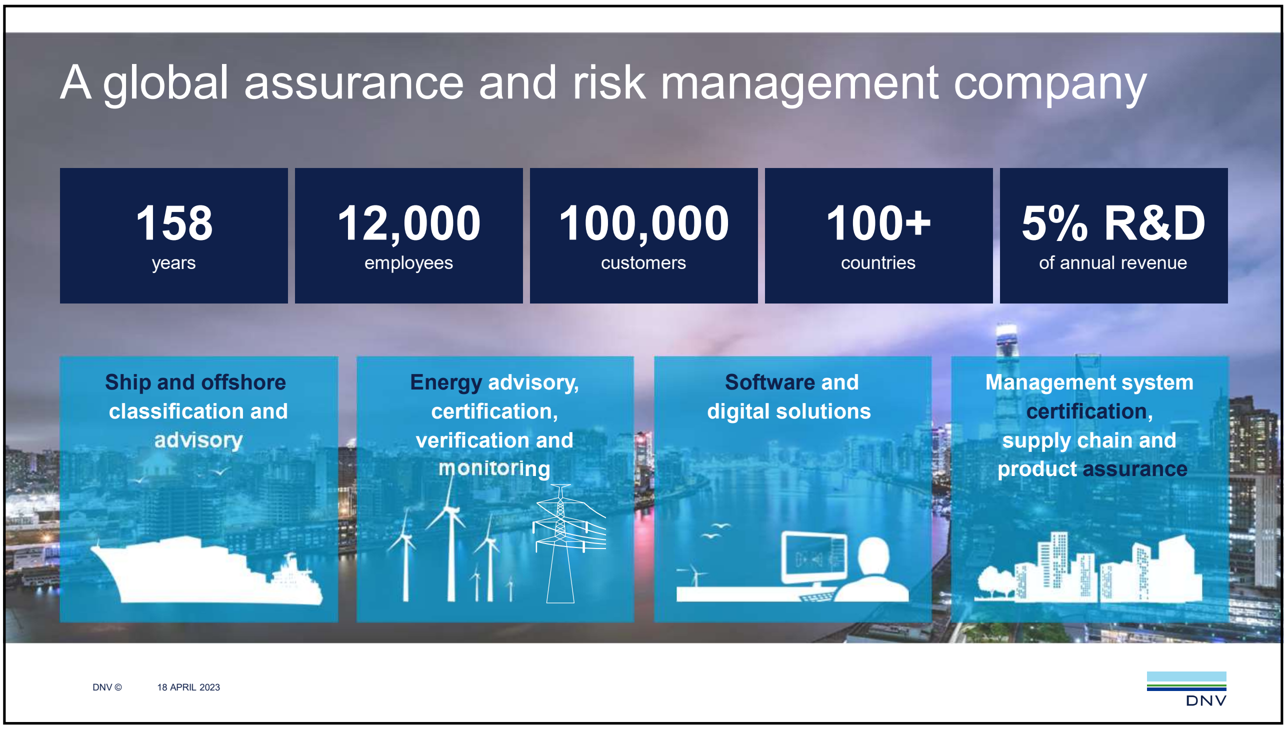
2004 – 2018:
Corporate R&D: Project Manager > Team Manager
R&D / Technology Manager, for FACTS, Substations,
Product Manager for Power Quality Solutions

2019 – today:
Business Director, Power System Analysis
Head of Department Power Systems, Northern Europe

IEEE Senior Member
Member since 1999

Cigré Member

Board member of
Kraftkvinnorna
and Power Circle



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4000 experts
provide local access to global best practice delivering safe and effective energy systems

90+ years
serving the energy industry, including the oil and gas, wind and solar sectors

24
laboratories and test centres including facilities for full-scale testing

170
industry standards, guidelines and recommended practices, and approx. 30 joint industry projects per year

65%
of offshore pipelines designed and installed to DNV standards

42 GW
of real-time operational data from solar PV, wind and storage assets under management

>100
large power utility companies trust us as their technical advisor

World 1st
hydrogen full-scale testing facility supporting safety, infrastructure and policy

How did we get here?

DNV·GL

DNV

KEMA

gothia power

NOBLE DENTON

GARRAD HASSAN

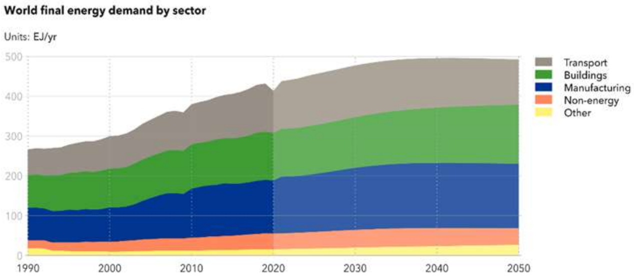
ADVANTICA

GL Group

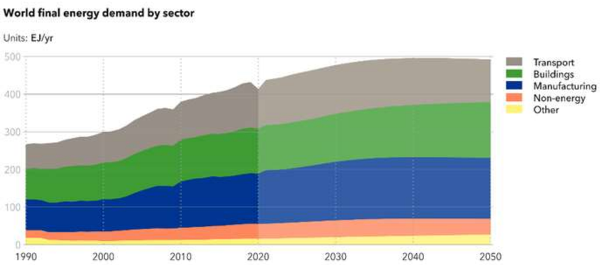
Suite of publications available on **eto.dnv.com**

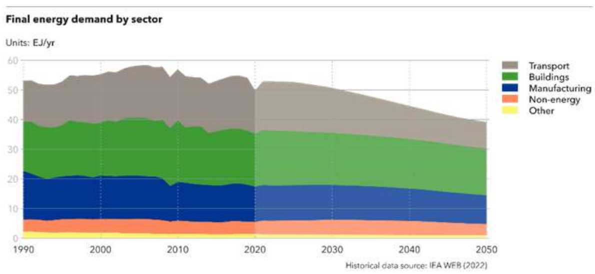
Final energy demand levels off from 2030

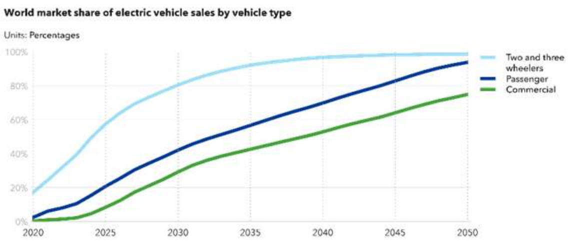
- Energy demand getting back to pre-Covid levels
- Final energy demand peaks around 2040, slightly above 2021 figures (13%), and remains then flat to 2050
- Reduction in energy intensity
  - energy consumed per unit of GDP will reduce by 2.4%/yr over the next 30 years
- Energy efficiency achieved via electrification
  - Transport: electric vehicles + hydrogen
  - Buildings: heat pumps
  - Industry: decarbonization by using hydrogen

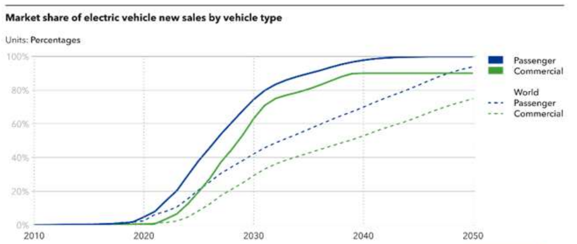


Europe vs Global





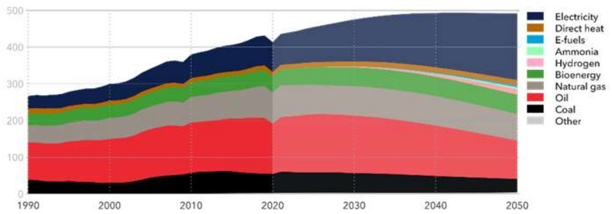




Europe vs Global

World final energy demand by carrier

Units: EJ/yr



Final energy demand by carrier

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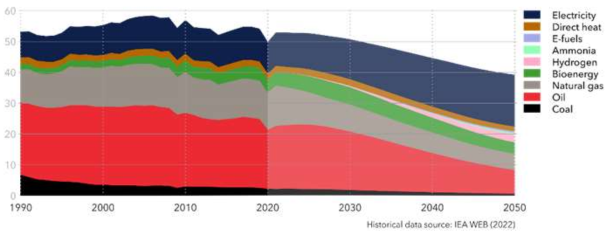
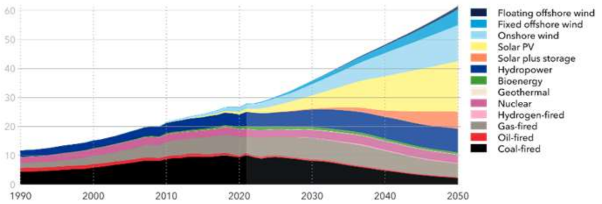


Historical data source: IEA WEB (2022)

World grid-connected electricity generation by power station type

Units: PWh/yr



Grid-connected electricity generation by power station type

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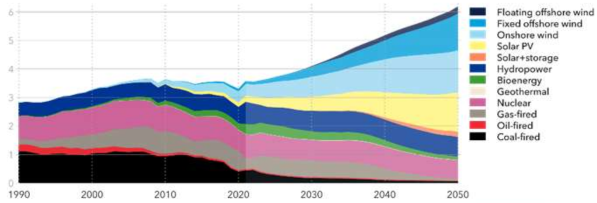


Historical data source: IEA WEB (2022), GlobalData (2022)

Trends in Power & Energy: Decarbonization

DEMAND | **SUPPLY**

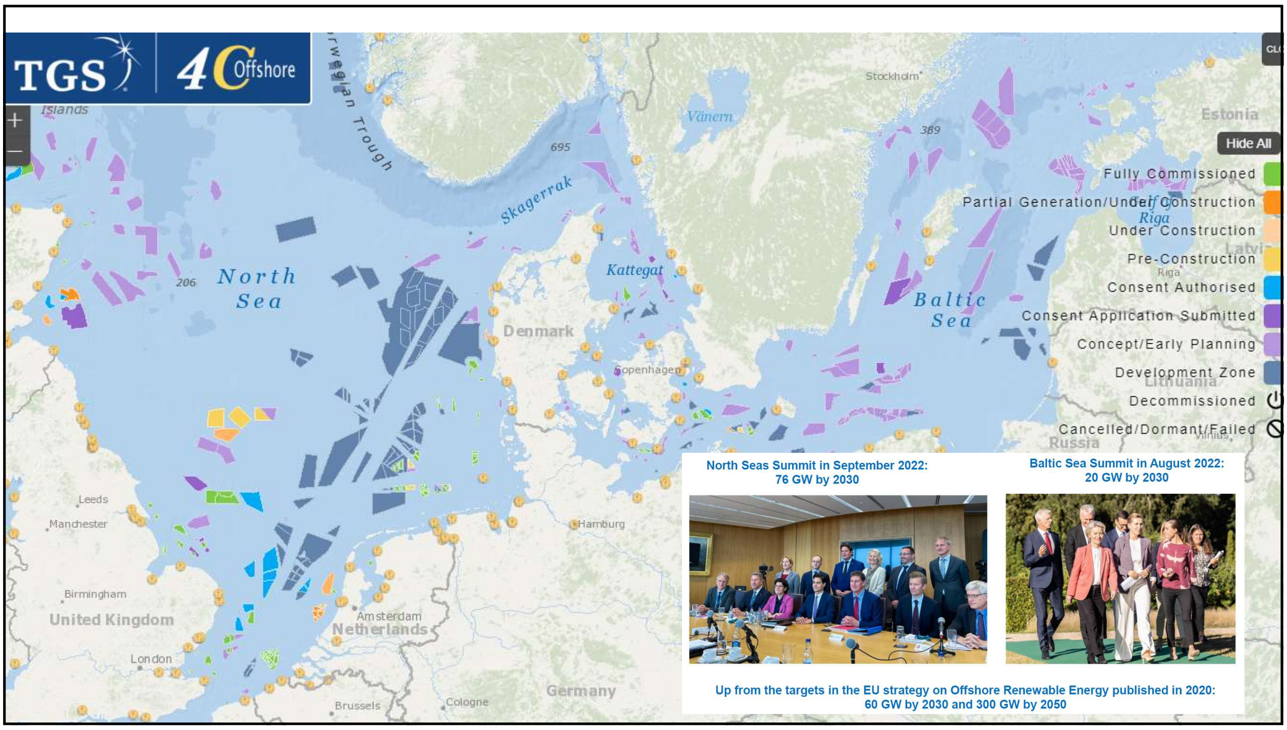
INDUSTRY
Hydrogen electrolysers

BUILDINGS
Heat pumps

POWER GRID

Electricity brings more efficient energy use with low climate impact, **if generated in a green way**

