Generation cost of wind power
Offshore wind costs and cost drivers

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Wind power costs - Offshore cost drivers

Agenda

- Onshore and offshore wind power cost curves
- Offshore DK developments and cost drivers
- Nearshore wind farm sites are scarce but cost may potentially be attractive compared to further offshore wind
- Cost drivers for nearshore and offshore wind - what makes it cheaper
- Illustrative cost advantage for nearshore based on cost drivers
- Competition among developers and bidders in auctions?

Background: Cost curves

Costs vary depending on technology and site-specific characteristics and low cost options (sites) are limited

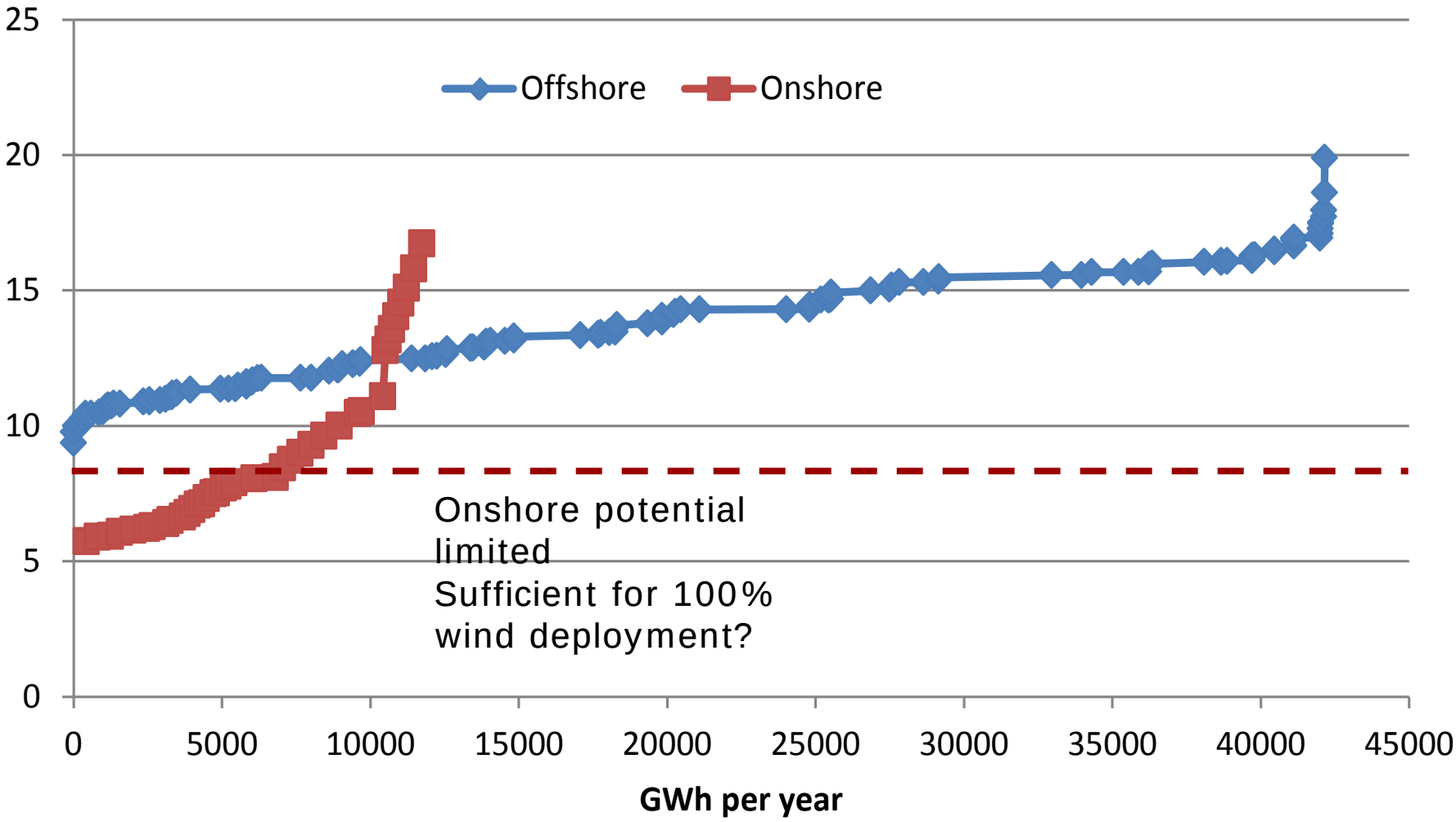
Total lifetime generation costs including investment and operational costs

- Levelized costs: average cost per generated unit (kWh)
- Comparison between technologies including investment cost and with different generation profiles (full load hours)

Issues with levelized cost curves

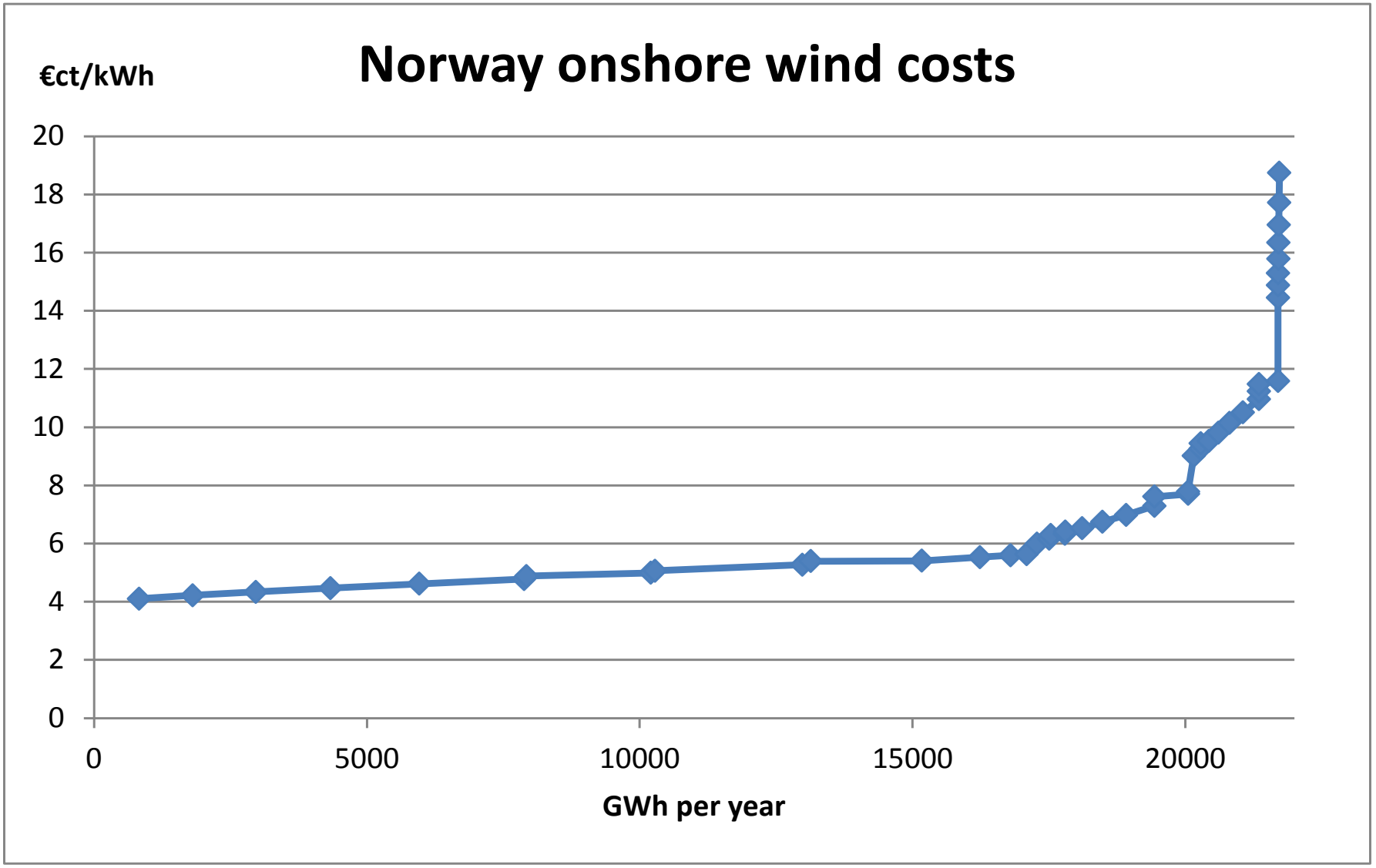
- Do not distinguish between time of generation (generation at different hours has very different value)
- Difficult to compare technologies with very different lifetime
- Cost curves are normally static - the real world is not

