The Danish Technology Catalogues - providing robust data for energy planning

Christoph Wolter, Danish Energy Agency

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Danish Energy Agency

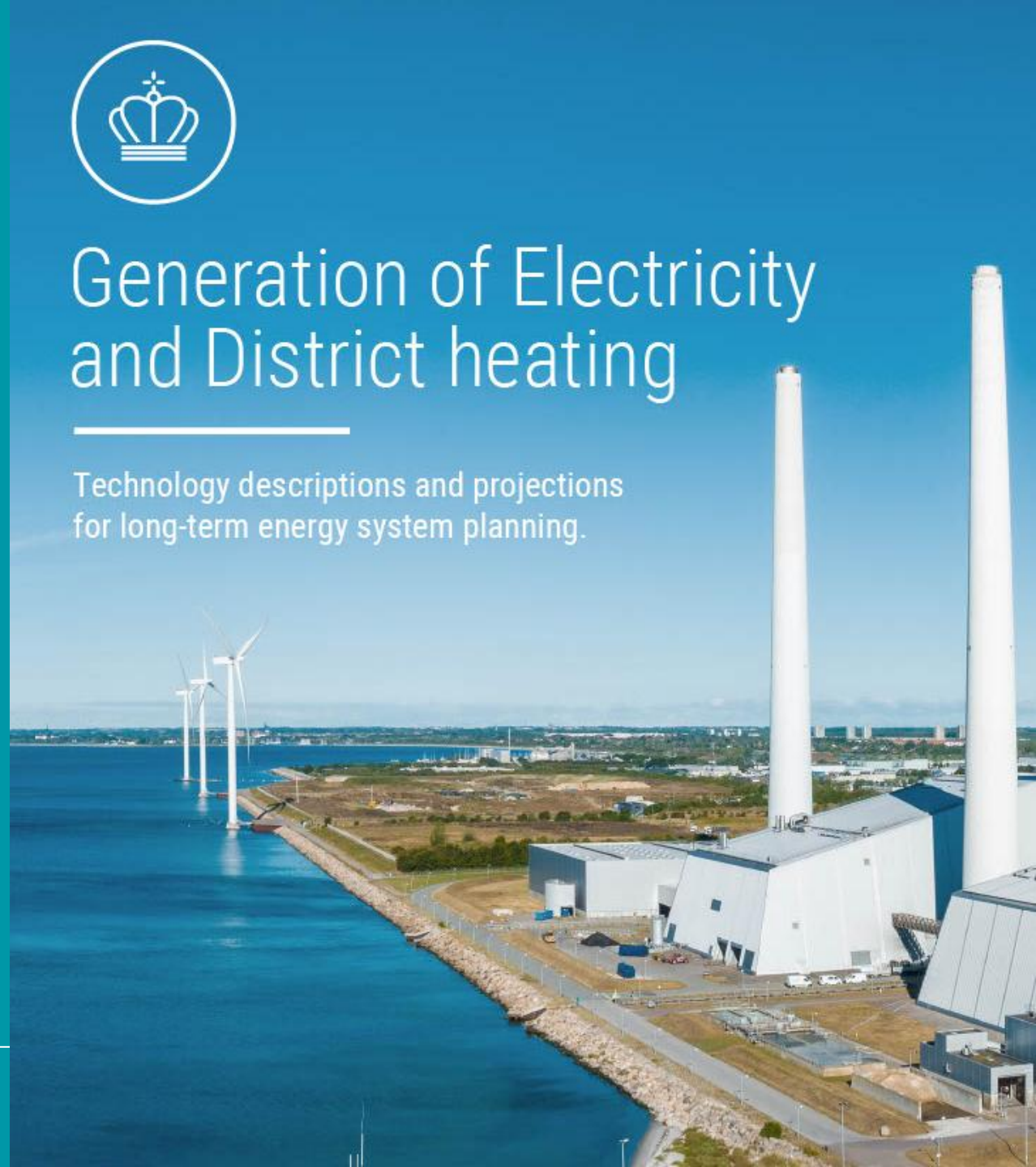
“The primary objective of publishing technology catalogues is to establish a

1) uniform,

2) commonly accepted, and

3) up-to-date

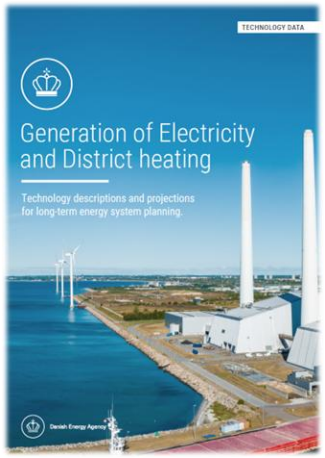
basis for energy planning activities, and evaluations of security of supply, environment and market development for system operators, universities, consultancies and the Danish Energy Agency.”

