Research on the deployment of modern nuclear reactors in the urban environment

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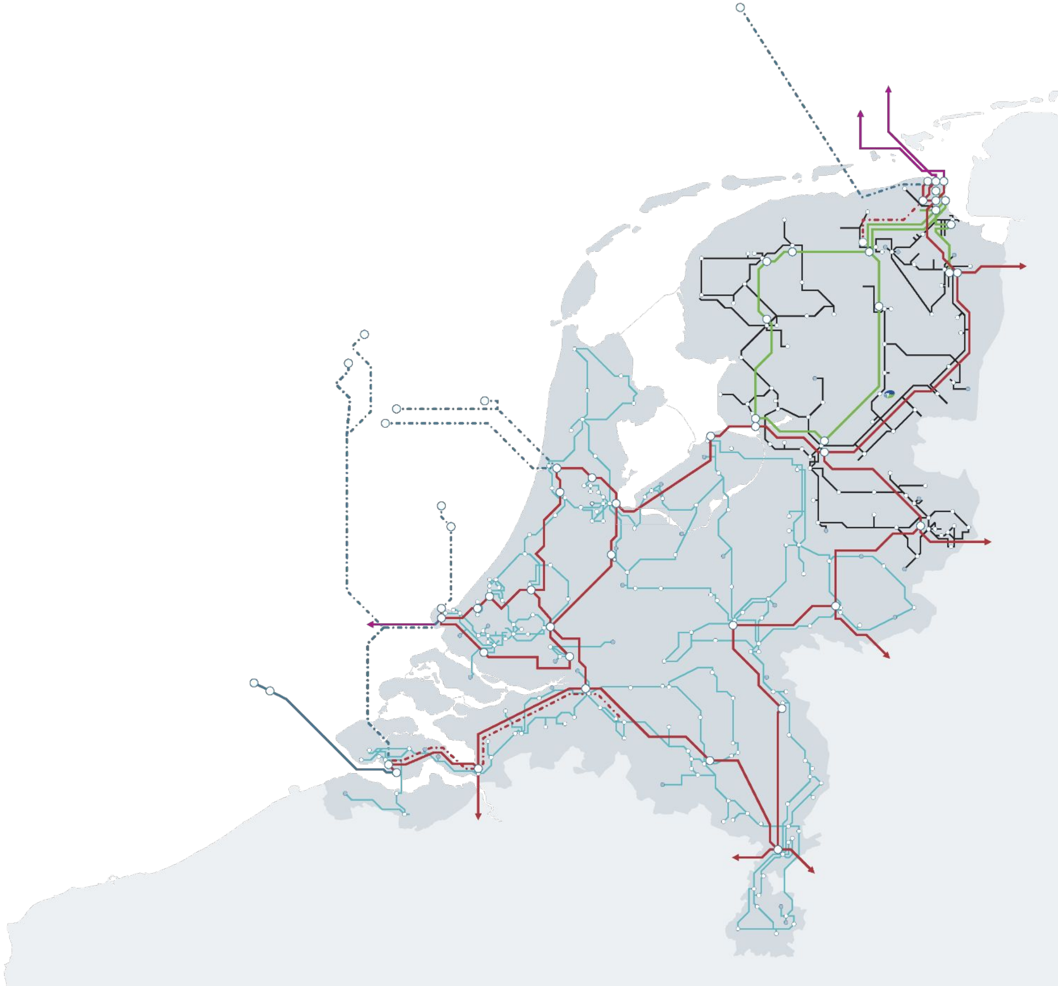


I. PROBLEM

The sustainable energy transition

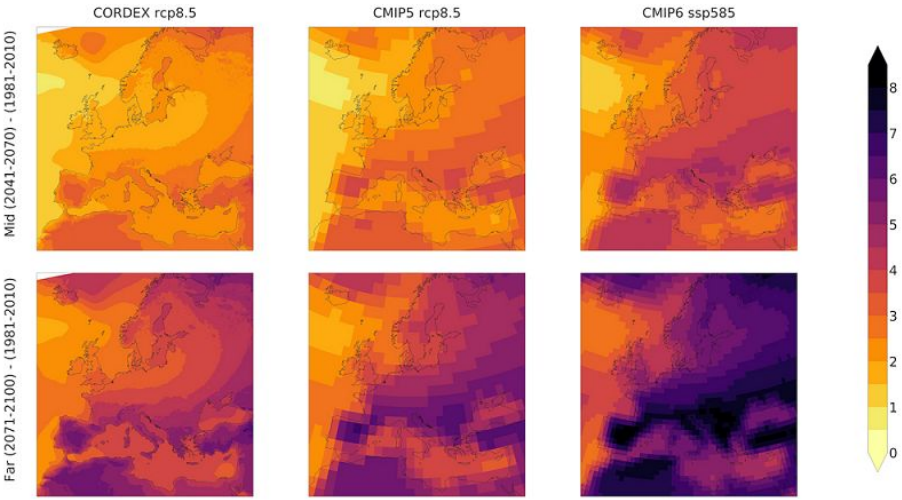


Figure 1. Climate change projections for Europe. Shown data is from the CMIP6 global projections. Reprinted from Coppola et al. [1].

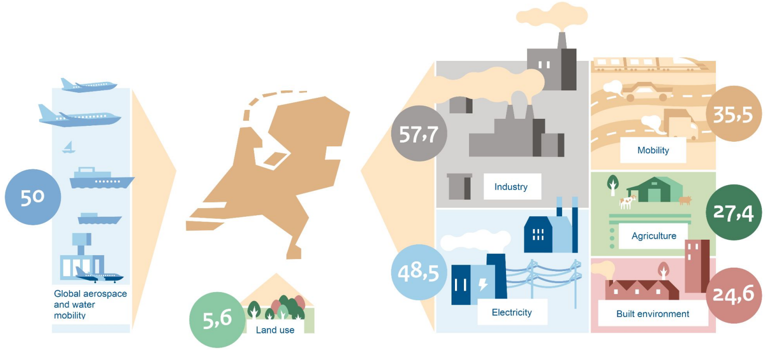


Figure 2. Greenhouse gas emissions of the Netherlands (2017) per sector in Mton CO2-equivalent. Reprinted and modified from Ministry of Economic Affairs and Climate Policy [2].

The sustainable energy transition

Figure 3. Onyx coal power plant, Maasvlakte, Rotterdam, the Netherlands [3].

Figure 4. Climate change consequences for the Netherlands. Reprinted from KNMI [4].

The sustainable energy transition

National strategy: *klimaatakkoord*

2030

- 49-55% GHG-emissions compared to 1990
- 27% renewable electricity share in energy mix
- Energy savings of more than 906 PJ

2050

- 95% GHG-emissions compared to 1990
- 100% carbon neutral electricity production

Figure 5. Energy system of the netherlands. (a) energy fuel flows per sector. (b) sustainable energy goals representing current energy system. Goals reprinted from United Nations [5].

The sustainable energy transition

Transition *energy system* implications

1. Society
   a. *Affordability*
   b. *Spatial implications*
2. Environment
   a. *Technology footprint*
   b. *Waste flows*

Figure 6. Proposed energy system of the netherlands in 2050. (a) energy fuel flows per sector. (b) sustainable energy goals representing current energy system. Goals reprinted from United Nations [5].

Figure [illegible]

Alternatives: *nuclear energy*

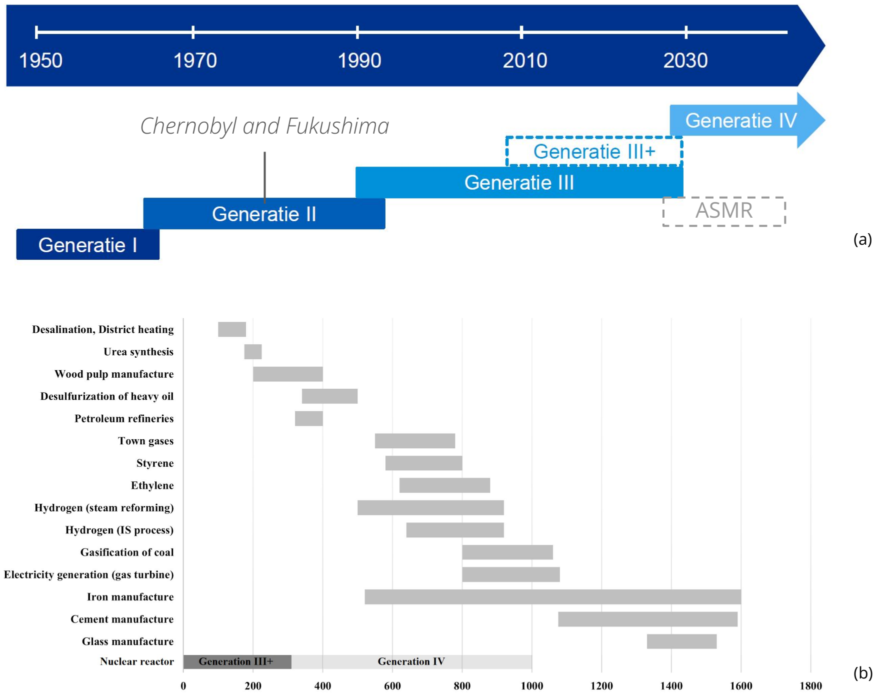


Figure 11. (a) Nuclear reactor technology timeline, including primary generation types. Reprinted and modified from KPMG [10]. (b) High temperature industrial thermochemical applications. Reprinted and modified from Generation IV International Forum (GIF) [11].

Generation III+

- More efficient fuel cycle, less waste
- High safety standards
- Approved, licensed and constructed designs

Advanced Small Modular Reactors

- Reduced construction period and cost (4-6 years)
- Flexible and adaptable
- Significantly reduced safety risks
- Generation III+ and IV

Generation IV

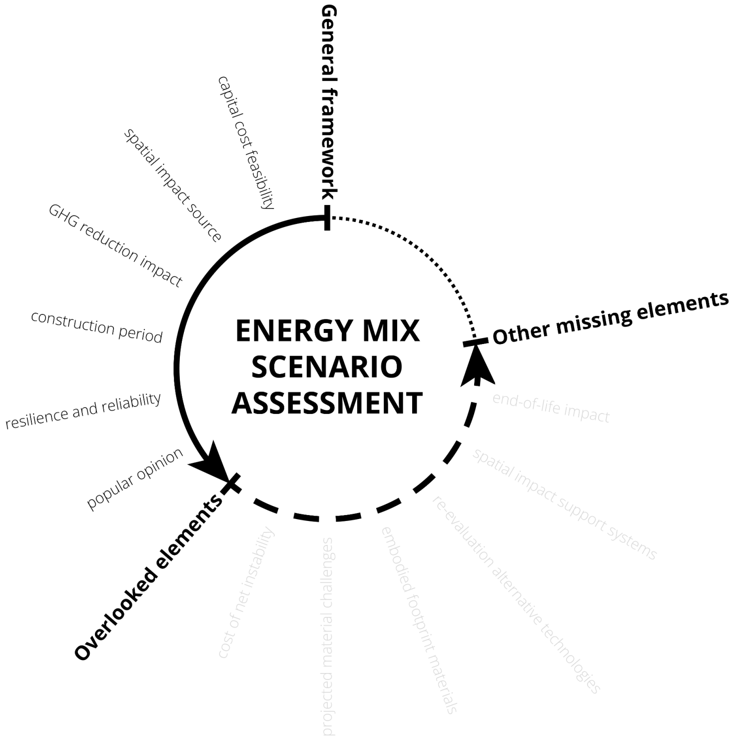
- High thermal output temperatures
- Spent nuclear fuel (old waste) recycling
- Full passive safety
- Reduced cost and construction time

Figure 12. Generation-II nuclear reactor: Borssele. Reprinted from ANP [12].

Figure 13. Example of a small modular reactor design. Reprinted from Fermi Energia [13].

II. KNOWLEDGE GAP

Sustainable strategy assessment

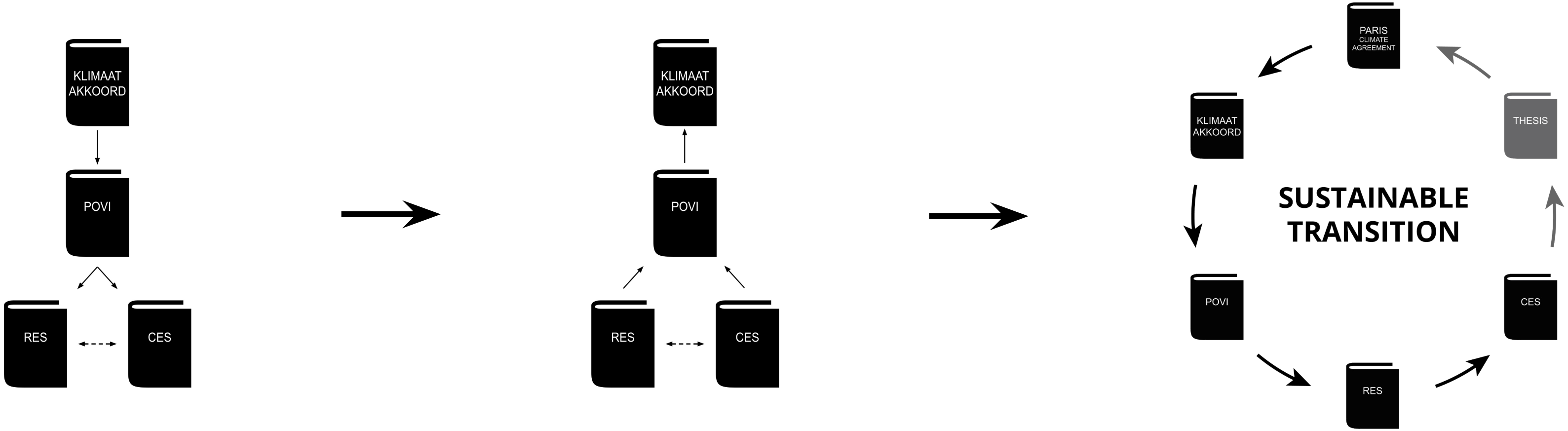


Re-evaluating assessment framework

- Whole energy system focus
- Indirect technology implications
- Post-transition risks

Figure 14. Sustainable energy goals represented in assessment framework. Reprinted from United Nations [5].

