MESSAGE based Energy System Analysis:

Transition Pathways to 2050

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Background and objectives

Toward the 12th Basic Plan

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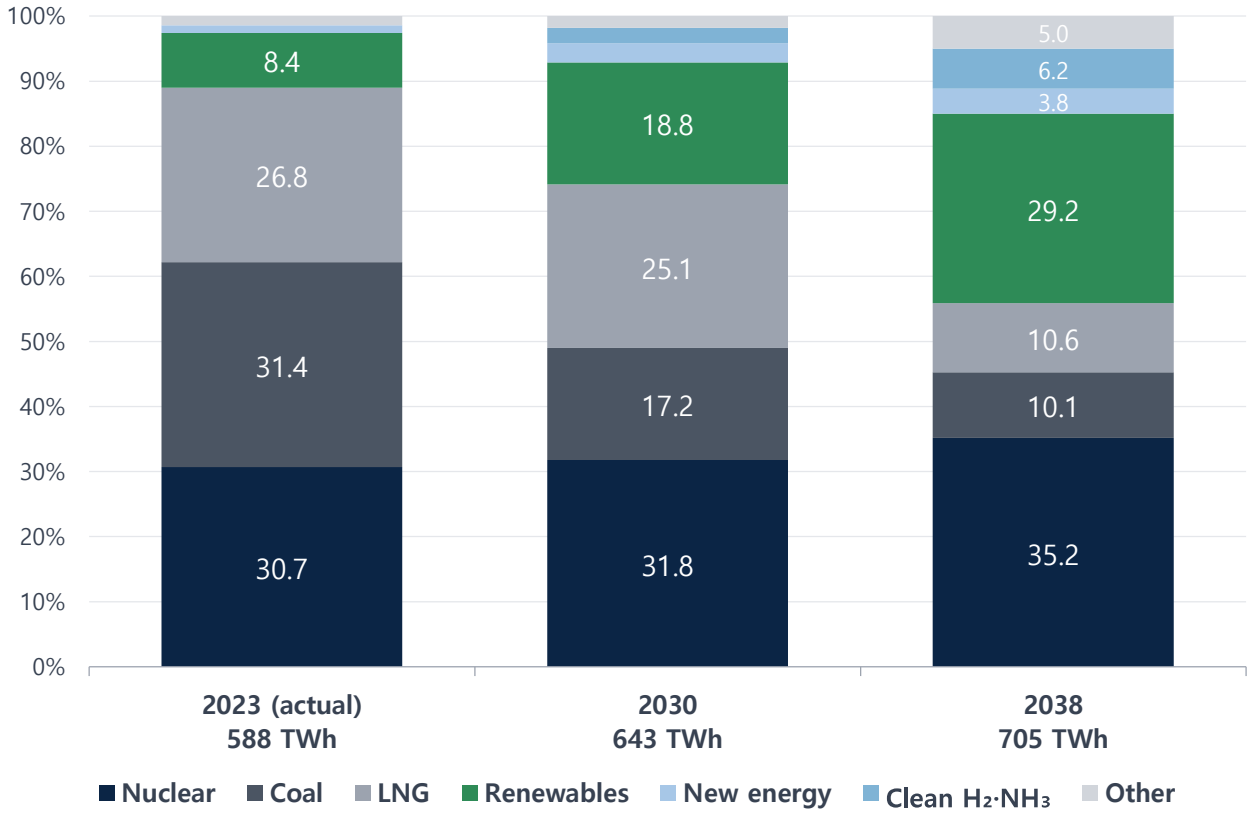
Background

- 2021 Carbon Neutrality Scenario: nuclear 6–7% of generation in 2050.
- 2025 11th Basic Plan: nuclear 35.2% in 2038 (about five times higher, four years later).
- The 11th Basic Plan ends in 2038; the 2039–2050 pathway is still undecided.

Objective

Using IAEA MESSAGE, we compare capacity and total system cost for the same carbon free electricity target (CFE ≈ 75%) met by different nuclear renewable combinations.

11th Basic Plan: power mix to 2038



- Carbon-free share 70.7% in 2038
- Nuclear 35.2%, renewables 29.2%, H_2/NH_3 6.2%
- 93% of 2038 capacity already committed

Source: 11th Basic Plan for Electricity Supply and Demand (MOTIE, 2025); generation shares in %