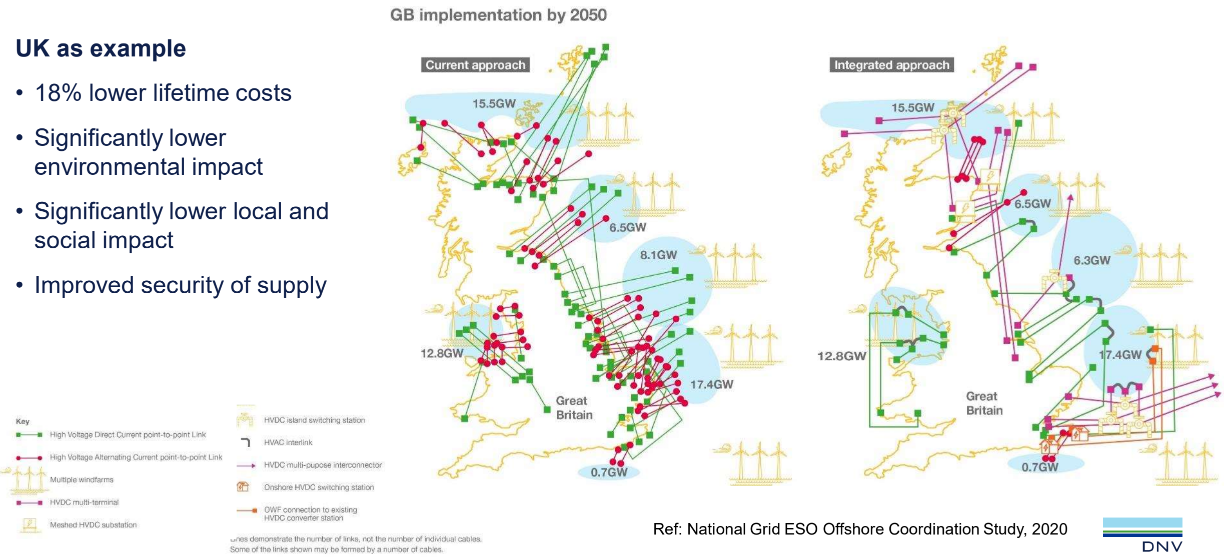
Power grids investment to grow by 50% in the next 10 years
of which 15% in digital infrastructure
Transmission lines will double, distribution > double by 2050



Multi-terminal HVDC grid benefits

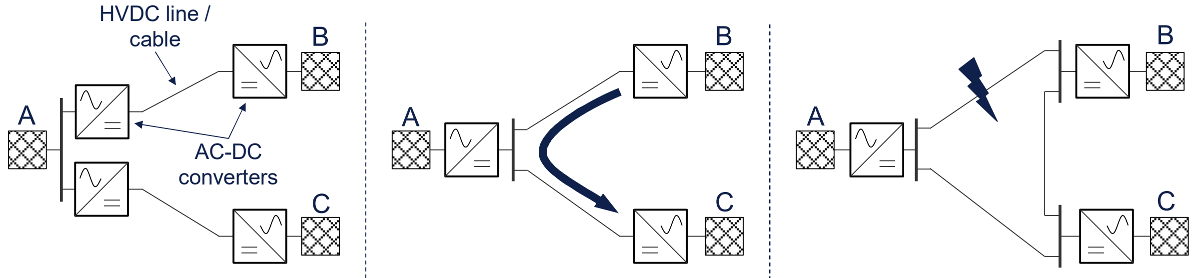
UK as example

- 18% lower lifetime costs
- Significantly lower environmental impact
- Significantly lower local and social impact
- Improved security of supply



Ref: National Grid ESO Offshore Coordination Study, 2020

HVDC systems



Point-point systems

- Bespoke projects
- Easier project development
  - Single vendor procurement
  - Single purpose
- Mature and widely applied

Radial multi-terminal system

- Multi-purpose
- Fewer converters
  - Lower cost
  - Lower footprint
  - Lower losses
- Requires compatibility

Meshed multi-terminal system

- Redundant paths
  - Increased availability
  - Reduced impact on AC grids
- Requires DC protection system

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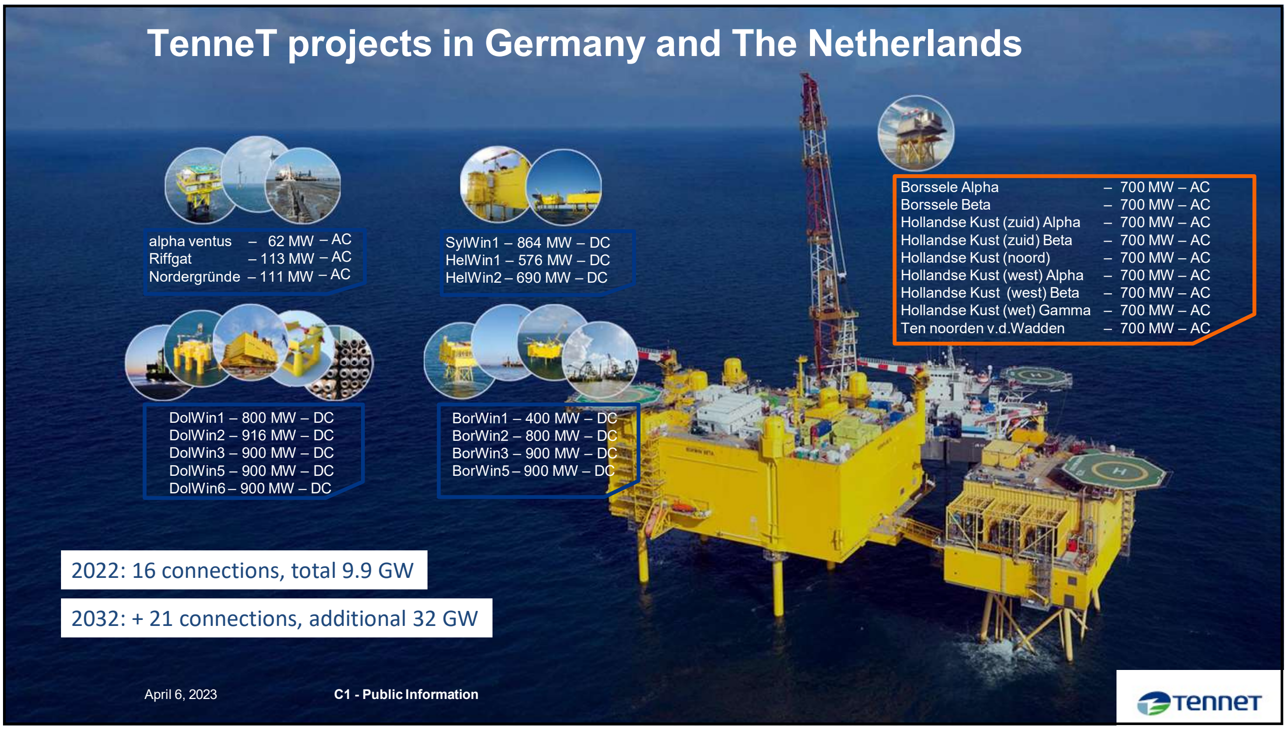

2 GW concept

- End of March 2022, Tennet awarded 11 connections for total 23 bnEUR
- based on new 2GW concept developed together with the market
- The 2 GW concept consists of
  - Standardized cable
  - Standard platform design
  - Standard contract
- The 2 GW concept is
  - Standardized in design
  - Procured at scale
  - DC grid-ready

