NEA
NUCLEAR ENERGY AGENCY

System costs Korea

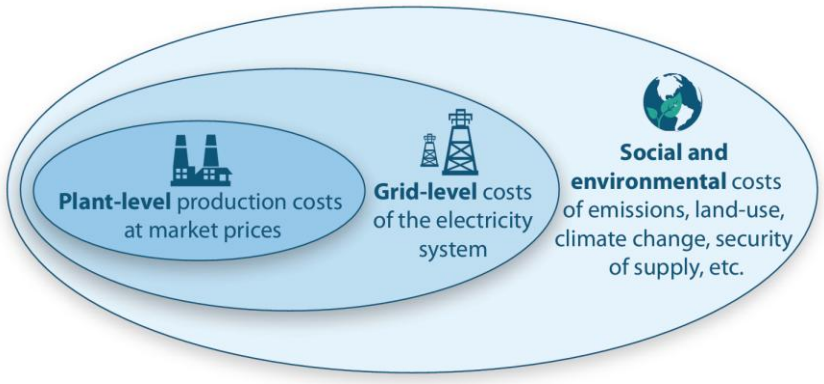
Assumptions and methodology

Guillaume Krivtchik
Energy systems modeller



© 2026 OECD/NEA

System costs method



Plant-level	Investment, fixed and variable O&M, fuel and decommissioning of every technology
Profile	Demand met in all 8,760 hours: storage, backup and curtailment chosen to match
Balancing	Hourly reserve requirement held by eligible units
Grid	AC and HVDC links with losses, DC power flow, maintenance and transaction costs
Connection	Connection cost for each technology

© 2026 OECD/NEA

System costs – the optimisation problem

Optimisation variables

- Capacity of each technology in each region
- Hourly output of every unit
- Storage charge, discharge, level
- Flows on every link
- + many technical variables
    - timing of nuclear refuelling
    - reserve held by each unit

Objective

Minimization of total system cost

Total system cost

=

Annualised investment costs

+ Fixed and variable O&M costs

+ Fuel costs

+ Decommissioning costs

+ Grid maintenance & expansion costs

Subject to

Scenario constraints

- Scenario floors and ceilings
- Hourly balance of electricity and hydrogen in each zone
- $CO_2 \leq 20.7$ Mt/y

Technical constraints

- Ramping, minimum load, commitment
- DC power flow, transfer limits
- Hourly reserve requirement

© 2026 OECD/NEA

Nosy: composable modelling framework

Building blocks

Component = one archetype (source, sink, converter, storage)
+ behaviours + joint flows

Library of composable, modular behaviours

- Capacity: fixed, optimised or composed
- Costs: fixed, variable, start-up, no-load etc.
- Ramping; unit commitment, continuous or integer etc.
- Up and down reserves, limited by ramp and stored energy
- Joint flows: additional flows as a function of the rest

Time and solving

- 8760 timesteps = hours per year; finer or coarser steps per node
- Several weather years in one problem
- Any JuMP solver; dual prices; infeasibility diagnosis

Example: a dispatchable plant

```
plant = Component("plant",
  DispatchableSource(elec),       # archetype
  [
   VariableCapacity("output", energy),
   FixedCost(:investment, "output", energy, 6e4),
   VariableCost(:fuel, "output", energy, 50.0),
   LinkedJointFlow(
     "output", elec, :output, "output", x->x*0.350
     )
   ]
)
```

Open-source (MIT license)

Extensive documentation

Thoroughly tested (1500+ unit tests, doctests)

Nosy.jl



https://github.com/oecd-nea/Nosy.jl

© 2026 OECD/NEA

Posy2: Power System Model based on Nosy

This study
Modelling and optimization of the Korean power sector

Posy2
Technology library, input workbooks, data pre-processing,
Automated post-processing and generation of result tables

Nosy
Components, behaviours, time, optimisation

Posy2.jl



https://github.com/oecd-nea/Posy2.jl

User-friendly power system model based on Nosy

Technology library

- Nuclear with unit commitment and planned refuelling
- Dispatchable plants, PV, wind, hydro, batteries
- Demand response, electric vehicles
- Electrolysers, hydrogen storage and demand
- AC and HVDC links: transport model or DC power flow