DK wind costs and potentials



Based on database from European projects 2010-2013: Resolve and Res4Less
Covering all Member States and all renewable technology country specific costs and potentials

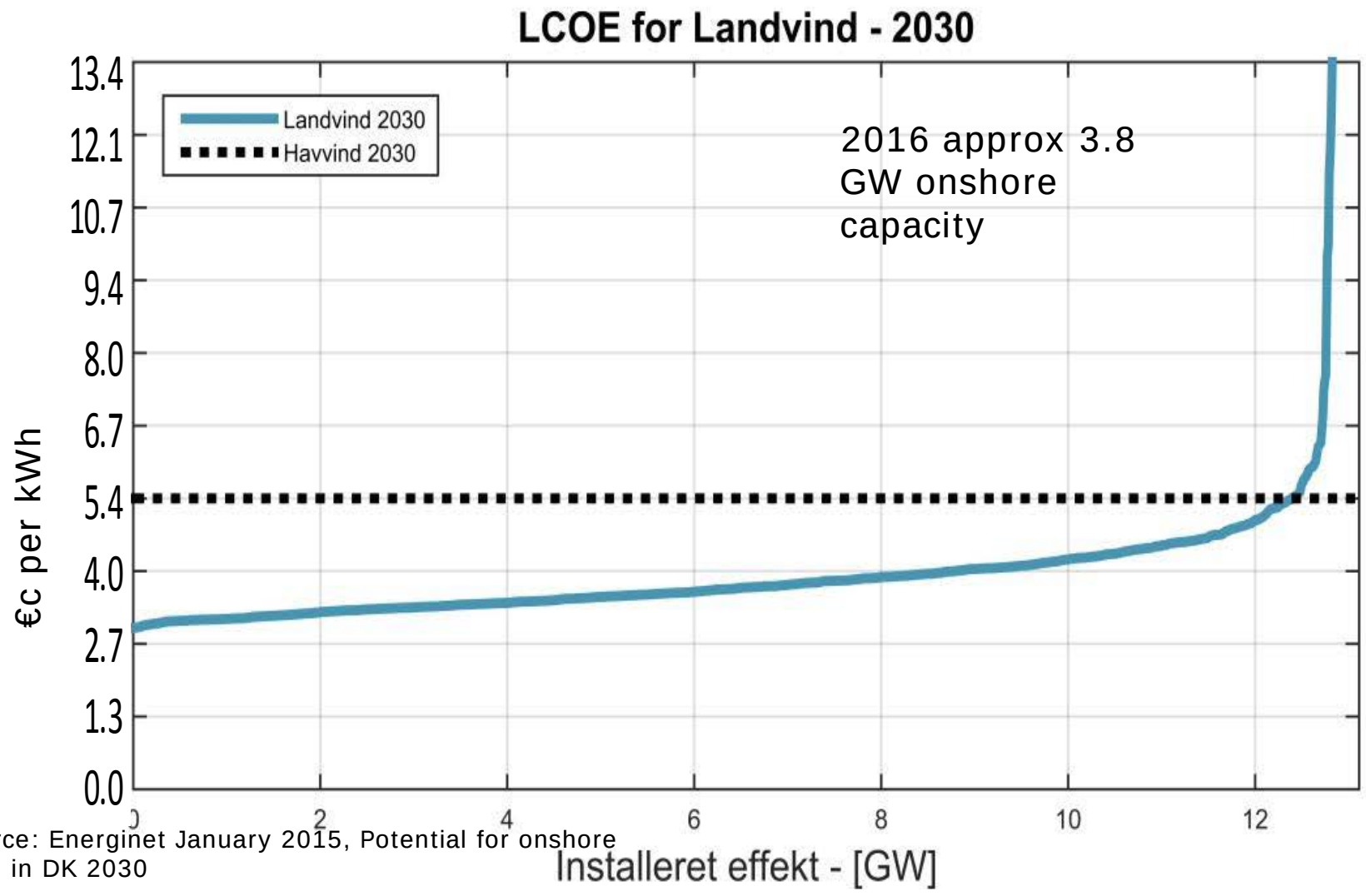
Wind onshore cost curve for Norway



Onshore versus Off-shore: Barriers and acceptance issues limits onshore development

- The cost advantage of onshore is clear but onshore development in DK has been slow during the last 5-10 years (now everything slow due to low prices)
- Preferences against onshore wind limits the sites actually available for onshore wind development
- Additional costs have to be added to facilitate further onshore development
  - Compensation payments (individual neighbours) - can be brought to court
  - Green fund - Support for municipalities
  - Local minimum ownership (20%)
  - Developer risk of delay and spending on procedures/hearings increases basic technology costs
- Is the cost gap sufficiently large to account for these additional acceptance cost?
  - Probably yes for some part of the onshore potential as illustrated by Energinet

