Nuclear Energy: Risk and Cost of Capital

& The likely required government subsidies for Wind

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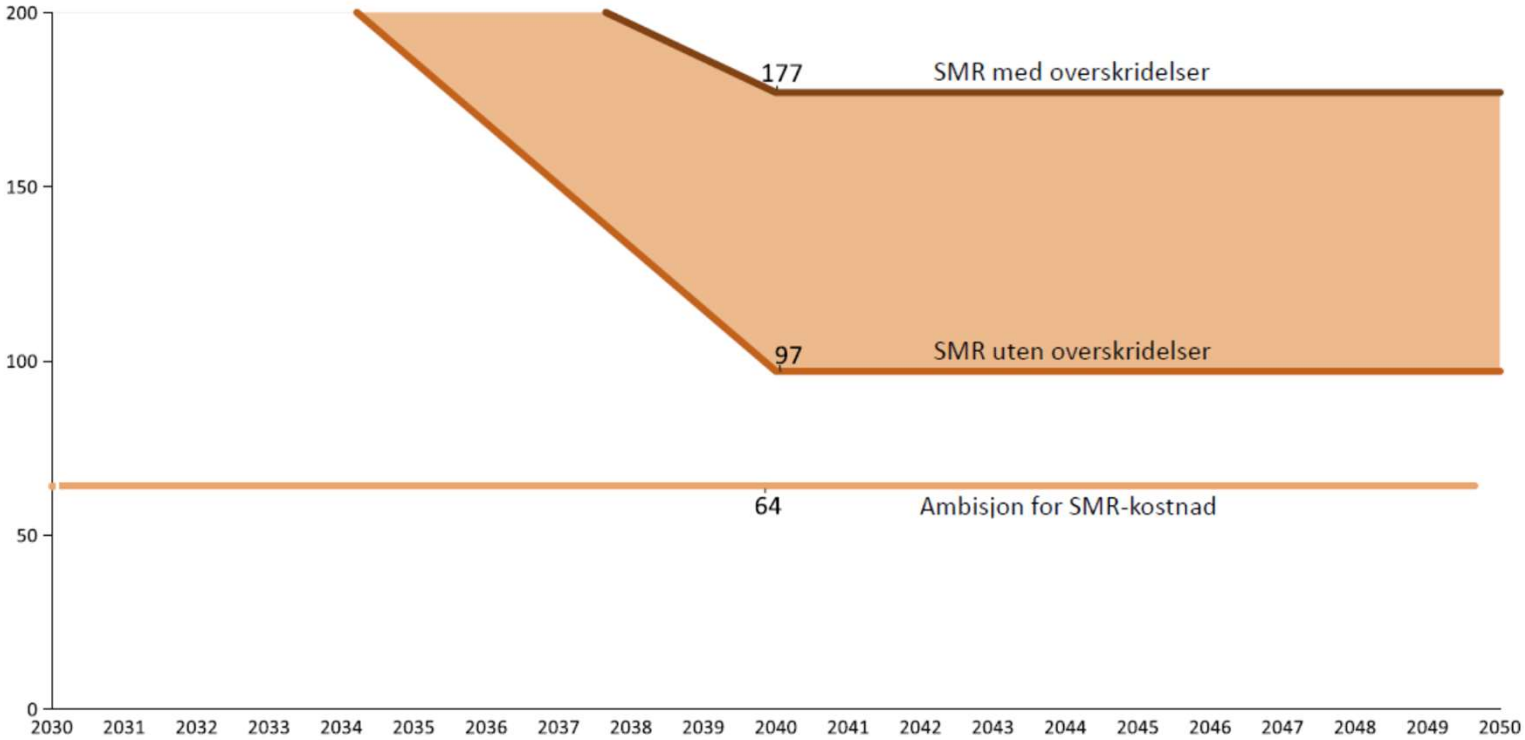
Thore Johnsen, NHH