Assessment of the 11th Basic Plan

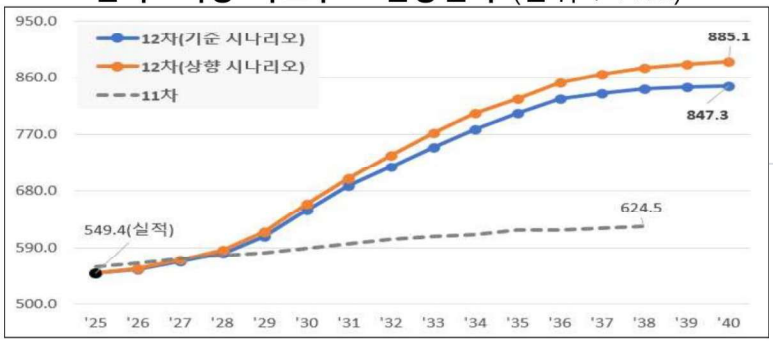
1 Demand outlook too low

2 Short planning horizon

3 High share of committed capacity

4 No alternative scenarios

< 전력소비량 목표수요 전망결과 (단위 : TWh) >

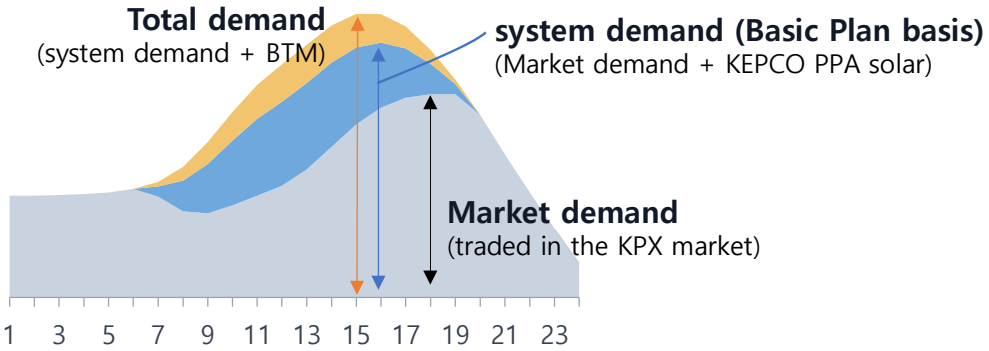


Source: 11th Basic Plan for Electricity Supply and Demand (MOTIE, 2025)

Demand definition and derived demand

Market, system and total demand

- Basic Plans are built on system demand
- So the model load uses system demand, not the public KPX market data
- In 2023, PPA and BTM were about 4.8% and 2.7% of total demand



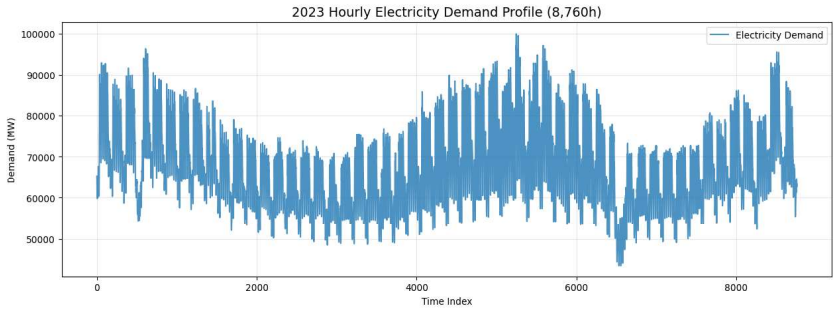
Supply demand balance in the model

Gross generation = **Final demand** exogenous input + **auxiliary power** + **T&D losses** + **Storage charging** + **RE surplus**

Endogenous terms (determined by the power mix)

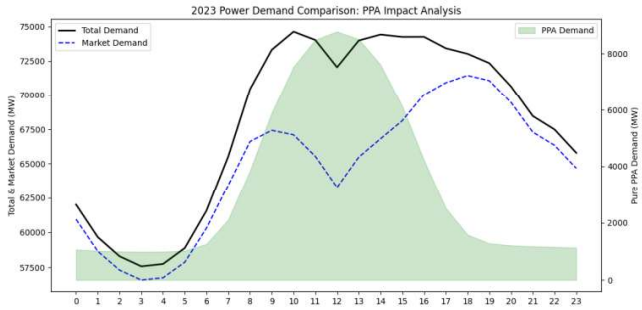
Load pattern analysis: from 2023 data to the 2050 shape

① 2023 base year



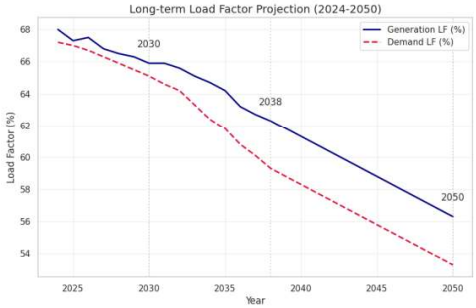
Peak 100 GW, mean 68.1 GW, load factor 68.1%

② PPA solar



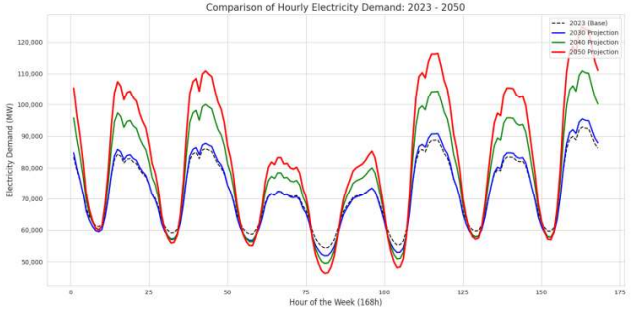
Fills the midday dip in market demand (PPA share 9.7–15.7%)

③ Load factor to 2050



68% → 53% (demand side); −0.5%p per year after 2038

④ Weekly shape in 2050



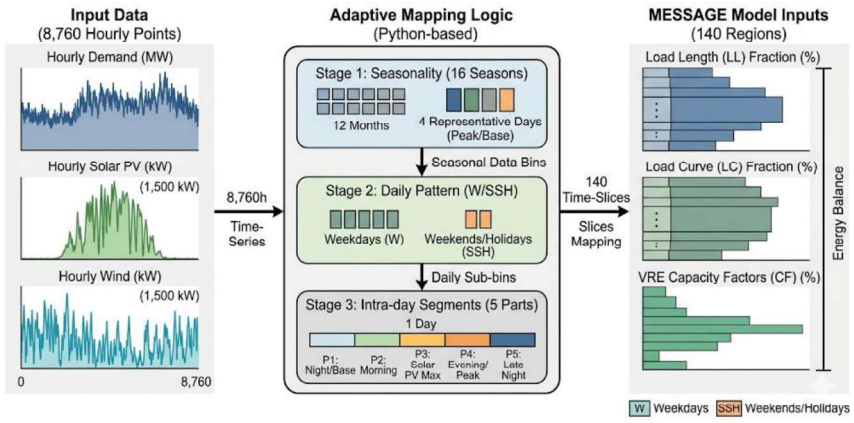
Wider peak–trough gap, mapped to the 140 time slices