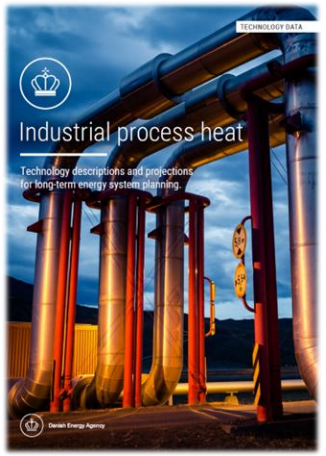


Continously developed and expanded since 1983

…from oil crisis over municipal heat planning to liberalisation of the power sector…

1800+ pages,
describing
technoeconomic data on
energy technologies





Usage of Technology Catalogues (TC) today

Technology Catalogues

Danish Energy Agency

Input for energy system models

- General equilibirum model
- Hourly dispatch model
- District heating investment model
- Stochastic model for security of supply
- …

Danish Ministry of Climate, Energy and Utilities

Data source for policy impact analysis and marginal abatement curve assessments

Input into socioeconomic assessment models among which

- CCS-model
- Waste model
- Gas/heat model
- …

Danish Ministry of Finance

Data source for financial public investement analyses
(in collaboration with the Ministry of Climate, Energy and Utilities)

External usage

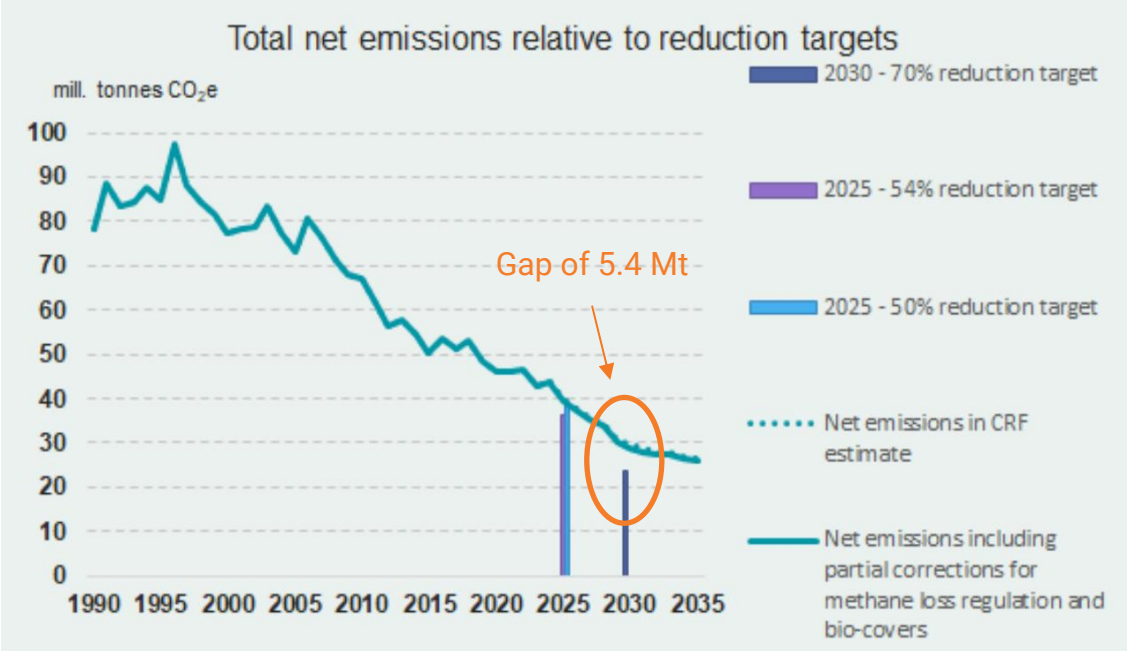
A wide range of external users use the TC for energy system modelling and technology analyses, such as

- Energinet (Power and Gas TSO)
- Advocacy groups
- Private consultancies
- Utilities
- Danish Climate Council
- Academia