Rystad report from Dec 2023 on Norwegian Nuclear Energy

- Very detailed on the likely relative competiveness of Nuclear Energy in the Norwegian energy system
- Focused on Små Modular Reactors (SMR)relative to Solar and Wind power
- **Conclusion: SMR is not relevant for Norway before this technology has a proven commercial sucess, and also assuming a strong government involvement – viz. Large subsidies. Anyway, a start-up is not likely before 2050, and then following a 10 year development period**
- Low relative competiveness is due in particular to a very high and risky Capex, and a long and a construction period of risky length. This higher risk requires a significantly higher Cost of Capital (CoC) both for the construction and production period
- An increased risk premium in the CoC has been questionned by NHH asst. professor Finn Kinserdal (DN 8. Jan 2024), suggesting Rystad is using a double counting of risk. Rystad suggests that Kinserdal has misunderstood part of the report (DN 15. Jan 24) .
- **I will discuss and evaluate the relevancy of this disagreement about the CoC in Rystad's analysis. This shows that the difference does not make Nuclear a viable private investment option without significant government subsidies**
- **At the end, I will evaluate the very recent cost estimates from NVE, and evaluate the likely fixed price government subsidies for UK and Norwegian Fixed and Floating Wind projects**

Det er et stort spenn i læringskurven for SMR-kraftverk som gjenspeiler usikkerheten i estimater

Læringskurve for SMR-kraftverk
$EUR_{Reelt('23)}$/MWh



- Kostnadsestimatene baserer seg på utfallsrommet for enhetskostnader og læringskurven for SMR-kraftverk mot 2040. Det antas at investeringskostnaden utenom finansiering vil være minst 20% høyere i Norge enn internasjonalt.
- Dersom noen av SMR-teknologiene lykkes er det forventet at kostnadsnivået for «serieproduserte» SMR-kraftverk kan nåes i 2040.
- «SMR med overskridelser» baserer seg på dagens kostnader og tidsoverskridelser på vestlige kjernekraftverk.
- «SMR uten overskridelser» baserer seg på forventet kostnad for et eventuelt neste, suksessfullt prosjekt i vesten som bruker AP 1000 teknologien til Westinghouse.
- «Ambisjon for SMR-kostnad» tilsvarer minstekravet for at SMR skal være relevant del av transisjonen i USA ifølge DOEs analyser. Det er ikke sikkert at de ambisjonene nåes.

Kilde: Rystad Energy analyser; *Pathways to Commercial Liftoff: Advanced Nuclear* U.S. Department of Energy; MIT - Shirvan 2022; Ekspertintervju