Demand pathways and load regions

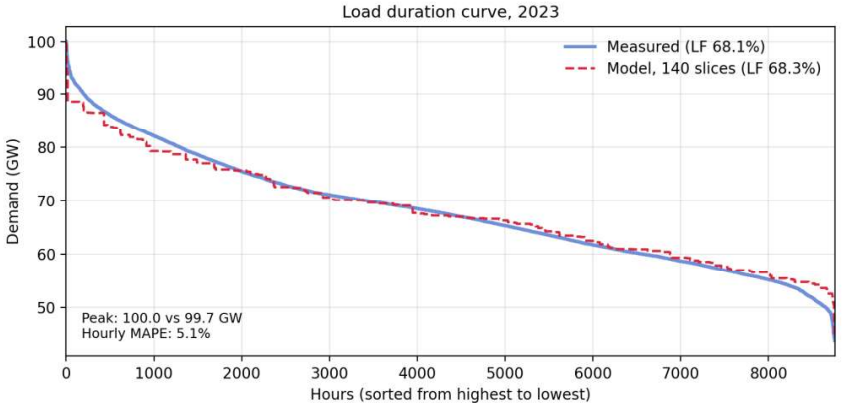
Demand pathways

Path 1 (high)	11th Plan demand to 2038, then +5%/yr → 1,123 TWh in 2050
Path 2 (low)	11th Plan demand to 2038, then +3%/yr → 890 TWh in 2050 (sensitivity)

140 representative time slices (load regions)



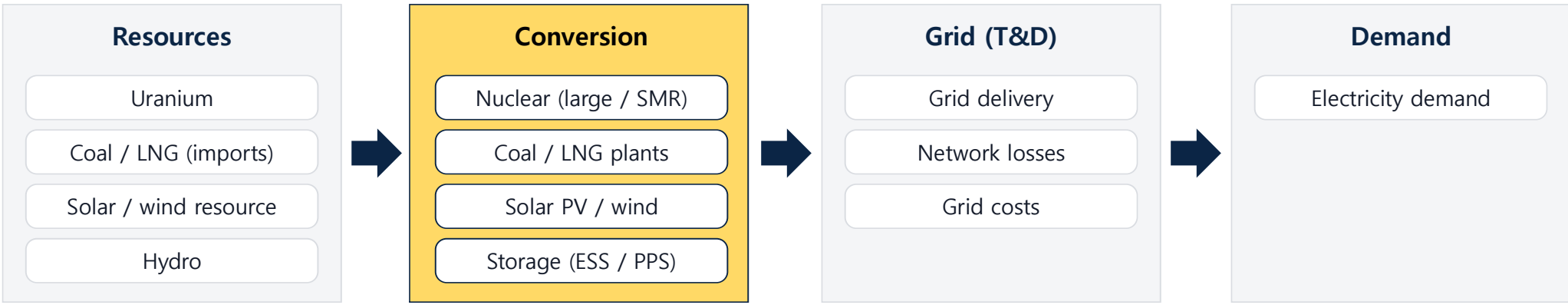
8,760 h data → 140 time slices (MESSAGE input)



Hourly mean absolute % error (MAPE): 5%

Energy system modeling with MESSAGE

Reference energy system



Least cost optimization

$$\min \ \Sigma_t \, (1 + r)^{-t} \times (\text{investment} + \text{O\&M} + \text{fuel})$$

subject to demand, capacity, CO_2 and reserve constraints

Static vs. dynamic, greenfield vs. brownfield

	Greenfield	Brownfield
Static	**GenX (MIT)** Ideal mix for one year, no legacy plants	**Posy2 (NEA)** Target year mix; the fleet in that year is assumed
Dynamic	**Rarely used**	**MESSAGE, WASP** Pathway from today's system: what, when, how much

Why a dynamic, brownfield model

- Existing plants retire by vintage; new builds become next year's existing fleet
- Investment timing and annual build limits (e.g., 2–3.5 new nuclear units a year)
- Path dependence: LNG built before 2050 stays on as reserve (capacity factor 9–16% in 2050)
- A static model annualizes investment and takes the target year fleet as given

Model constraints

CO_2 emission cap

2035 NDC and 2050 Carbon Neutrality Scenario B (20.7 $MtCO_2$ in 2050)

Reserve margin, coal phase out

Planning reserve margin of 22% of peak demand; coal phased out by 2040

Renewable mix

Solar:wind follows the Basic Plan to 2038, then 1:1; offshore wind takes one third of new renewables from 2028

Storage and carbon removal

Pumped hydro 17.4 GW, 4h batteries; carbon removal (90%, $600→130/t) as proxy for other CFE