Onshore wind cost
Energinet 2030 projection of LCOE



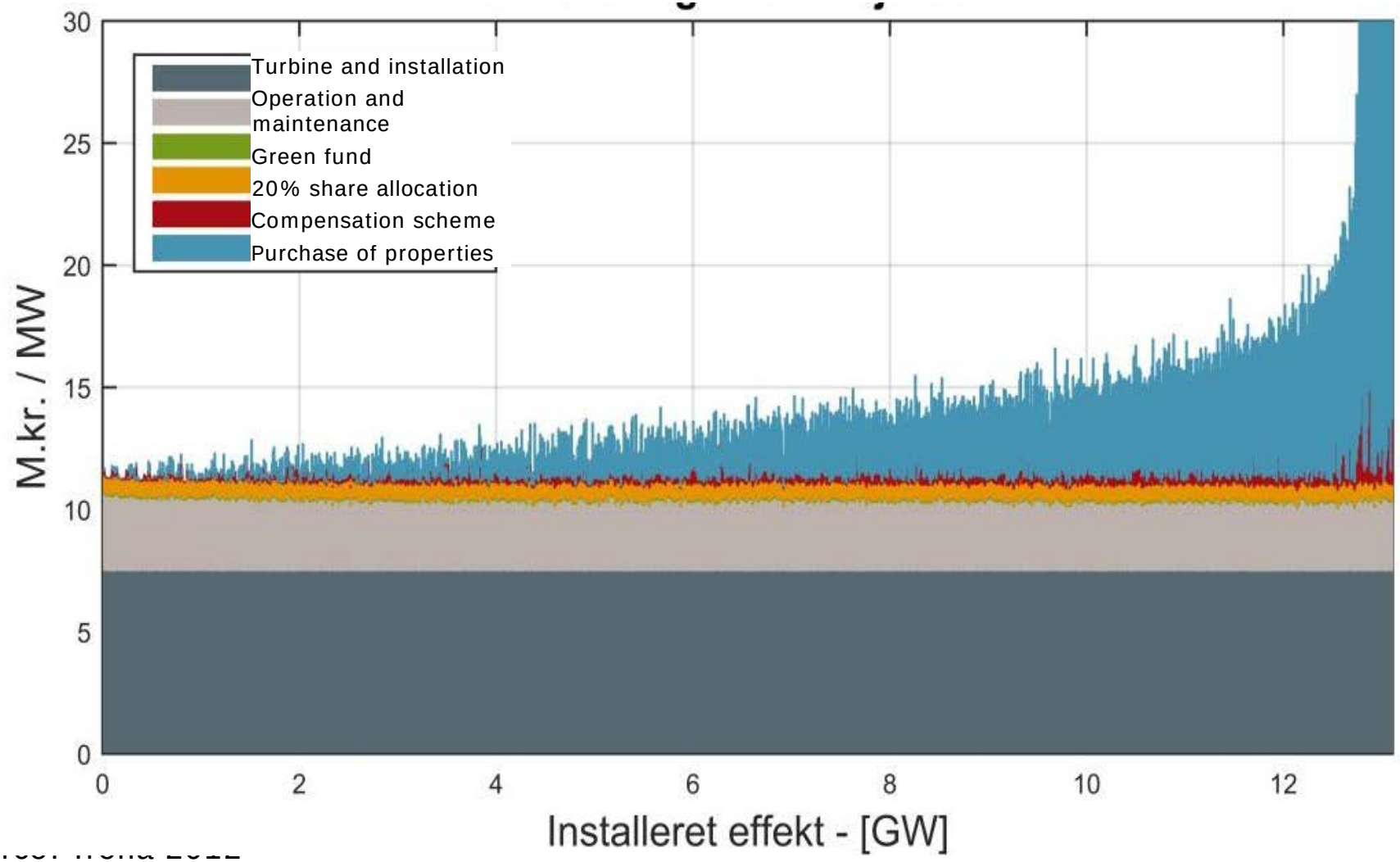
DEA 2016 offshore approx 8 €c per kWh

Source: Energinet January 2015, Potential for onshore wind in DK 2030

Uncertainties in onshore cost estimates DK 2030

- Investment cost assumptions based on Danish Energy Agency assumptions for 2030 (1000 €/kW)
- Lifetime 25 years
- Based on 3 and 5 turbine clusters (exclude smaller options) - exclude nature reserve areas etc. - average property costs - underestimate potential
- Exclude additional cost for measures promoting projects in broader municipality - no real compensation for visual dis-amenities
- All costs are for 2030 deployment - gradual deployment is necessary - individual properties may only be purchased in long run (1.5 times property value in property tax system)
- Energinet results: Annual savings estimate for 2030 is 4.5 billion DKK based on full 12 GW deployment - 6 GW provide 3 mill DKK annual savings