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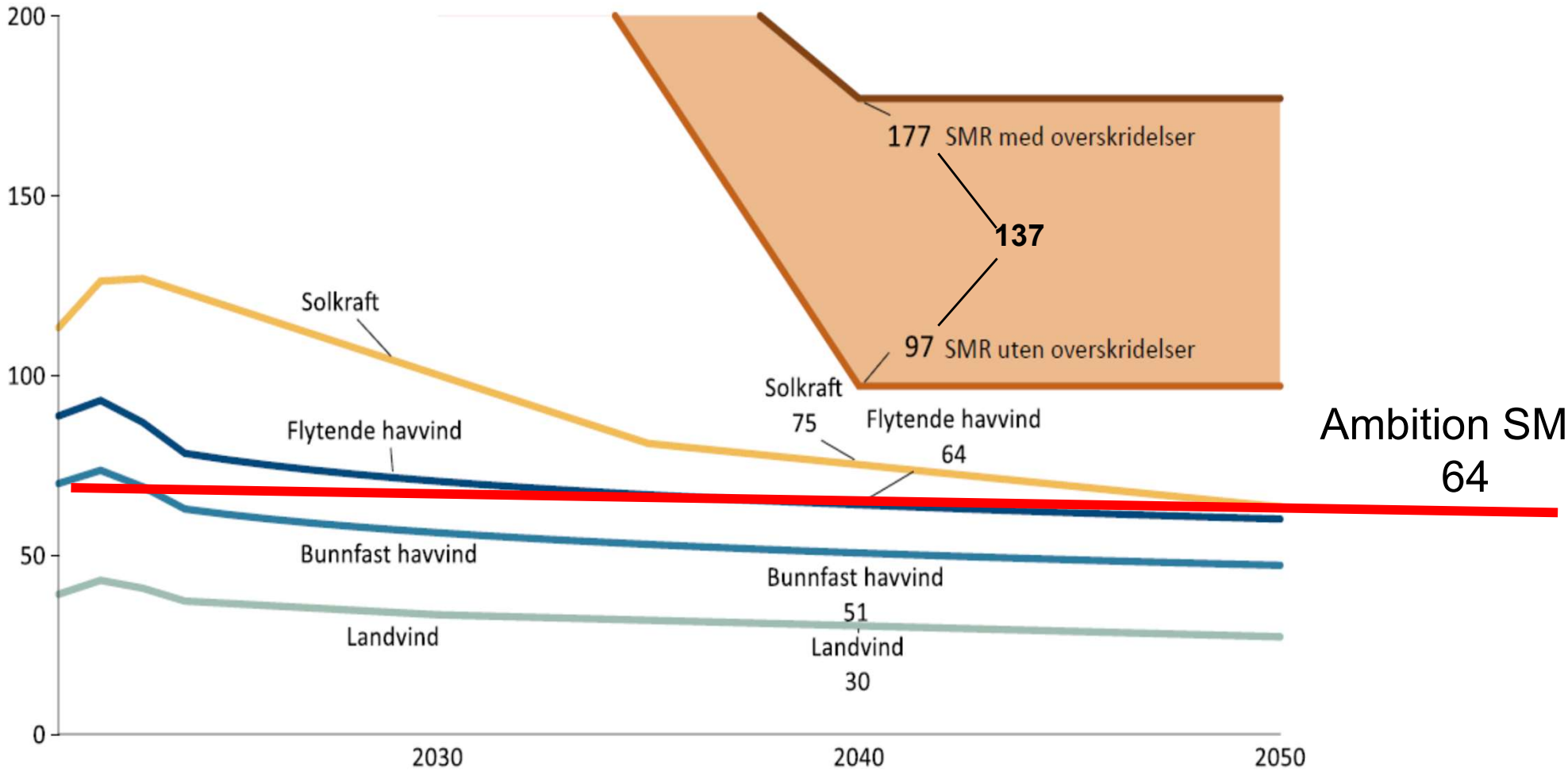
NVE's basis scenario for 2040: €49 /MWh i 2023-kroner
(kr 0,57 / kWh)

Kjernekraft må bevise lavere kostnadsnivå for å bli relevant

Læringskurve for enhetskostnad (LCOE) for energikilder i Norge*
$EUR_{Reelt('23)}$/MWh



*Forutsetter 5% avkastningskrav på vind og sol, kostnadene vil variere mellom prosjekter, men LCOE gir en god indikasjon på den relative konkurransedyktigheten.
Kilde: Rystad Energy analyser; NREL; NVE