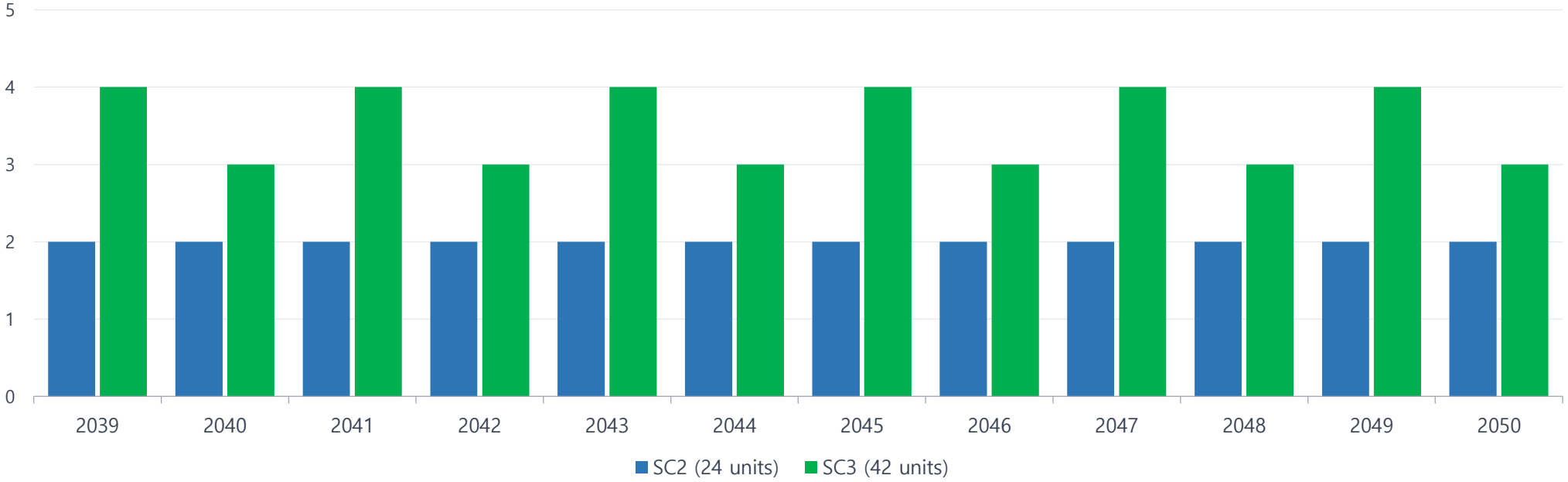
Scenario design

Item	SC1 NUC Constrained	SC2 NUC Maintained	SC3 NUC Expanded
2050 nuclear share	≈ 9–11%	35%	50%
2050 renewable share	65%	40%	25%
LTO of existing units	None	20 years	20 years
New nuclear cap* (units, high/low)	0 / 0	24 / 15	42 / 30

** 80% CF. Caps derived from target shares; 2050 nuclear 18.0 / 59.6 / 84.8 GW (high demand)*

New nuclear build schedule, 2039–2050

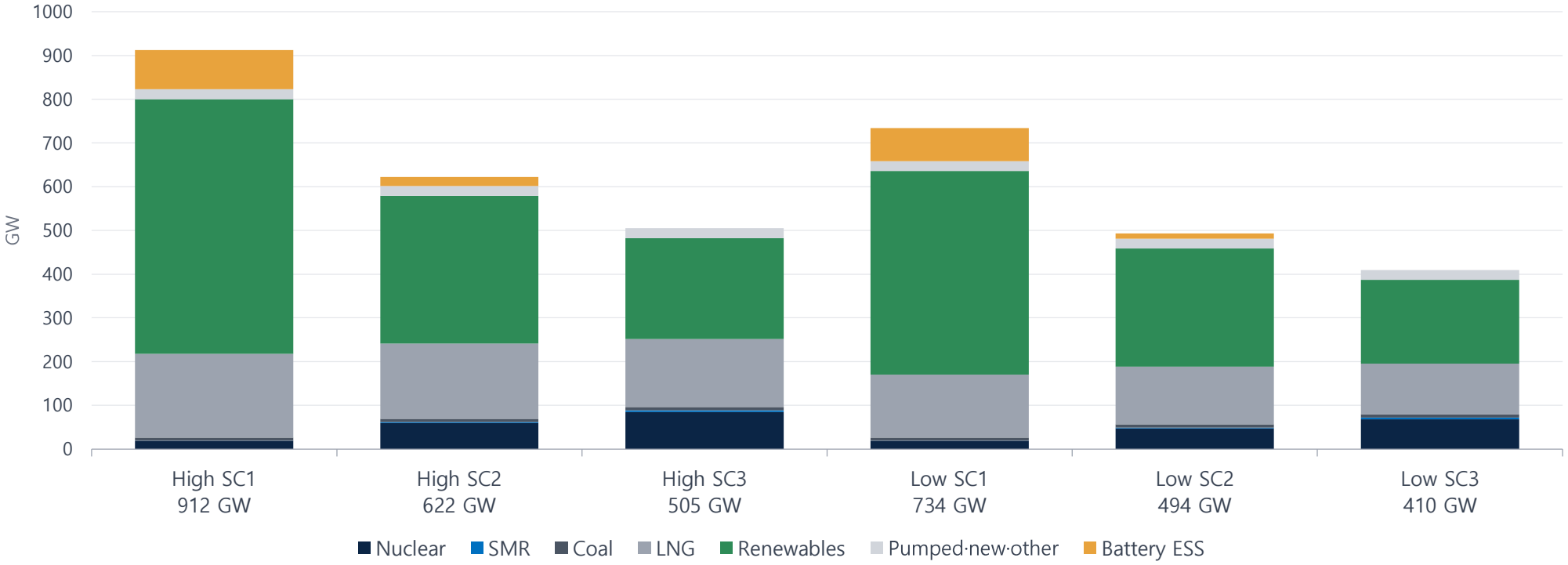
New 1.4 GW units per year, high demand



- SC2 needs 24 units (2 a year), SC3 42 units (3.5 a year); under low demand, 15 and 30 units
- With lead times over 10 years, the decisions fall in the 12th–13th Basic Plans