Energinet study of additional costs onshore 2030



Source: Ivana 2012

Specific turbine costs 2004-2012 - Fluctuations

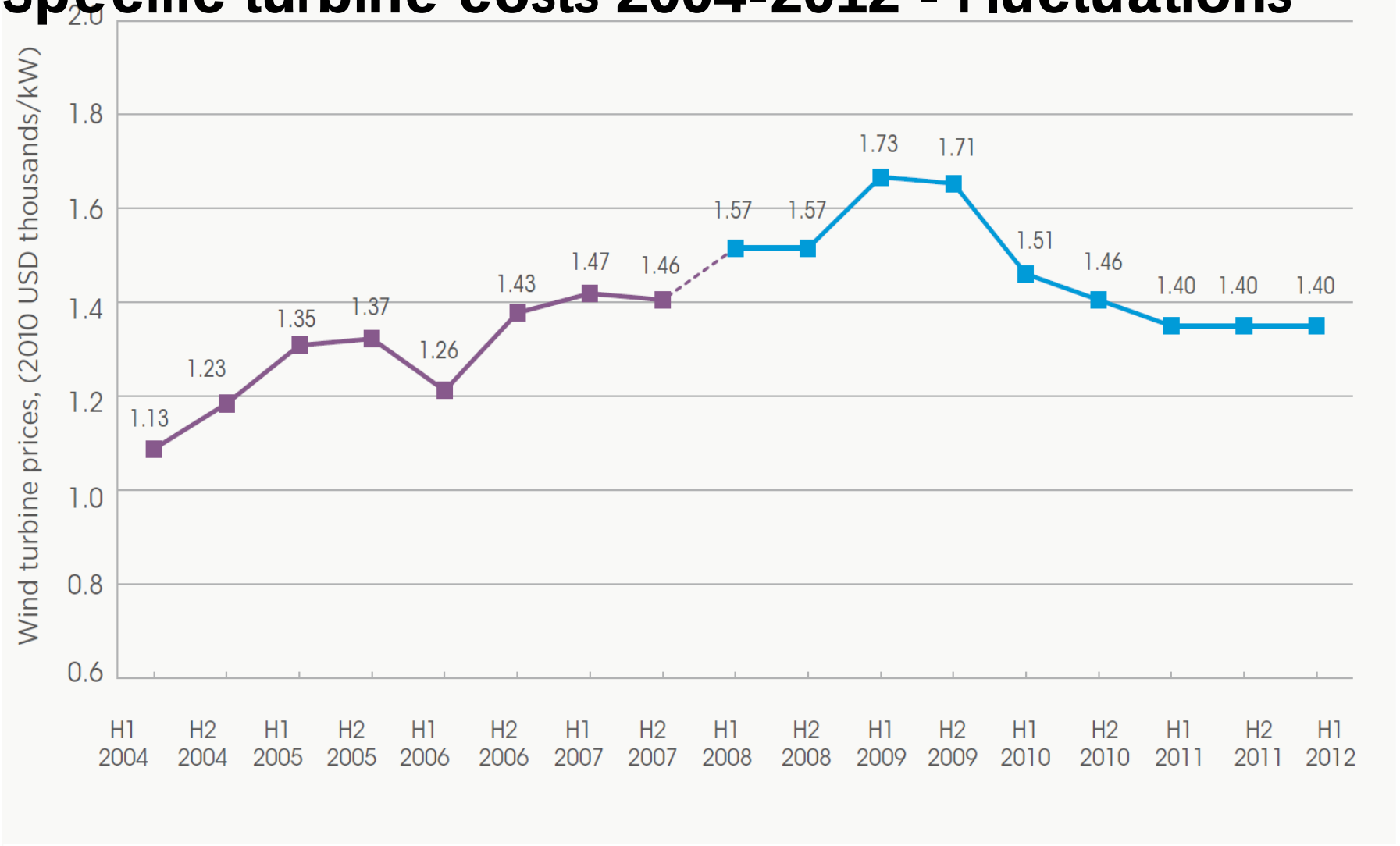


FIGURE 4.2: WIND TURBINE PRICE INDEX BY DELIVERY DATE, 2004 TO 2012

Source: Irena 2012

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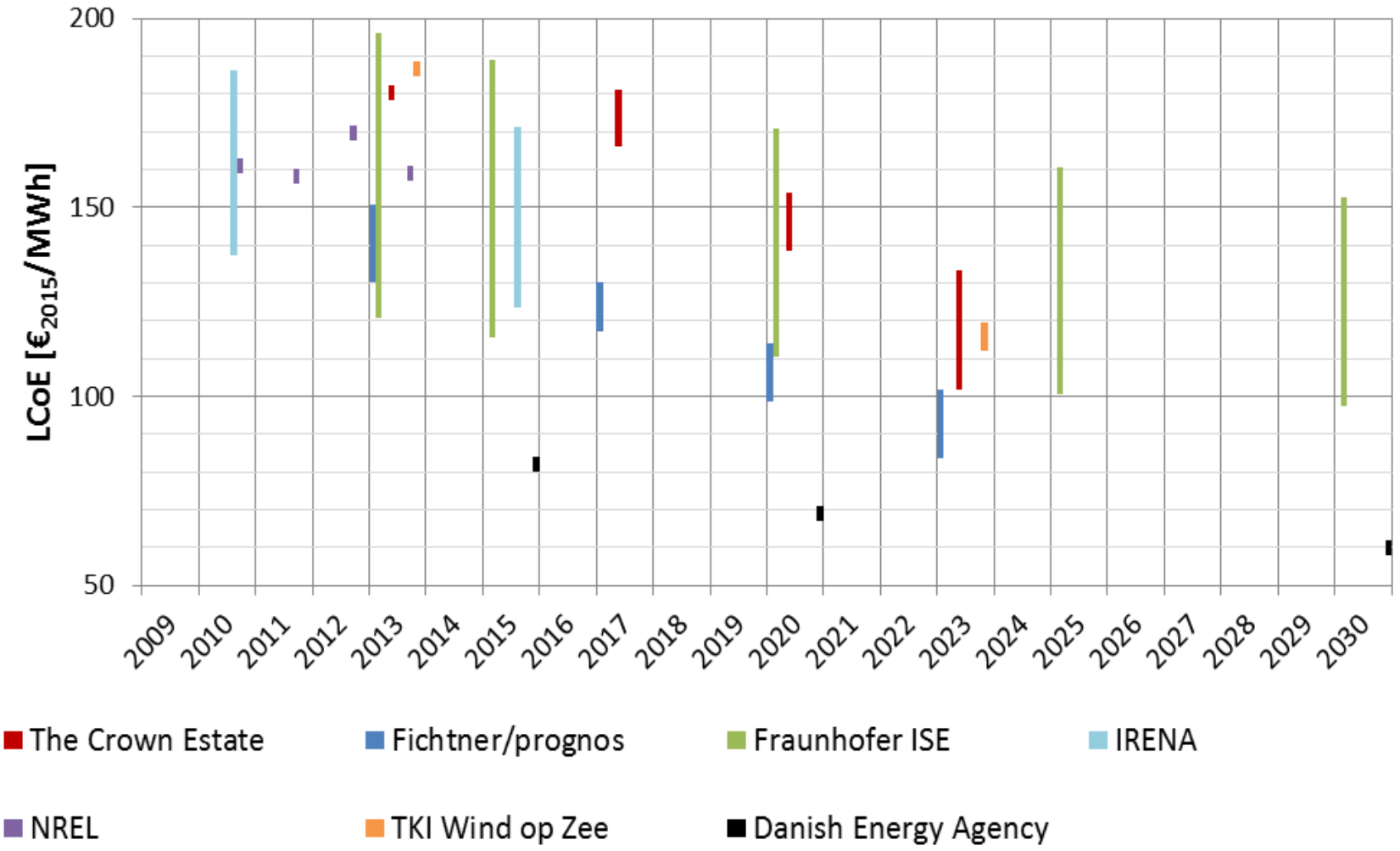
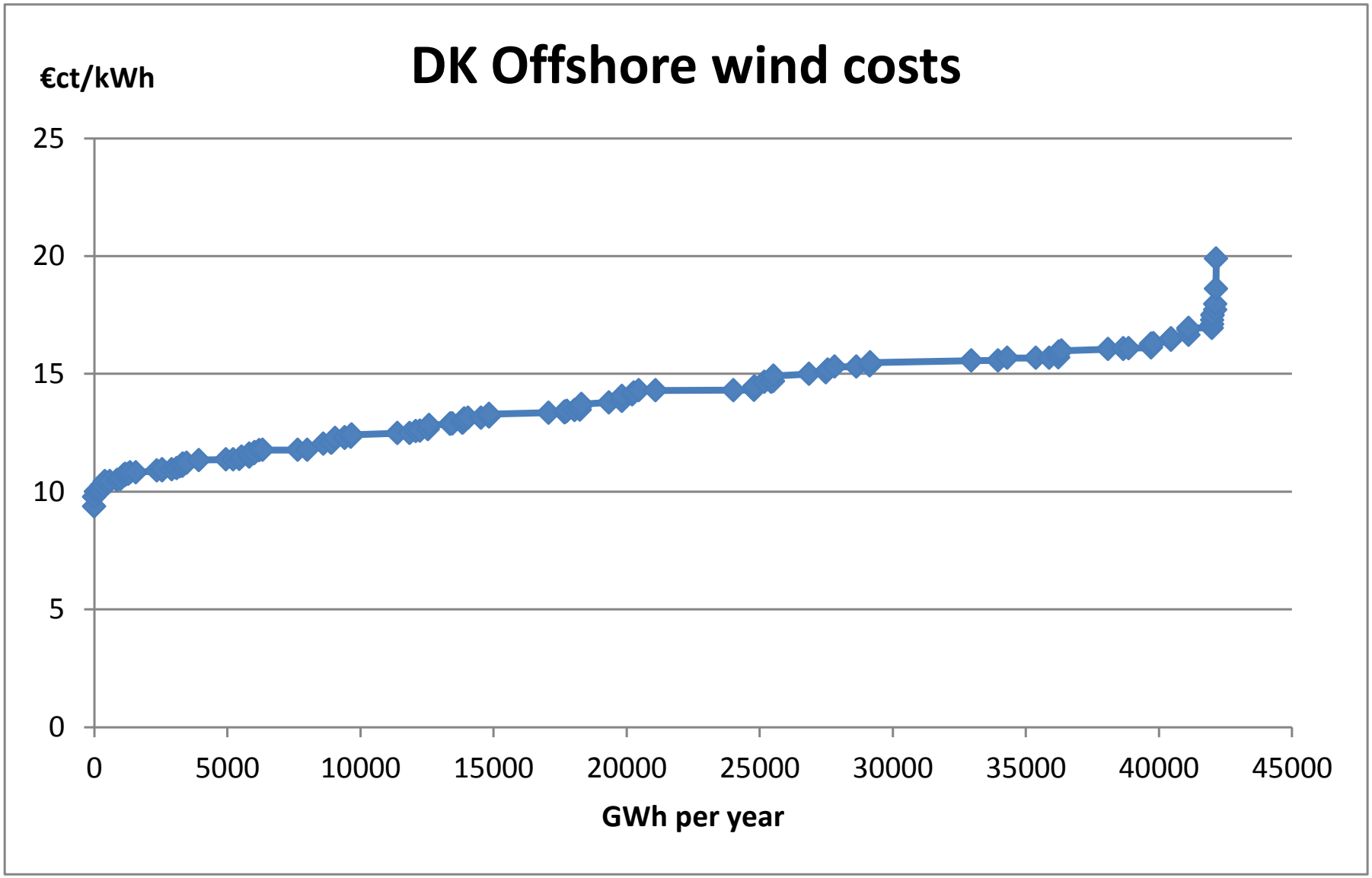
Offshore costs projections - wide range!