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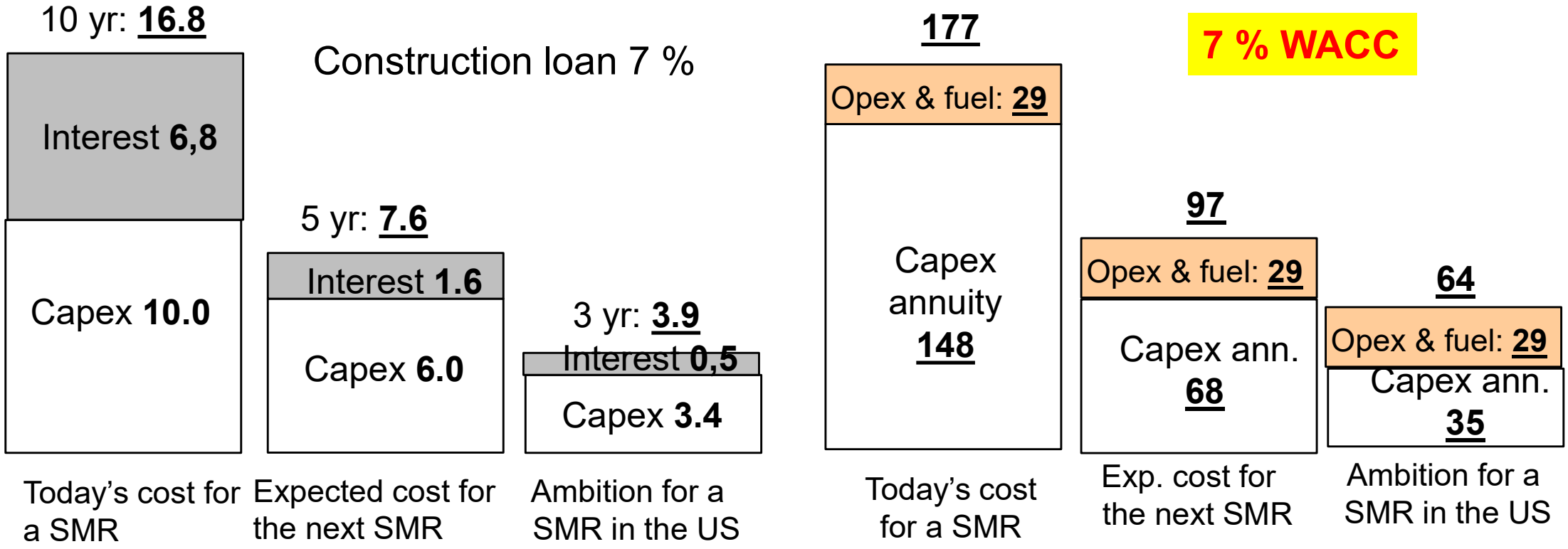
LCOE for Nuclear SMRs using a CoC of 7 % for Capex and Income

Total CAPEX pr. 2040
€ / W construction period

LCOE SMRs per 2040
€ / MWh 60 yr production



Capex Annuity €/MWh = (Total Capex) x [1mill / (0.9x8760) x **7.1 %**

Annuity factor **7.1 %** = **7 %** / (1 – **1.07^**60)

Capex annuity with NVE's 6 % CoC = (Total Capex) x [1mill / (0.9x8760) x **6.2 % = 121**

Annuity factor: **6.2 %** = **6%** / (1 – **1.06**^60)

WACC and CoC for power production – Real after tax

- Rystad used a WACC of 7 % for both the construction and proction period Nuclear energ, but only 5 % for Wind and Solar power
- Rystad: Larger construction risk for nuclear projects requires an extra risk premium relative to other egnergy alternatives

- This may well justify a higher CoC for the borrowing costs during the construction period, but why use this added risk premium for the CoC also for the much longer production period

- **After all, the income risk in the production period is probably no higher than for e.g. the Wind alternatives, and may in fact be lower due to possibly more flexible production: The Value Factor for Nuclear Energy is likely to be (significantly) higher than for Wind and Solar**

- I suggest the use of a 5 % CoC (WACC) 5 % for the production income risk a Nuclear energy project. This CoC is used by Rystad for the other energy alternatives for both the construction income risk
- A WACC of 5 % may be calculated as a sum of e.g. a 3% risk free real rate and a 2 % beta-adjusted 4 % market risk premium, using an estimated beta factor of 0.6. Alternatively, we may use a 2 % risk free rate and a 3 % beta-adjusted 5 % market risk premium

$$WACC = R_f + \beta_A \cdot MP = \mathbf{3\ \%} + 0.6 \cdot \mathbf{4\%} \approx \underline{\mathbf{5\%}}$$