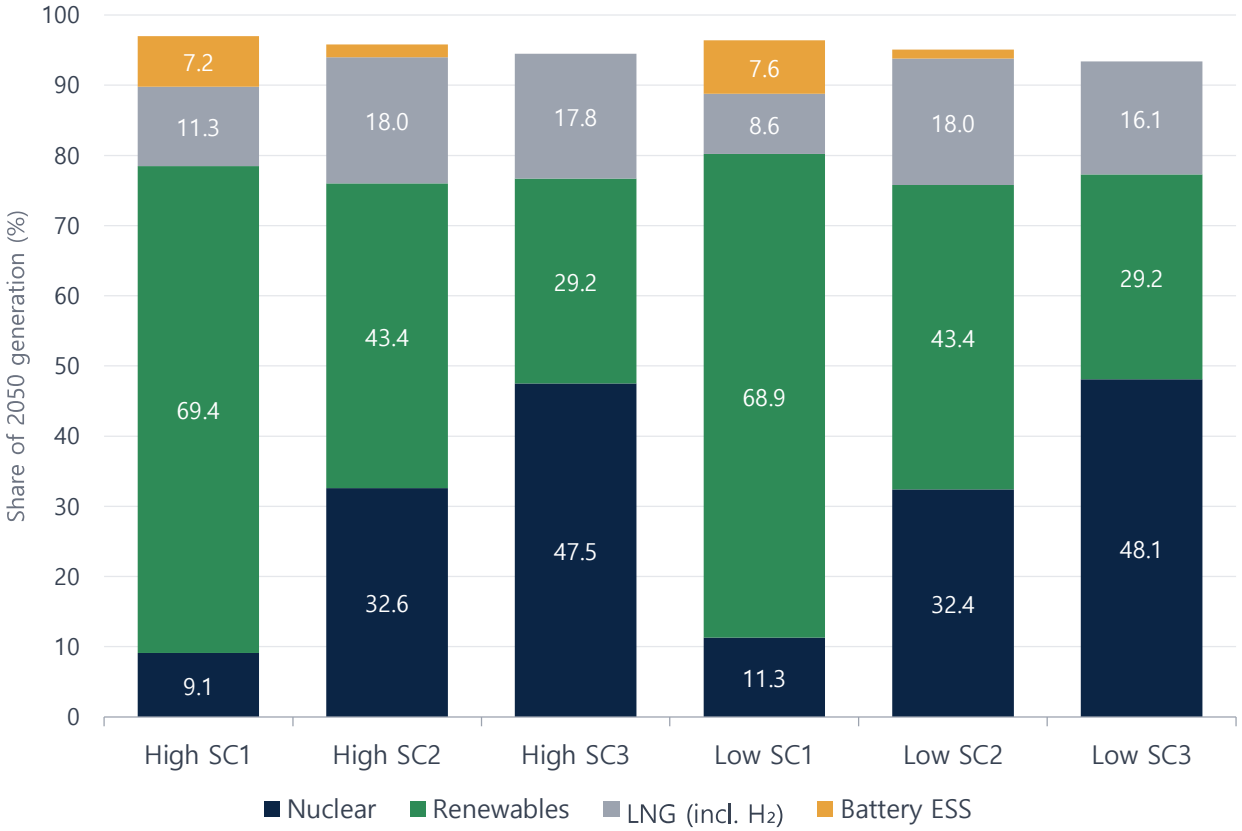
Installed capacity in 2050

Total generation and storage capacity in 2050 (GW)



Solar + wind 583 → 231 GW and batteries 89 → 0 GW account for most of the gap; low demand 734 → 410 GW (−44.2%)

Generation mix in 2050



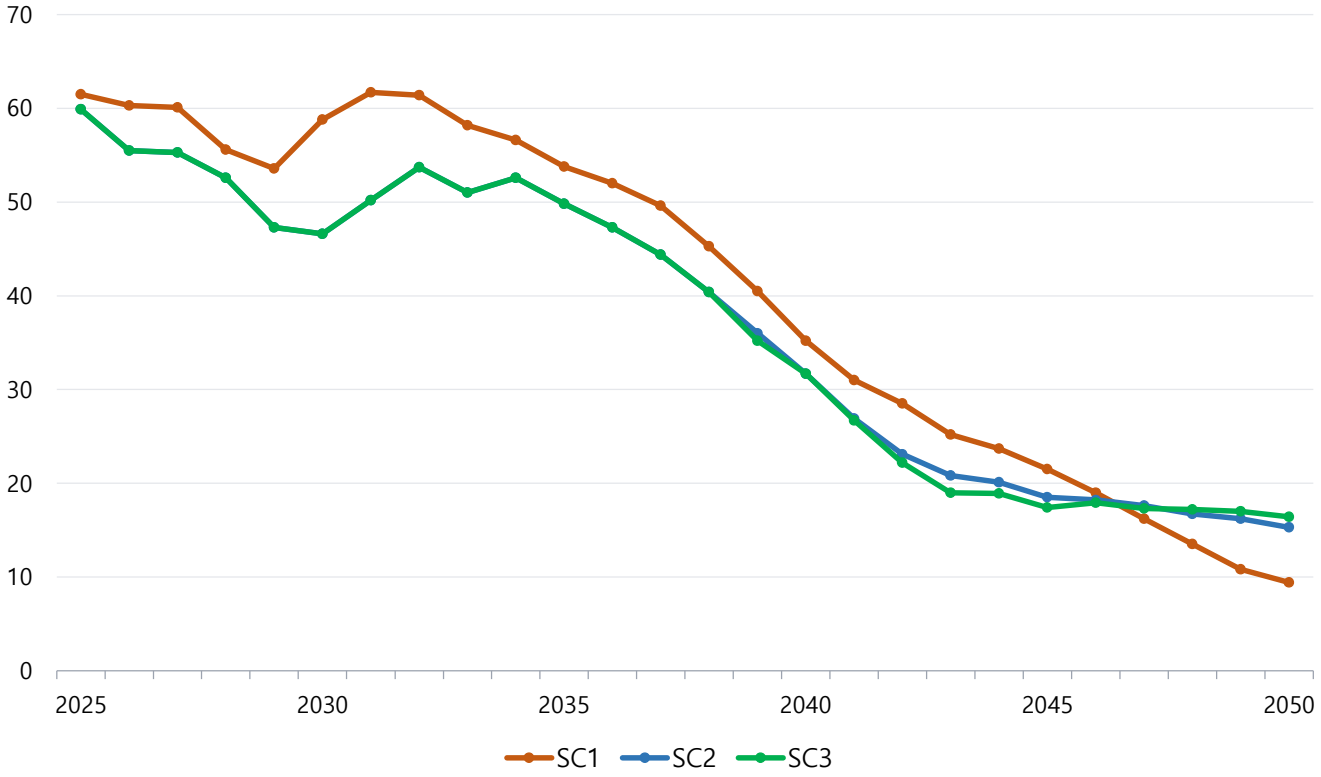
Derived demand, 2050 (high demand)