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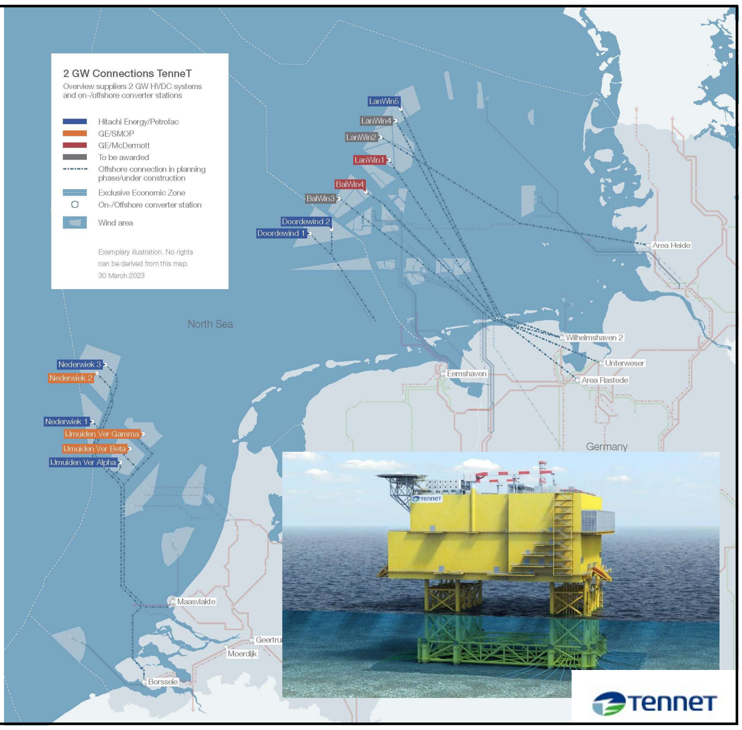
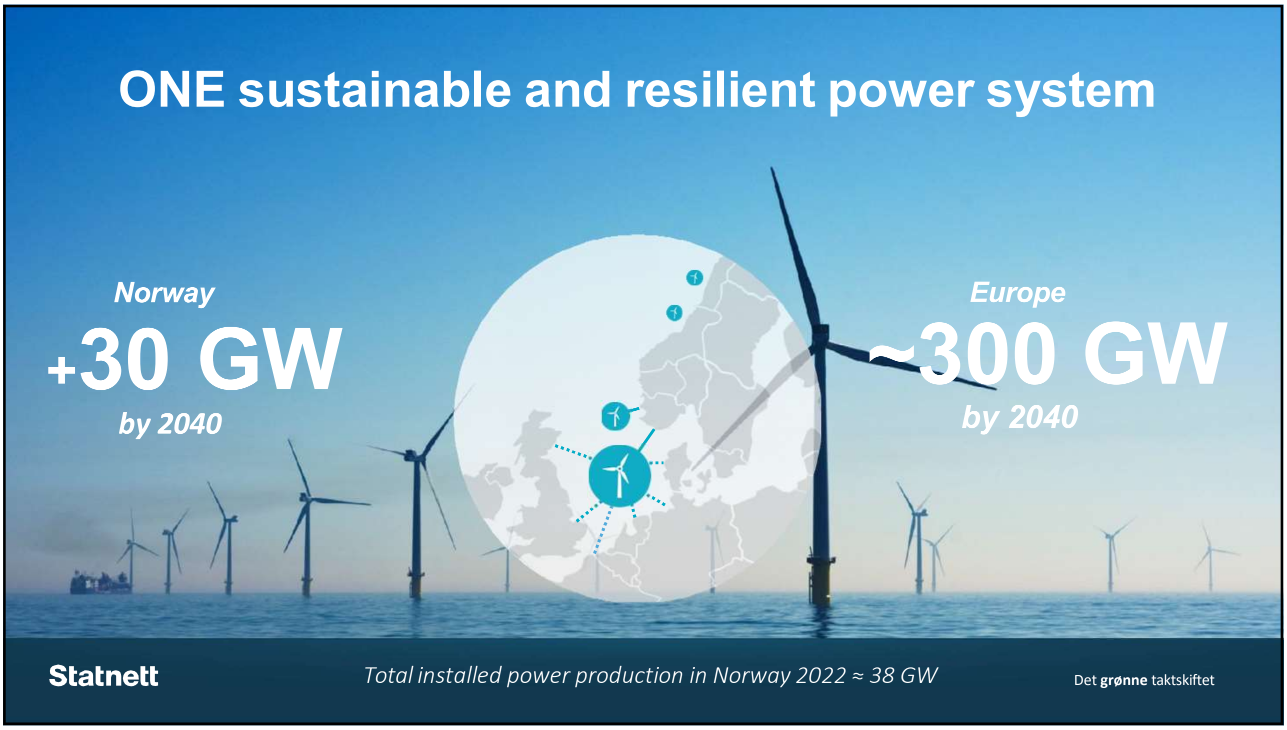
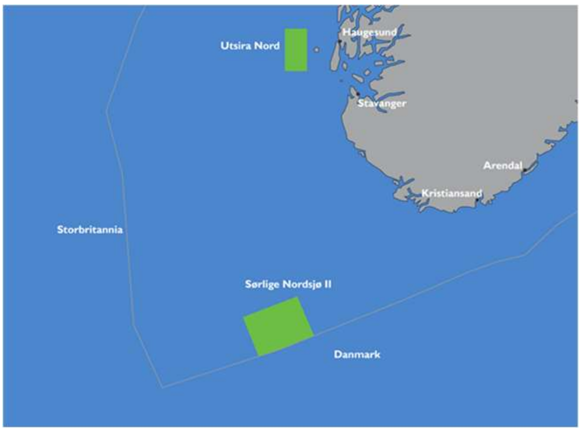




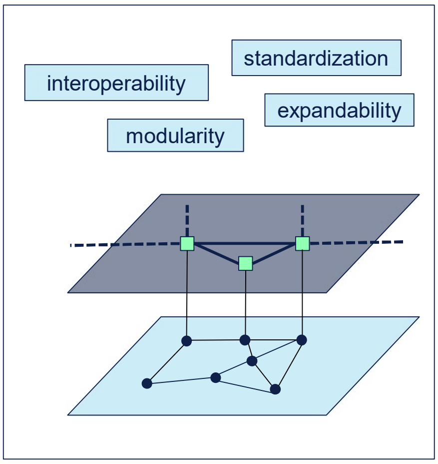
Norway – First step

- Two areas:
  - Utsira Nord, potential 1.5 GW, floating
  - Sørlige Nordsjø II, potential 3 GW, fixed
- Auction for first chunk of SNII opened end of March, sites will be awarded in Dec
- SNII first phase will be a 1500 MW radial link to Norway. For the second phase, a hybrid interconnector to other countries may be considered.
- Statnett's analyses show that a hybrid solution would be more socioeconomically beneficial than a radial link.



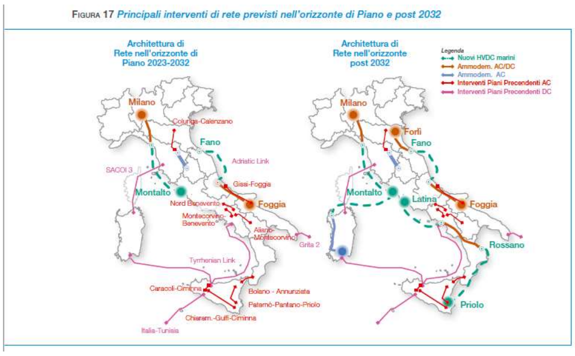
HVDC grids – Opportunities

- Benefits of HVDC grids:
  - Better use of wind resource
  - Better market integration
  - Relieve transmission grid congestion
- Overlay DC grid as **backbone of the 2050 European grid**
  - Coordination to unlock **project synergies** and realize **societal benefits**
  - Standardisation to enable **technical compatibility** and interoperability
  - Integration with the existing AC grid



Example: Terna's Hypergrid

- New Development Plan of Italy's transmission grid unveiled in mid March
- Investment in the next 10 yrs up by +17% to a total of €21bn, of which €11bn for five HVDC backbones
- Power transmission capacity from south to north doubles from today's 16 GW to 30 GW
- Terna has connection requests for 300GW today
- The plan includes 500kV marine connections and extensive use of DCCBs by 2032

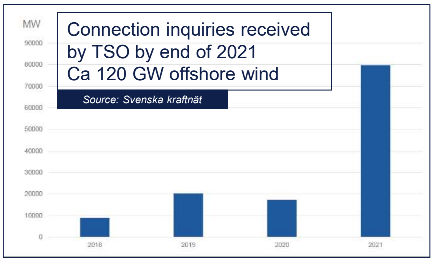


Source: Terna

Five new HVDC backbones combined with existing and already planned HVDC links (eg Thyrrenian link) create an overlay DC grid (Hypergrid)

Now Sweden is moving

- Dramatically increased activity in past few years
- In 2022, the Swedish government tasked the TSO with expanding the transmission into territorial waters
- In the first round, 6 areas have been prioritized.
- No prior choice of technology, can be AC or DC



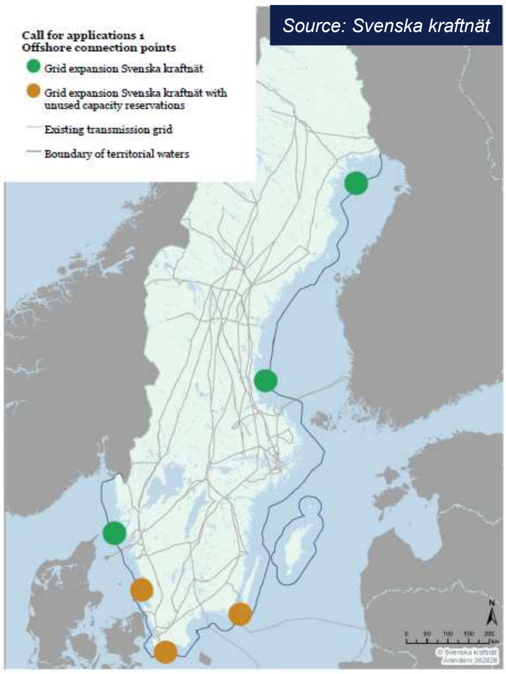


Figure 2. Offshore connection points in call for applications 1.

Baltic Sea Conference Sept 2022

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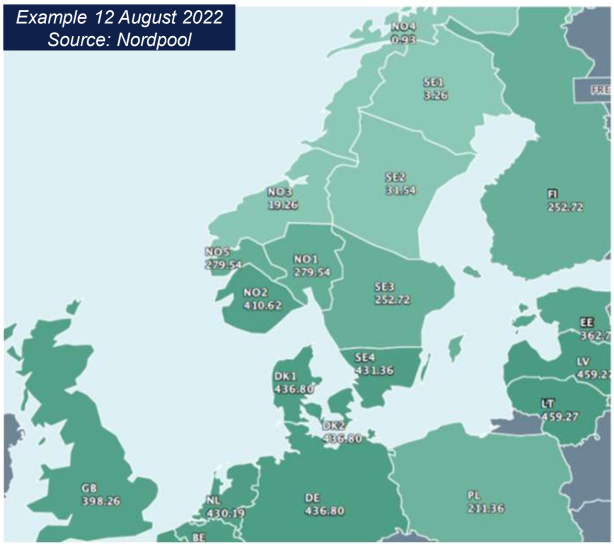
Today's situation in Sweden

Example 12 August 2022
Source: Nordpool



- Generation reduced in the South due to decommissioning of nuclear reactors
- Strong development of wind power (on land) concentrated in the North
- Insufficient transfer capacity North – South, leads to price differences >100 times across the country (similar in Norway).
- Huge reinforcement program under way, but will take years to build more transmission → urgent need for generation in the South

Many other EU countries have similar congestions issues

Potential next step?

- No prior choice of technology, can be AC or DC
- Possibility to create a parallel North-South path
- Support the existing AC grid with eg additional transfer capacity, but also voltage support / inertia
- Could be expanded into transnational / hybrid interconnector
- Could be prepared for further additions eg on or close to Gotland

- Expandability is key!
- *Note: this is NOT in Svenska kraftnät's current plan*

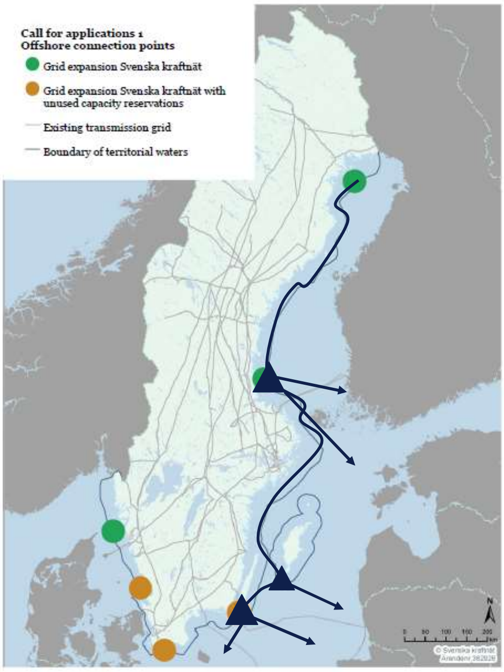
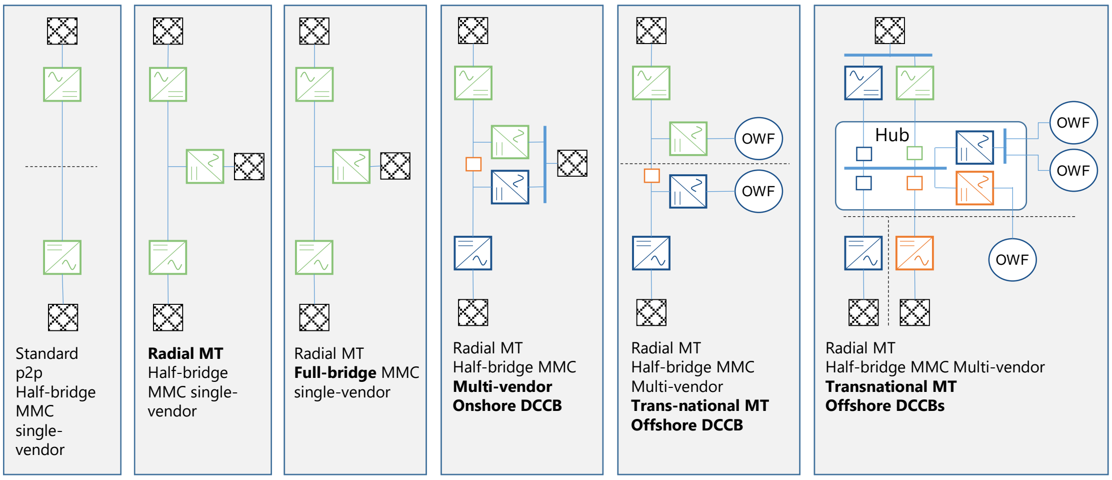


Figure 2. Offshore connection points in call for applications 1.