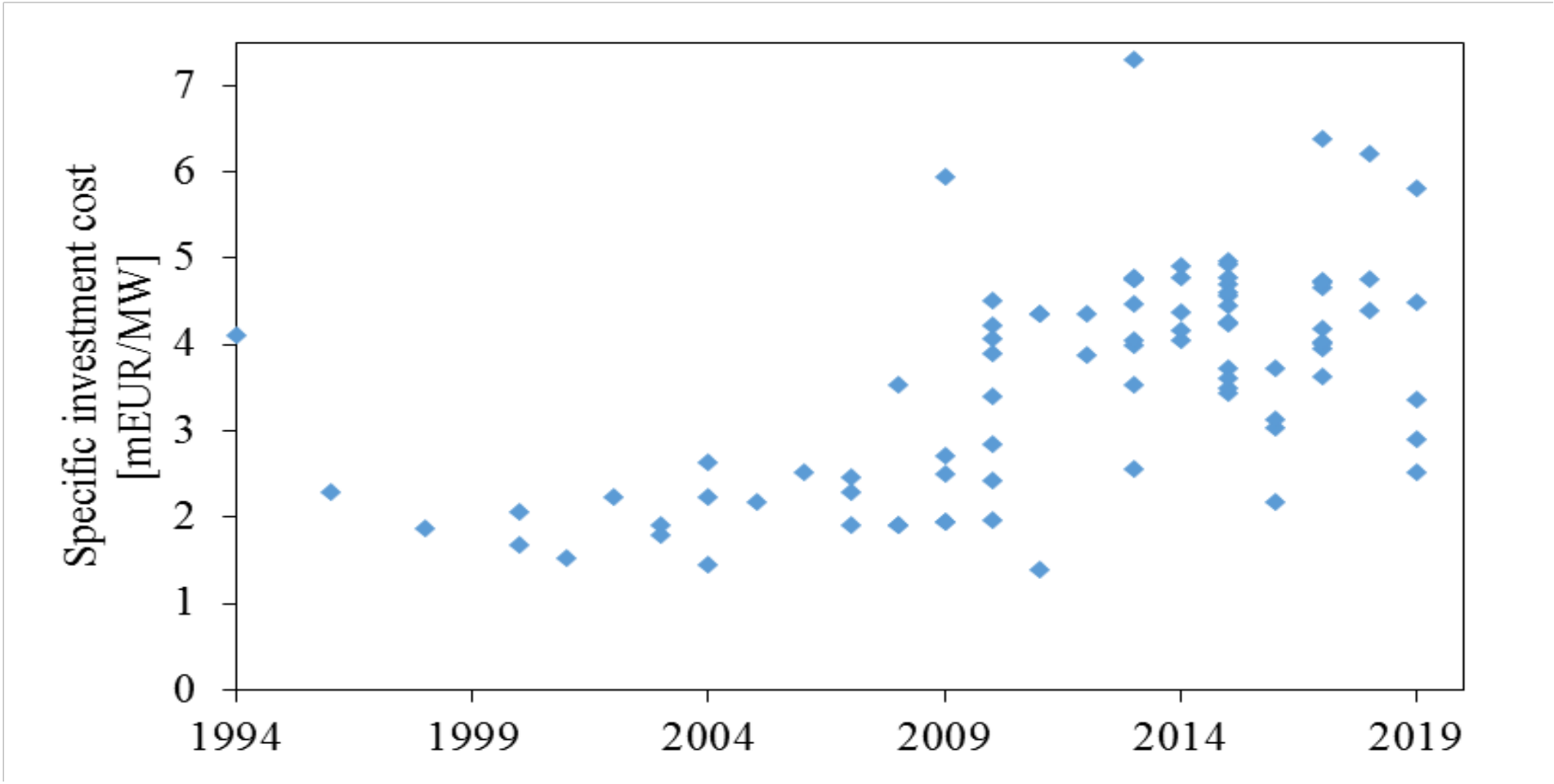


Off shore cost in the range 10-20 €ct/kWh (2020)



Off shore projects 1994-2019 - Investment cost

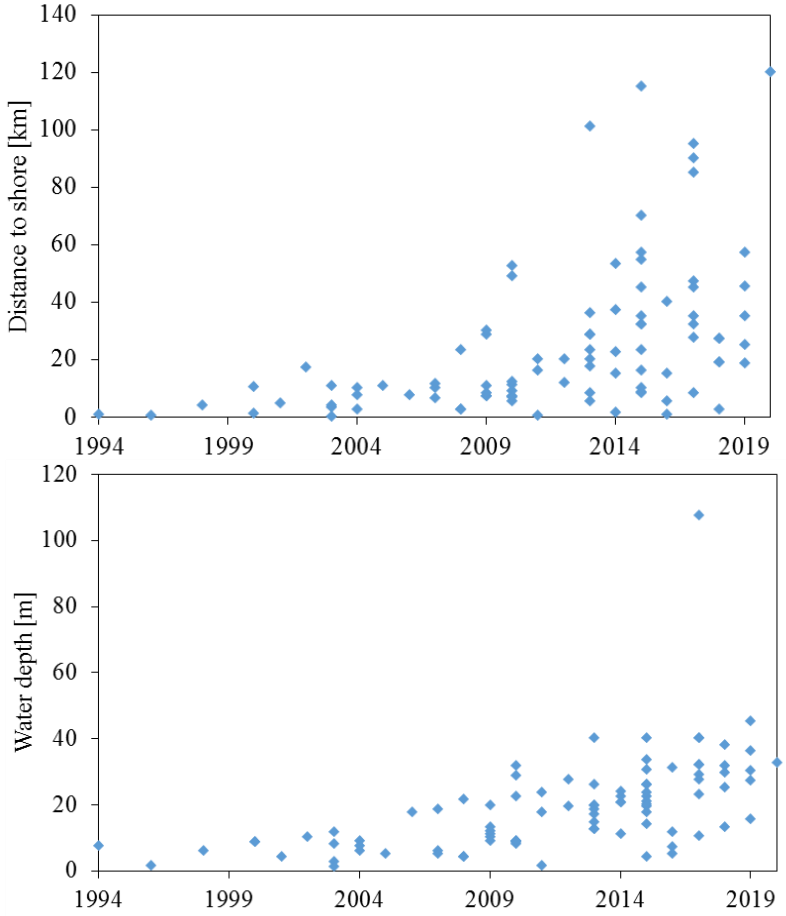
(investment costs for 90 offshore wind farms)