TWh	SC1	SC2	SC3
Final demand	1,123	1,123	1,123
Gross generation	1,387	1,282	1,251
Gen. ÷ demand	**1.23**	**1.14**	**1.11**
Battery discharge	≈100	≈23	0
RE surplus (%)	19.5	8.5	4.7

- Carbon-free share is 76–78% in all pathways
- SC1 generates 136 TWh more for the same demand: stored power counted twice, storage losses and curtailed surplus

Capacity factors by technology

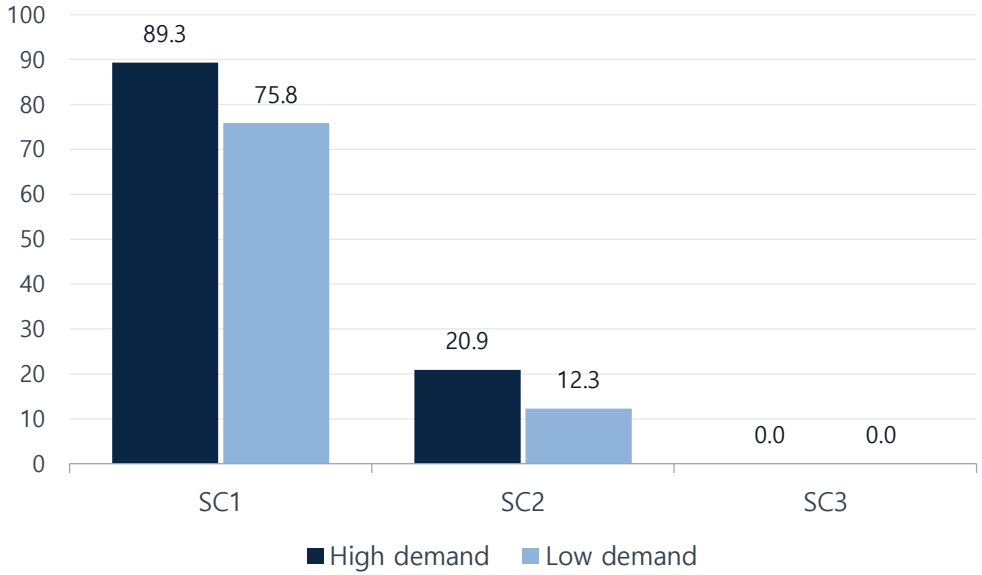
LNG capacity factor, 2025–2050 (%, high demand)



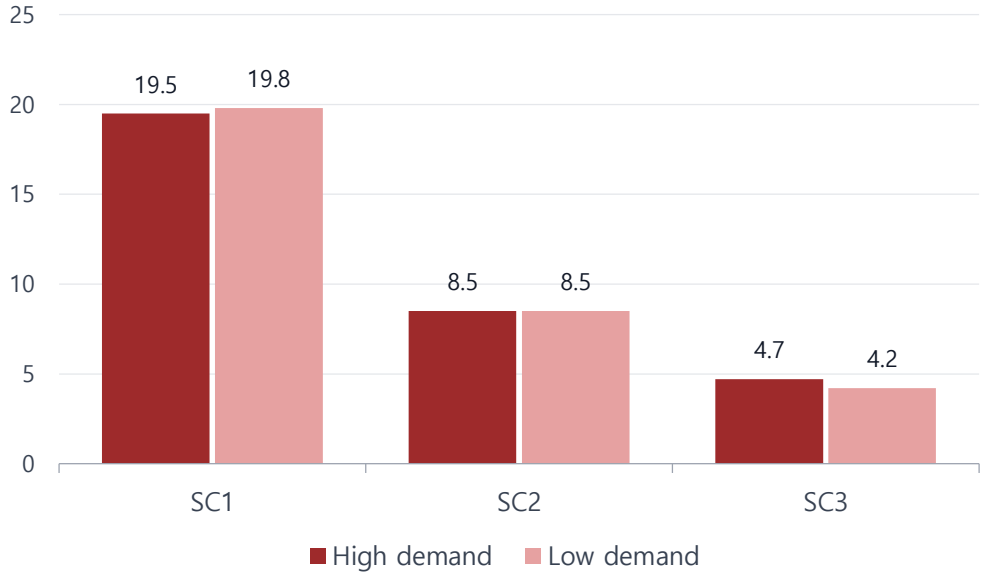
- LNG: about 60% in 2025, 9–16% in 2050
- 155–192 GW of LNG is still installed in 2050
- Nuclear runs at 80% in all scenarios