TC data as assumptions for e.g.…

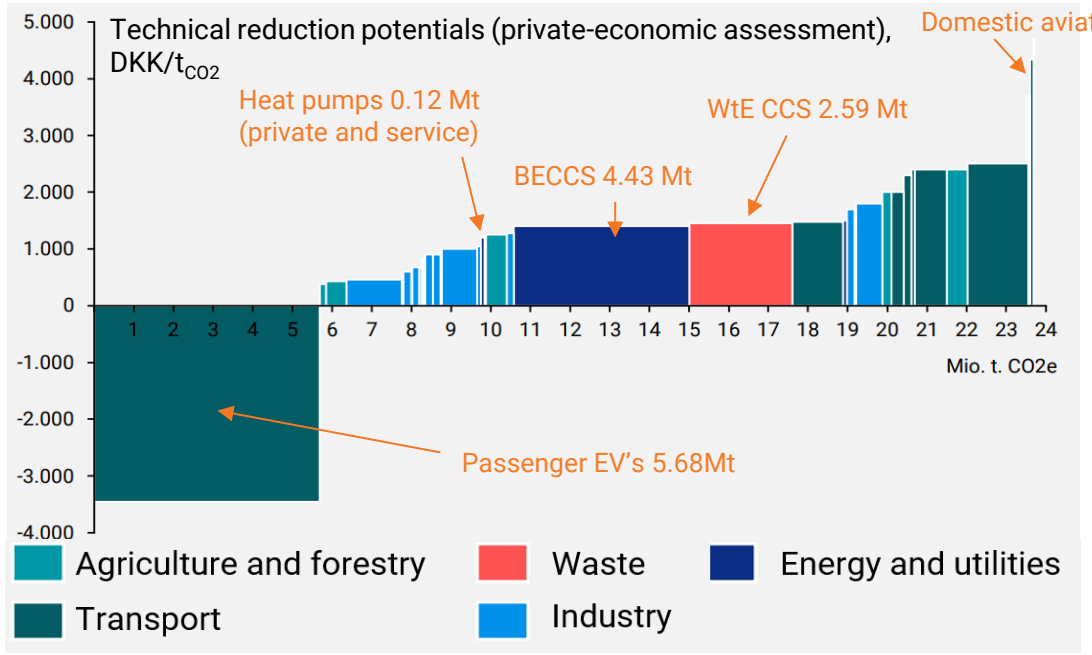
Denmark's Climate Status and Outlook (Danish Energy Agency, Ministry of Climate)

Climate Status and Outlook (2023) emission reduction compared to targets



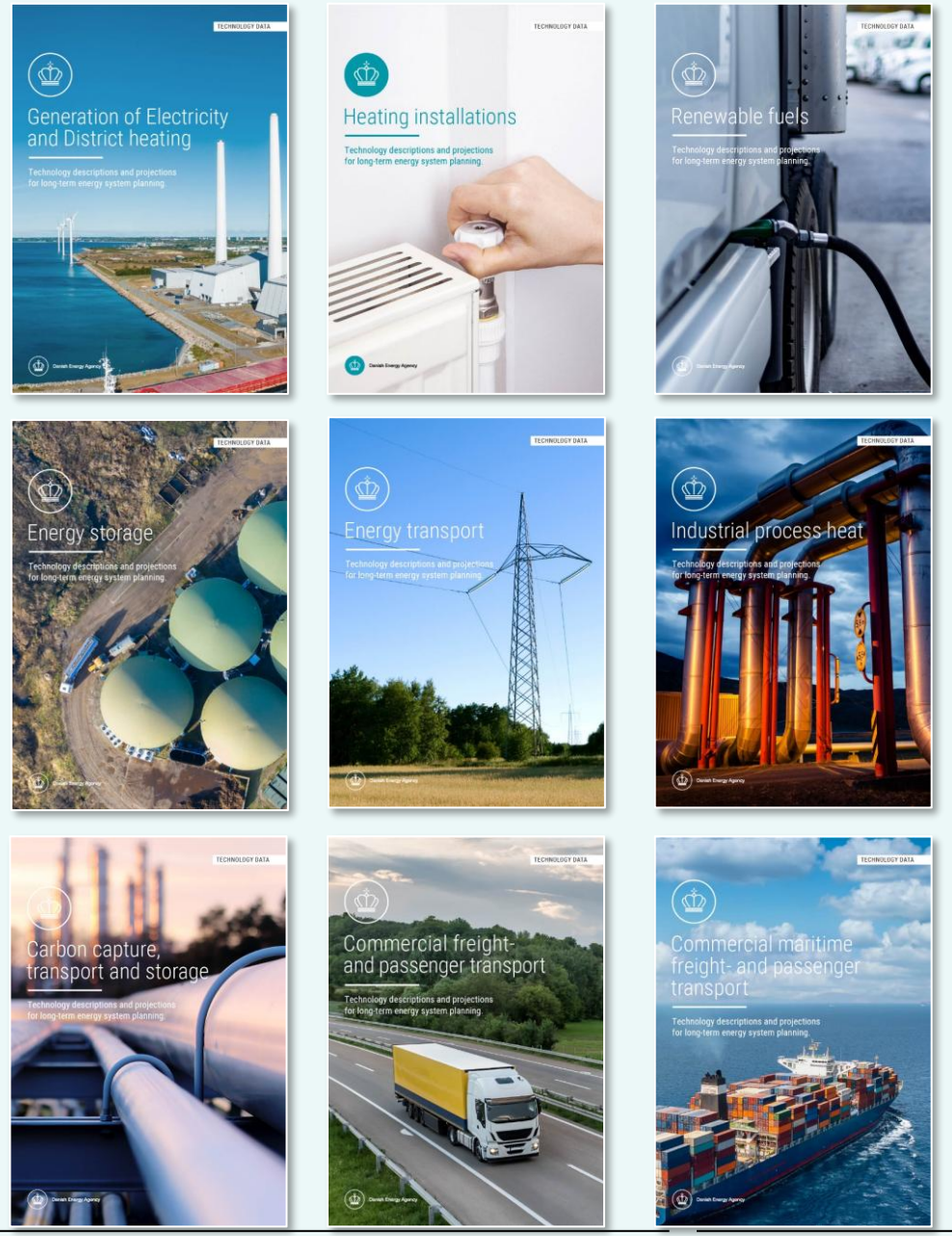
Denmark's Climate Programme (Danish Ministry of Climate)