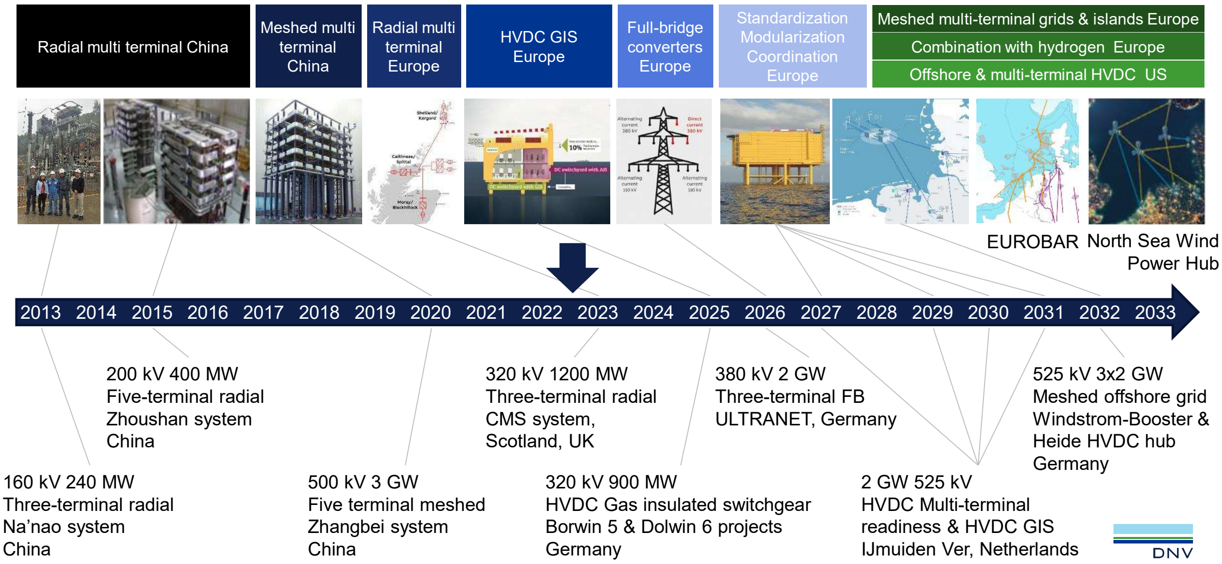
Pilot projects

Full scale demonstrators of feasibility and benefits



Pilot projects

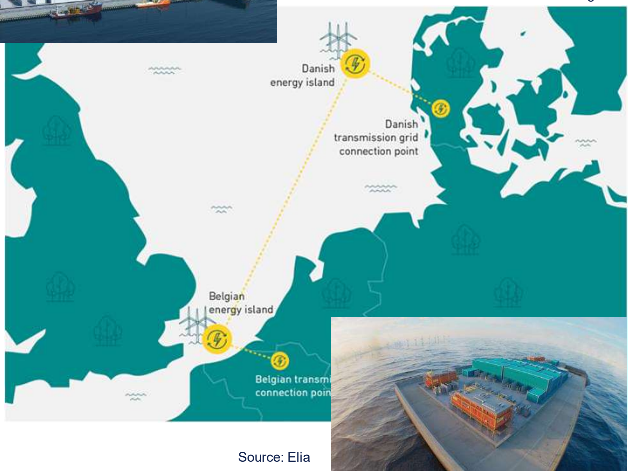
Full scale demonstrators of feasibility and benefits



Energy Islands

Source: Danish Energy Agency

Source: Energinet



Source: Elia

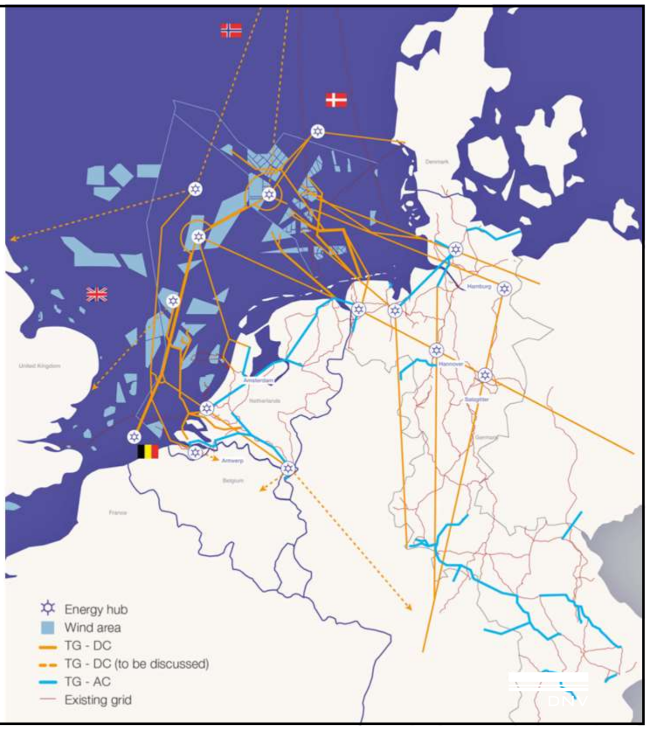
Source: Elia

- June 2020: DK decides to build 2 energy islands
  - Bornholm energy island: capacity of 3 GW,
  - North Sea energy island: capacity of 3 GW in 2033, and 10 GW in the longer term.
- TritonLink will transfer offshore wind energy to DK and BE via two artificial energy islands
  - Studies are ongoing
  - Construction to start in 2026-27, energization in 2031-32
- Energinet also works since 2017 in the NSWPH consortium (with Gasunie and TenneT) on offshore wind hubs

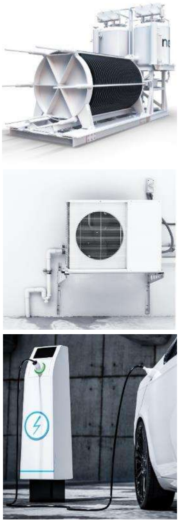
Initial focus on green electricity with additional production of green fuels such as hydrogen or ammonia in the future

Target Grid 2045

- A network of DC superhighways and energy hubs, and a significantly improved existing AC grid
- In 2045, DE and NL face more than doubling of electricity consumption
- They will be able to produce approximately 70 GW of offshore wind energy each
- to be delivered as efficiently as possible to industries and households in NL, DE, and other European countries.
- Look at animation here



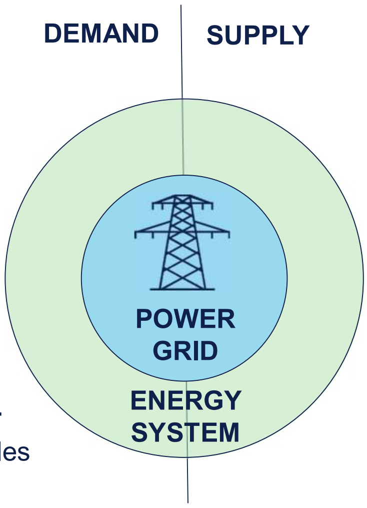
Sector coupling / System of systems



INDUSTRY
Hydrogen electrolysers

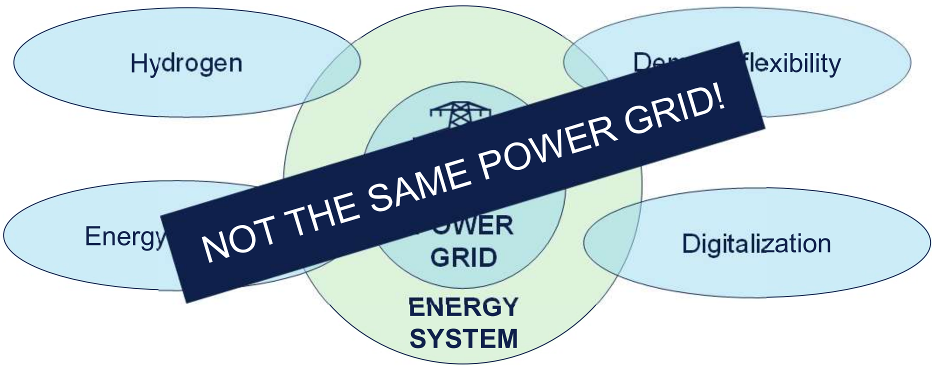
BUILDINGS
Heat pumps

TRANSPORT
Electric Vehicles



Electricity brings more efficient energy use with low climate impact, **if generated in a green way**

Some other things we have not talked about….



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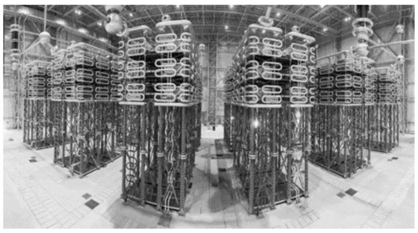
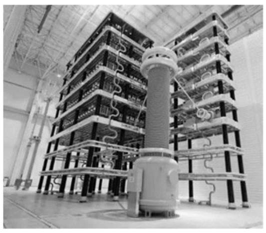
State-of-the-art of technology?