Pre- and post-processing

- Input data as excel files or directly in the code
- Economic pre-processing: annualization etc.
- Output as excel files or using the Nosy API to query the results

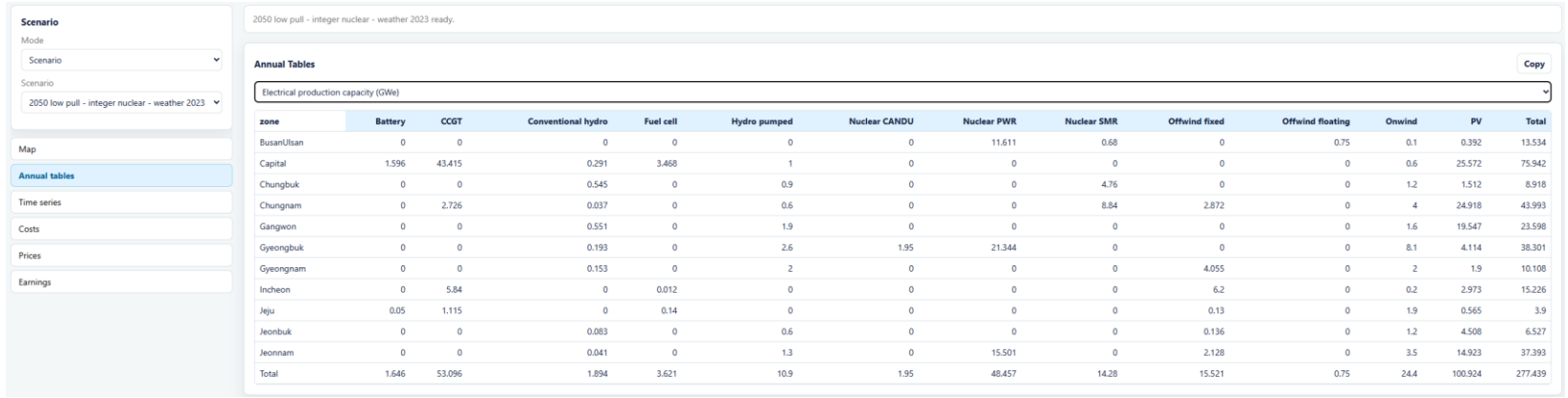
Advanced modelling functions

- Multi-node, multi-carrier
- Co-optimization of hydrogen network
- Non-constant time steps
- Detailed nuclear refuelling (see Yuri Bae's presentation)
- DC-OPF (DC Optimal Power flow)
- Two-stages stochastic capacity expansion (multiple weather years)
- Explicit modelling of operating reserve

