



Review of Investment Model Cost Parameters for VSC HVDC Transmission Infrastructure

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The Linear Cost Model

$$C_{est,i}^k = \sum_j B_j^k(I_j, p_j) + \sum_g N_g^k(p_g) + \sum_h S_h^k(p_h) \quad (1)$$

$$B_j^k(I_j, p_j) = B_{ip}^k \cdot I_j \cdot p_j + B_{ij}^k \cdot I_j + B_{i0}^k \quad (2)$$

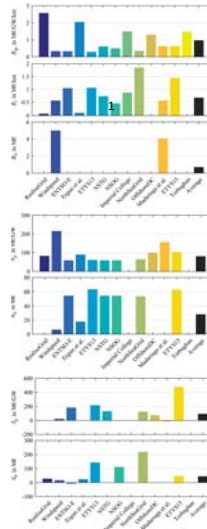
$$N_g^k(p_g) = N_p^k \cdot p_g + N_0^k \quad (3)$$

$$S_h^k(p_h) = S_p^k \cdot p_h + S_0^k \quad (4)$$

$$I_j = I_{SMC,j} + \frac{5}{4} I_{UGC,j} + \frac{2}{3} I_{OHL,j} \quad (5)$$

The Collected Cost Parameter Sets

- RealiseGrid
- Windspeed
- ENTSO-E's technology cost report
- Ergun et al. (KU Leuven)
- ETYS13 (the Electricity Ten Year Statement)
- North Sea Transnational Grid
- North Sea Offshore Grid
- Imperial College
- North Sea Grid
- OffshoreDC
- Madariaga et al. (ORE Catapult)
- ETYS15
- Torbaghan (TU Delft)



Parameter	Value	Unit
B_{ip}^{ref}	0.97	M€/GW·km
B_{ij}^{ref}	0.68	M€/km
B_{i0}^{ref}	0.70	M€
N_p^{ref}	80.88	M€/GW
N_0^{ref}	28.38	M€
S_p^{ref}	93.45	M€/GW
S_0^{ref}	44.81	M€

The Collected Reference Projects

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Project name	Rated power MW	Contracted cost (C _{con,i} ^{ref}) Converters M€ ⁺	Source
TresAmigas	750	150.0	[36]
Mackinac	350	68.0	[37]
KriegersFlak	500	125.7	[38]

Interconnector

Project name	Rated power MW	Line length				Contracted cost (C _{con,i} ^{ref})			Source(s)
		SMC* km	UGC* km	OHL* km	Line M€ ⁺	Converters M€ ⁺	Platform M€ ⁺	Total M€ ⁺	
EstLink1	350	74	31	-	84.8	-	-	84.8	[19]
EWIC	500	186	76	-	291.1	130.6	-	421.7	[20], [21]
NordBalt	700	400	13	40	268.7	169.9	-	438.6	[22], [23]
Åland	100	158	-	-	-	99.1	-	99.1	[24]
Skagerrak4	700	138	92	12	127.0	131.9	258.9	258.9	[25], [26], [27]
NordLink	1,400	516	54	53	936.5 ^a	395.9 ^a	1,332.3	1,332.3	[28], [29]
NorthSeaLink	1,400	720	7	-	890.0	408.9	1,298.9	1,298.9	[30], [31], [32]
COBRA	700	299	26	-	250.0	170.0	420.0	420.0	[33], [34]

Offshore Wind Connections

Project name	Rated power MW	Line length				Contracted cost (C _{con,i} ^{ref})			Source(s)
		SMC* km	UGC* km	OHL* km	Line M€ ⁺	Converters M€ ⁺	Platform M€ ⁺	Total M€ ⁺	
BorWin1	400	125	75	-	-	422.8 ^a	-	422.8	[39]
BorWin2	800	125	75	-	300.0	445.3 ^a	-	745.3	[40], [41]
HelWin1	576	85	45	-	150.0	595.3 ^a	-	745.3	[41], [42]
DofWin1	800	75	90	-	-	682.4 ^a	-	682.4	[43], [44]
SylWin1	864	160	45	-	250.0	495.3 ^a	-	745.3	[45], [46], [47]
DofWin2	916	45	92	-	-	479.6 ^a	353.0 ^a	832.6	[48], [49]
HelWin2	690	85	45	-	200.0	645.3 ^{ab}	-	845.3	[50], [51]
DofWin3	900	83	79	-	350.0	800.0	-	1,150.0	[52], [53], [54]
BorWin3	900	132	29	-	250.0	1000.0	-	1,250.0	[55], [56], [57]

Estimation of Overhead-Cost

$$C_{inv,i}^{ref} = \frac{11}{10} C_{con,i}^{ref} \quad \forall i \in I_{B2B}$$

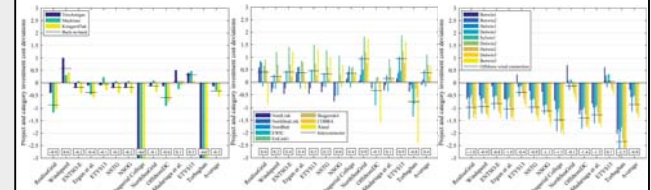
$$C_{inv,i}^{ref} = \frac{5}{4} C_{con,i}^{ref} \quad \forall i \in I_{IC}$$

$$C_{inv,i}^{ref} = \frac{5}{4} C_{con,i}^{ref} \quad \forall i \in I_{OWC}$$

Cost Parameter Set Evaluation Project- and Category-Deviation

$$D_i^k = \log_2 \left(\frac{C_{est,i}^k}{C_{inv,i}^k} \right)$$

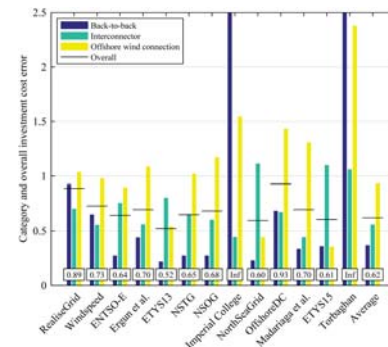
$$D_j^k = \frac{1}{|I_j|} \sum_i D_i^k$$



Category- and Overall-Error

$$E_j^k = \sqrt{\frac{1}{|I_j|} \sum_i (D_i^k)^2}$$

$$E^k = \sqrt{\frac{1}{|I|} \sum_j (E_j^k)^2}$$



Conclusion

- High level of uncertainty (large differences between project cost data and between cost parameter sets)
- Few reference projects, many influencing factors (market situation/power, fast progress, steel/copper price, risk perception, type of client, weather dependence, location aspects,...)
- Large differences between cost estimates (different purposes, different foci, different assumptions, level of simplification,...)

Future Work

- Better cost estimates are needed for grid planning studies
- This review laid a solid basis
- All the collected information will be used to generate an improved cost parameter set