Climate Program (2023) marginal abatement curve



Technology Catalogues by the numbers

- Currently **9** catalogues with quantitative data and supplementing technology descriptions for different energy sectors
- **103** technology chapters
- **292** data sheets
- **7** employees within the Danish Energy Agency's Center for Systems Analysis and Innovation (as part of **65** full-time employees)
- Annual budget of ca. **250,000 EUR**



Technology Catalogue framework

Guidelines
Framing and guidance for description of **chapters** and **datasheets**, socio-economic assumptions
System scope definition (technical and financial), definition of standard sizes [e.g. households] etc.

Technology chapter (qualitative part)

- Understandable for generalists and energy system analysts
- Contextualizes the quantitative assumptions
- Uniform section across the chapters, among which:
  - Brief Technology Description
  - Input/output streams
  - Examples of standard market technology
  - R&D perspectives
  - Projection of performance and cost

Technology datasheet(s) (quantitative part)

- Representative data for current technology and projection for future years
- Uniform division across the technologies:
  - Technical and operational data
  - Environmental data
  - Financial data
  - (Technology-specific data)
- Uncertainties around the central assumptions

The Qualitative Description

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Publication date
August 2016

Amendments after publication date

Date	Ref.	Description

Qualitative description

Brief technology description

The typical large onshore wind turbine being installed today is a horizontal-axis, three bladed, upwind, grid connected turbine using active pitch, variable speed and yaw control to optimize generation at varying wind speeds.

Wind turbines work by capturing the kinetic energy in the wind with the rotor blades and transferring it to the drive shaft. The drive shaft is connected either to a speed-increasing gearbox coupled with a medium- or high-speed generator, or to a low-speed, direct-drive generator. The generator converts the rotational energy of the shaft into electrical energy. In modern wind turbines, the pitch of the rotor blades is controlled to maximize power production at low wind speeds, and to maintain a constant power output and limit the mechanical stress and loads on the turbine at high wind speeds. A general description of the turbine technology and electrical system, using a geared turbine as an example, can be seen in figure 1.

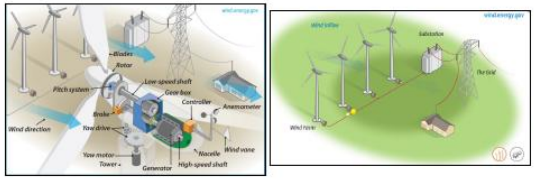


Figure 1: General turbine technology and electrical system.

Wind turbines are designed to operate within a wind speed range which is bounded by a low "cut-in" wind speed and a high "cut-out" wind speed. When the wind speed is below the cut-in speed the energy in the wind is too low to be utilized. When the wind reaches the cut-in speed, the turbine begins to operate and produce electricity. As the wind speed increases, the power output of the turbine increases, and at a certain wind speed the turbine reaches its rated power. At higher wind speeds, the blade pitch is controlled to maintain the rated power output. When the wind speed reaches the cut-out speed, the turbine is shut down or operated in a reduced power mode to prevent mechanical damage.

Onshore wind turbines can be installed as single turbines, clusters or in larger wind farms.

Commercial wind turbines are operated unattended, and are monitored and controlled by a supervisory control and data acquisition (SCADA) system.

Input

Input is wind.

Cut-in wind speed: 3 – 4 m/s.

Rated power generation wind speed: 10-12 m/s, depending on the specific power (defined as the ratio of the rated power to the swept rotor area).

Cut-out or transition to reduced power operation at wind speed: 25 m/s.

In the future, it is expected that manufacturers will apply a soft cut-out for high wind speeds (indicated with dashed red curve in figure 2) resulting in a final cut-out wind speed around 30 m/s.

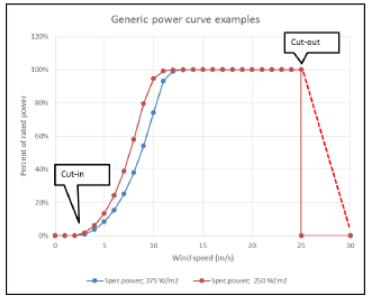


Figure 2: Turbine power curves (Information's from expert workshop held by DEA 27-4-2015)Specific power values refer to e.g. 3 MW with 124m rotor diameter (250 W/m^2) and 3 MW with 101 m rotor diameter (375 W/m^2)

...