Sustainable strategy assessment



1. Connect different scales of *ambitions* and *requirements*.

2. Examine crucial components for both the transition goal and sustainable development.

3. Evaluate regional strategies based on regional characteristics.

Figure 15. Sustainable energy goals represented in assessment framework. Reprinted from United Nations [5].

Rotterdam-The Hague metropolitan area (MRDH)

Strengths

- Logistic centre of EU: Port of Rotterdam
- Strong innovative industrial cluster
- Very developed built environment

Weaknesses

- High energy demand
- Scarcity of available land

Opportunities

- Heat grid development (energy cooperation)
- Strong investment climate from industry
- Allocated location for nuclear power plant

Threats

- Energy transition feasibility
- Affordability of energy

Area: 1,256 km^2 | Gross regional product: 87.25 bn EUR/y | Unemployment: ~ 200,000 people

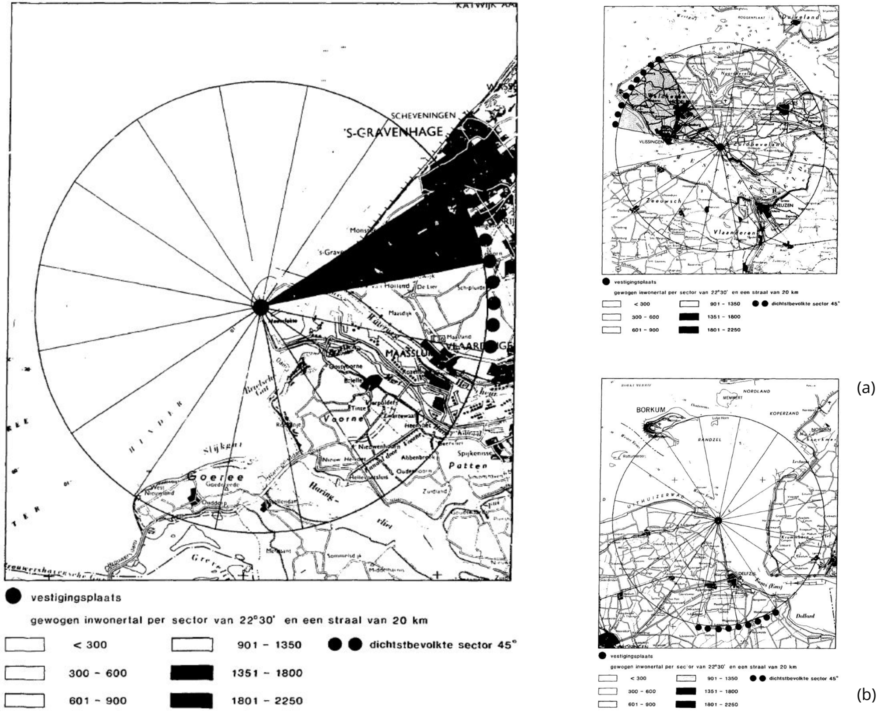


Figure 16. The three approved locations for nuclear power plants in the Netherlands following the 'Waarborgingsbeleid kernenergie' agreement. Reprinted and modified from Ministry of Economic Affairs [7].

Research question

"To what extent can modern nuclear reactors benefit the future of the Rotterdam-The Hague metropolitan area sustainable transition and energy mix compared to other energy sources classified as sustainable?"

Research sub-objectives

1. Determine the current proposed energy transition strategy its challenges, bottlenecks, and benefits.

2. Investigate the integration of various nuclear energy scenarios, including the use of the sustainable assessment method.

3. Compare the benefits and drawbacks of various energy generation strategies and their associated techniques.

III. THEORY

Computational system analysis

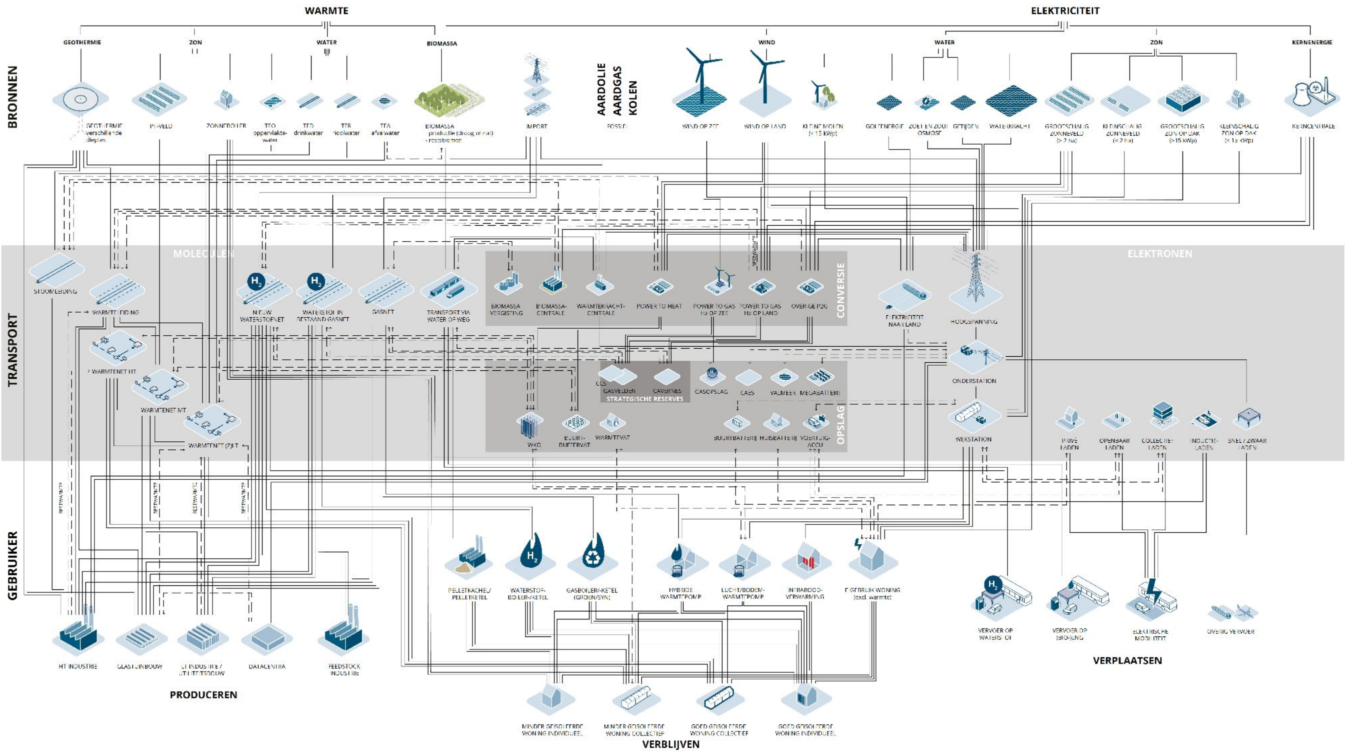


Figure 17. Energy system relation diagram. Reprinted and modified from Stuurgroep Energiestrategie regio Rotterdam Den Haag [15].

Energy system model: *python*

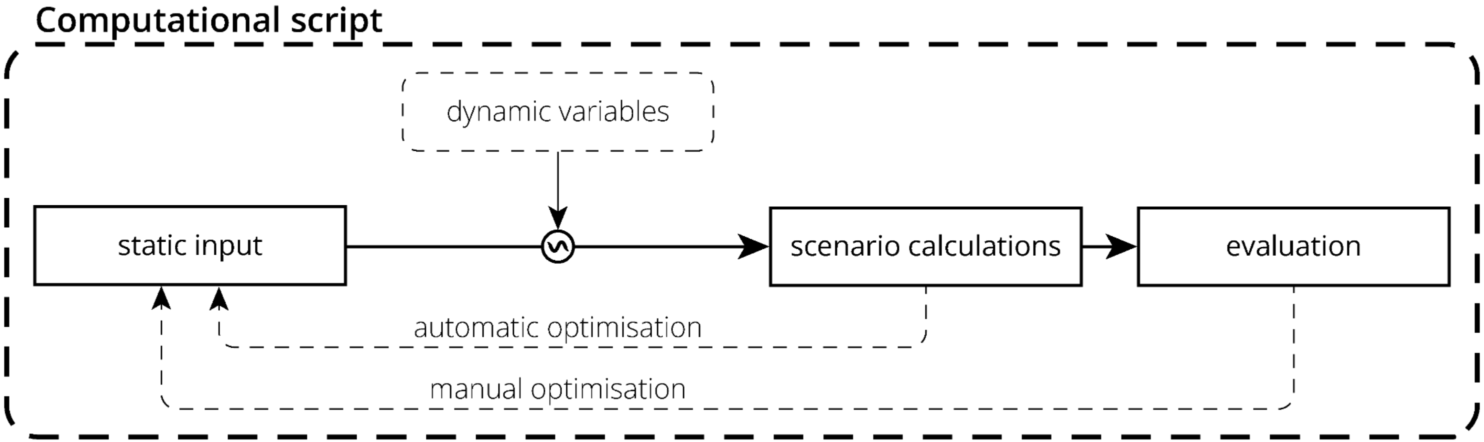
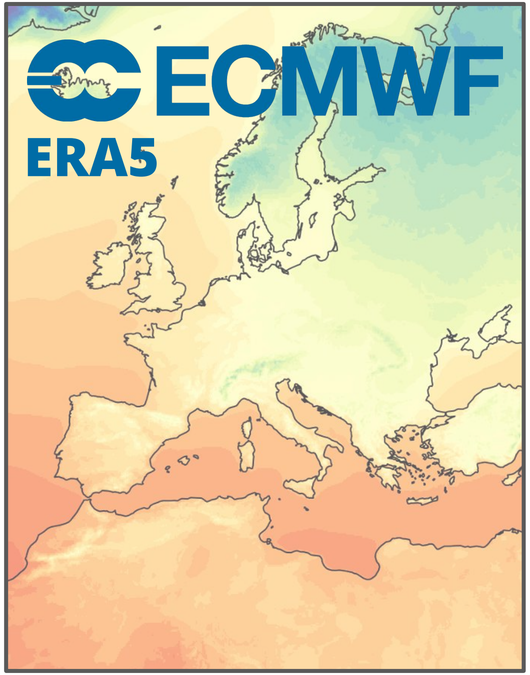
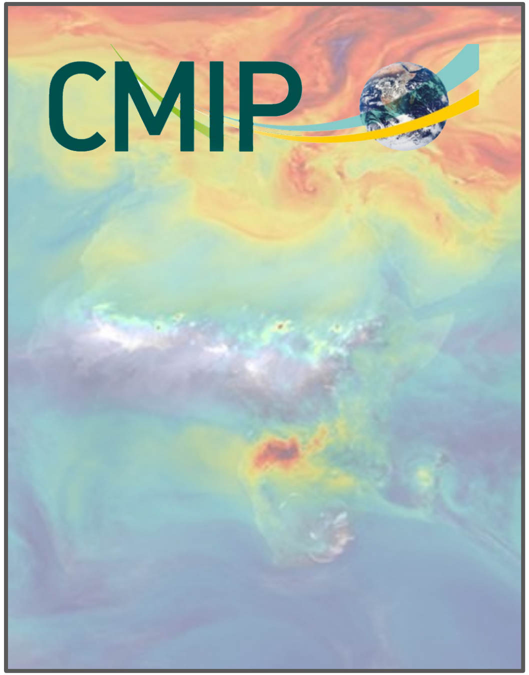


Figure 18. Overview of simulation assessment tool and its section division methodology.