Battery storage and surplus generation in 2050

Battery ESS in 2050 (GW)



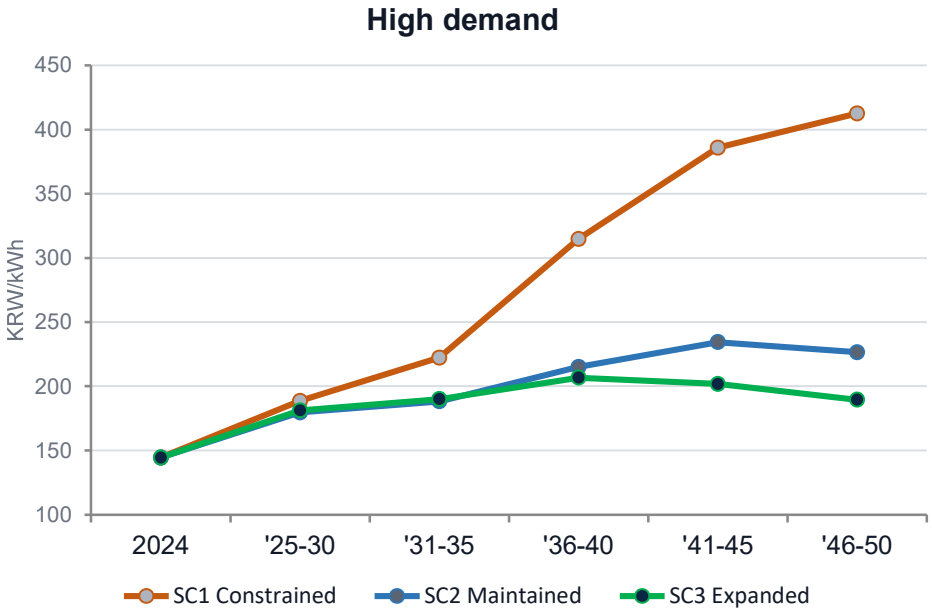
Renewable surplus generation ratio (%)



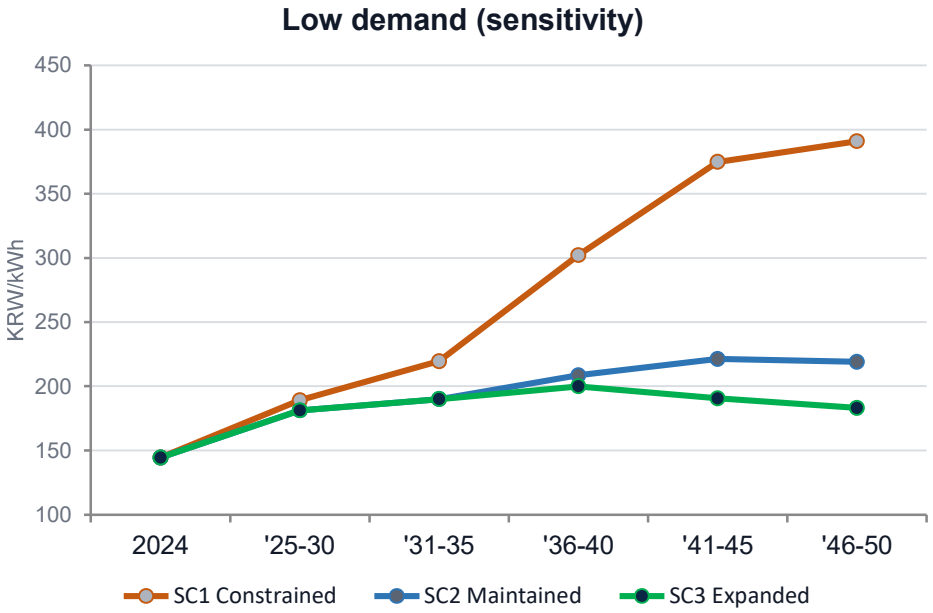
- In SC3, pumped hydro (17.4 GW) alone is enough; no batteries are selected

System cost by period

Period average cost (KRW/kWh) = cumulative cost ÷ cumulative sales



'46–50 avg: SC1 412.5 / SC2 226.5 / SC3 189.5



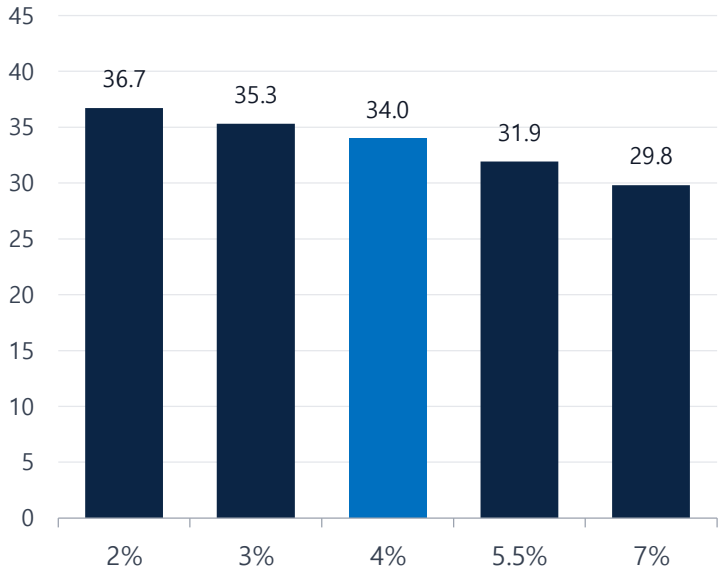
'46–50 avg: SC1 390.9 / SC2 219.1 / SC3 183.2