The Quantitative Datasheets

Data up to 2050 | Uncertainty range | Notes/ references

Technology	Onshore wind turbine, utility - renewable power - wind - large										
year	2020	2025	2030	2040	2050	2020	2020	2050	2050	Note	Ref
est	ctrl	ctrl	ctrl	ctrl	ctrl	lower	upper	lower	upper	-	-
cat par											
Energy/technical data											
Generating capacity for one unit [MW_e]	4.2	4.5	5	5.5	6	2	6	1.5	8	A1	2
Forced outage [%]	2.5%	2.5%	2.0%	1.8%	1.5%	1.0%	5.0%	1.0%	5.0%	B	18
Planned outage [%]	0.3%	0.3%	0.3%	0.3%	0.3%	0.1%	0.5%	0.1%	0.5%	C	18
Technical lifetime [years]	27	27	30	30	30	25	35	25	40	D	11
Construction time [years]	1.5	1.5	1.5	1.5	1.5	1	3	1	3	E	18
Space requirement [1000 m2/MW_e]	-	-	-	-	-	-	-	-	-	F	
Regulation ability											
Primary regulation (of full load, per 30 seconds) []	-	-	-	-	-	-	-	-	-	G	
Secondary regulation (of full load, per minute) []	-	-	-	-	-	-	-	-	-	G	
Minimum load (of full load, additional to existing plant) []	-	-	-	-	-	-	-	-	-		
Warm start-up time (additional to existing plant) [hours]	-	-	-	-	-	-	-	-	-		
Cold start-up time (additional to existing plant) [hours]	-	-	-	-	-	-	-	-	-		
Environment											
SO2 (degree of desulphuring) []											
NOX [g/GJ_i]	-	-	-	-	-	-	-	-	-		
CH4 [g/GJ_i]	-	-	-	-	-	-	-	-	-		
N2O [g/GJ_i]	-	-	-	-	-	-	-	-	-		
Particles [g/GJ_i]	-	-	-	-	-	-	-	-	-		
Financial data											
Nominal investment (*total) [MEUR/MW_e]	1.11	1.18	1.15	1.11	1.09	0.87	1.31	0.80	1.19	[I, M]	[12, 1, 18]
Nominal investment (equipment) [MEUR/MW_e]	0.78	0.86	0.83	0.79	0.78	0.63	0.94	0.62	0.93		20
Nominal investment (installation/development) [MEUR/MW_e]	0.09	0.09	0.09	0.08	0.08	0.07	0.11	0.06	0.10		20
Nominal investment (decommissioning of existing turbines) [MEUR/MW_e]	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04		20
Nominal investment (grid connection) [MEUR/MW_e]	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.02	O	20
Nominal investment (purchase of neighbour settlements) [MEUR/MW_e]	0.08	0.07	0.07	0.07	0.07	0.06	0.09	0.06	0.09	[Q]	[20, 21]
Nominal investment (land purchase/rent) [MEUR/MW_e]	0.11	0.11	0.11	0.11	0.11	0.09	0.13	0.09	0.13	P	20
Variable O&M (*total) [EUR/MWh_e]	2.11	2.06	1.98	1.89	1.85	1.69	2.54	1.48	2.22	[J, N]	[13, 21]
Fixed O&M (*total) [EUR/MW_e/y]	16,397	17,387	16,663	15,965	15,602	13,118	19,676	12,482	18,722	[J, N]	[20, 21]
Technology-specific data											
Availability [%]	97.2%	97.0%	97.7%	97.7%	98.2%	98.9%	94.5%	98.9%	94.5%		[18, 21]
Hub height [m]	85	90	100	105	110	85	120	85	150		[18, 21]
Rotor diameter [m]	130	135	145	155	165	90	130	100	150	K	[18, 21]
Specific power [W_e/m2]	316	310	303	291	281	314	452	191	453		
Average capacity factor []	39%	40%	41%	42%	43%	23%	46%	23%	51%		[18, 21]
Average annual full-load hours [MWh_e/MW_e]	3400	3500	3600	3700	3800	2000	4000	2000	4500	[A, L]	2