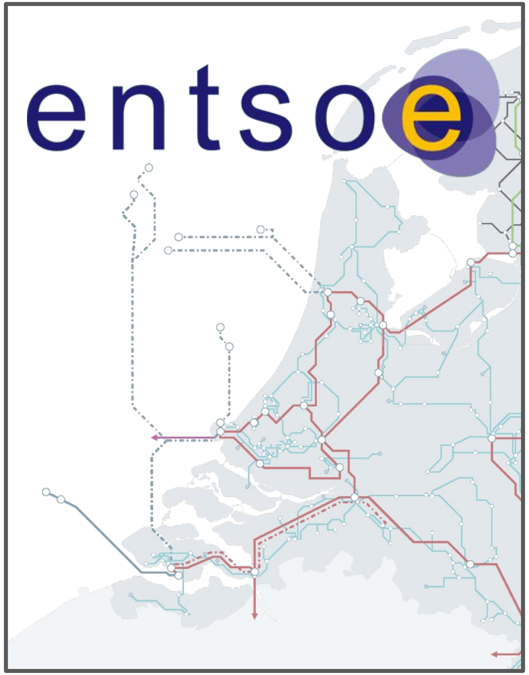
Simulation databases



Historical weather data



Climate change projections



Historical electricity consumption & trading price

Energy mix assumptions

Energy mix development projections

- Energy consumption outlook
- Heat grid integration
- Energy production trends

Behaviour and patterns

- Technology efficiency and performance
- Consumption and weather parameters
- Calculation *approximations*
- Trendline growth curves

Objective assessment framework

Technology	Lifetime [year]	Direct cost [M EUR/MW]	Indirect cost [EUR/MWh]	Spatial footprint [MW/km^2]	Direct emissions [kg CO_{2-eq}/MWh]	Indirect emissions [t CO_{2-eq}/MW]	Fuel demand [MWh/t]	Chemical waste [cm^3/MWh]
PV	25	1.6230	21.29	0.0643	0	5394.00	0	3.79
Onshore wind	25	2.2713	12.95	19.80	0	495.33	0	2.02
Offshore wind	25	4.3051	23.49	7.20	0	1,125.75	0	2.02
Natural gas*	30	0.9107	7.76	6,020.0	203.76	4,980.67	13.10	2.89
Biomass	30	1.2451	21.06	558.28	394.56	2,723.80	4.28	1.13
Coal	30	0.9670	14.88	558.28	338.40	10,982.02	8.06	4.42
Nuclear	60	1.9627	4.00	3,954.0	0	174.86	438,638.74	0.24
Alkaline	10	0.5	0	16,719.5	0	-	33.32	-
PEM	10	1.1	0	16,719.5	0	-	33.32	-
SOEC	10	2.8	0	16,719.5	0	-	33.32	-
Li-ion battery	10	0.339	0	2,000	0	44.1696	0	-

Technology	Radioactive waste [cm^3/MWh]	Water pollution [kg DCB_{-eq}/MWh]	Biodiversity reduction [PDFm2a/MWh]	Spatial nuisance [-]	Employment Employment [fte/MW]	Innovation potential [fte/MW]	Human health risk [μDALY/Mwh]	Fuel cost [EUR/MWh]
PV	0.04	10.00	0.29	4	1.17	6.70	392.31	0
Onshore wind	0	56.00	0.10	5	0.51	4.70	123.08	0
Offshore wind	0	56.00	0.10	3	1.28	15.60	123.08	0
Natural gas*	0	1.30	0.81	3	0.21	0.93	355.00	36.25
Biomass	0.10	0.74	3.12	3	2.28	2.90	414.62	115.17
Coal	0.03	0.74	3.12	3	1.72	5.40	414.62	14.88
Nuclear	4.09	0	0.05	3	2.20	1.30	35.54	7.93
Alkaline	-	-	-	1	1.2	1.35	-	-
PEM	-	-	-	1	1.2	1.35	-	-
SOEC	-	-	-	1	1.2	1.35	-	-
Li-ion battery	-	-	-	1	0.2	1.35	-	-

Table 1. Quantified evaluation framework for each included technology. Data is retrieved from the various sources listed in this section. Missing data is indicated with a dash. **Construction data on natural gas corresponds to high calorific gas combustion plants.*

Model	Generation	Thermal capacity [MW]	Thermal efficiency [%]	Outlet temperature [°C]	FOAK cost [M EUR/MW]	Post-FOAK cost [M EUR/MW]	Spatial footprint [MW/km^2]	Fuel efficiency [%]	Waste production [%]
EPR2	III+	4,500	37.0	313	3.00514	2.16376	3,954	100	100
AP1000	III+	3,200	33.0	303	2.34894	1.69125	3,954	100	100
APR1400-EUR	III+	3,983	35.0	307	1.43115	1.0304	3,954	100	100
MSR	IV	1,000	50.0	700	3.27113	1.96268	3,954	3.7	10.0
VHTR	IV	545	55.0	900	3.27113	1.96268	3,954	100	100
SFR	IV	2,500	40.0	500	3.27113	1.96268	3,954	3.7	10.0
SCWR	IV	2,200	45.0	510	3.27113	1.96268	3,954	100	100
Nuscale	ASMR	200	30.0	321	1.32917	0.957	17,142.9	100	100
BWRX-300	ASMR	870	32.2	287	0.424861	0.3059	5,178.57	100	100
SMART	ASMR	365	29.3	322	2.52306	1.8166	4,055.56	100	100
UK SMR	ASMR	1275	34.7	327	2.30851	1.66213	31,875	100	100
NUWARD	ASMR	540	31.5	307	2.57337	1.85283	7,714.29	100	100
IMSR	ASMR	440	44.3	700	2.79336	2.01122	9,777.78	3.7	10.0

Table 2. Quantified evaluation framework for each included nuclear model. Data is summarised from section 2.7.2-2.7.6. The cost of post-FOAK reactors is reduced by 40% for generation IV reactors and 28% for small modular reactors. Cost on the generation III+ reactors are more available therefore original estimates are given.

Computational system analysis

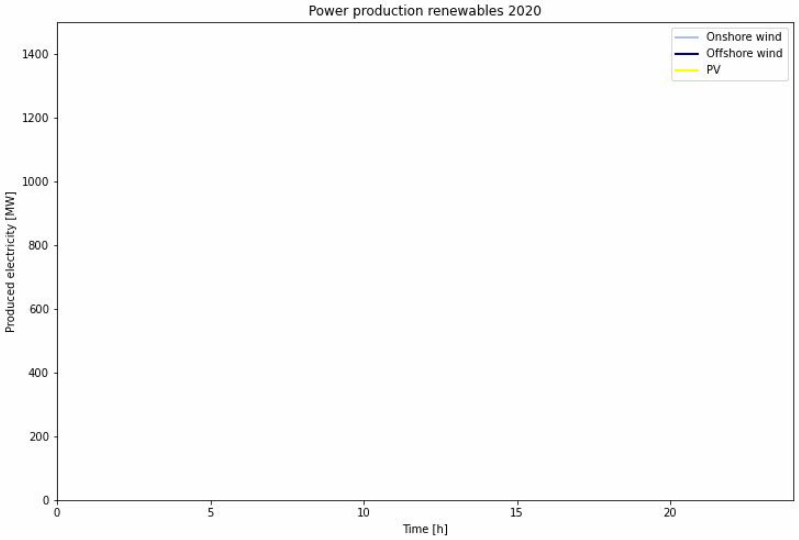


Figure 19. Simulated power production for renewables in January 2020.

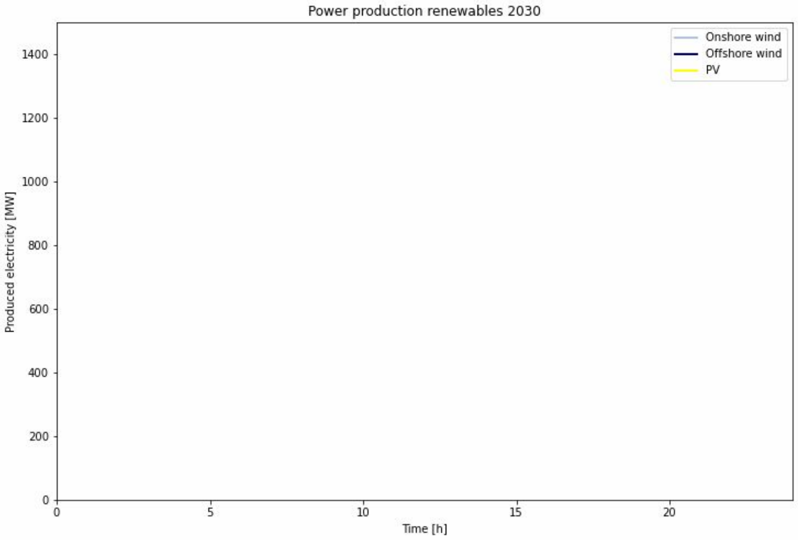


Figure 20 Simulated power production for renewables in January 2030.

Computational system analysis

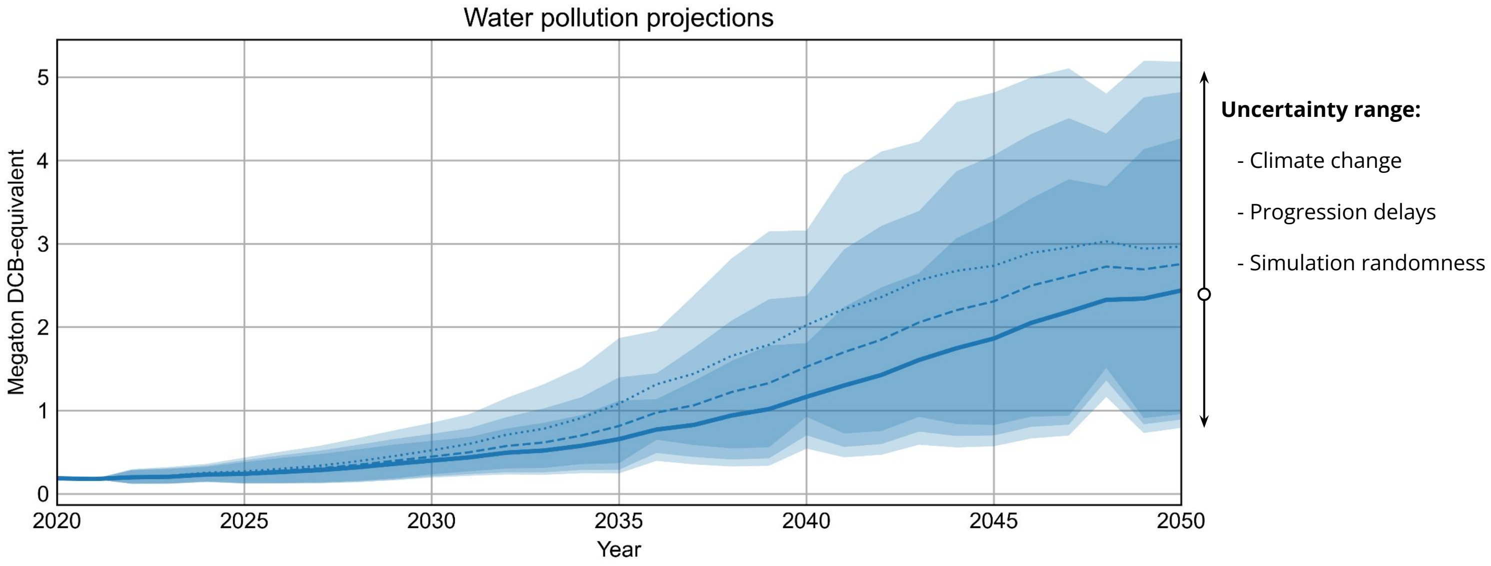


Figure 21. Example simulation projection graph. Data represents results from the reference scenario.

IV. METHODOLOGY

Conditions and parameters

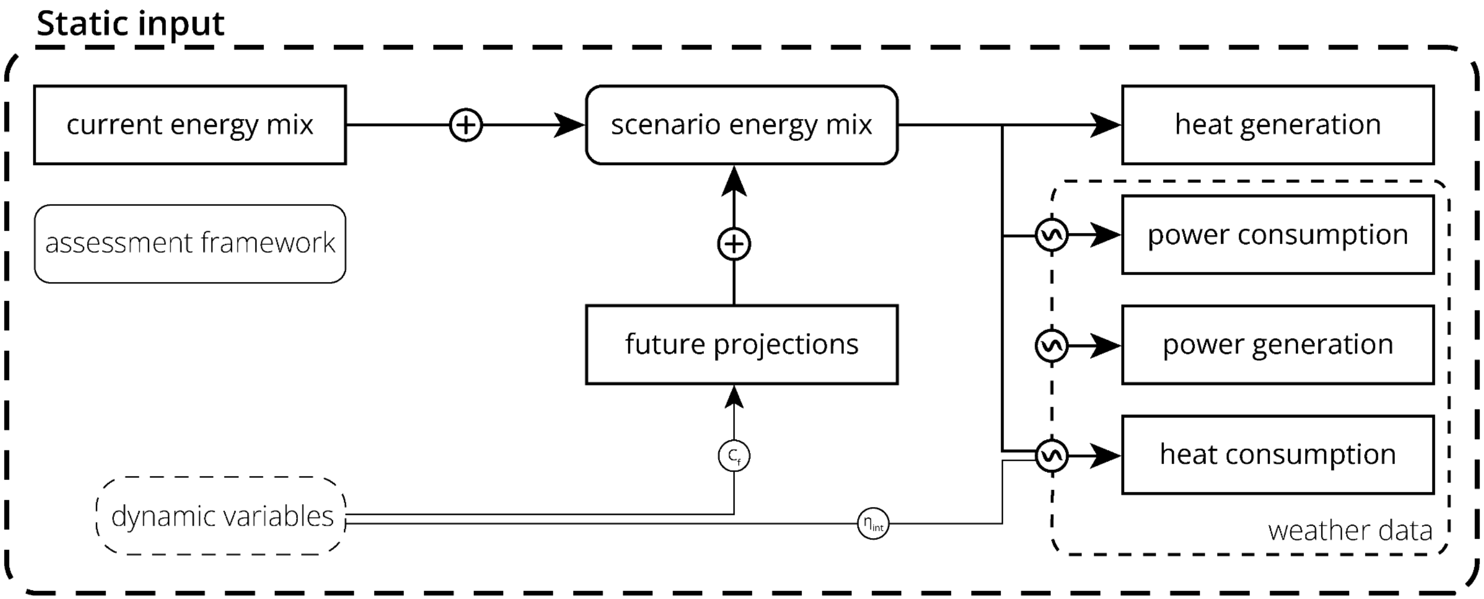


Figure 22. Overview of the static input methodology of the script.