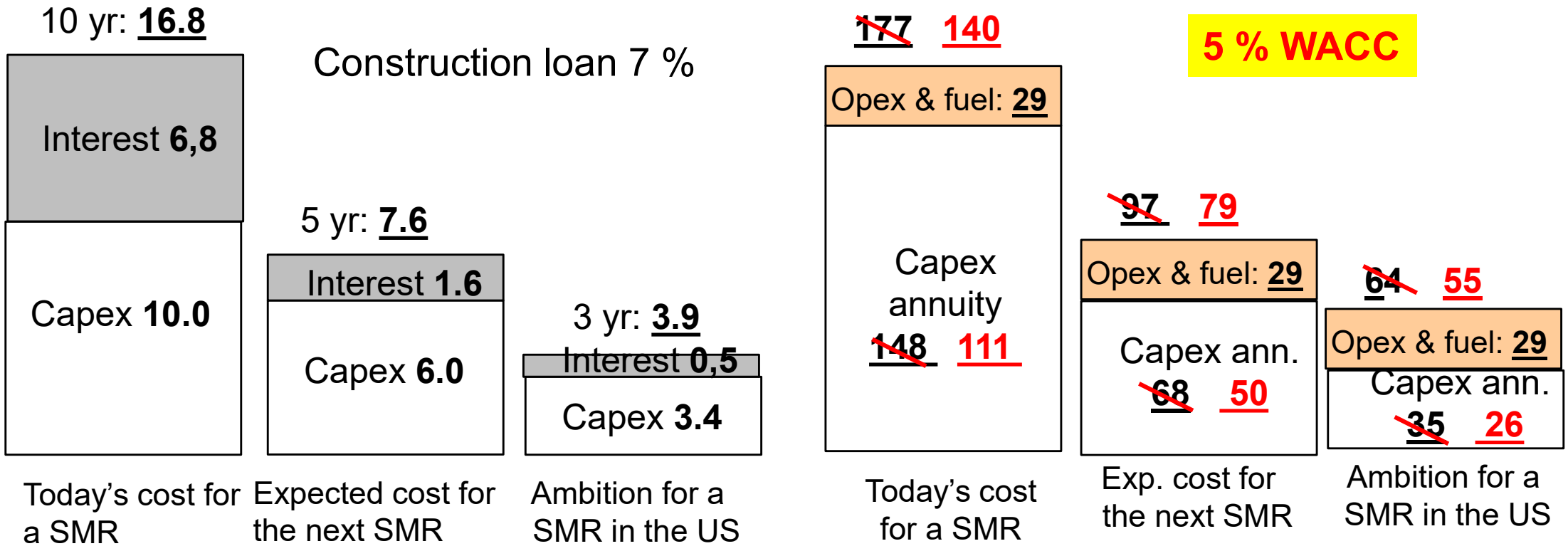
$$\textit{(= } \mathbf{\textit{2 \%}} + \textit{0.6} \cdot \mathbf{\textit{5\%}}\textit{)}$$

- The beta value of 0.6 is calculated as an average for the enterprise value of European listed energy producers; viz. the producers' enterprise value on average moves 0.6 % for a 1.0 % change in the value of the European stock exchanges through the business cycle
- NVE in the recently updated cost estimates for Norwegian energy projects is using a CoC of 6 % for the investment and income risk of all energy alternatives