Technical data

Operational data

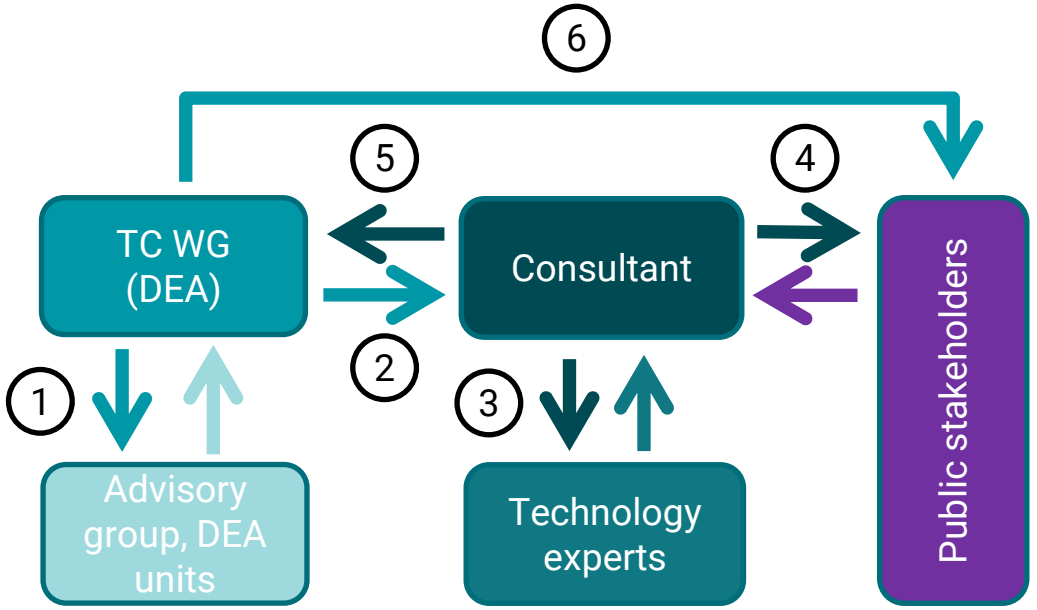
Environmental data

Financial data

Technology-specific data
(non-uniform parameters across technologies)

Stakeholder network and continous process

1. **Advisory Group Consultation:** Experts guide the TC's scope and priorities.
2. **Consultant Input:** External consultants ensure objectivity in data preparation.
3. **Industry and Research Contributions:** Technology experts provide detailed data.
4. **Stakeholder Review:** Drafts are shared for feedback to improve quality and gain broader acceptance.
5. **Finalization:** DEA and consultants finalize the catalogue.
6. **Publication:** The TC is published as a free public resource.



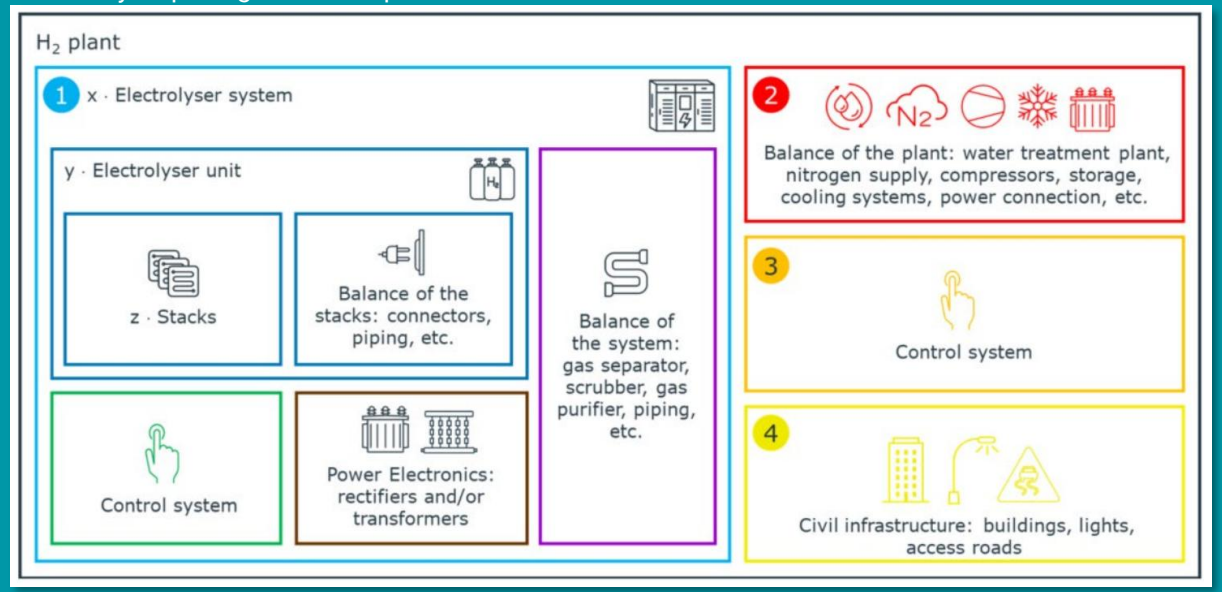
Insights and examples

The risk of not using updated data

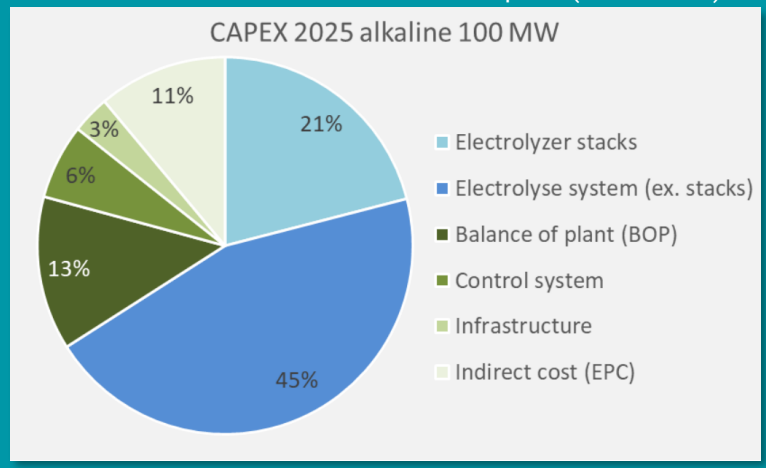
CASE 1: Investment costs of hydrogen production through electrolysis