Source: DTU Management, Offshore cost database

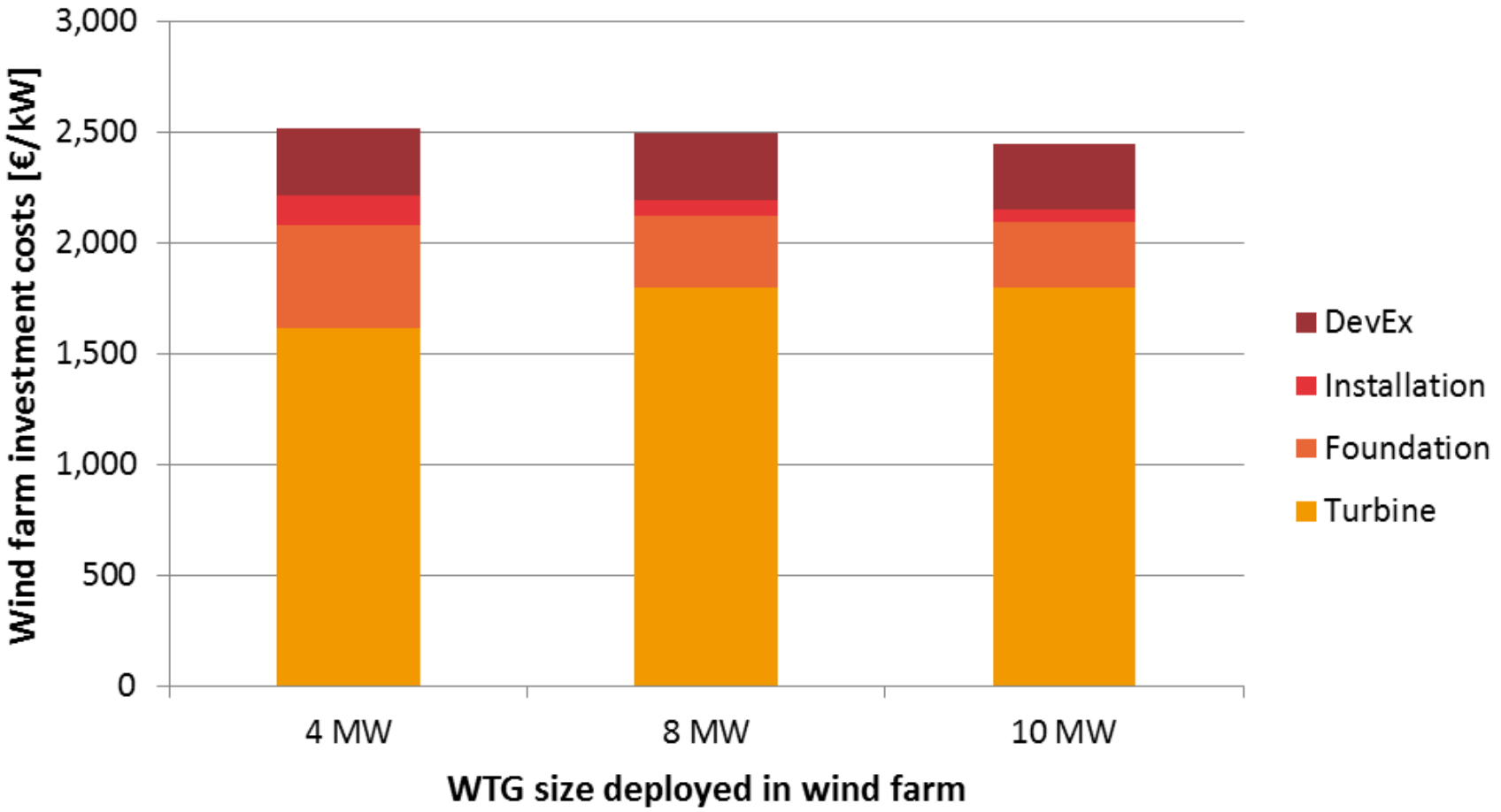
Off shore basic cost drivers

- Distance from shore:
  - Cost of cables (per km)
  - Offshore substation (avoidable nearshore)
  - Service/maintenance costs (distance to port)
  - Installation costs - (distance to port)
- Sea depth:
  - Cost of Foundations - size
  - Cost of foundation technology
  - Weather (wawes etc - comb w distance)
- Wind speed: (generation potential)
  - Average speed - profile
  - Variation and extremes (wear and tear)
- Seabed condition
- Wind farm size and outlay restrictions
  - Economies of scale up to 600MW



DK offshore investment cost composition 2015

Smaller WT size is relatively more competitive in shallow (nearshore) since installation is a larger fraction of investment cost for this turbine size



Composition of offshore wind farm investment cost

Table 2.1: Indicative cost breakdowns of offshore wind farms in the literature

	EWEA (2009)	IRENA (2012)	Kitzing & Morthorst (2015)
Turbine	49%	44%	40%–60%
Foundation	21%	16%	20%
Electrical	21%	17%	-
Installation	-	13%	25%
Other	9%	10%	-

Table 4.4: Estimated cost breakdown of the exemplary Danish wind farm project

	Average Danish offshore wind farm (wind farm only)	**Average Danish offshore wind farm (wind farm & transmission)**
Planning and development	12%	10%
Turbines (with array cables)	72%	59%
Foundations	13%	11%
Installation turbines and foundations	3%	2%
Offshore substation	-	7%
Export cable	-	4%
Onshore substation	-	5%
Installation export cable	-	2%
Offshore wind farm	100%	82%
Transmission system	-	18%

Source: Wolter, Christoph MSc Thesis DTU, 2016: Analysis of overplanting for large offshore wind farms

