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Comparison of Swiss Electricity Scenarios 2050

Laboratory for Energy Systems Analysis

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The studies

Study	Full name	Author (Modeller)	Year	System scope
BFE	Energieperspektiven für die Schweiz bis 2050	BFE (Prognos AG)	2012	Energy system
VSE	Stromzukunft Schweiz	VSE (Pöyry AG)	2012	Electricity
ETH / ESC	Energiezukunft Schweiz	G. Andersson, K. Boulouchos, L. Bretschger	2011	Energy system
SCS	SCS-Energiemodell	A. Gunzinger (SCS AG)	2013	Electricity
Greenpeace	Energy [r]evolution	S. Teske, G. Heiligtag (DLR, SCS AG)	2013	Energy system
Cleantech	Energiestrategie	F. Barmettler, N. Beglinger, C. Zeyer	2013	Energy system
PSI-sys	Transformation strategies towards a sustainable Swiss energy system – energy-economic scenario analysis	N. Weidmann	2013	Energy system
PSI-elc	Swiss electricity supply options (Energie-Spiegel 21)	R. Kannan, H. Turton	2012	Electricity

Scope and types of models

- Demand models: to estimate electricity demand
- Capacity expansion models:
  - Input: Demand
  - Output: Capacities of generation technologies, production mix;
    time horizon 2010-2050, time steps 5-10 year
- Dispatch models:
  - Input: Demand, capacity mix
  - Output: Hourly dispatch of generation technologies and of imports over 1 year
- Integrated models (combination of above types)

- Optimization models: Technology deployment is by minimizing system-costs
- Simulation models: Technology deployment is a function of an internal state
  - costs are calculated after the result of the simulation

Generally in all studies:

- No new nuclear plants (except in some scenarios for comparison purpose)
- Power grid is not modelled (!)
- Deterministic models (optimization/simulation is over a single realization (scenario-path))

Demand models (all studies)

Demand models are usually separated from supply models

- Exceptions: PSI-sys, 3rd model of ETH, (Greenpeace)

→Demand cannot be influenced directly by the supply mix (only by scenario assumption)

Accounting (spreadsheet-) models (Simulation)

- Demand for device at time t = $(\text{Number of devices})_t$ / $(\text{Efficiency of device})_t$,
  where device = heat pump, car, cell phone,…
- Initial input: Population, floor area, car-km/person, efficiency, share for heat pumps, (GDP)

Large differences in reported (or claimed) model complexity, for example

- BFE/PSI-sys: Reports details for demand sectors (residential, commerce, transport, industry)
- VSE: mentions 23 **power-**demand sectors with seasonal profiles and potential of flexibility
- ETH: mentions only driving factors (GDP, electricity prices, “structural change”, “innovation”)

BFE study

Demand variants:

- Assumptions for all scenarios: Pop.: 9 Mio. (2050); living area: +20%; GDP: +1.1% p.a.
- WWB (Weiter Wie Bisher): Increase in efficiency and regulations as of today
- POM (Politische Massnahmen): Strong efficiency increase
- NEP (Neue Energiepolitik): CO_2-target scenario (~1.5 tons CO_2/year/person), even stronger efficiency increase, behavioural changes (e.g., more public transport)

Supply variants:

- C (central gas plants): Support for renewables as of today; annual import = 0
- E (more support for renewables): no central gas plants; annual import ≥ 0