- 2024 update showed an increase in cost, suggesting that previous techno-economic plant assumptions were too optimistic
- Cost development potential through scaling varies for electrolyzer stacks (only 20 pct. of total CAPEX) compared to residual system and BOP

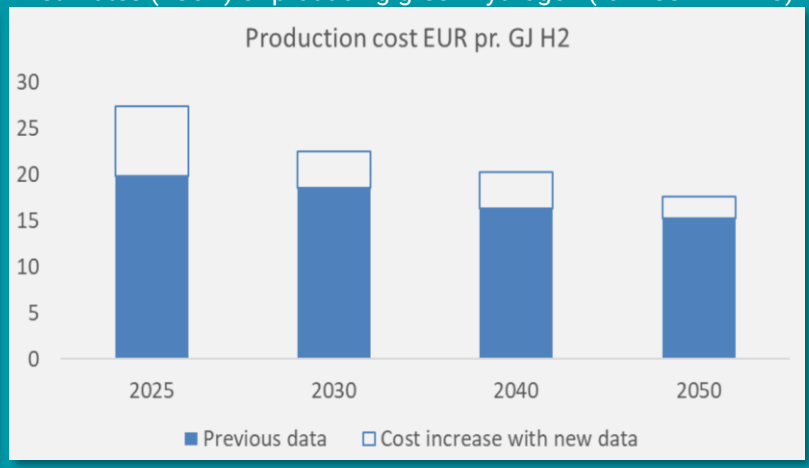
Electrolysis plant general components



CAPEX breakdown for a 100 MW alkaline plant (FID in 2025)



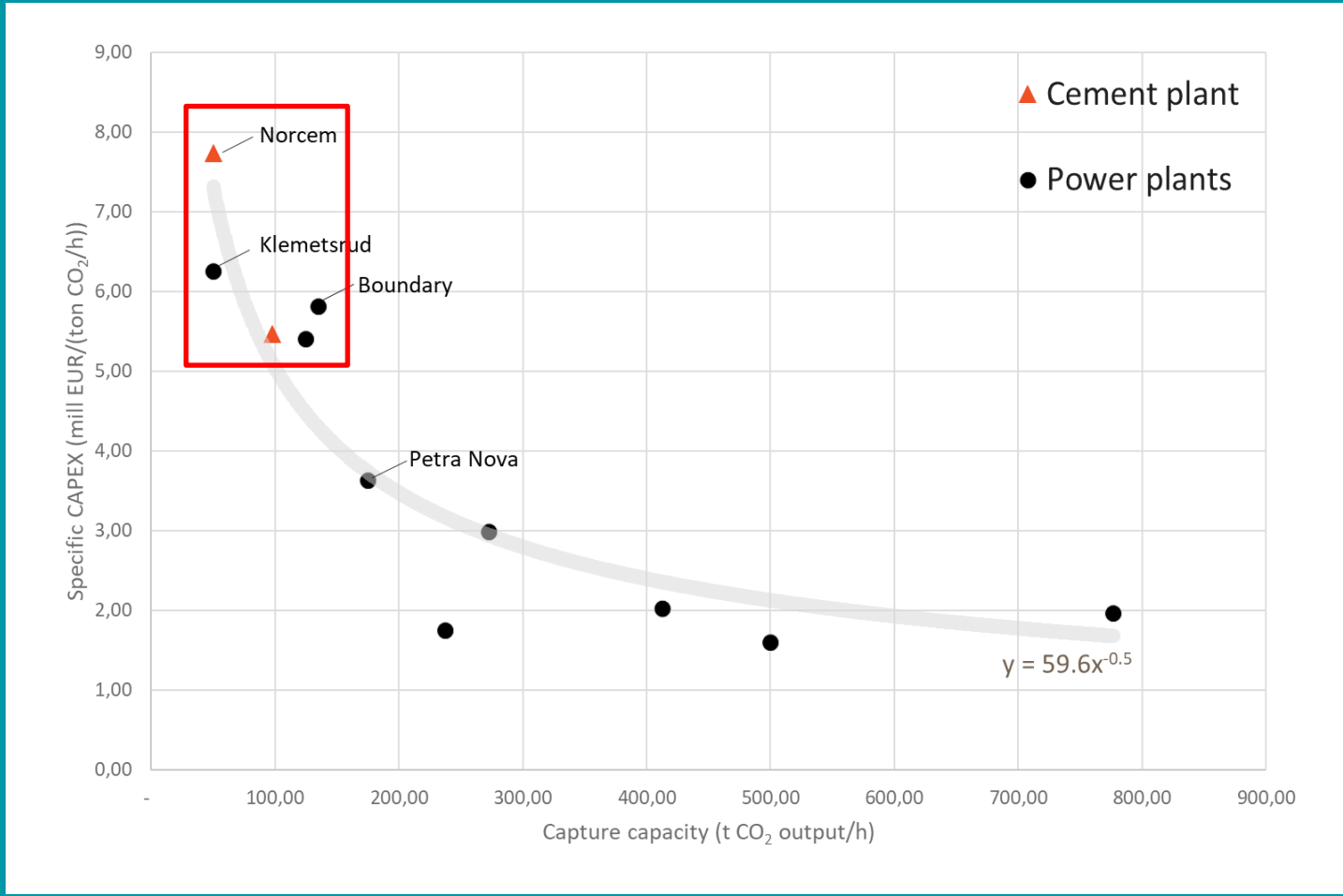
Estimates (LCoH) of producing green hydrogen (for 100MW AEC)