© 2026 OECD/NEA

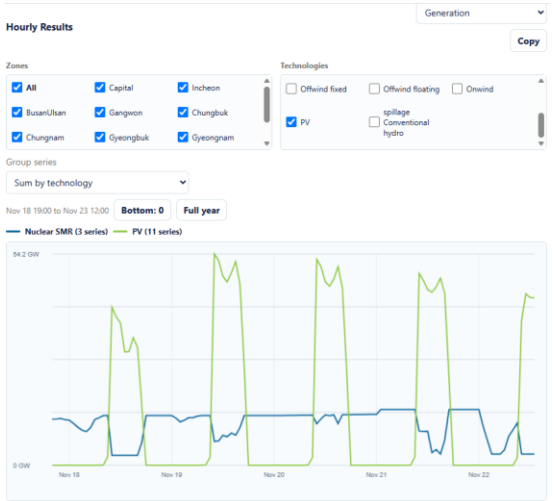
NEA NTE System Costs Dashboard

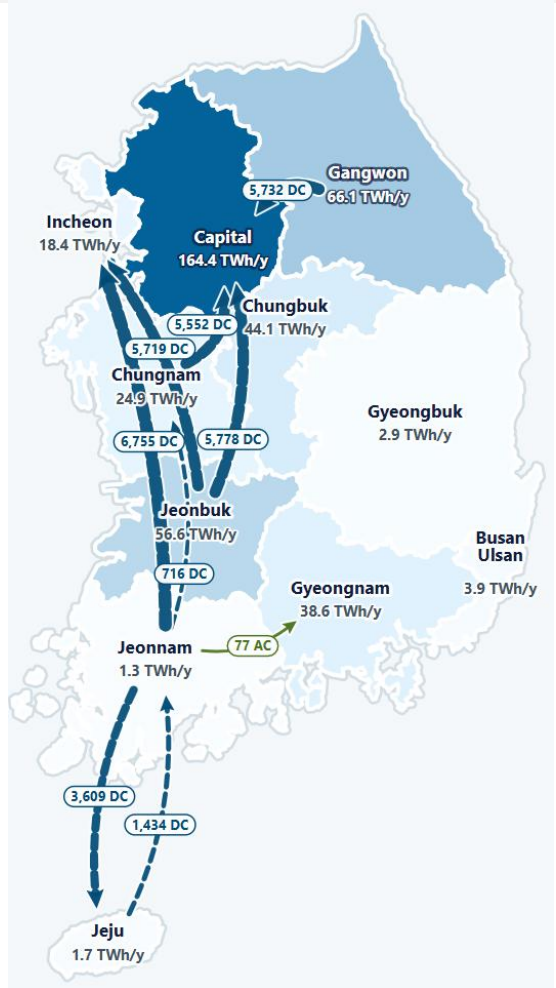
- **Interactive dashboard with tables, figures, maps**
- **Many post-processing layers (cost, capacity, CO2, congestion etc.)**



zone	Battery	CCGT	Conventional hydro	Fuel cell	Hydro pumped	Nuclear CANDU	Nuclear PWR	Nuclear SMR	Offwind fixed	Offwind floating	Onwind	PV	Total
BusanUlsan	0	0	0	0	0	0	11.611	0.68	0	0.75	0.1	0.392	13.534
Capital	1.596	43.415	0.291	3.468	1	0	0	0	0	0	0.6	25.572	75.942
Chungbuk	0	0	0.545	0	0.9	0	0	4.76	0	0	1.2	1.512	8.918
Chungnam	0	2.726	0.037	0	0.6	0	0	8.84	2.872	0	4	24.918	43.993
Gangwon	0	0	0.551	0	1.9	0	0	0	0	0	1.6	19.547	23.598
Gyeongbuk	0	0	0.193	0	2.6	1.95	21.344	0	0	0	8.1	4.114	38.301
Gyeongnam	0	0	0.153	0	2	0	0	0	4.055	0	2	1.9	10.108
Incheon	0	5.84	0	0.012	0	0	0	0	6.2	0	0.2	2.973	15.226
Jeju	0.05	1.115	0	0.14	0	0	0	0	0.13	0	1.9	0.565	3.9
Jeonbuk	0	0	0.083	0	0.6	0	0	0	0.136	0	1.2	4.508	6.527
Jeonnam	0	0	0.041	0	1.3	0	15.501	0	2.128	0	3.5	14.923	37.393
Total	1.646	53.096	1.894	3.621	10.9	1.95	48.457	14.28	15.521	0.75	24.4	100.924	277.439

- **Reads Posy2 result files**
- **Can analyze one scenario or compare two scenarios (difference tracker)**
- **Portable format, can be shared with non-modelers, no setup required**
- **Can copy-paste all values to excel**