→Scenarios: WWB+C, WWB+C+E, POM+C,…

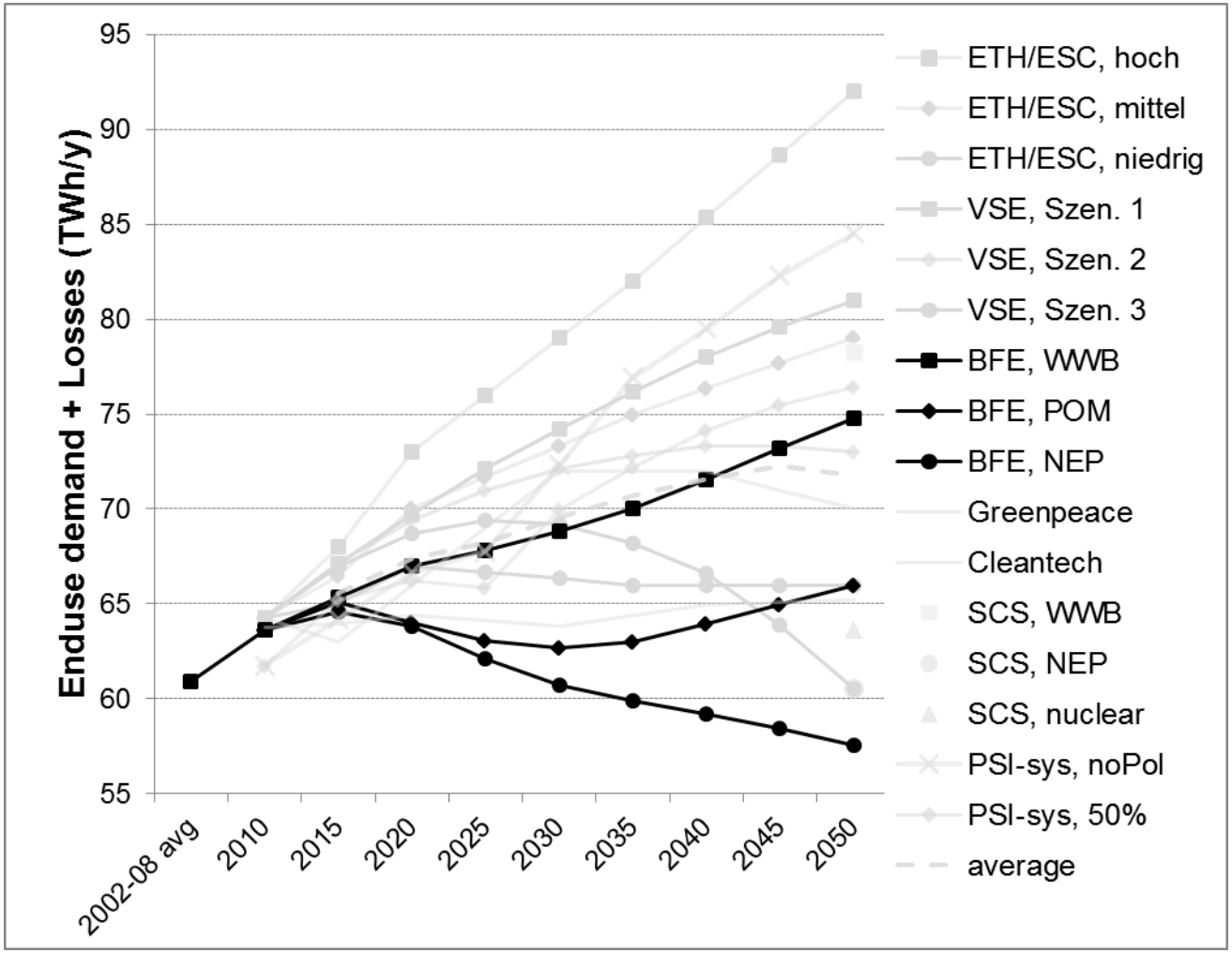
Capacity expansion model (Simulation):

- Renewables: are deployed fixed by scenario assumption (C or E)
- Gas plants, imports: are variable; but implicitly also fixed, because either (annual import = 0) in C or (no gas plants) in E

Dispatch model (Simulation): Pre-determined annual production mix as input.

- Fixed order of dispatch: 1. (Pumped-) hydro storage, 2. gas plants.