The risk of not consulting locally representative data

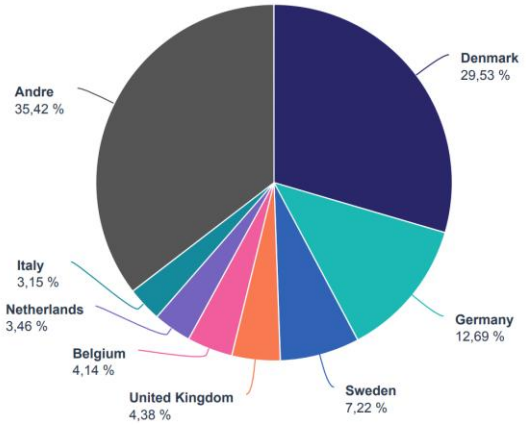
CASE 2: Investment costs of Carbon capture plants in different use cases

- Empirical data (USA, Canada, Norway) suggests significant economy of scale
- Danish industry relevance: Cement production plants, or biogas plants, with ~30…150 t_{CO2}/h
- Technology Catalogue data sheets quantify different plant sizes



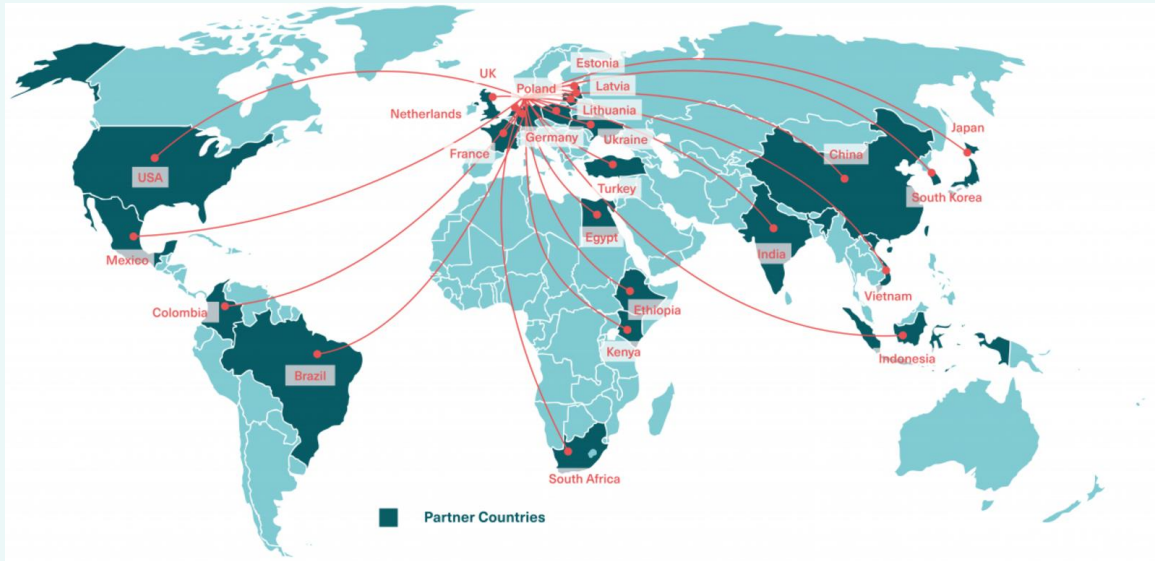
International reputation and usage

+115 countries with readers/users[1]



1) Aggregated data count from 2018-2024

25 Gvt-to-Gvt partnerships with the DEA



Collaborations on national Technology Catalogues in

- Germany,
- India,
- Colombia,
- Ethiopia
- … etc.

Thank you!

Christoph Wolter

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https://ens.dk/technologydata

Danish Energy Agency