LCOE for Nuclear SMRs using a CoC of 5 % for the production period

Total CAPEX pr. 2040
€ / W construction period

LCOE SMRs per 2040
€ / MWh 60 yr production

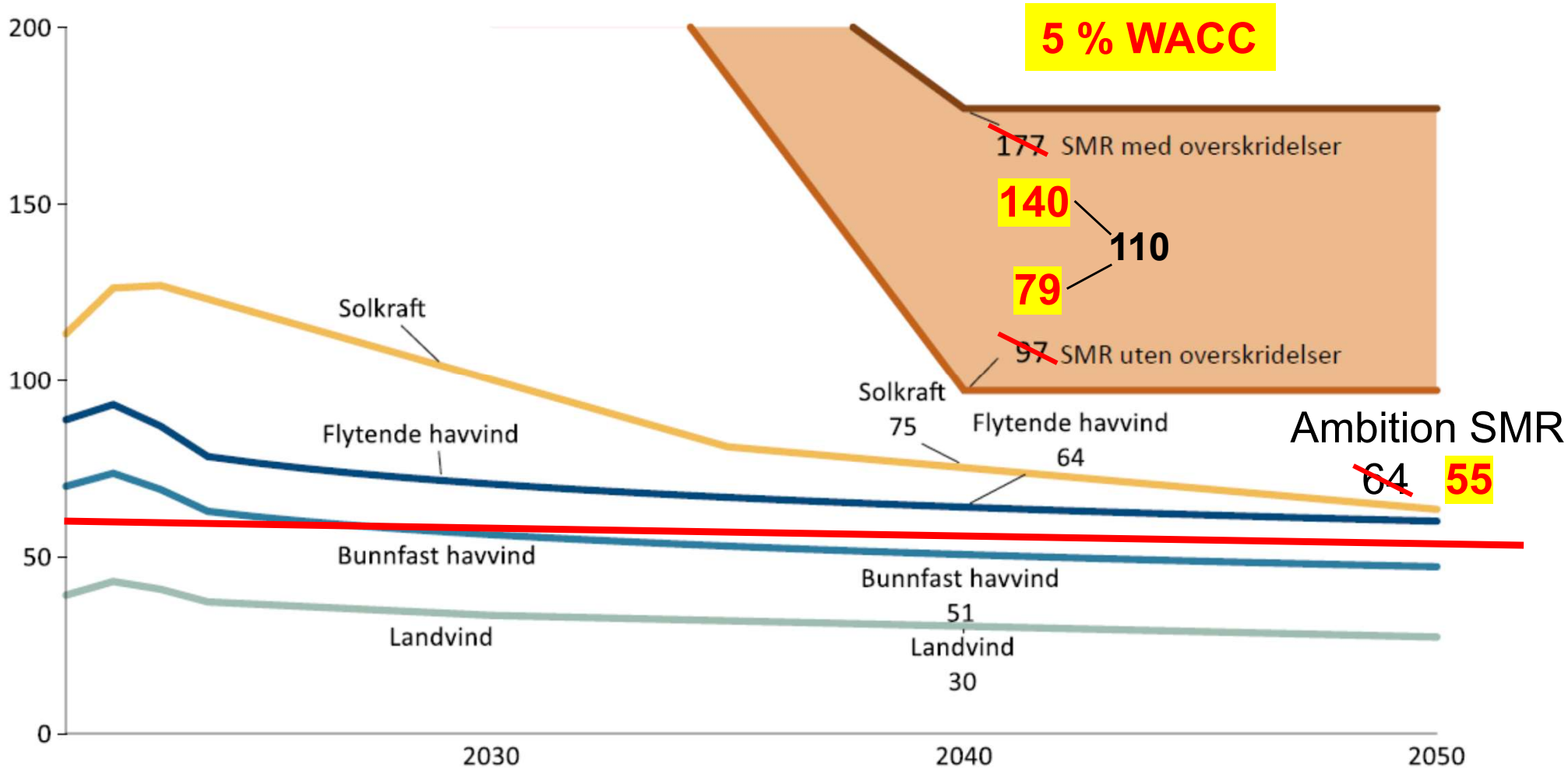


Capex Annuity €/MWh = (Total Capex) x [1mill / (0.9x8760) x **5.3 %**

Annuity factor **5.3 %** = **5** % / (1 – **1.05**^60)