BFE: Demand

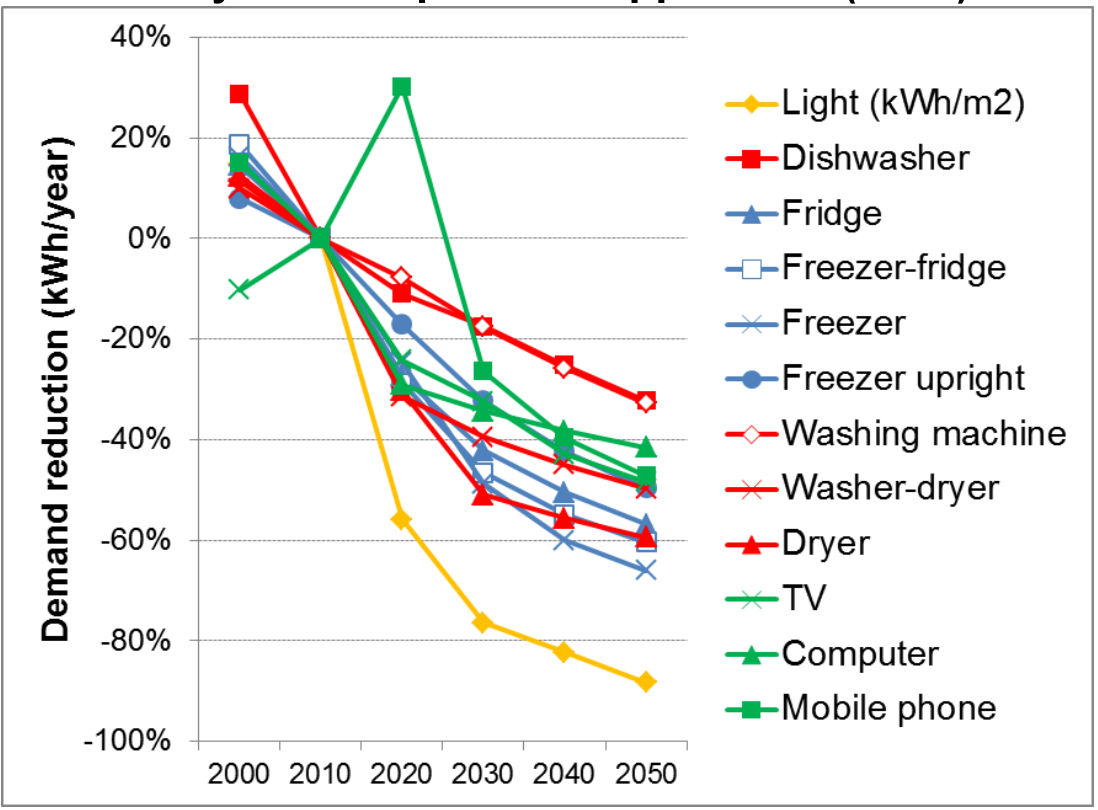


PSI (2014): Comparison of Swiss Electricity Scnearios

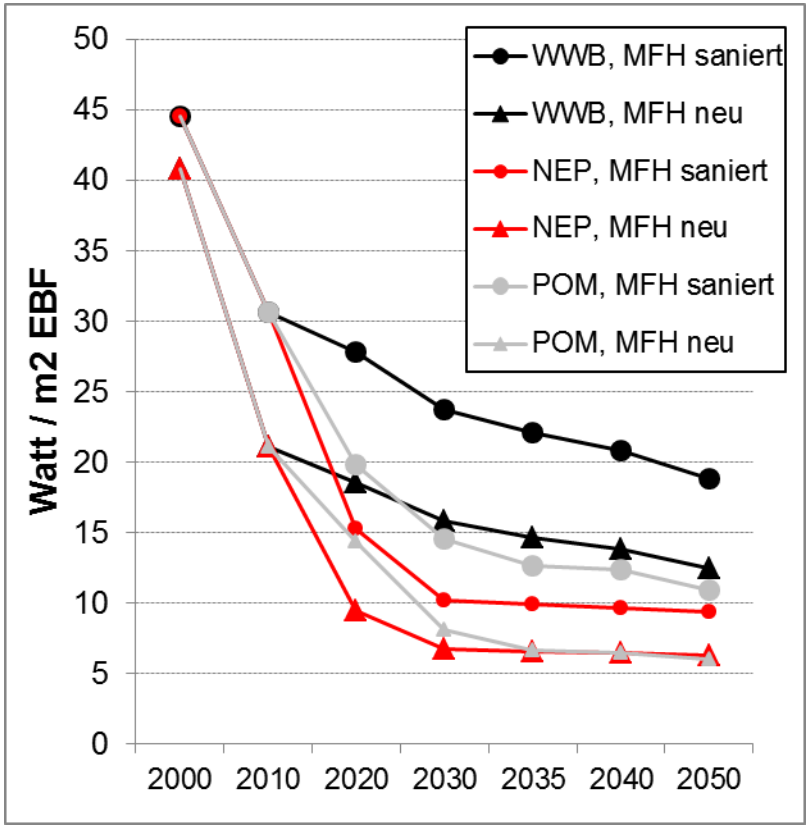
Demand reduction in **POM** and **NEP** by aggressive efficiency measures

BFE: Exp. efficiency measures in POM and NEP

Electricity consumption for appliances (POM):



Heat for a multi-family house:



Aggressive efficiency measures until 2050:

- ~100% light by LED
- all houses (new and old) have Minenergy standard in **NEP**

VSE and ETH/ESC study

VSE

- Szenario 1: like WWB of BFE; gas plants allowed, annual imports ≥ 0
- Szenario 2: higher efficiency (electric mobility, heat pumps); gas/import mid-term
- Szenario 3: target of 100% renewable supply(!) mix; annual import = 0 in 2050; aggressive efficiency measures (e.g. only Energy+ buildings); behavioural changes