Arrows: Hours of congestion per year
Zones: imports in TWh

© 2026 OECD/NEA

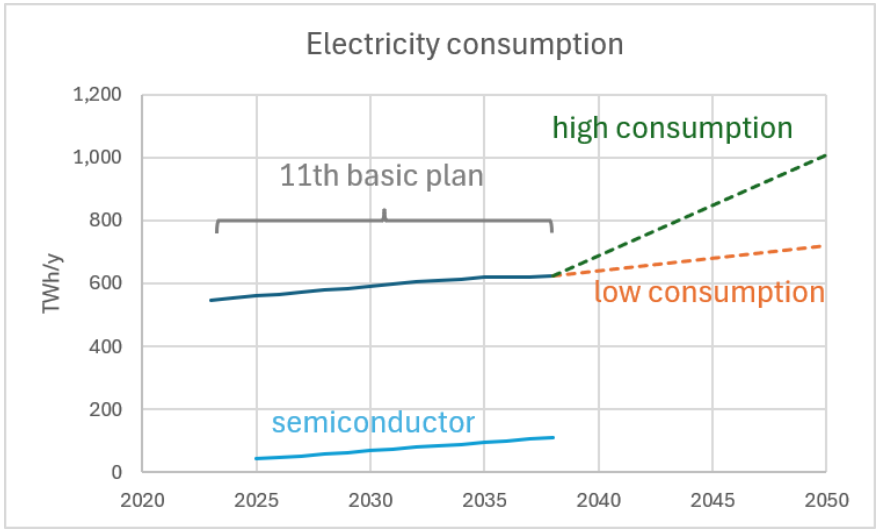
Demand and CO2 target

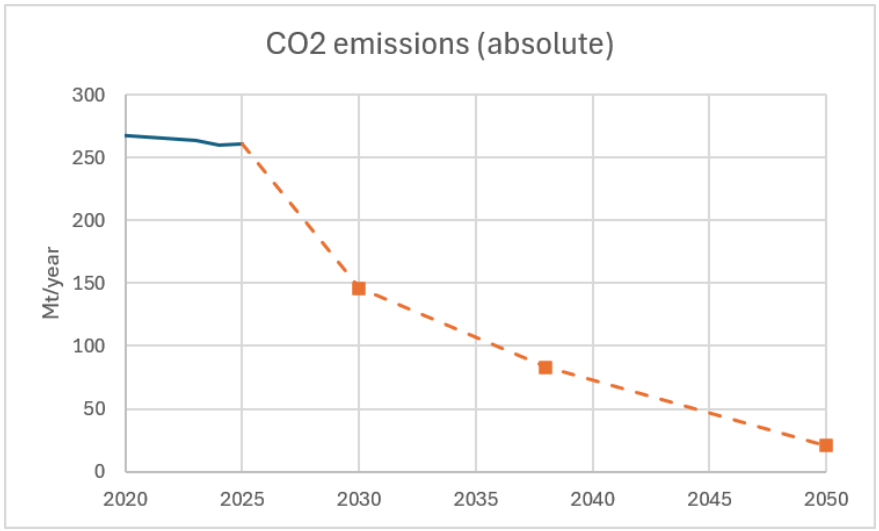
Consumption derived from projections by KERI

- 2 main scenarios
  - Low consumption: 757 TWh (losses included)
  - High consumption: 1070 TWh

CO2 target

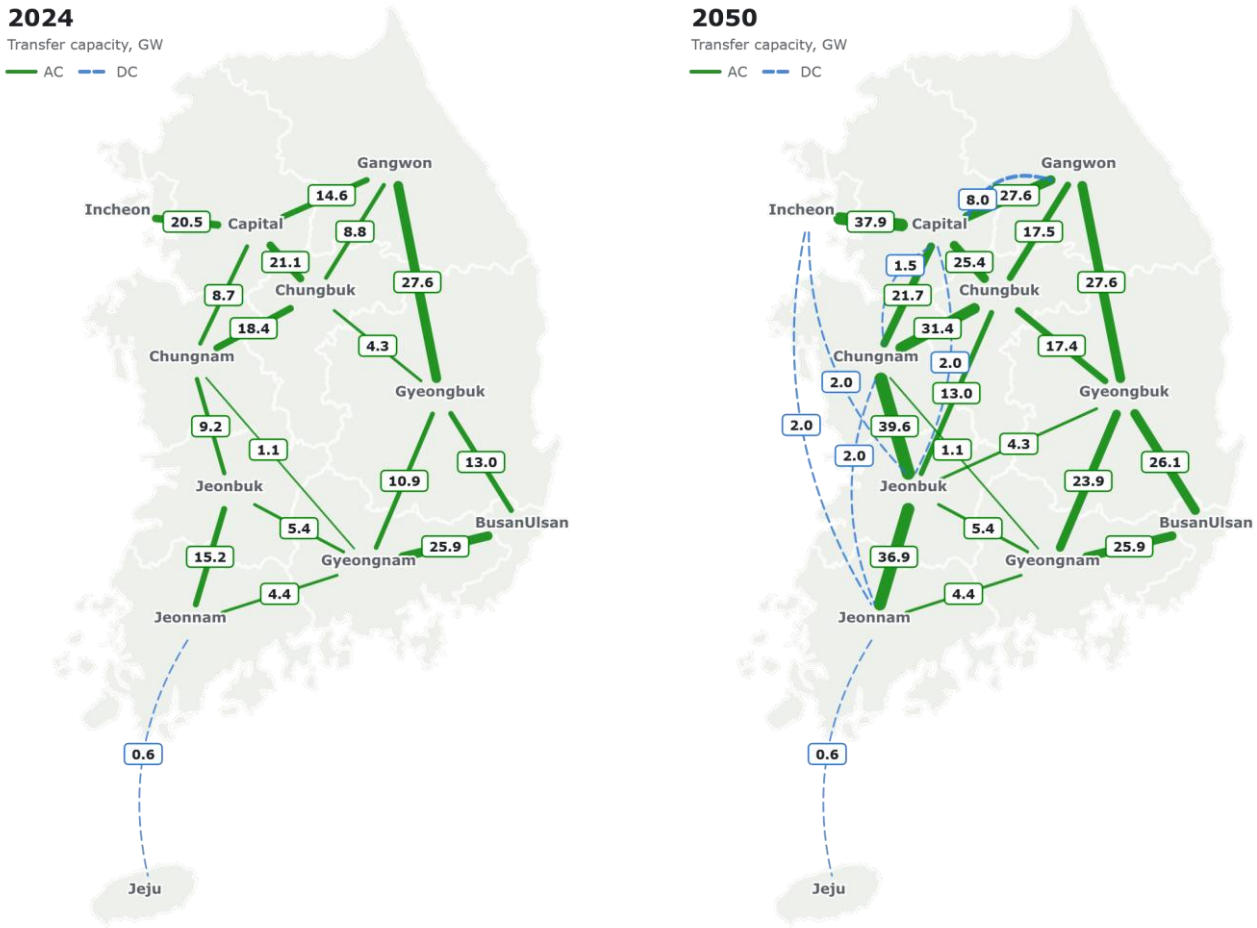
- CO2 constraint @ 20.7 Mt/year from *2050 탄소중립 시나리오안* (2050 Carbon Neutrality scenarios), "Scenario B", adopted 2021
- Approx. 27 g/kWh for low consumption, 19 g/kWh for high consumption scenario