- Cables
  - Mass-impregnated paper
    - 600 kV, 2.2 GW in operation (PPL)
    - 800 kV
  - Extruded polymer
    - 525 kV, 2.1 GW qualified
    - 640 kV, type tested
- Converters
  - Voltage sourced converters
    - 800 kV, 5 GW in operation
  - Line commutated converters
    - 1,100 kV, 12 GW in operation
- Switchgear
  - HVDC circuit breakers
    - 500 kV, 25 kA in operation
  - HVDC gas insulated switchgear
    - 250 kV in operation
    - 525 kV qualified

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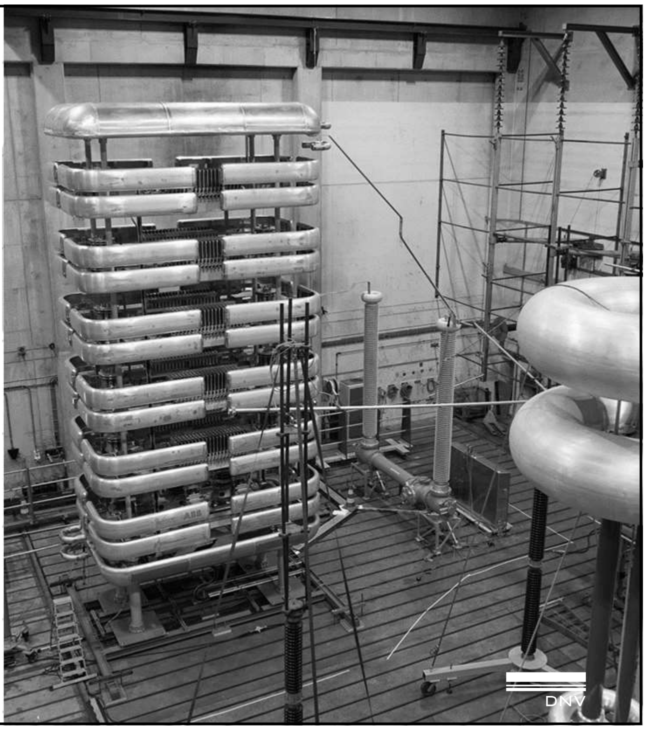
What are the main barriers?

- Inadequate cross-jurisdiction coordination
- Incompatible regulatory frameworks
- Insufficient operational experience
- Lack of standardization
- Unsolved vendor interoperability issues
- Limited supply chain
- Onshore AC grid constraints



HVDC grids – related collaborations

2014 2016 2018 2020 2022 2024 2026

Best Paths
Oct 2014-Sep 2018
Total budget: 62.8 M€
EC contribution: 35.5 M€
39 Partners from
11 European countries

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
Jan 2016 - Dec 2019
Total budget: 42M €
34 Partners from
11 European countries

HVDC grids feasibility proven

READY4DC
Apr 2022 – Sep 2023
Total budget: 1M€
EC contribution: 1 M€
7 Partners

HVDC-WISE
Oct 2022 – Mar 2026
Total budget: 6.9 M€
EC contribution: 6.5 M€
14 Partners from
11 European countries

InterOPERA – Enabling multi-vendor HVDC grids
Jan 2023 – Apr 2027
Total budget: 69 M€
EC contribution: 50 M€
17 Partners

Summary

- Multi-terminal HVDC transmission grids:
  - have **significant benefits** over multiple point-point links
  - already exist → the **technology is ready**
  - are a **key enabler of the energy transition**
- **Pilot projects** needed to demonstrate technical feasibility and project benefits
- **Cooperation and collaboration** across all stakeholder levels needed to achieve:
  - Standardisation to enable **technical compatibility** and interoperability
  - Coordination to unlock **project synergies** and realize societal benefits
- Looking further: combine **offshore wind** and **hydrogen storage** in **energy island** concepts

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To go back in levels use **SHIFT-TAB**

Alternatively, **Increase** and **Decrease** list level can be used

Reset slide

Click the **Reset** menu to reset position, size and formatting of the slide placeholders to their default settings

Reset

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Click on the menu **New Slide** in the **Home** tab to insert a new slide

New Slide

Change layout

Click on the arrow next to **Layout** to view a dropdown menu of possible slide layouts

Layout

PICTURES

On slides with pictureplaceholder, click on the icon and choose **Insert**

Crop picture

1. Click **Crop** to change size or focus of the picture

Crop

2. If you want to scale the picture, hold **SHIFT**-key down while dragging the corners of the picture

HINT: If you delete the picture and insert a new one, the picture may lie in front of the text or graphic. If this happens, select the picture, right-click and choose **Send to Back**

HEADER & FOOTER

Do this at the very end to apply the changes on all slides

Click on **Header and Footer** in the **Insert** tab (write the desired text, click date or page number from or to)

Header & Footer

Click **Apply to All** or **Apply** if only used on one slide

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Click the **View** tab and set tick mark next to **Guides**

HINT: Alt + F9 for quick view of guides

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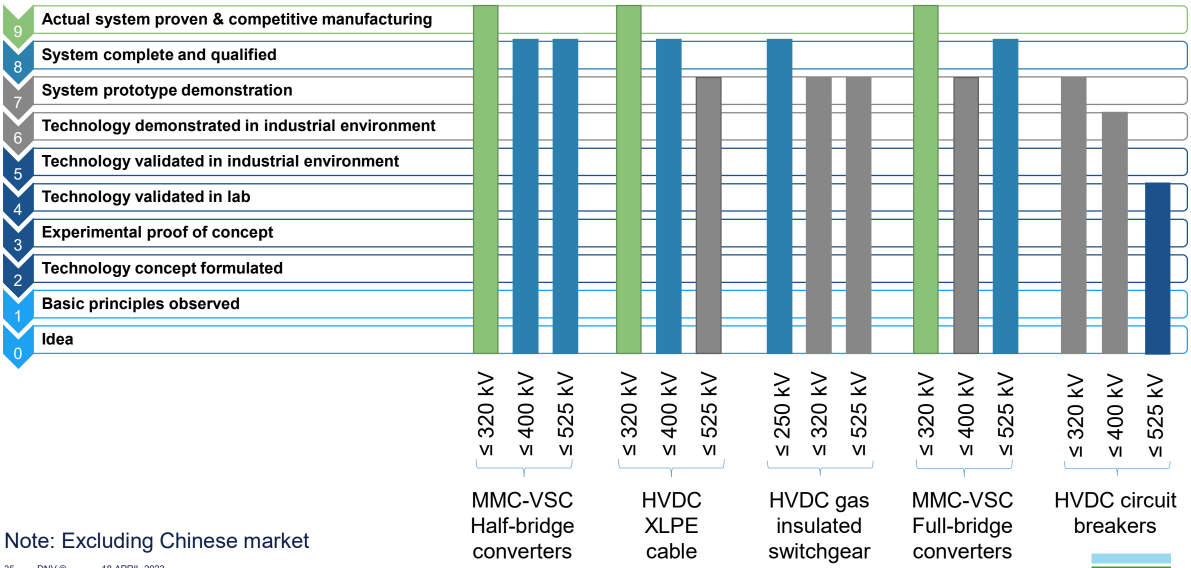
When copying old content to your new presentation, 2 options are available:

1. Best practice: Create a slide in your new presentation and copy one piece of content at a time (e.g. copy all text from one textbox)

2. Or copy an entire slide into your new presentation and then choose a fitting layout. Remember to delete the old, wrong layouts (go to View > Slidemaster and delete them)

Technology readiness

Ref: EU project PROMOTioN (with updates)



Note: Excluding Chinese market

What is the difference?

Multiple point-point links

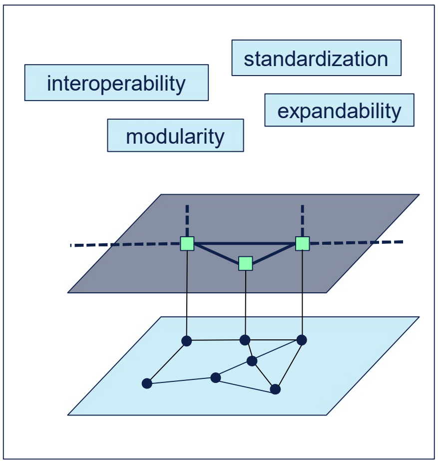
- Allows different technologies and voltage levels for each link
  - Optimise design & operation of each link
- Avoids project dependencies
  - Schedule
  - Terminal locations
  - Anticipatory investments for expandability
- Simplifies multi-vendor interoperability
  - Systems from different vendors coupled at AC side guided by AC grid codes
- Proven, accepted technology

Multi-terminal grid

- Fewer converters
  - Lower losses
  - Lower footprint
    - Lower socio-environmental impact
    - Lower permitting burden
  - Higher availability
- Better utilization
  - Multi-purpose use
- Fewer cables (for meshed systems)
  - Use redundant paths to satisfy most severe single contingency constraints

HVDC grids – Opportunities

- Benefits of HVDC grids:
  - Better use of wind resource
  - Better market integration
  - Relieve transmission grid congestion
- Overlay DC grid as **backbone of the 2050 European grid**
  - Coordination to unlock **project synergies** and realize **societal benefits**
  - Standardisation to enable **technical compatibility** and interoperability
- Integration with the AC grid, some aspects to consider
  - Availability vs redundancy
  - Protection coordination
  - Additional support functionalities
  - Control interactions and other power quality concerns

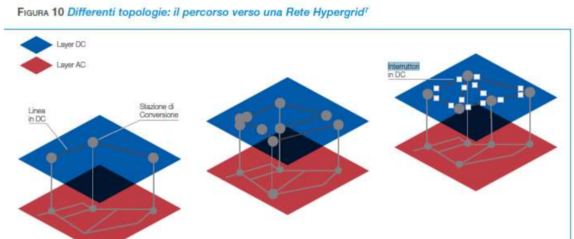


MT-HVDC grid as a backbone?

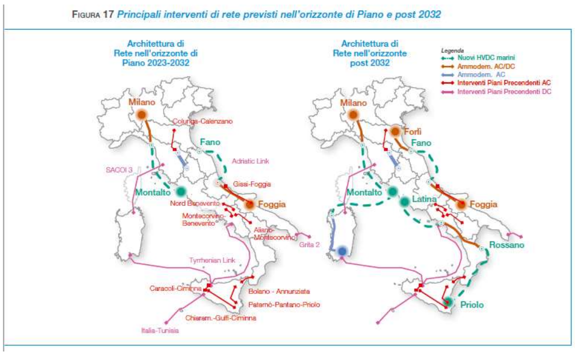
- A multiterminal, overlay DC grid can become the **backbone of the European grid to 2050**
  - How will the 2050 grid look like? HVDC grids will evolve organically → need to be expandable
  - How to enable and prepare for expansion? Standardization, modularization, extra space on platforms?
- **Integration of HVDC grid with the AC grid**, some aspects to consider
  - Availability vs redundancy, how much redundancy is needed?
  - Protection coordination, make use of faster fault clearing in HVDC links?
  - Additional support, eg reactive power, voltage support functionality, inertia
  - Control interactions and other power quality concerns
- **Cooperation** across all stakeholder levels needed to achieve
  - Standardisation to enable **technical compatibility** and interoperability
  - Coordination to unlock **project synergies** and realize societal benefits

Terna’s Hypergrid project

- In March, Terna unveiled its 2023 Development Plan of Italy’s transmission grid, totaling €21bn of investments in the next 10 yrs, (+17% compared to the previous plan)
- The Hypergrid project comprises five new electricity 'backbones’ (total €11bn investment) that – combined with Thyrrenian link and existing HVDC links – will create an overlay DC grid
- Double the power transmission capacity from south to north from today’s 16 GW to 30 GW
- Terna has connection requests for 300GW today
- The plan includes 500kV marine connections and extensive use of DCCBs by 2032