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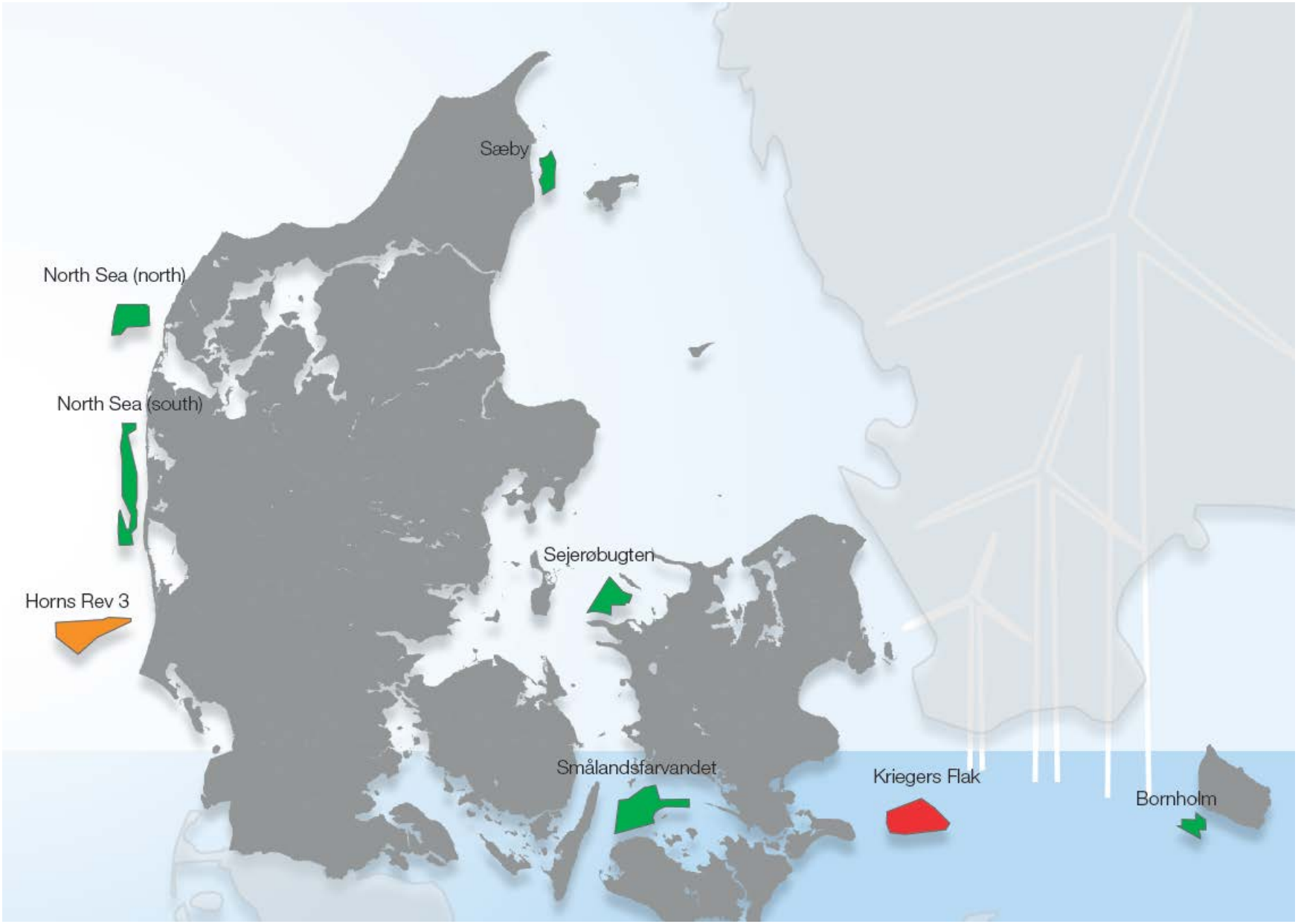
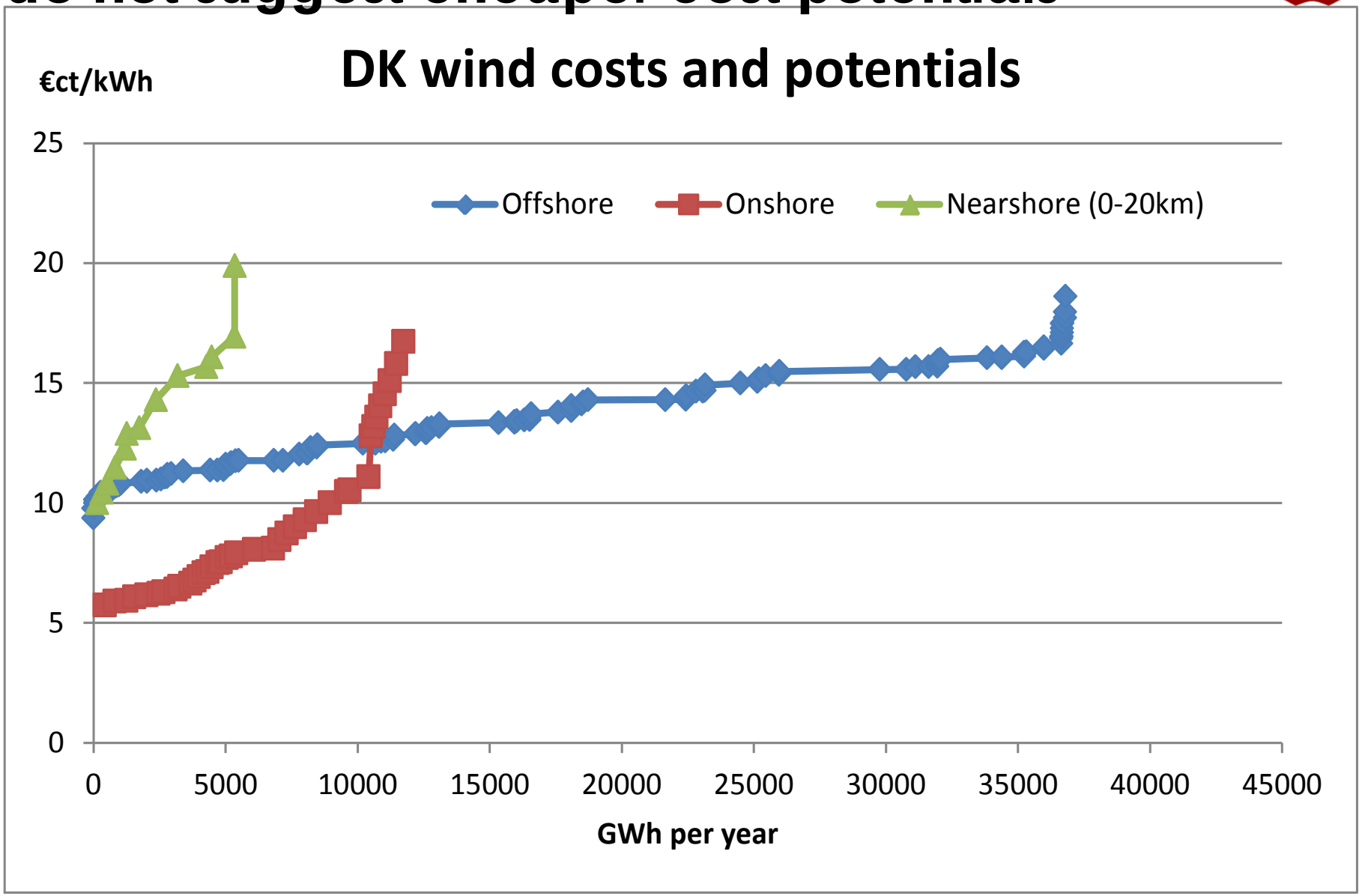
Comparing in a Danish setting - Future developments? Nearshore on hold?



Paradox in 2012 data set: Near-shore data do not suggest cheaper cost potentials



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Cost drivers for nearshore and offshore wind - what makes it cheaper?

Site characteristics +: benefit -: disadvantage

- Depth +
- Distance to shore +
- Distance to port +
- Sea-bed condition
- Size - scale ?
- Wind condition -

Country specific factors

- Regulatory requirements eg. site density - wind farm outlay
- Mandatory measures to mitigate wildlife impacts etc. -
- Labour cost +
- Competition in bidding procedures ?