© 2026 OECD/NEA

11 zones modelling of Korea



Transfer capacity (GW): 2024 grid, and the planned grid used for 2050. Green AC, dashed blue HVDC.

Zones

- 10 mainland zones + Jeju
- Each with its own demand, capacity expansion, dispatch and storage

Physics of the network

- DC power flow on AC lines: flows follow line impedances
- HVDC links dispatched directly
- Losses by link type and length; maintenance and transaction costs
- Bottleneck of power to capital area (voltage stability)

Grid of the 11th Basic Plan

- Fixed input, not optimised
- North–south AC reinforcement; HVDC from the south-west to the capital area

© 2026 OECD/NEA

Technologies: overview

Technology	2024 (GW)	2050 (GW)
Large nuclear (PWR)	26.05	LTO 2 × 20 y + new build ≥ 0
SMR (i-SMR)	0	fixed by scenario
LNG (CCGT)	36.17	≥ 0
Coal / oil	40.22 / 0.63	none
Fuel cell (hydrogen)	1.16	≥ 3.62
PV	27.1	≥ 77.2
Onshore wind	2.25	≥ 24.4
Offshore wind	0.26	≥ 16.3
Hydro / pumped hydro	1.81 / 4.7	1.89 / 10.9
Battery	–	≥ 0
Electrolysers	0	≥ 0
Hydrogen storage	0	2 weeks of demand
Biomass, other	4.0	not modelled

Optimized Set by assumption Not modelled

Floors

- Regional VRE of our 2038 model guided by 11th Basic Plan
- Nothing built by 2038 is undone

Ceilings

- PV and wind market potential by region, KIER/KNREC Renewable Energy White Paper 2020

Siting

- Renewables (PV, onshore wind, offshore wind) capacity factors differ by region
- Nuclear (large reactors, SMR) only deployed in permitted area