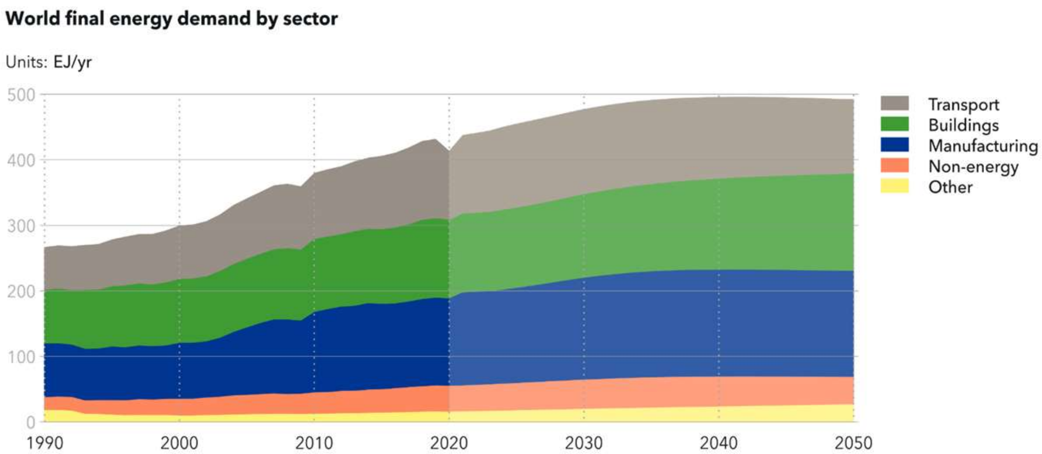


Source: Terna

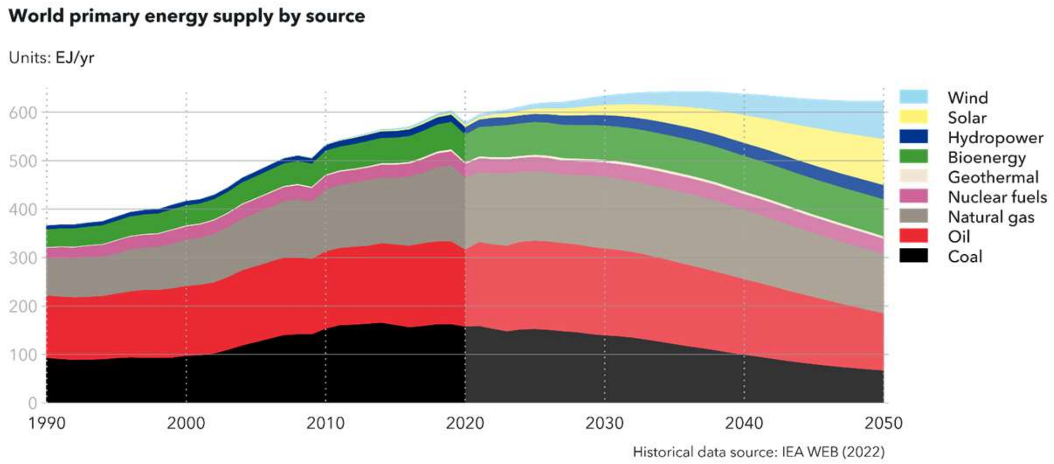


Source: Terna

Final energy demand levels off from 2030

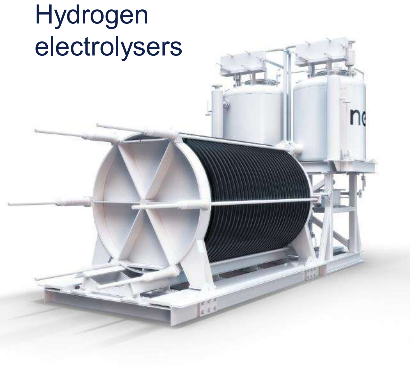


Primary energy supply peaks in 2036



The world is electrifying at high speed

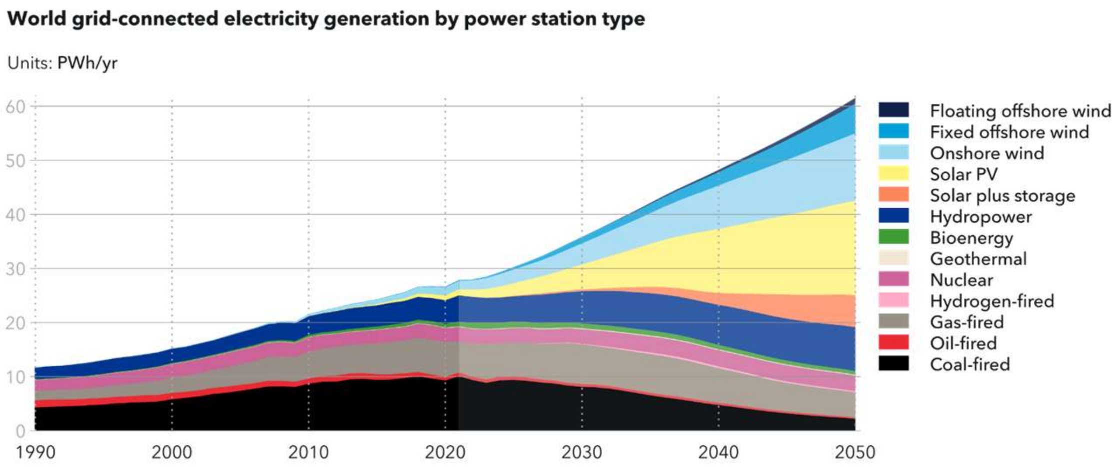
Hydrogen electrolysers



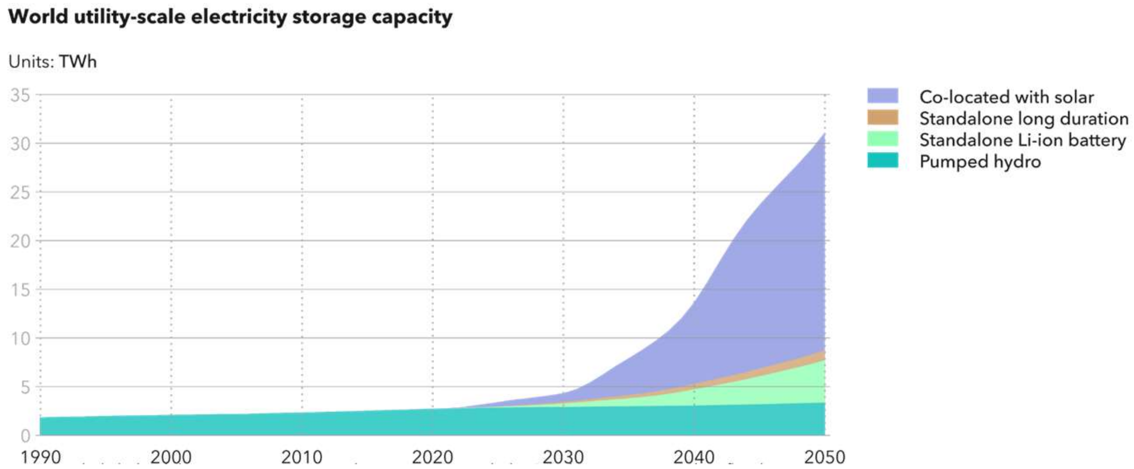
Heat pumps

EVs

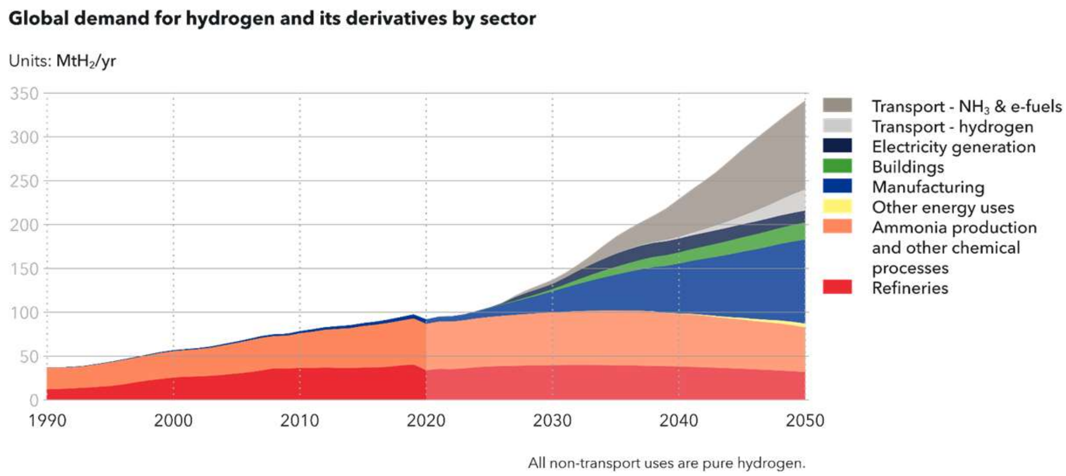
70% of electricity will come from solar and wind



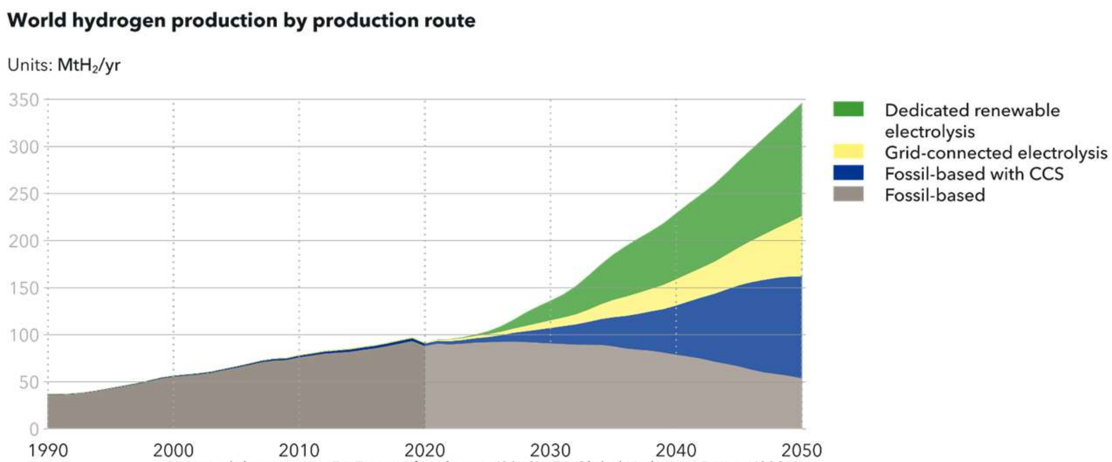
Storage is essential for the inclusion of variable renewables in electricity



Hydrogen - late but strong growth: 5% of global energy demand in 2050

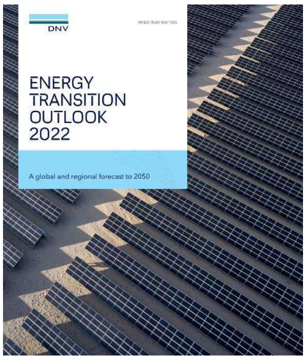


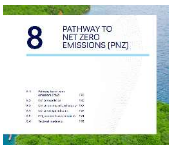
Hydrogen production dominated by electrolysis from dedicated renewables

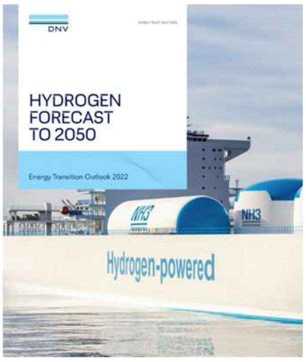


Historical data source: IEA Future of Hydrogen (2019), IEA Global Hydrogen Review (2021).