Simulation conditions

Initial conditions (scenario parameters)

- Proposed energy plants (model, fuel and capacity)
- Total installed renewables capacity in 2050;
  - Offshore/onshore wind turbines
  - PV solar panels
  - Hydrogen electrolysers
- Daily short-term battery peak coverage
- Pre-simulation energy production performance

Boundary conditions (simulation quality)

- Climate change scenario (CMIP)
- Plant capacity factor reduction order (emission or cost)
- Integration trendline progression factor [η_{int}]
- Heat grid implementation factor [c_f]
- Accuracy (amount of random runs)

Simulation accuracy

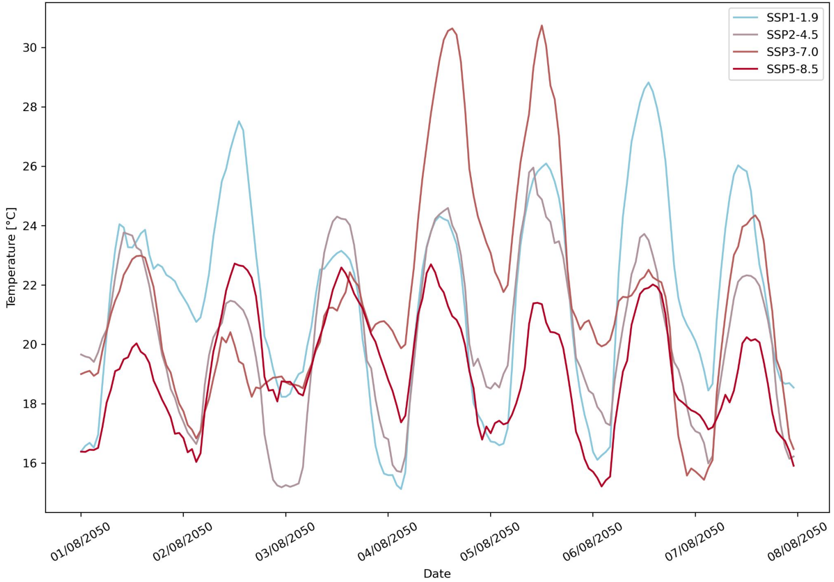


Figure 23. Effect of climate change on ambient temperature for different climate projections.

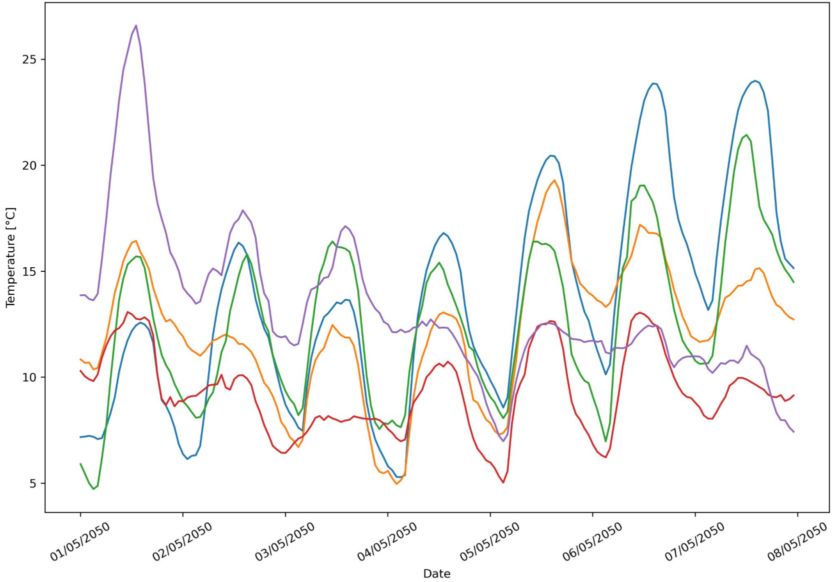


Figure 24. Random weather projections for 5 different seed values.

Scenario calculations: *example*

Solar PV panel output

Requirements:

- Weather data
  - Downwards solar irradiation (G)
  - Ambient temperature (T_a)
  - Wind speed (v)
- PV technical specifications
  - Efficiency (η_{eff})
  - Module temperature performance loss (η_{temp})
  - Cell age degradation loss (η_{degr})
  - Reference check correction loss (η_{loss})
  - Module area (a)

Approximation method:

- Faiman correlation

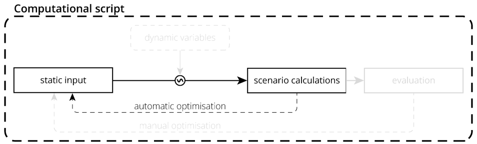
$$T_m(T_a, G, v) = T_a + \frac{\tau\alpha \cdot G}{30.02 + 6.28 \cdot v}$$

$$\eta_{temp}(T_m) = \begin{cases} (T_m - 25) \cdot \beta & \text{, if } T_m > 25°\text{C} \\ 1 & \text{, if } T_m \leq 25°\text{C} \end{cases}$$

Equation 1. Faiman module temperature losses approximation.

$$P_{PV}(t) = G(t) \cdot \eta_{eff} \cdot (1 - \eta_{loss}) \cdot (1 - \eta_{degr}) \cdot (1 - \eta_{temp}) \cdot A_{PV}$$

Equation 2. Power output of a single PV panel following hourly weather conditions.



Automatic optimisation

Energy imbalance handling

Power surplus:

1. Reduce power plant output
2. Charge present batteries
3. Electrolyse hydrogen
4. ⅓rd year average daily surplus
   → construct 100MW battery park
5. Export

Power shortage:

1. Discharge present batteries
2. Import

Heat surplus:

- Reduce thermal plant output

Heat shortage:

1. Use higher temperature heat
2. Construct new thermal plant (following strategy)

Scenario evaluation

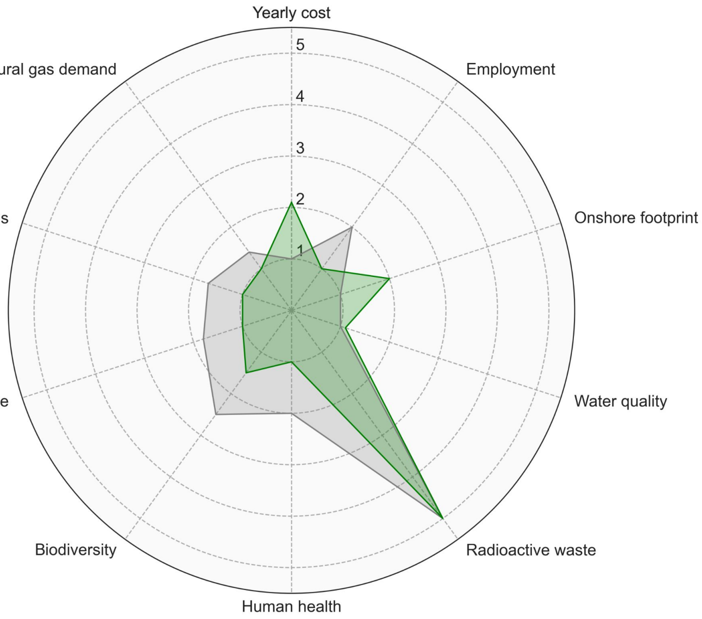
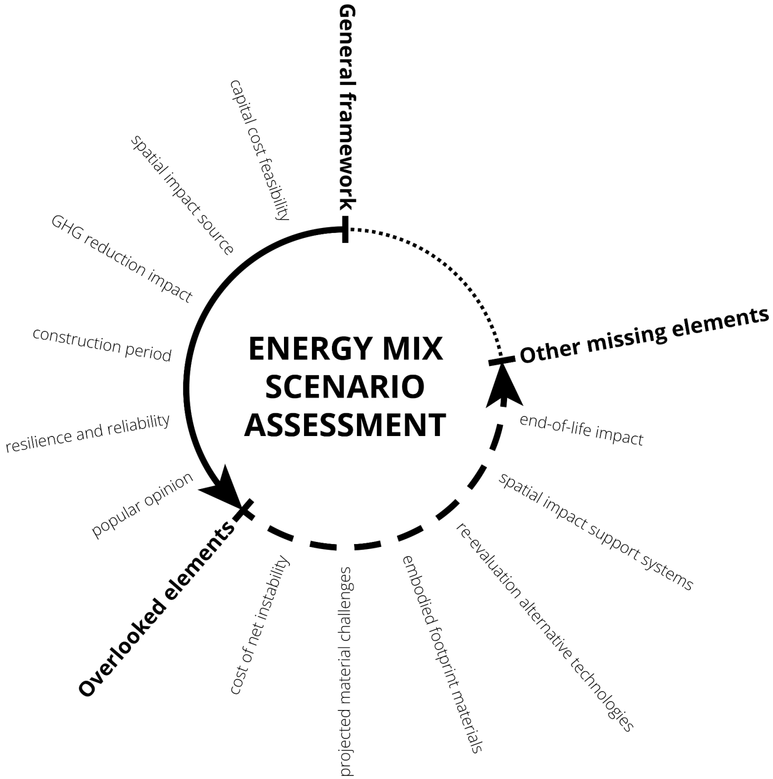


Figure 25. Example of simulation results presented in an assessment radar chart.



Alternative strategy investigation

Scenario 1: light nuclear

- Construction of a *twin EPR2* reactor in 2030 (Hinkley point-C equivalent)
- Reduce renewable share
- Heavy industrial electrification

Scenario 2: strong nuclear

- Construction of a *twin EPR2* reactor in 2030
- Further renewable share
- After 2036: *Small Modular Reactors* (replacing thermal energy float)
- Only low thermal industrial electrification

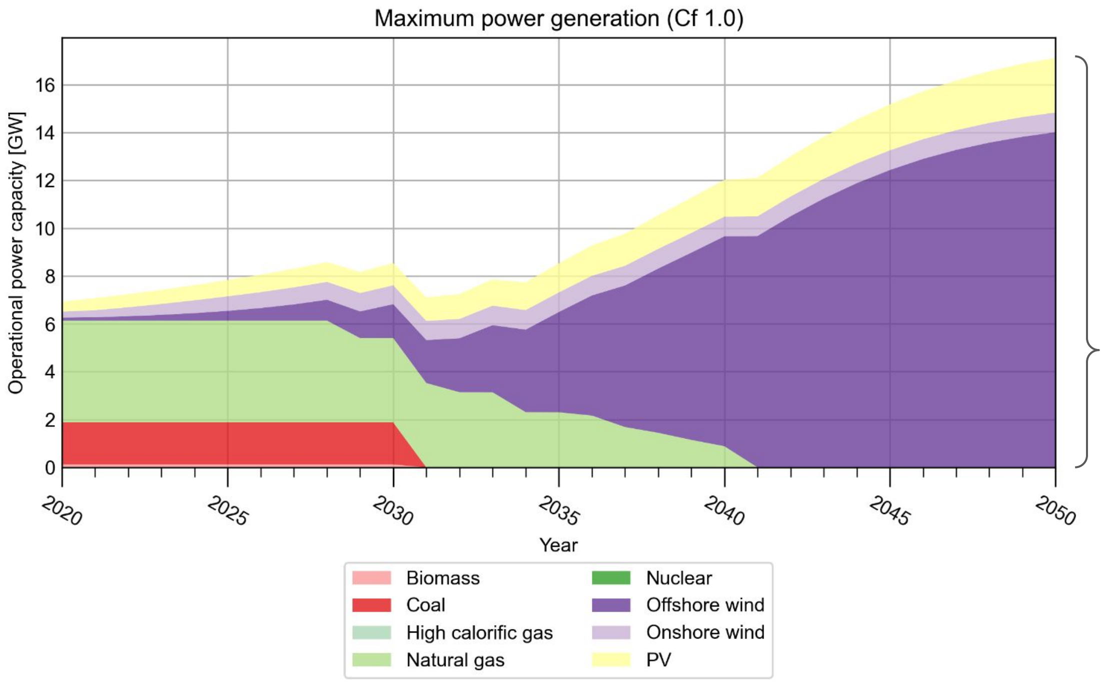
V. RESULTS

Reference scenario

-

RES strategy

Reference scenario: electrification



Onshore area
107 km^2 required
(8.6% total area)

Figure 26. Total power generation capacity energy system over time.

Reference scenario: electrification

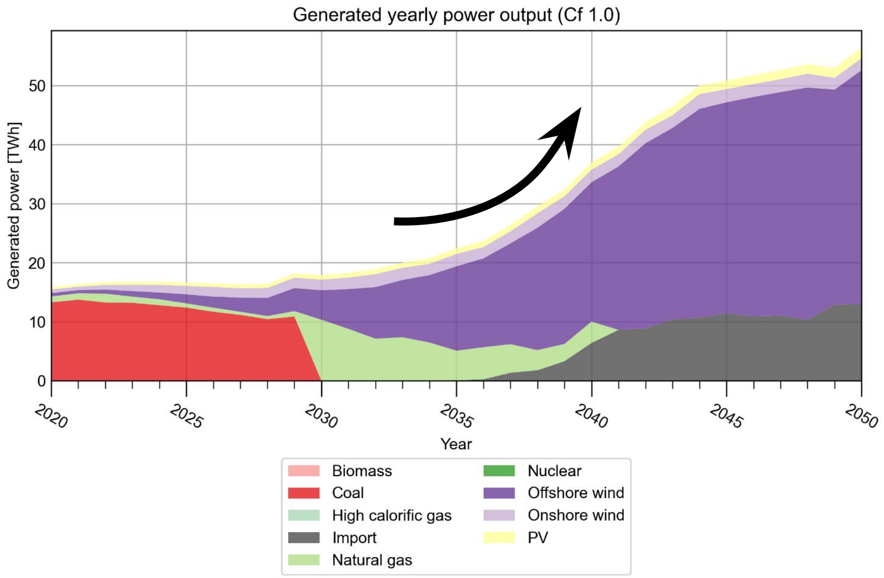


Figure 27. Power consumption/demand over time for the reference strategy with heavy industrial electrification