© 2026 OECD/NEA

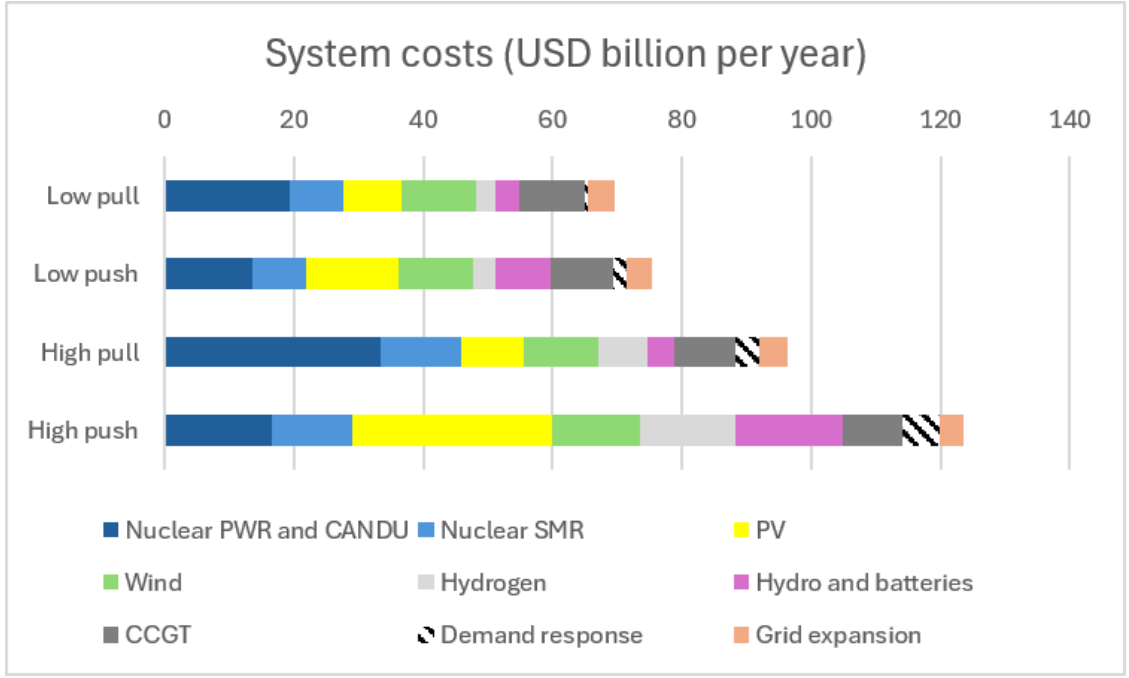
Cost assumptions: technology data

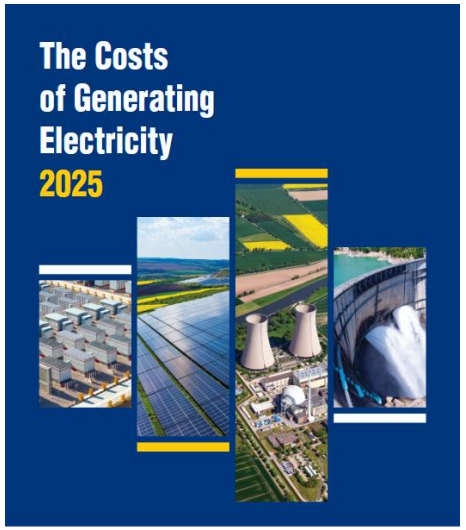
Category	Technology	Overnight USD/kW	Fixed O&M USD/kW/y	Var O&M + fuel USD/MWh	Life y	Build y	Annual fixed USD/kW/y	Source
Nuclear	**Large PWR (APR-1400)**	2,487	116.6	20.8	40	4	**271**	CGE 2025 Korea
	SMR (i-SMR, NOAK)	5,437	154.8	10.5	40	5	**505**	CGE 2025 Korea
Renewables	**PV**	998	19.2	0.0	30	1	**87**	CGE 2025 Korea
	Onshore wind	1,977	38.6	0.0	30	2	**174**	CGE 2025 Korea
	Offshore wind (fixed)	4,345	95.2	0.0	30	3	**427**	CGE 2025 Korea
	Offshore wind (floating)	9,087	124.4	0.0	30	3	**876**	Derived from CGE
Thermal	**CCGT**	803	38.6	82.1	30	3	**93**	CGE 2025 Korea
	CCGT CCS	1,560	77.4	98.3	30	3	**183**	Derived from CGE
	Fuel cell (H_2)	4,500	120.0	5 + H_2	20	2	**498**	NEA assumption
Storage	**Battery (6 h)**	1,746	7.6	0.0	16	1	**174**	KEEI 2025 Korea
	Pumped hydro (10 h)	2,252	12.6	0.0	60	8	**140**	KEEI 2025 Korea
Electrolysis	**Electrolyser (PEM)**	1,500	60.0	–	20	1	**178**	NEA assumption