Present value of total system cost, 2025–2050 (Discount rate 4%, 2024 base)

	SC1 NUC Constrained	SC2 NUC Maintained	SC3 NUC Expanded
High: PV cost (KRW tn)	**3,170**	**2,234**	**2,093**
High: vs. SC2	**+41.9%**	**base**	**–6.3%**
Low: PV cost (KRW tn)	2,870	2,072	1,944
Low: vs. SC2	+38.5%	base	–6.2%

- Relative to SC2: SC1 +936 tn, SC3 –141 tn (high demand)
- SC3 is KRW 1,077 tn (34.0%) lower than SC1 under high demand, and KRW 926 tn (32.3%) under low demand

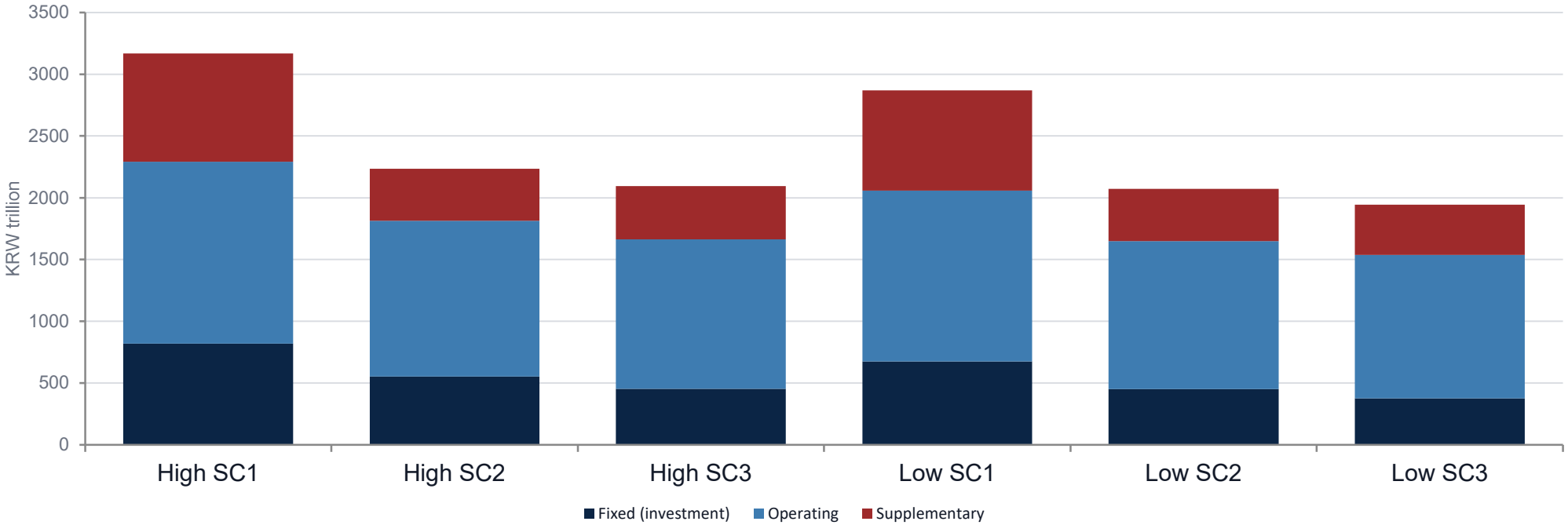
SC3 saving vs. SC1 by discount rate (%)



- Ranking holds at every discount rate

Composition of system cost

KRW trillion, 2025–2050, 4% discount rate, 2024 base



Of the KRW 1,077 tn gap (high demand), 42% is supplementary cost and 34% is investment

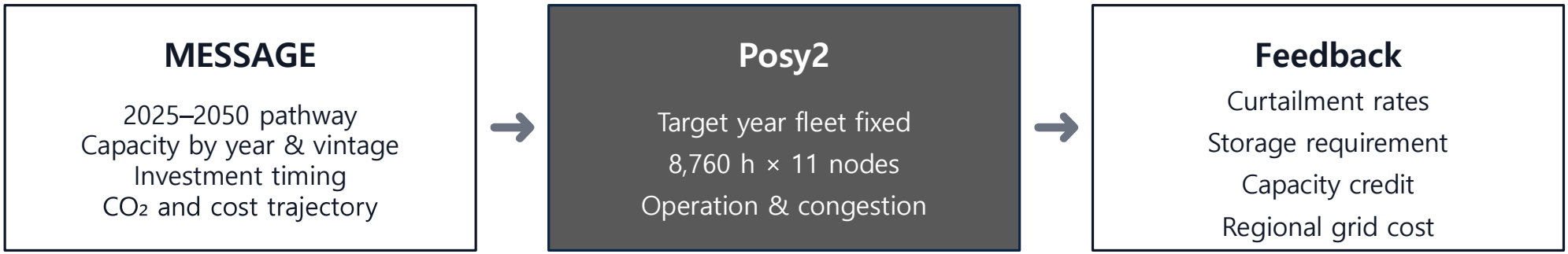
Limitations of the current model

1 **Temporal resolution: 140 time slices**

2 **Single node (copper plate)**

3 **No unit commitment (LP)**

Soft Linking MESSAGE and Posy2



Conclusions

1 The mix, not the target, sets system size and cost

Same CFE 75%: 912 vs. 505 GW in 2050, up to KRW 1,077 tn (PV); the gap comes mostly from integration costs

2 A question of combination, not competition

Renewables grow about 7× even in the nuclear-heavy path; keeping the nuclear share avoids most of the cost rise

3 Timing matters

Costs diverge from the late 2030s; new nuclear decisions fall in the 12th–13th Basic Plans

Thank you

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