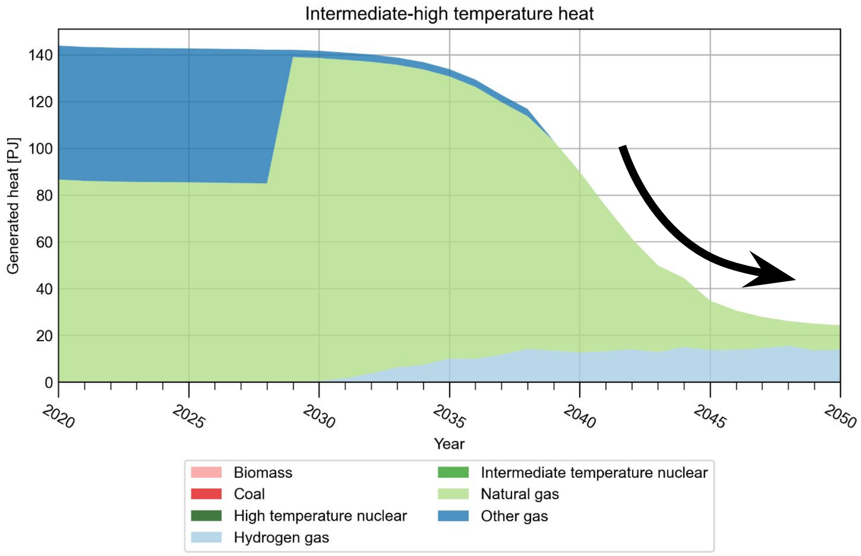


Figure 28. Heat consumption/demand over time for the reference strategy with heavy industrial electrification

Reference scenario: material demand

	Aggregates	Aluminium	Borate	Cadmium	Chromium	Cobalt	Copper	Dysprosium	Gallium	Germanium	Indium	Iridium	Iron ore	Lanthanum	Limestone	Lithium	Manganese	Molybdenum	Neodymium	Nickel	Niobium	Platinum	Praseodymium	Selenium	Silica sand	Silicon metal	Silver	Tellurium	Terbium	Titanium	Yttrium	Zinc	Zirconium
2021-2025	1.0	1.0	1.0	1.7	1.0	1.0	1.0	75.1	1.7	6.6	5.4	1.0	1.0	1.0	1.0	1.0	1.0	1.1	22.3	1.0	3.2	1.0	16.3	1.0	1.0	1.1	1.0	15.4	17.0	1.0	1.0	1.0	1.0
2026-2030	1.0	1.0	1.0	1.8	1.0	1.4	1.1	158.6	1.9	7.4	6.1	1.0	1.0	1.0	1.1	2.8	1.1	1.1	73.2	1.1	5.1	1.0	36.1	1.0	1.0	1.1	1.0	17.7	38.5	1.0	1.0	1.1	1.0
2031-2035	1.0	1.0	1.0	2.0	1.0	2.0	1.2	373.7	2.0	8.5	6.9	1.0	1.1	1.0	1.1	6.0	1.4	1.3	192.1	1.3	10.2	1.0	85.9	1.0	1.0	1.1	1.0	20.4	92.2	1.0	1.0	1.2	1.0
2036-2040	1.0	1.0	1.0	2.3	1.0	2.5	1.4	592.7	2.3	11.0	8.8	1.0	1.1	1.0	1.2	8.4	1.5	1.4	305.9	1.5	15.5	1.0	136.0	1.0	1.1	1.1	1.0	26.8	146.0	1.0	1.0	1.3	1.0
2041-2045	1.0	1.1	1.0	3.5	1.0	3.1	1.3	430.8	3.5	19.9	15.9	1.0	1.1	1.0	1.2	11.6	1.6	1.3	221.6	1.5	11.6	1.0	99.0	1.0	1.1	1.2	1.0	50.0	106.2	1.0	1.0	1.2	1.0
2046-2050	1.0	1.0	1.0	2.8	1.0	2.3	1.2	248.7	2.8	14.4	11.6	1.0	1.1	1.0	1.1	7.4	1.4	1.2	112.8	1.3	7.4	1.0	56.0	1.0	1.1	1.1	1.0	35.8	59.7	1.0	1.0	1.1	1.0

Figure 29. Material demand intensification related to system transition. Electrification scenario B.

Reference scenario: natural gas demand

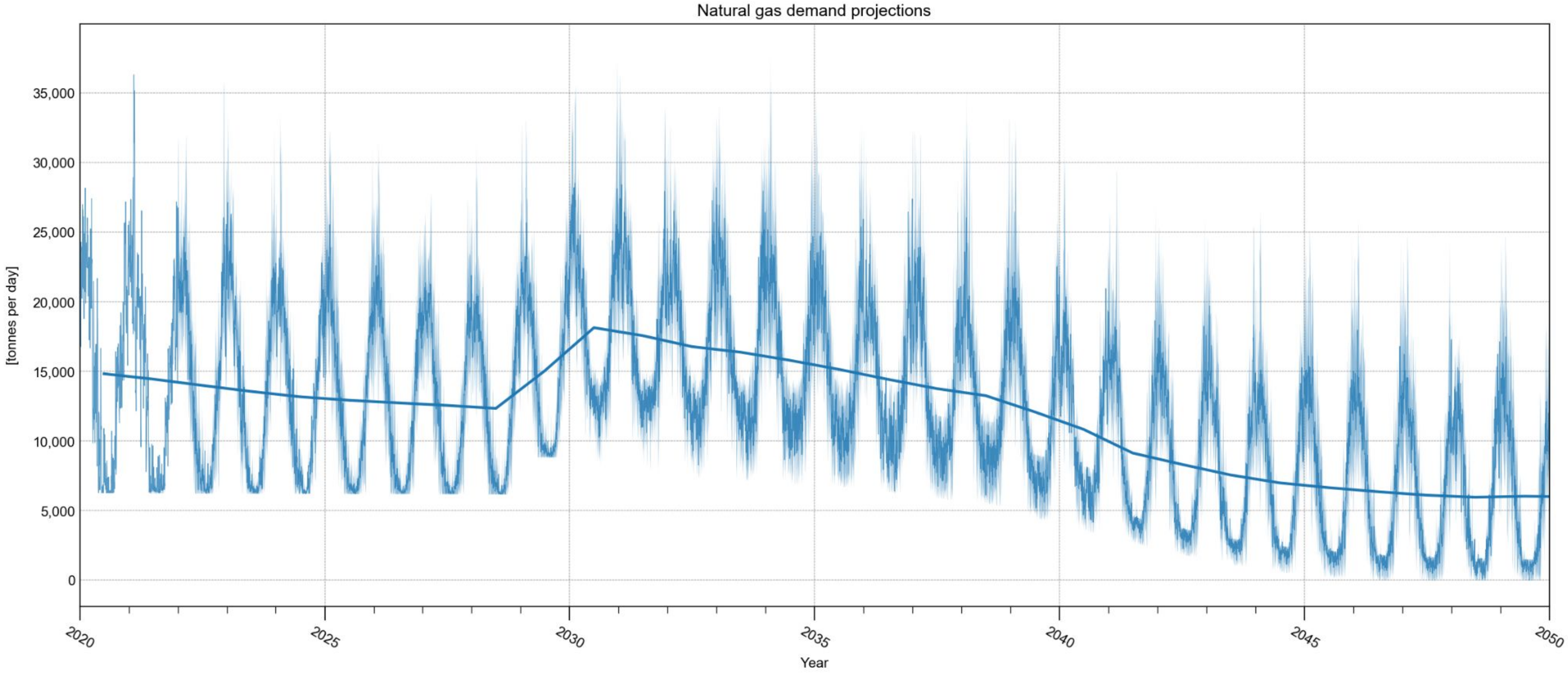


Figure 30. Natural gas demand projections for the reference strategy with heavy industrial electrification.

Reference scenario: operational effects

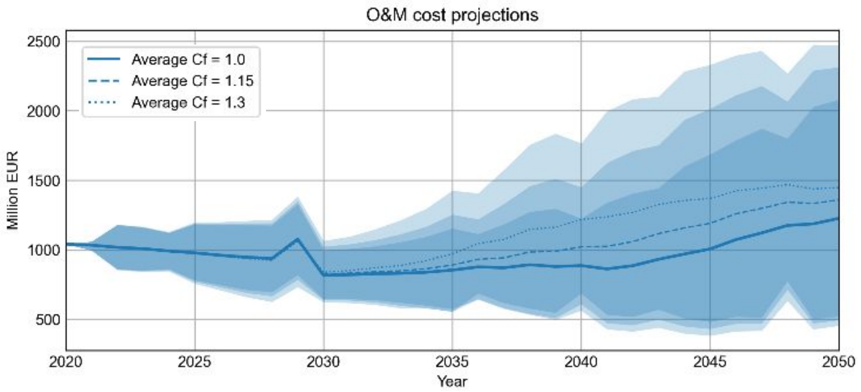


Figure 31. Energy import cost for the reference scenario with heavy electrification.

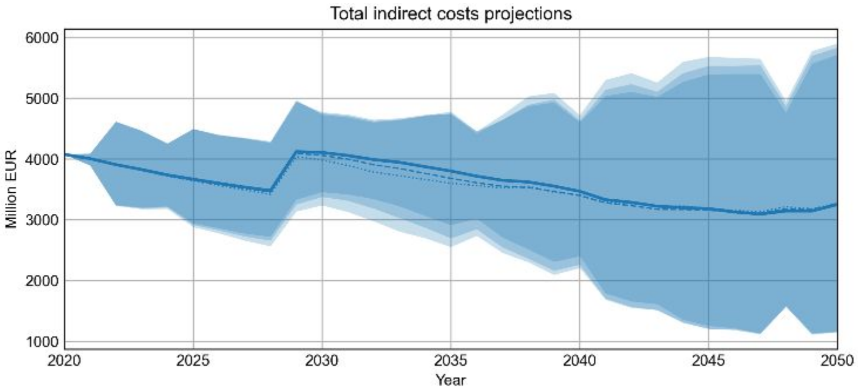
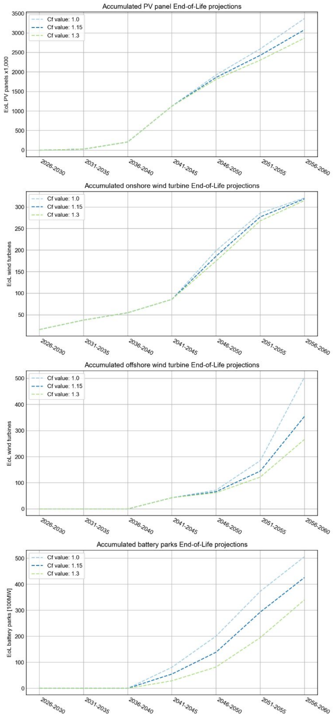


Figure 32. Total operational upkeep costs for the reference scenario with heavy electrification.

Electronic waste accumulation



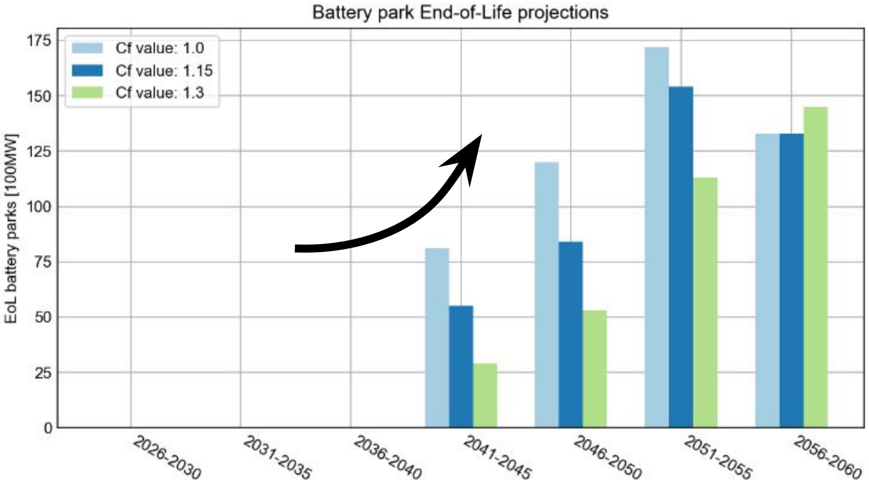


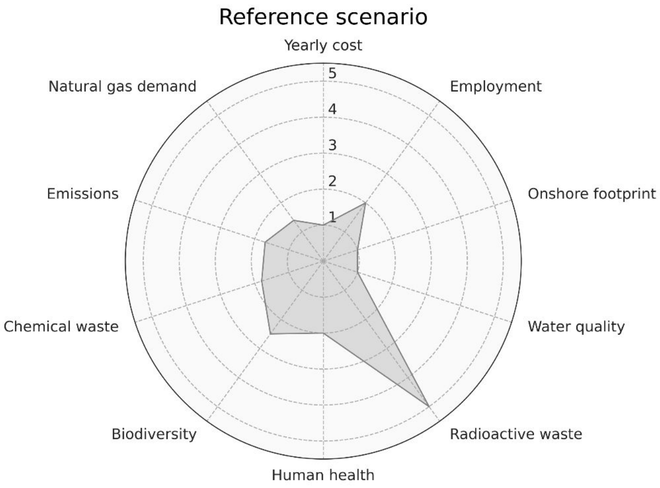
Figure 33. Lithium battery storage End-of-Life flow for the reference scenario with heavy electrification.

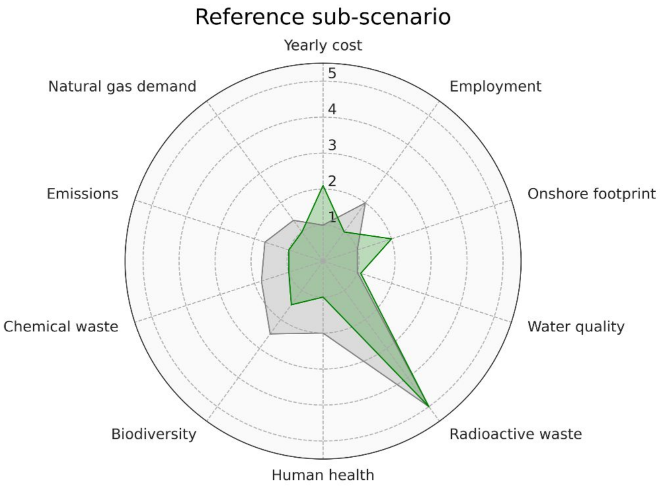
Additional system support

Figure 34. Lithium battery park located in Victoria, Australia. Reprinted from Vorrath [16].