Suite of publications available on eto.dnv.com



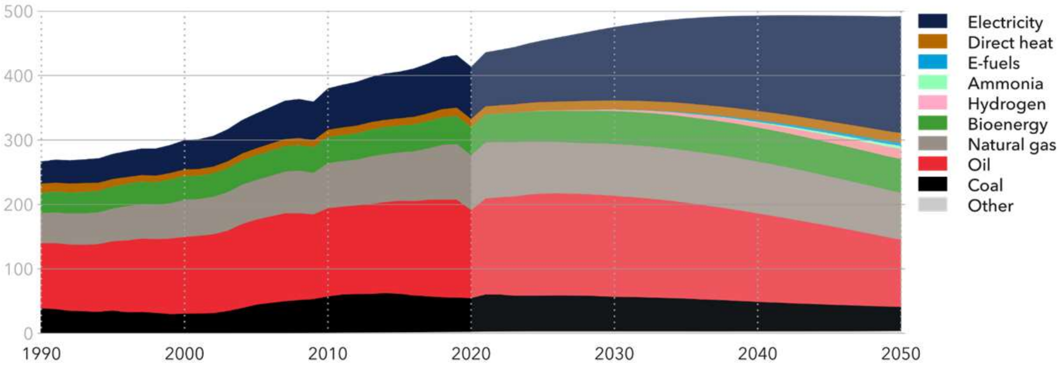




The share of electricity in the final energy demand mix doubles by 2050

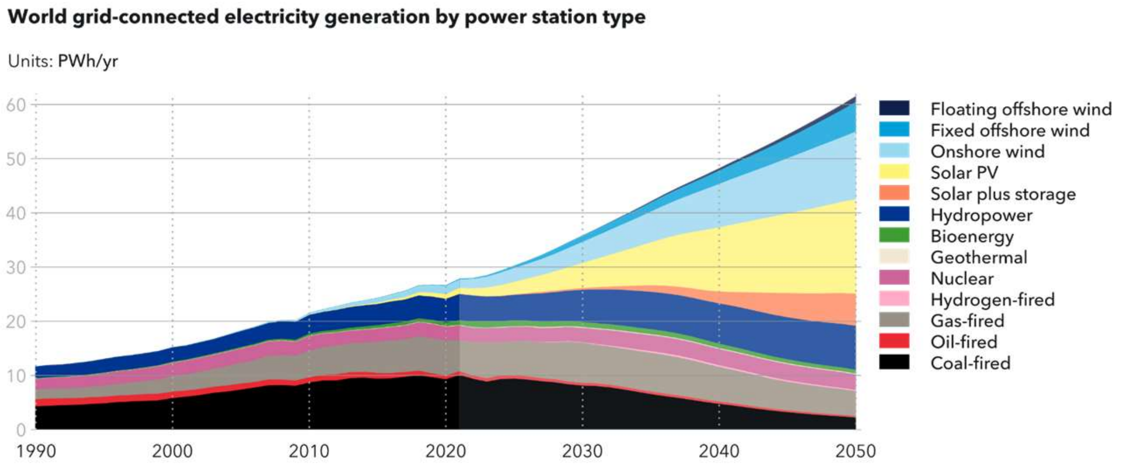
World final energy demand by carrier

Units: EJ/yr



DNV's ETO 2022

Renewables will dominate this shift making up 83% of electricity production by 2050

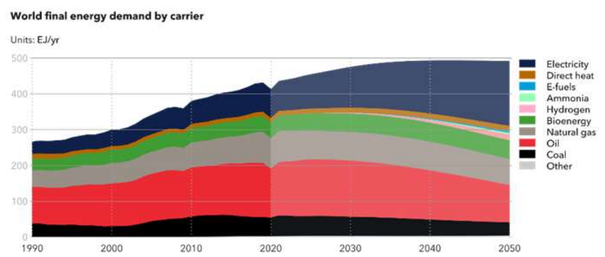


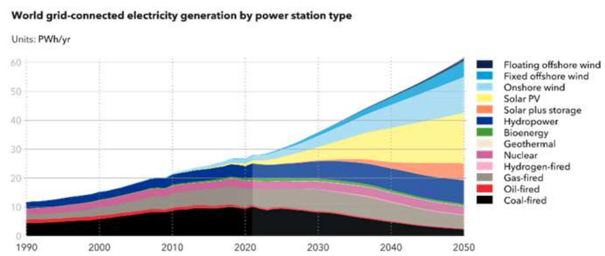
DNV's ETO 2022

Electrification is key to the energy transition

- By 2050, the share of electricity has almost doubled, from ca 19% to ca 36%
- Hydrogen from 0 to ca 5% of global demand
- Coal and oil reduce their share
- Use of gas will decline slightly

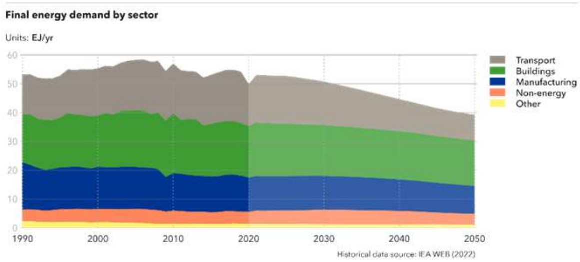
- Electricity will be generated for >80% by renewables, wind and solar combined give 70%
- Solar+storage grows despite the high price compared to solar only

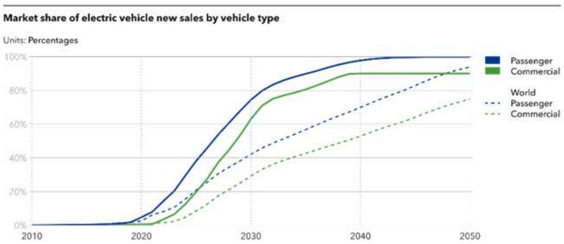


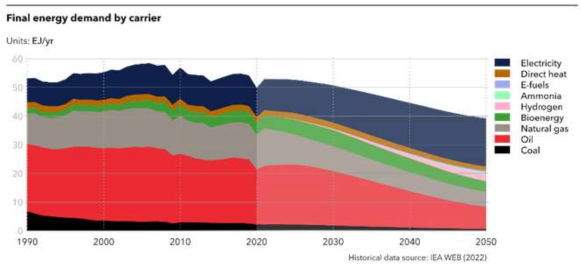


A closer look at Europe (1)

- Significant reduction of energy demand, already started and in 2050 ca 20% lower than today
- Population stays constant while GDP grows by 50% and energy use goes down by ca 25%
- Stronger trend towards electrification + hydrogen

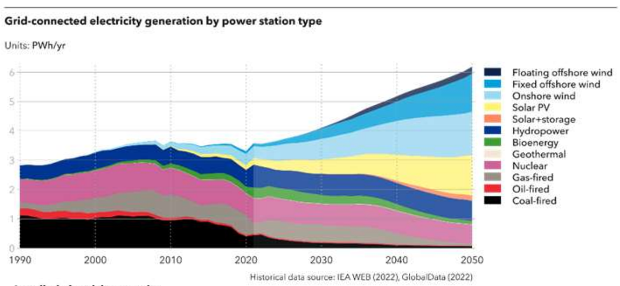


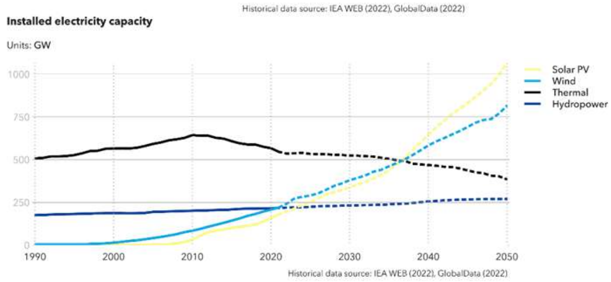




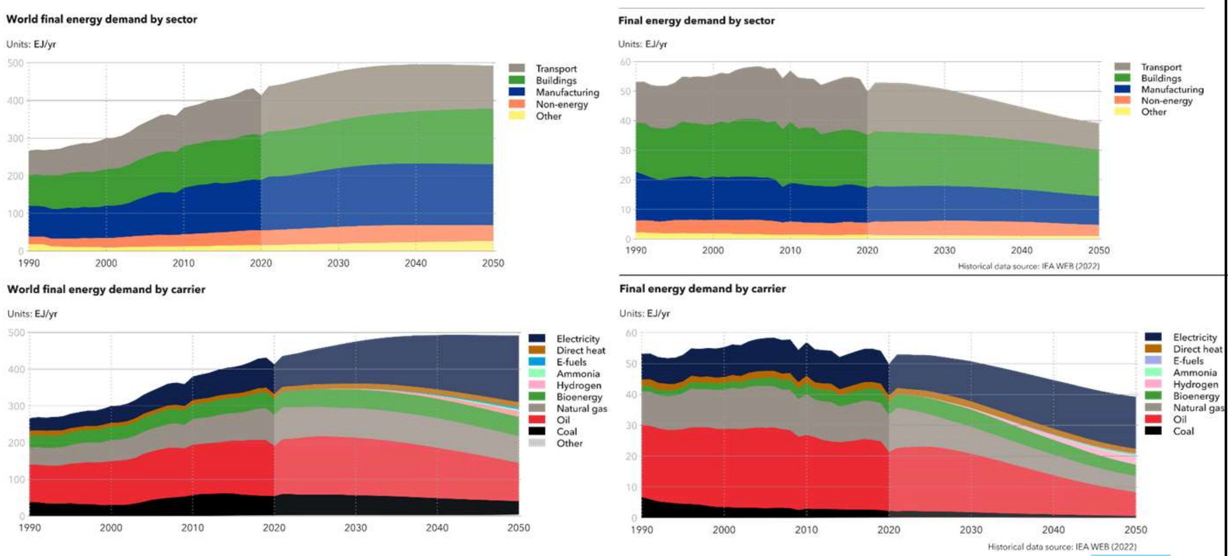
A closer look at Europe (2)

- Coal and oil reducing drastically in electricity generation from 2025 and onwards
  - Natural gas takes longer
- 50% of the electricity is generated from wind of which half from offshore wind
- Continued strong trend of new installed capacity from wind and solar, even steeper from 2040