© 2026 OECD/NEA

Technologies costs

- **Profile, grid connection and balancing costs included for each technology**





Most costs taken from *The Costs of Generating Electricity 2025* (Korean data)

- Overnight construction costs (OCC) of nuclear LLWR nuclear are low (2487 USD/kW) corresponding to costs at Shin Hanul;
- SMR costs considered higher (5437 USD/kW, NOAK)
- CAPEX of PV relatively high, region-dependent (high cost of land) and associated with large profile costs
- Overnight construction costs for PV 998 USD/kW, for Onshore wind 1977 USD/kW and for Offshore wind 4345 USD/kW.

© 2026 OECD/NEA

Nuclear: fleet, siting, refuelling



Large PWR (APR-1400)

- Existing fleet: 40 years + 2 × 20 years LTO
- New units only in the three historical regions: Busan-Ulsan, Gyeongbuk, Jeonnam
- Overnight cost: 2487 USD/kW in main scenarios + sensitivity studies

SMR (i-SMR, 4 × 170 = 680 MWe)

- Siting: any mainland region outside the capital area (Capital, Incheon)
- Overnight cost: 5437 ISD/kW

Refuelling outages

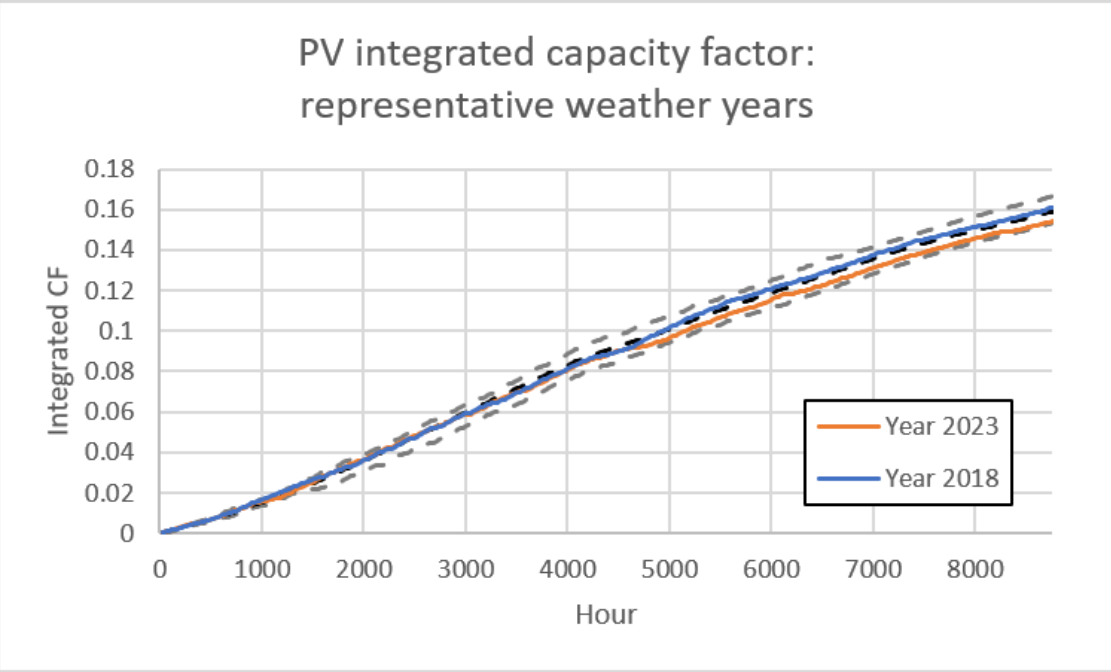
- PWR: 18-month cycle, 35-day outage; SMR: 24-month cycle
- The optimiser schedules them over the year

© 2026 OECD/NEA

Renewables and weather uncertainty

Hourly capacity factors per region

- PV: EC JRC PVGIS 5.3, 2005–2024
- Onshore wind: MERRA-2, 1980–2025
- Offshore wind: ERA5 corrected with the Global Wind Atlas