Kjernekraft må bevise lavere kostnadsnivå for å bli relevant

Læringskurve for enhetskostnad (LCOE) for energikilder i Norge*
$EUR_{Reelt('23)}$/MWh



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Kilde: Rystad Energy analyser; NREL; NVE

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Conclusions

- Only marginal effects for the LCOE of SMRs relative to solar and Wind by using a CoC of 5 % for the production period
- A significantly lower Capex is needed for Nuclear relative to Solar and Wind

- Therefore, let us look at NVE's recently updated LCOEs for all energy alternatives
- And then evaluate the likely government subsidies for Fixed and Floating Wind projects, based on recent fixed-price (CfD) UK and Norwegian government auctions

Comparison of NVE's revised cost estimates with Rystad

- NVE presented their updated cost estimates on 26. september

NVE kostnad pr 2024 - 30

	NVE ; sep. 2024		Rystad 2040
	Kr / KWh	**EUR / MWh***	**EUR / MWh**
Kjernekraft store	1,60	**137**	**137**
Flytende havvind	1,54	**132**	**70**
Bunnfast havvind	1,16	**99**	**65**
Landvind	0,42	**36**	**30**
Solkraft	0,66	**56**	100
Vannkraft	0,43	**37**	
NVEs ref.pris	**0,57**	**49**	

* Basert på EUR/NOK 11,70

- Same LCOE of € 137 per MWh for conventional nuclear plants as for SMR from Rystad. Almost 100 % higher LCOE for floating Wind and 50 % higher for Fixed Wind
- **Nuclear and Floating Wind are equally costly, in particular when accounting for the likely higher flexibility and Value Factor of Nuclear**

UK and Norwegian government subsidies for Wind

- UK fixed price-auction (CfD) on 26. Sep. 2024 / For SNII on 20. Mar 24

Prosjekt	Sted	Type anlegg	Kapasitet MW	Fastpris Kr / kWh[1]	NOK mrd Subs. / år[2]	NOK mrd 15 år (6 %)	NOK mrd Max støtte[3]	Støtte Kr / MW	Investorer
Doggerbank	UK	Bunnfast	3700	**1,46**	14,4	**140**	Fritt	Fritt	60:20:20 SSE & Vårgrønn & Equinor
Green Volt	UK	Flytende	500	**3,50**	6,4	**62**	Fritt	Fritt	Vårgrønn: 50:50 Hitec Vision ; ENI
Sør. Nordsjø II	Norge	Bunnfast	1500	**1,15**	3,8	**37**	**23**	***1,5***	Ventyr = 51:49 Parkwind & IKEA
			2500		*6,4*	*62*			
Utsira Nord	Norge	Flytende	500	***2,50***	4,2	**41**	**35**	***7,0***	*50:50 Vårgrønn & Equinor ??*
				3,50	6,4	**62**			
			2500	***2,50***	*21,1*	*205*			

[1] Inflaterte terminpriser til 2024 (**Contract for Difference**): Auksjon for UK 3. september 2024; norsk auksjon for SNII 20.mars 2024
Utsira Nord 500MW er departementets "referanseprosjekt". Fastpris 2,50 = snitt av 3,50 (Greenvolt) og 1,50 (NVE's kost 26. sep. 2024).

[2] Basert på NVEs **referansepris kr 0,57** /MWh. Subsidium pr. år: (CFD - 0,57) x (Kapasitetsfaktor 0,5) x (Kapasitet MW) x 8760

- SNII: Sintef simulation based on actual wind series showed that the Norwegain government' max. subsidy amount of NOK 23 bn would on average be used after 6.5 yrs ! *Andresen; Sintef-blogg 8. april 2024*
- Have used a Value Factor of 1.0. Using a likely lower factor value (VF) will proportionally increase the estimated subsidies: Subsidy per yr / VF