Figure 35. Fire caused by faulty battery. Reprinted from Aroged [17].

Reference scenario: transition strategy impact





Rating: 1 - 5
(poor - excellent)

Excluding battery storage:
Affordable with stable energy prices!

Scenario 1:

light nuclear

Scenario 1: electricity

Reference scenario

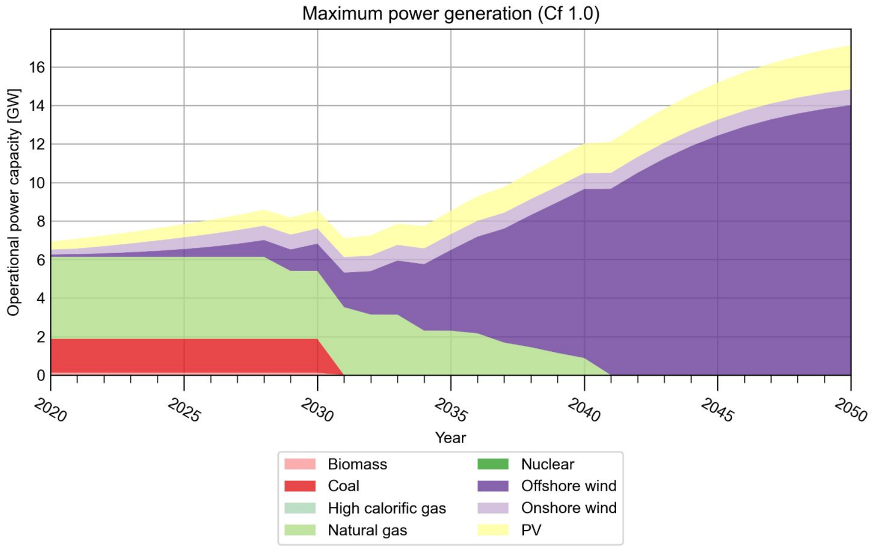
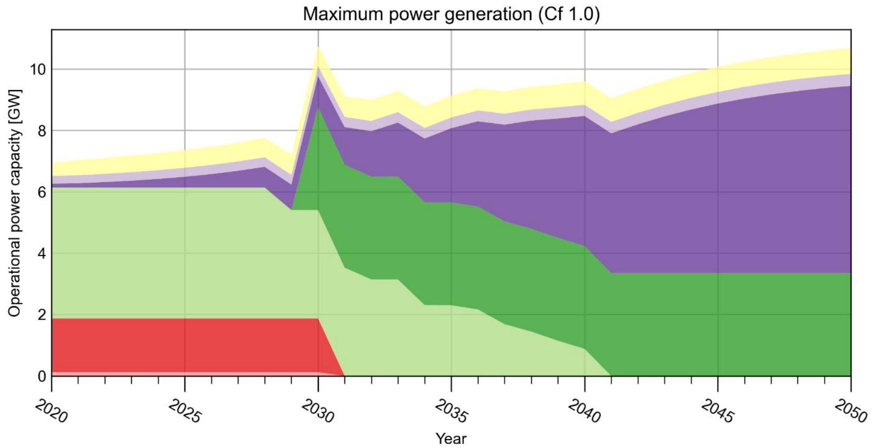


Figure 36. Total power generation capacity energy system over time, reference scenario.

Scenario 1



Onshore area

50 km^2 required

(3.9% total area)

Figure 37. Total power generation capacity energy system over time, scenario 1.

Scenario 1: material demand

Reference scenario

	Aggregates	Aluminium	Borate	Cadmium	Chromium	Cobalt	Copper	Dysprosium	Gallium	Germanium	Indium	Iridium	Iron ore	Lanthanum	Limestone	Lithium	Manganese	Molybdenum	Neodymium	Nickel	Niobium	Platinum	Praseodymium	Selenium	Silica sand	Silicon metal	Silver	Tellurium	Terbium	Titanium	Yttrium	Zinc	Zirconium
2021-2025	1.0	1.0	1.0	1.7	1.0	1.0	1.0	75.1	1.7	6.6	5.4	1.0	1.0	1.0	1.0	1.0	1.0	1.1	22.3	1.0	3.2	1.0	16.3	1.0	1.0	1.1	1.0	15.4	17.0	1.0	1.0	1.0	1.0
2026-2030	1.0	1.0	1.0	1.8	1.0	1.4	1.1	158.6	1.9	7.4	6.1	1.0	1.0	1.0	1.1	2.8	1.1	1.1	73.2	1.1	5.1	1.0	36.1	1.0	1.0	1.1	1.0	17.7	38.5	1.0	1.0	1.1	1.0
2031-2035	1.0	1.0	1.0	2.0	1.0	2.0	1.2	373.7	2.0	8.5	6.9	1.0	1.1	1.0	1.1	6.0	1.4	1.3	192.1	1.3	10.2	1.0	85.9	1.0	1.0	1.1	1.0	20.4	92.2	1.0	1.0	1.2	1.0
2036-2040	1.0	1.0	1.0	2.3	1.0	2.5	1.4	592.7	2.3	11.0	8.8	1.0	1.1	1.0	1.2	8.4	1.5	1.4	305.9	1.5	15.5	1.0	136.0	1.0	1.1	1.1	1.0	26.8	146.0	1.0	1.0	1.3	1.0
2041-2045	1.0	1.1	1.0	3.5	1.0	3.1	1.3	430.8	3.5	19.9	15.9	1.0	1.1	1.0	1.2	11.6	1.6	1.3	221.6	1.5	11.6	1.0	99.0	1.0	1.1	1.2	1.0	50.0	106.2	1.0	1.0	1.2	1.0
2046-2050	1.0	1.0	1.0	2.8	1.0	2.3	1.2	248.7	2.8	14.4	11.6	1.0	1.1	1.0	1.1	7.4	1.4	1.2	112.8	1.3	7.4	1.0	56.0	1.0	1.1	1.1	1.0	35.8	59.7	1.0	1.0	1.1	1.0

Scenario 1

	Aggregates	Aluminium	Borate	Cadmium	Chromium	Cobalt	Copper	Dysprosium	Gallium	Germanium	Indium	Iridium	Iron ore	Lanthanum	Limestone	Lithium	Manganese	Molybdenum	Neodymium	Nickel	Niobium	Platinum	Praseodymium	Selenium	Silica sand	Silicon metal	Silver	Tellurium	Terbium	Titanium	Yttrium	Zinc	Zirconium
2021-2025	1.0	1.0	1.0	1.3	1.0	1.0	1.0	29.4	1.3	3.4	2.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	14.2	1.0	1.7	1.0	7.3	1.0	1.0	1.0	1.0	7.2	7.8	1.0	1.0	1.0	1.0
2026-2030	1.1	1.0	1.0	1.3	1.4	1.0	1.2	73.4	1.3	2.9	2.5	1.0	1.1	1.0	1.7	1.0	1.1	1.5	34.5	1.9	2.9	1.0	17.2	1.0	1.0	1.0	1.0	6.0	18.3	1.0	1.0	1.0	1.0
2031-2035	1.0	1.0	1.0	1.2	1.0	1.0	1.1	137.5	1.2	2.7	2.3	1.0	1.0	1.0	1.1	1.0	1.1	1.1	69.1	1.1	4.4	1.0	31.9	1.0	1.0	1.0	1.0	5.4	34.2	1.0	1.0	1.1	1.0
2036-2040	1.0	1.0	1.0	1.4	1.0	1.3	1.1	214.8	1.4	3.9	3.3	1.0	1.0	1.0	1.1	2.7	1.2	1.1	108.2	1.1	6.3	1.0	49.5	1.0	1.0	1.0	1.0	8.6	53.0	1.0	1.0	1.1	1.0
2041-2045	1.0	1.0	1.0	2.4	1.0	1.0	1.1	183.1	2.4	11.8	9.5	1.0	1.0	1.0	1.1	1.0	1.1	1.1	92.0	1.1	5.5	1.0	42.3	1.0	1.0	1.1	1.0	28.8	45.3	1.0	1.0	1.1	1.0
2046-2050	1.0	1.0	1.0	1.4	1.0	1.3	1.1	135.5	1.4	4.0	3.4	1.0	1.0	1.0	1.1	2.7	1.1	1.1	69.1	1.1	4.3	1.0	31.6	1.0	1.0	1.0	1.0	8.7	33.8	1.0	1.0	1.1	1.0

Figure 38. Material demand intensification related to system transition. Electrification scenario B.

Scenario 1: electricity

Reference scenario

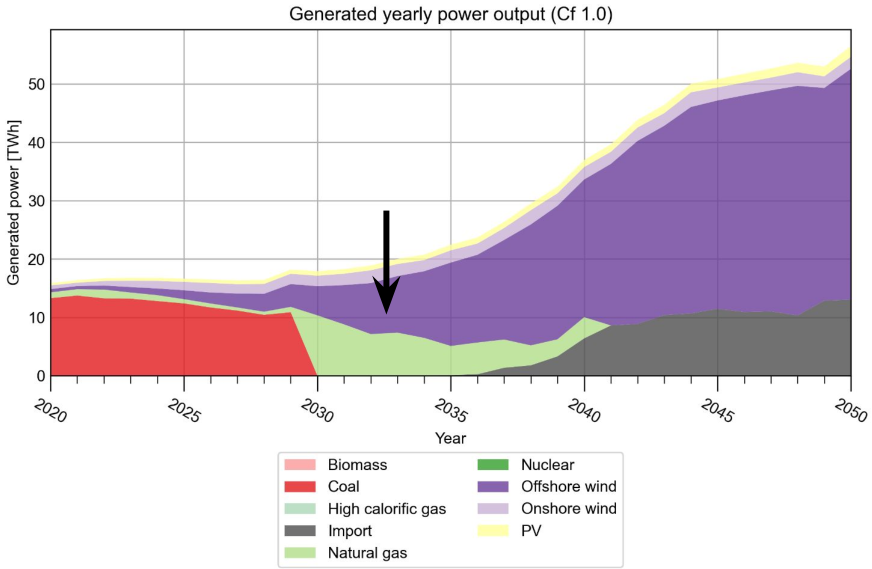


Figure 39. Power consumption/demand over time, reference scenario.

Scenario 1

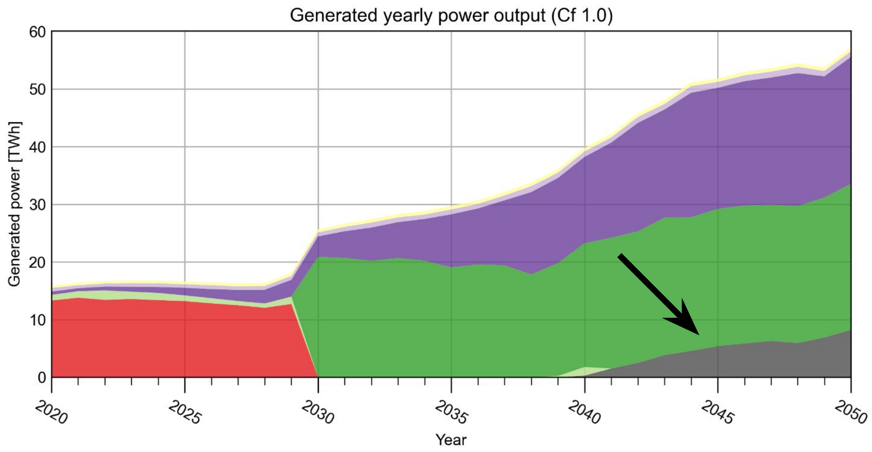


Figure 40. Power consumption/demand over time, scenario 1.