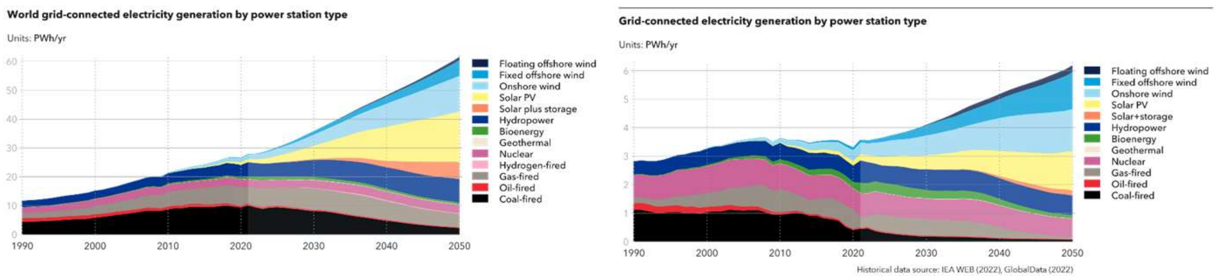




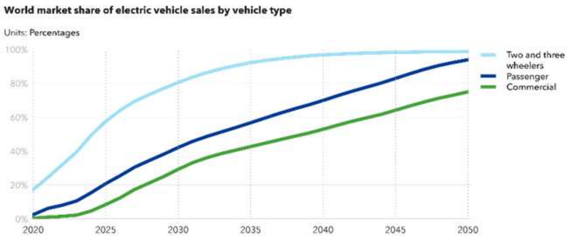
Europe vs Global

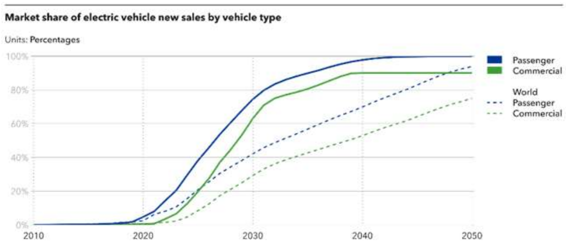


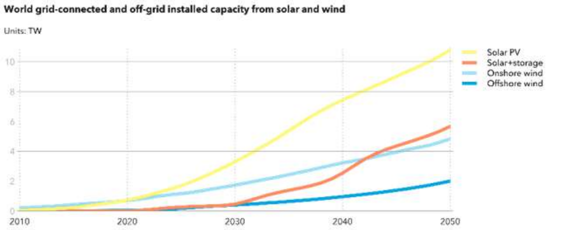
Europe vs Global (2)

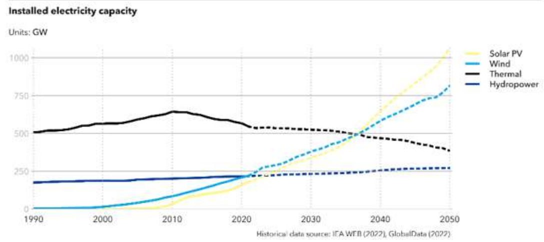


Europe vs Global







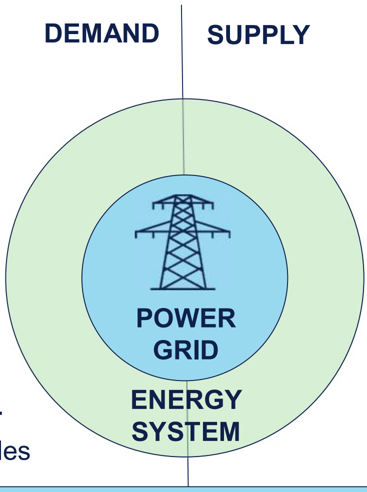


Trends in Power & Energy: Decarbonization

INDUSTRY
Hydrogen electrolysers

BUILDINGS
Heat pumps

TRANSPORT
Electric Vehicles

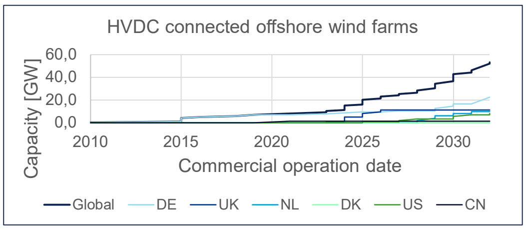


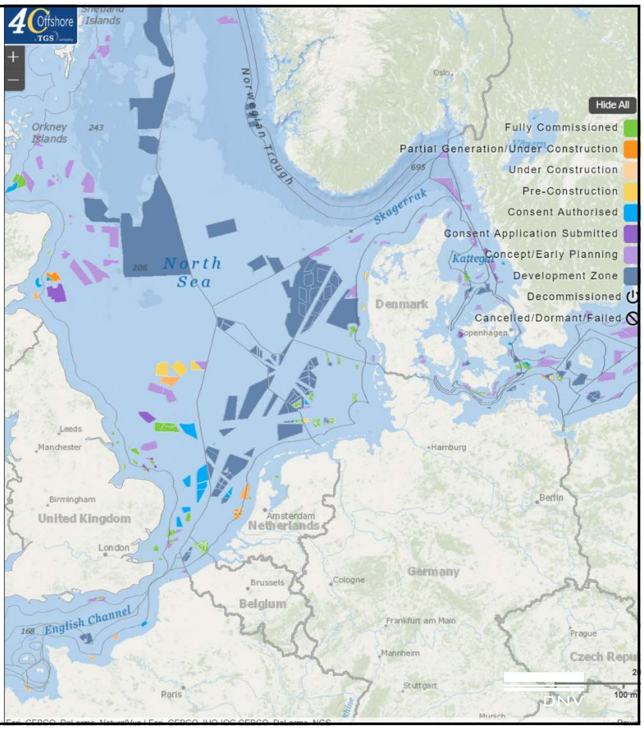
Electricity brings more efficient energy use with low climate impact, **if generated in a green way**

Power grids investment to grow by 50% in the next 10 years
of which 15% in digital infrastructure
Transmission lines will double, distribution more than double by 2050

Offshore Wind

- Strong global growth expected
- First MT (radial) VSC-HVDC grids
- Multi-purpose HVDC infrastructure appearing
- Some countries leading the development – with "new" ones quickly coming up





TenneT offshore at a glance

Current offshore transmission capacity
(Germany and the Netherlands)
9,932 MW

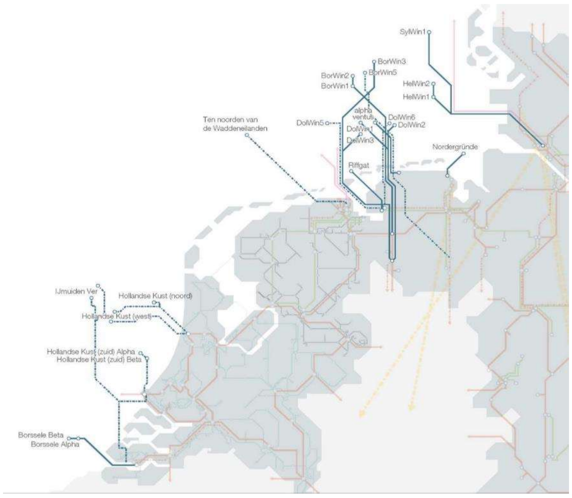
4
interconnectors

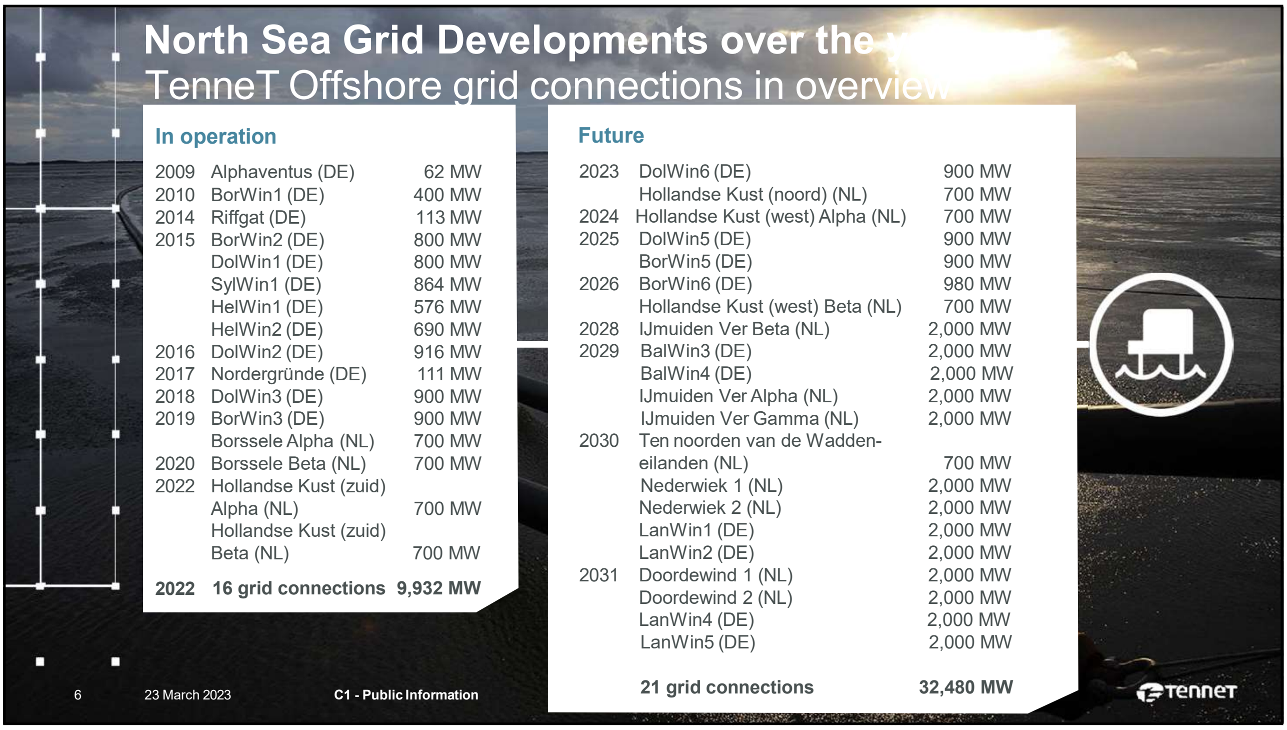
total cable length
~ 3,700 km

16 offshore
grid connections

29 TWh
transmission of offshore wind energy

Length up to
250 km
per connection




North Sea Grid Developments over the
TenneT Offshore grid connections in
In operation
2009 Alphaventus (DE) 62 MW
2010 BorWin1 (DE) 400 MW
2014 Riffgat (DE) 113 MW
2015 BorWin2 (DE) 800 MW
DolWin1 (DE) 800 MW
SylWin1 (DE) 864 MW
HelWin1 (DE) 576 MW
HelWin2 (DE) 690 MW
2016 DolWin2 (DE) 916 MW
2017 Nordergründe (DE) 111 MW
2018 DolWin3 (DE) 900 MW
2019 BorWin3 (DE) 900 MW
Borssele Alpha (NL) 700 MW
2020 Borssele Beta (NL) 700 MW
2022 Hollandse Kust (zuid) Alpha (NL) 700 MW
Hollandse Kust (zuid) Beta (NL) 700 MW
2022 16 grid connections 9,932 MW
Future
2023 DolWin6 (DE) 900 MW
Hollandse Kust (noord) (NL) 700 MW
2024 Hollandse Kust (west) Alpha (NL) 700 MW
2025 DolWin5 (DE) 900 MW
BorWin5 (DE) 900 MW
2026 BorWin6 (DE) 980 MW
Hollandse Kust (west) Beta (NL) 700 MW
2028 IJmuiden Ver Beta (NL) 2,000 MW
2029 BalWin3 (DE) 2,000 MW
BalWin4 (DE) 2,000 MW
IJmuiden Ver Alpha (NL) 2,000 MW
IJmuiden Ver Gamma (NL) 2,000 MW
2030 Ten noorden van de Wadden-eilanden (NL) 700 MW
Nederwiek 1 (NL) 2,000 MW
Nederwiek 2 (NL) 2,000 MW
LanWin1 (DE) 2,000 MW
LanWin2 (DE) 2,000 MW
2031 Doordewind 1 (NL) 2,000 MW
Doordewind 2 (NL) 2,000 MW
LanWin4 (DE) 2,000 MW
LanWin5 (DE) 2,000 MW
21 grid connections 32,480 MW
6
23 March 2023
C1 - Public Information
TenneT