International conditions

- Steel prices
- Turbine prices - competition among turbine manufacturers

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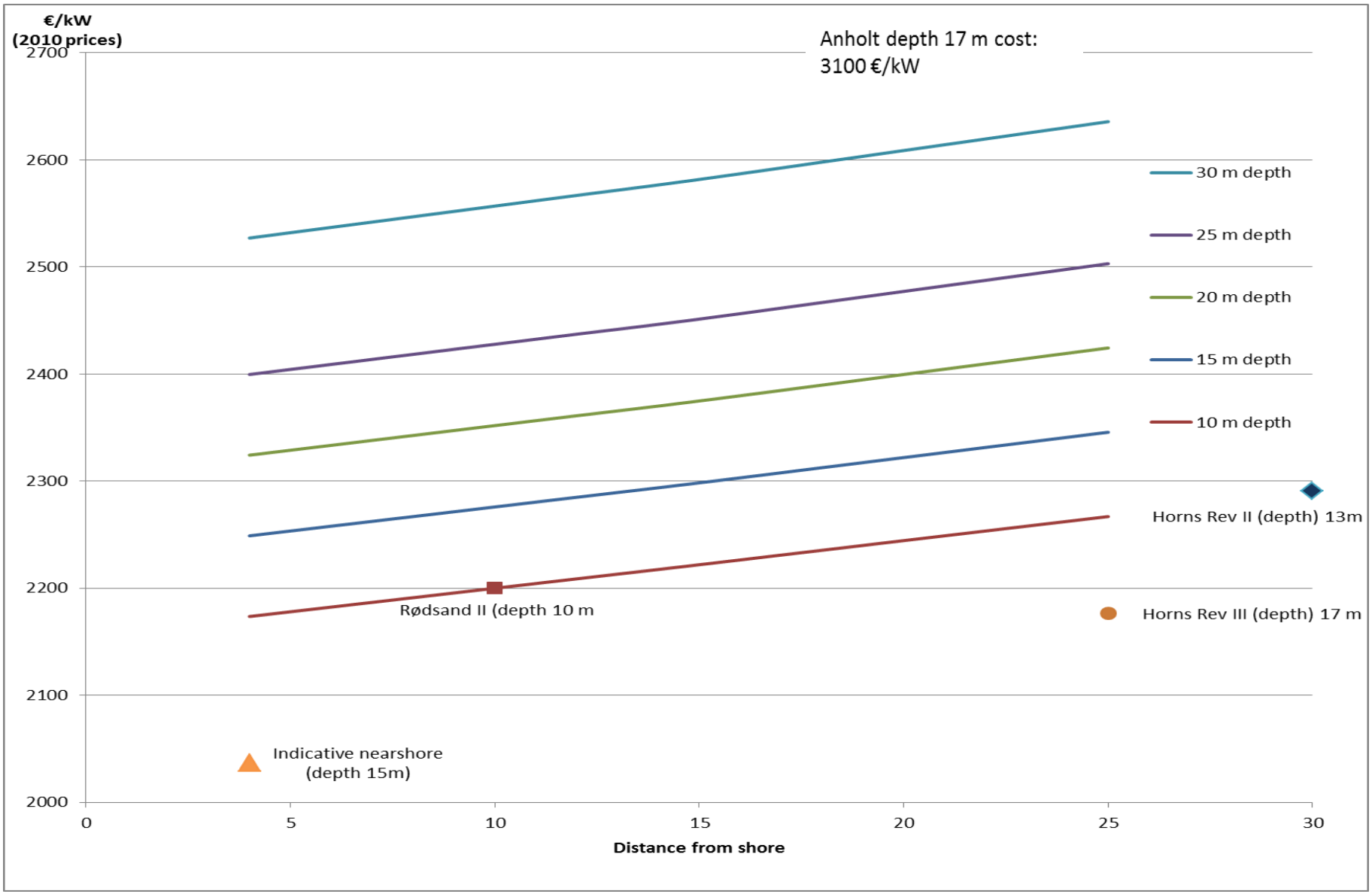
Cost drivers assumption - Scaling factors Based on EEA, 2009

Table 1 Investment cost scaling factors used for DK comparison
Source: Calculated based on EEA, 2009 (Table 6.4)

Water depth \ Distance from shore	4 km	8 km	10 km	12 km	15 km	20 km	25 km
5m							
10m	0.967	0.974	0.978	0.982	0.988	0.998	1.008
15m	1.000	1.008	1.012	1.016	1.022	1.033	1.043
20m	1.034	1.042	1.046	1.050	1.056	1.067	1.078
25m	1.067	1.075	1.080	1.084	1.090	1.102	1.113
30m	1.124	1.133	1.137	1.141	1.148	1.160	1.172
35m	1.237	1.247	1.252	1.257	1.264	1.277	1.290

Nearshore cost advantage?
Investment cost illustration for DK in 2010
Based on investment cost for Rødsand II and EEA 2008 scaling factors



How large is the cost reduction potential in Denmark

(based on limited data) cost benefits from siting 4 km from shore at 10-15 m depth

- Strictly using the curve (15m) from the graph the cost reduction moving from 25 km to 4-5 km is just 4%
- A comparison for DK in the short run has to be relative to alternative sites to the nearshore. Horns Rev III (2018) has investment costs around 2500€/kW at a relatively shallow site (around 17m)
- This is an attractive site in terms of depth and wind conditions, but within reasonable offshore potentials (1-2GW) there are similar options
- Using some very indicative prices for nearshore sites considered in DK the cost benefit of moving from 25km to approx. 5km is around 6% of the CAPEX
- This benefit first has to balance a possible (likely) difference in wind conditions
- The water depth is the dominating cost driver of the two limiting the benefits of getting closer to shore compared to finding shallower sites
- We are not arguing that water depth is unrelated to distance to shore. Moving further out clearly limits the availability of shallow areas

Competition
Will nearshore and smaller size induce more competition?

- Nearshore wind development can be developed relatively more efficient for smaller wind farm size because:
- The size of turbines, foundations etc. are smaller requiring less specialized equipment and the installation can be handled from smaller ports etc.
- This could potentially allow smaller domestic developers, local utilities, and even cooperatives to bid in auctions for nearshore development
- Whether this would be at competitive levels relative to international developers and large (European) utilities specializing in renewables is unclear
- If successful this may lead to increasing competition in bidding for smaller size renewables development in general and spreading geographically the development of offshore wind in Denmark.
- Nearshore development may create broader capacity improvement (skills and small business) in offshore installation and service bringing jobs and local participation in the wind development

Concluding remarks

- Onshore wind cost are cheaper than offshore - but slow to develop
- Including compensation payments and property acquisition may increase cost efficient onshore wind potential
- Offshore wind potential is large in Denmark - and in shallow waters
- Off shore cost drivers of importance are primarily lower depth and secondarily shorter connection cable
- A simple calculation illustrate a cost differential between nearshore and average Danish offshore conditions of between 4% and 10% of capex - that should be compared to preference for moving turbines out
- Finally the smaller possible size of the nearshore projects may facilitate more competition especially from domestic developers but may hinder economies of scale in wind farms

Thank you

Henrik and Pablo