Scenario 1: natural gas demand

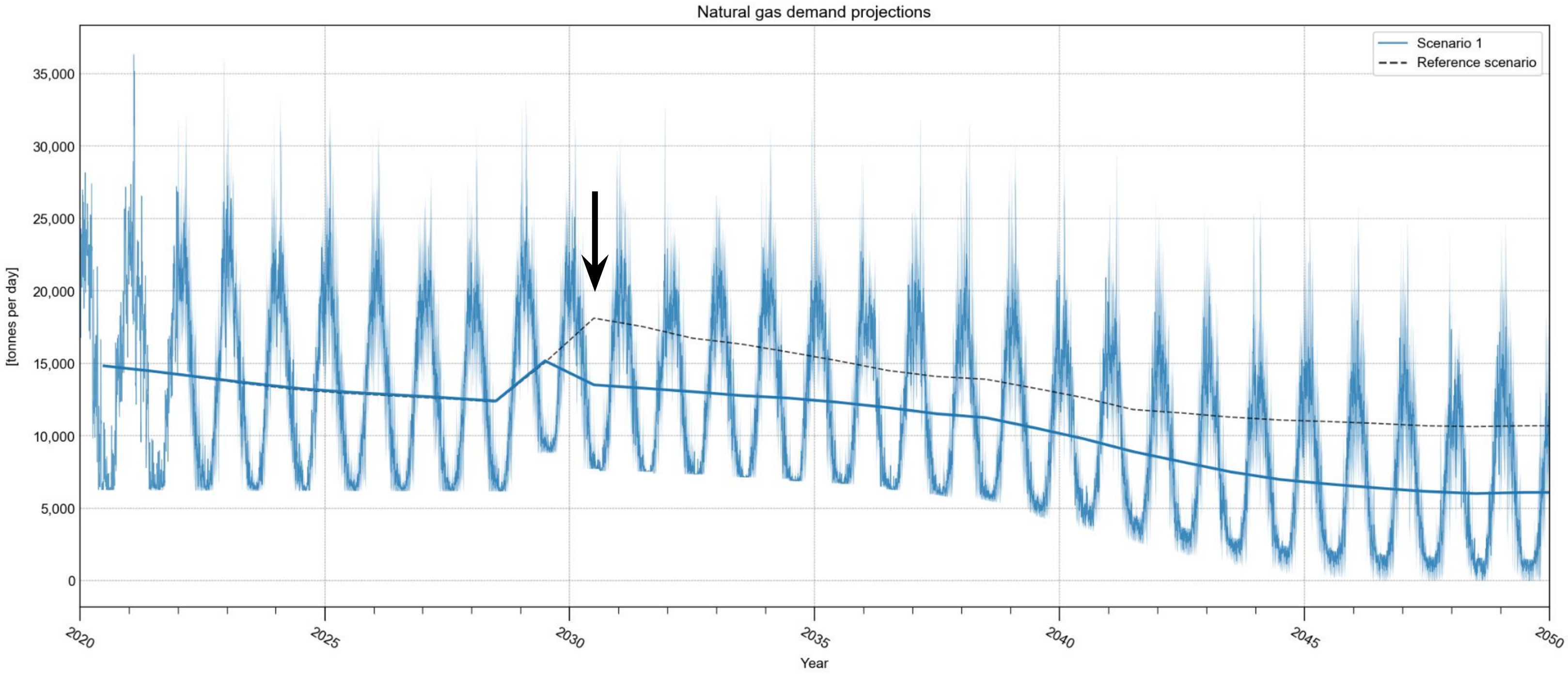
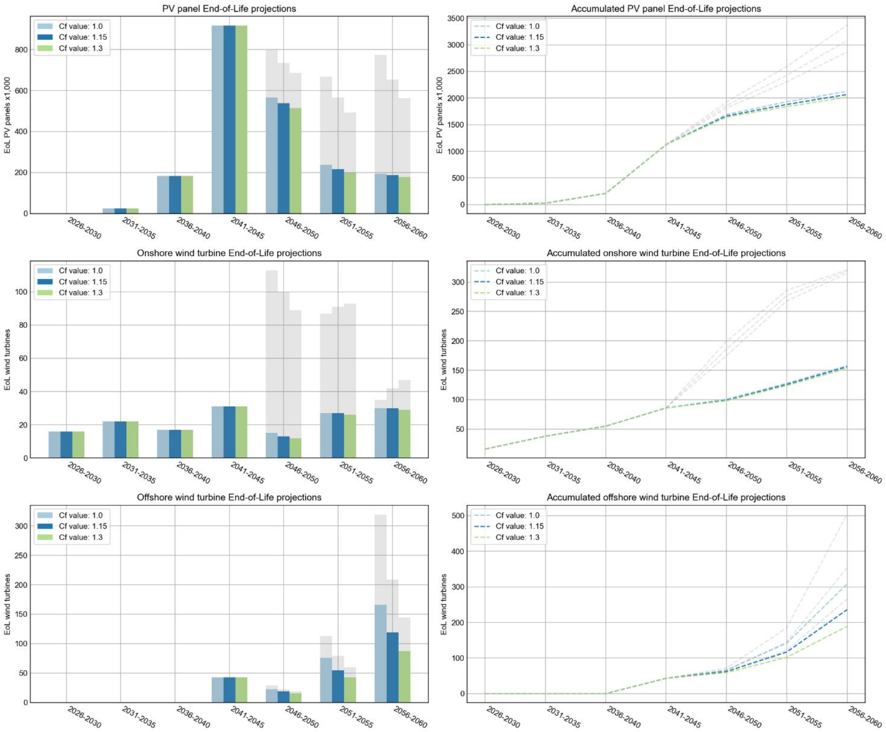


Figure 41. Natural gas demand projections for electrification scenario B. Grayscale represent reference scenario.

Scenario 1: End-of-Life projections



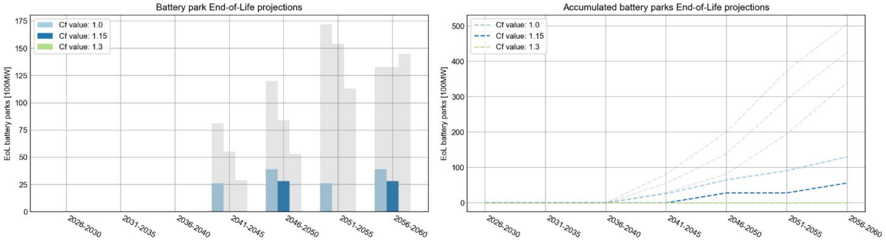
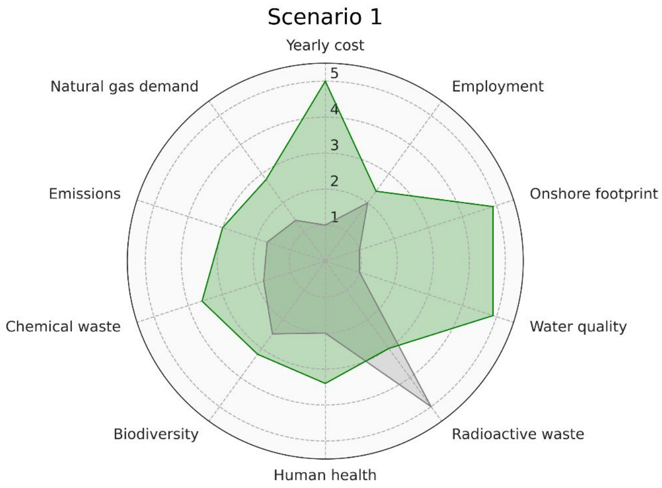
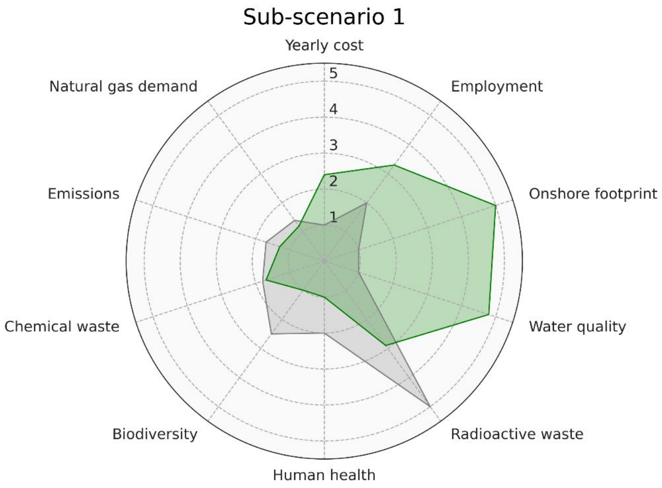


Figure 42. End-of-Life projections of renewable production and storage electronics. Electrification scenario B.

Nuclear reactor
drastic **reductions** in
results in
electronic waste
net **stability**

Reference scenario: transition strategy impact





Excluding battery storage:
Less affordable!

Rating: 1 - 5
(poor - excellent)

Scenario 2:
strong nuclear

Scenario 2: overview

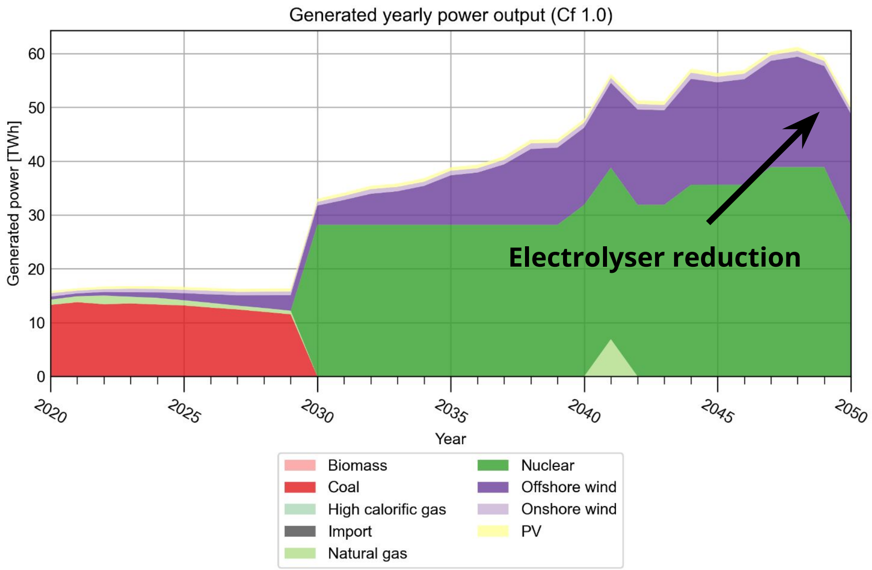


Figure 43. Power generation and consumption over time, scenario 2 with limited industrial electrification.

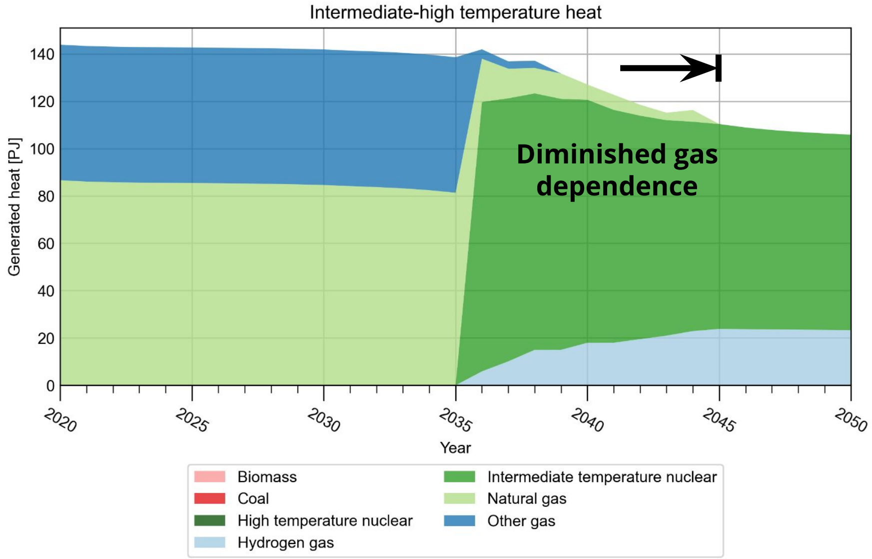


Figure 44. Heat generation and consumption over time, scenario 2 with limited industrial electrification.

Scenario 2: natural gas demand

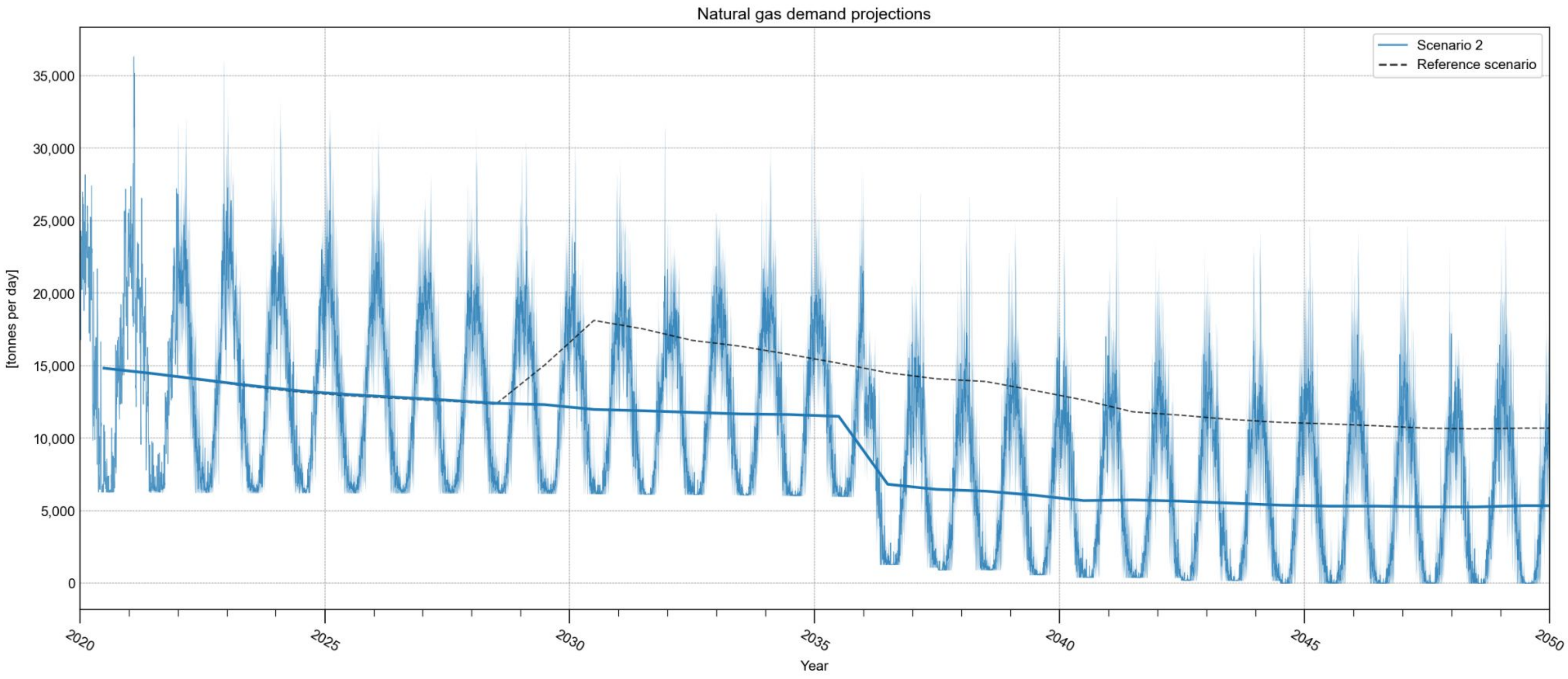


Figure 45. Natural gas demand projections for electrification scenario B. Grayscale represent scenario 1 electrification B.