Two-stage stochastic capacity expansion

Stage 1 one set of capacities

Built before the weather is known

Stage 2 Worst year

2023 for PV and wind
8,760 h dispatch, weight 50 %

Stage 2 Average year

PV 2018, wind 2024
8,760 h dispatch, weight 50 %

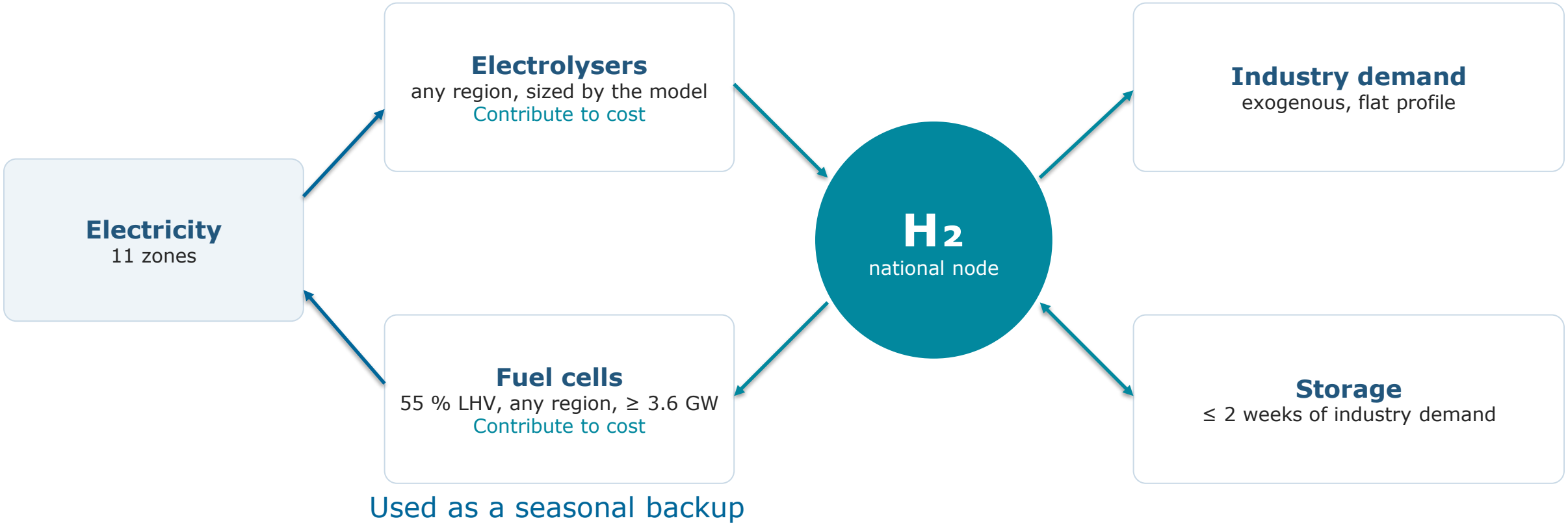
Years chosen from the full PV and wind records. The capacity mix must work in both weathers.

The optimization objective is the (probabilistic) expected cost.

© 2026 OECD/NEA

Hydrogen network

Explicit modelling of the hydrogen network



© 2026 OECD/NEA

Operating reserves, every hour

Frequency Containment Reserve

- Dedicated 2 GW, 1 h battery
- Cost included, energy not traded

Frequency Restoration Reserve

- Batteries, pumped hydro: stored energy for 35 min
- CCGT: committed headroom and ramp rate
- SMR: committed headroom and ramp rate
- Fuel cells: unused capacity and ramp rate
- Electrolysers: cut their consumption
- Curtailed energy: can be fed back

Upward Frequency Restoration Reserve requirement in hour t

One national pool; 10-min response; 30 min sustained

$$\mathrm{Req}(t) = \underbrace{3\ \mathrm{GW}}_{\text{765 kV line trip}} + \underbrace{1\,\% \times \mathrm{load}(t)}_{\text{load uncertainty}} + \underbrace{3\,\% \times \mathrm{VRE}(t)}_{\text{VRE forecast error}}$$

© 2026 OECD/NEA



Thank you for your attention

© 2026 OECD/NEA

Title page photo: Dry storage facilities (Creative Commons, NRCgov)