Scenario 2: transition strategy impact

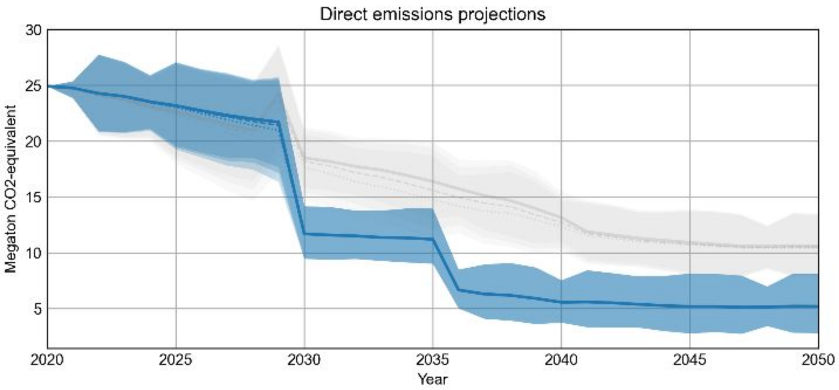
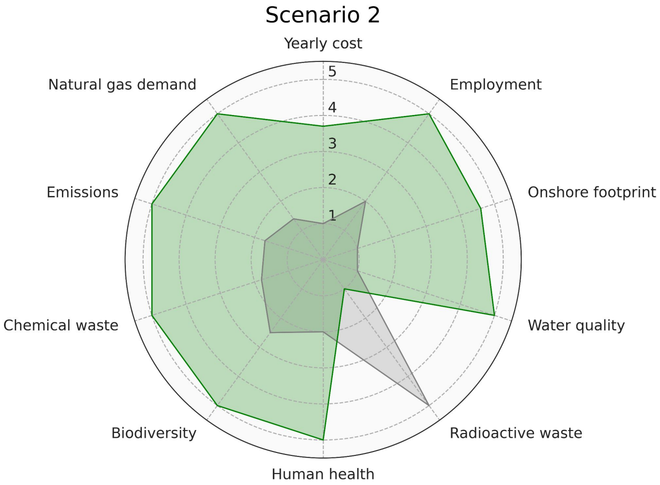
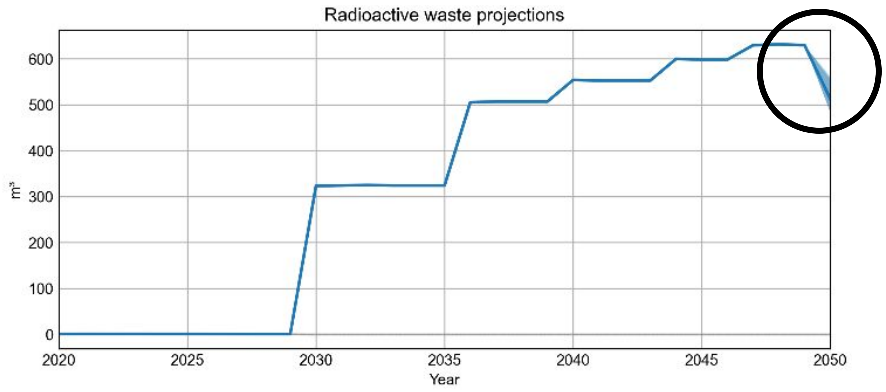


Figure 46. Transition direct emissions for scenario 2 with limited industrial electrification.



Rating: 1 - 5
(poor - excellent)

Scenario 2: generation IV reactors



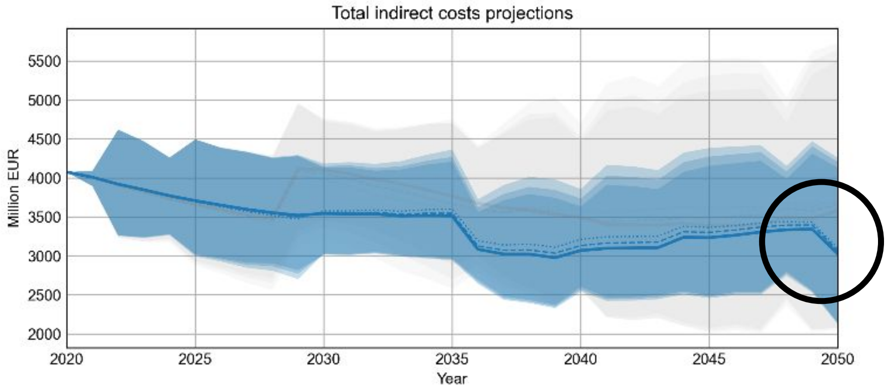


Figure 47. Operational effects of scenario 2 with limited industrial electrification.

VI. DISCUSSION

Simulation characteristics

Advantage

- considers wide range of conditioning factors → decent projection accuracy
- fast research tool

Disadvantages

- cannot include all external influences
- simulation flexibility reduced by additions (computing power)
- requires extensive literature research to form conditioning framework

Primary uncertainties

- Stable fuel and power import prices (pre-2019)
- Simplification climate change:
  - broad range of changing parameters
  - relation between consumption and weather
- Exclusion of outage plant rates
- Generalisation of projected generation and storage technologies
- Weather grid and spatial accuracy

VII. CONCLUSION

Sub-objectives

1. Determine the current proposed energy transition strategy its challenges, bottlenecks, and benefits.

Benefits

- Increase in employment
- Potential for new innovation industry
- Improved impact of many assessed elements

Challenges

- High spatial requirement
- Water quality issues turbine construction

Bottlenecks

- End-of-Life electronic waste accumulation
- Critical raw material demand supply risk
- Energy dependence resulting from net instability

Conclusion

- *Potential energy affordability issues*

Sub-objectives: light implementation scenario

2 & 3. Investigate the integration of various nuclear energy scenarios, including the use of the sustainable assessment method and compare the benefits and drawbacks of various energy generation strategies and their associated techniques.

Advantages

- Significant reduction in transition investment costs (34 billion EUR)
- More affordable electricity
- Reduction in biodiversity, water quality and human health impact
- Clustered job opportunities (reactor facility)
- Lower spatial footprint system
- Less material supply risk problems

(Potential) disadvantages

- Radioactive waste storage (minimal)
- Nuclear fuel demand (minimal)
- Lower innovation growth potential

Sub-objectives: strong implementation scenario

2 & 3. Investigate the integration of various nuclear energy scenarios, including the use of the sustainable assessment method and compare the benefits and drawbacks of various energy generation strategies and their associated techniques.

Advantages

- Exceptional improvement of system impact
- Further increase employment : potential *nuclear knowledge hub*
- Fossil fuel independence achievable

(Potential) disadvantages

- Slight increase investment cost
- Further increase in radioactive waste production, requires new storage facilities
- Early reactor replacements to generation IV models

Research question

"To what extent can modern nuclear reactors benefit the future of the Rotterdam-The Hague metropolitan area sustainable transition and energy mix compared to other energy sources classified as sustainable?"

Conclusion: expected findings

1. Significant decrease in potential future material supply risk issues

2. Lower chance of large-scale electronic EoL-waste accumulation

3. Drastic reductions in spatial footprint of entire energy system

Conclusion: interesting findings

1. Reduces required transition investment (average by 20%: 22 billion EUR)

2. Improved energy affordability due to net stability and system maintenance

3. Allows for drastic reductions in fuel dependency as early as 2030

Conclusion

"Both light to heavy implementation of nuclear energy sources will benefit the sustainable transition by lowering the negative operational impact of the energy system, both relative to the current situation as well as the proposed RES strategy."

VIII. RECOMMENDATIONS

Research recommendations

1. Investigation of many more strategies, technologies and regions.

2. Consumption trend correlation studies (e.g. heating demand and climate change).

3. Life cycle assessment studies on energy technologies.

4. Integration of multi-disciplinary strategy parameters.

but of course even after…

>7,500 lines of code, there is lots to improve…

Coalitieakkoord
2022 - 2026

Eén Stad

Rotterdam

4 Klimaat en energie

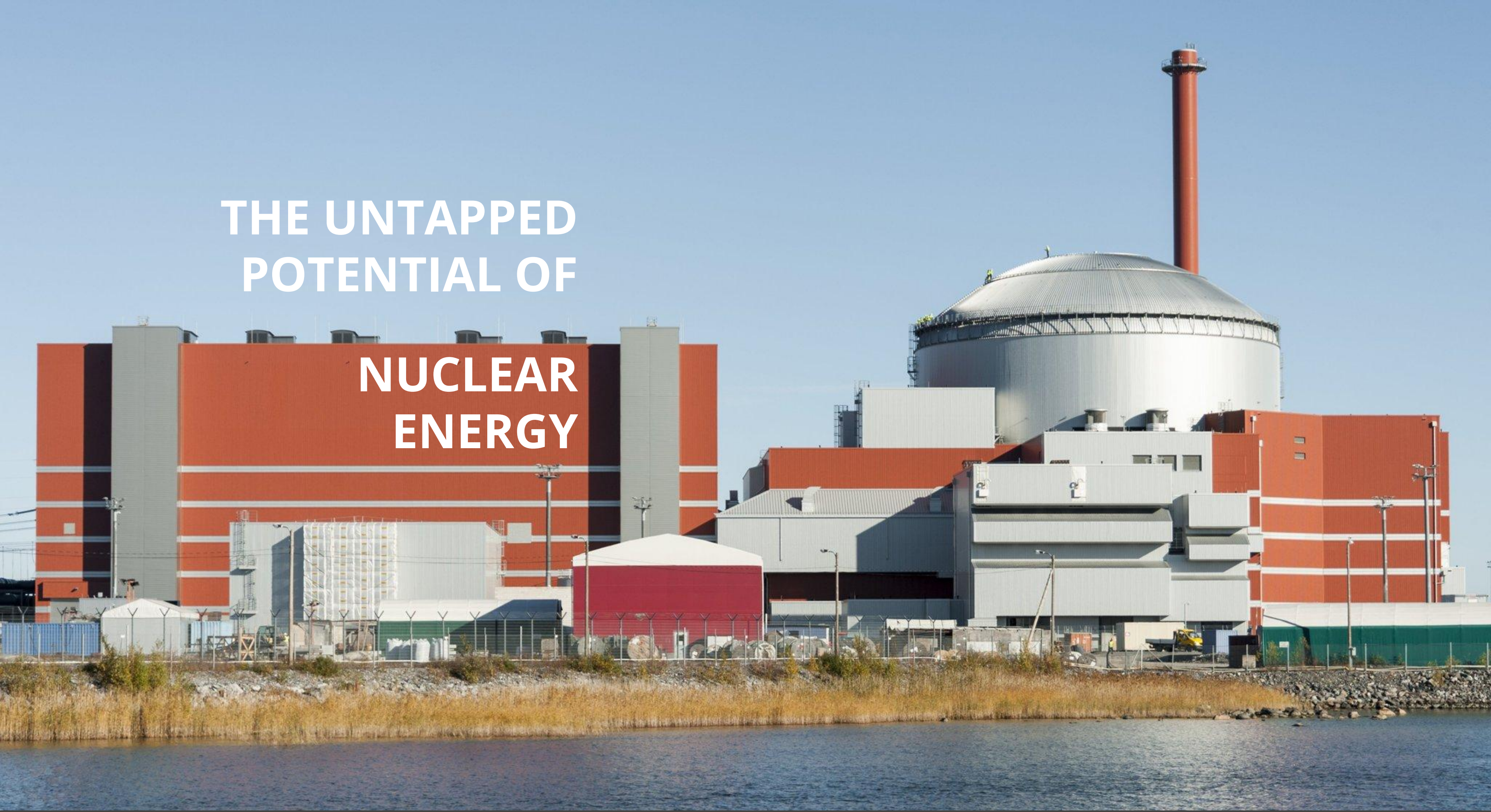
- We vormen een Duurzaamheidstransitiebudget (€ 100 mln)[1] om de juiste innovaties in de regio te versnellen en zo het verdienvermogen voor de stad en de werkgelegenheid voor Rotterdammers te bevorderen. Het fonds wordt ingezet voor de vergroening van de leefomgeving, duurzame opwek en opslag van zonne- en windenergie, waterstofproductie, de transitie naar een circulaire economie en het reduceren van energiegebruik.

- We zetten het Energietransitiefonds (€ 71 miljoen, revolverend) voort en ondersteunen hiermee de financiering van innovatieve bedrijven en grote duurzame projecten die bijdragen aan de Rotterdamse energietransitie en circulaire economie.

- Als het Rijk bij Rotterdam aanklopt over een kerncentrale in de haven, gaan we daarover met het Rijk in gesprek omdat onderzoek van alternatieve energiebronnen hoort bij de energietransitie.

- We willen Rotterdam weerbaar maken in tijden van crisis zoals de klimaatcrisis en economisch slechte omstandigheden. Daarom gaan we door met het ‘resilience aanjaagteam’.

THE UNTAPPED POTENTIAL OF NUCLEAR ENERGY



Reprinted from A. Ward [18]

CONTRIBUTING TO A FLEXIBLE, AFFORDABLE & RELIABLE ENERGY SYSTEM IN A COMPLEX REGION

Reprinted from Agro & Chemie [19]

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