Integrated capacity expansion and dispatch model (Optimization):

- for Switzerland and neighbouring countries, with transmission constraints
- dispatching with ramping times, minimal downtimes, 6 weather profiles simultaneously

ETH

Target scenarios: 1.6 ton CO_2/person/year in year 2050 (imports neglected)

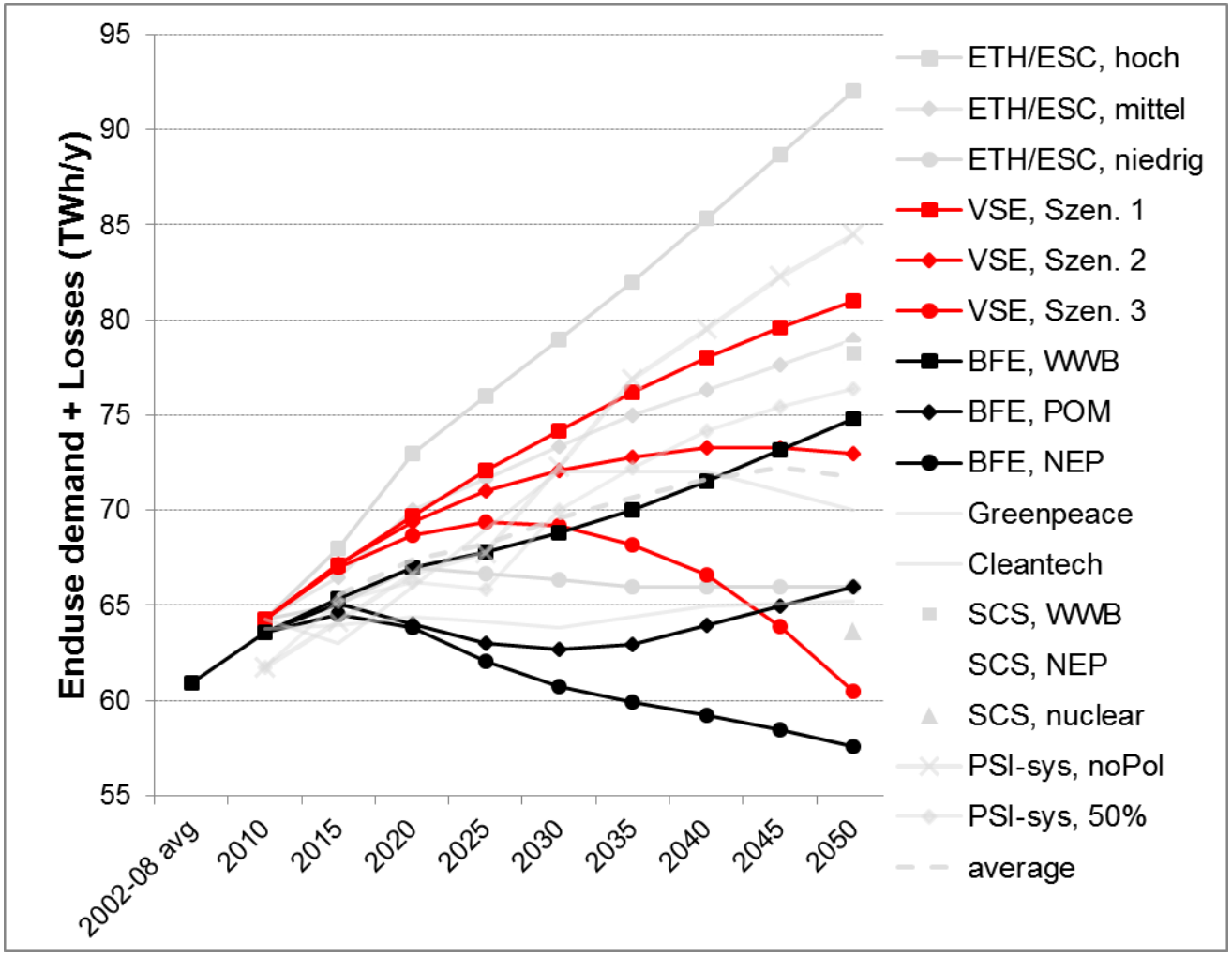
- HOCH, MITTEL, and NIEDRIG (according to population scenarios)

Capacity expansion model (Simulation): «bottom-up» (not much details given)

3rd model: Equilibrium model of the whole Swiss economy:

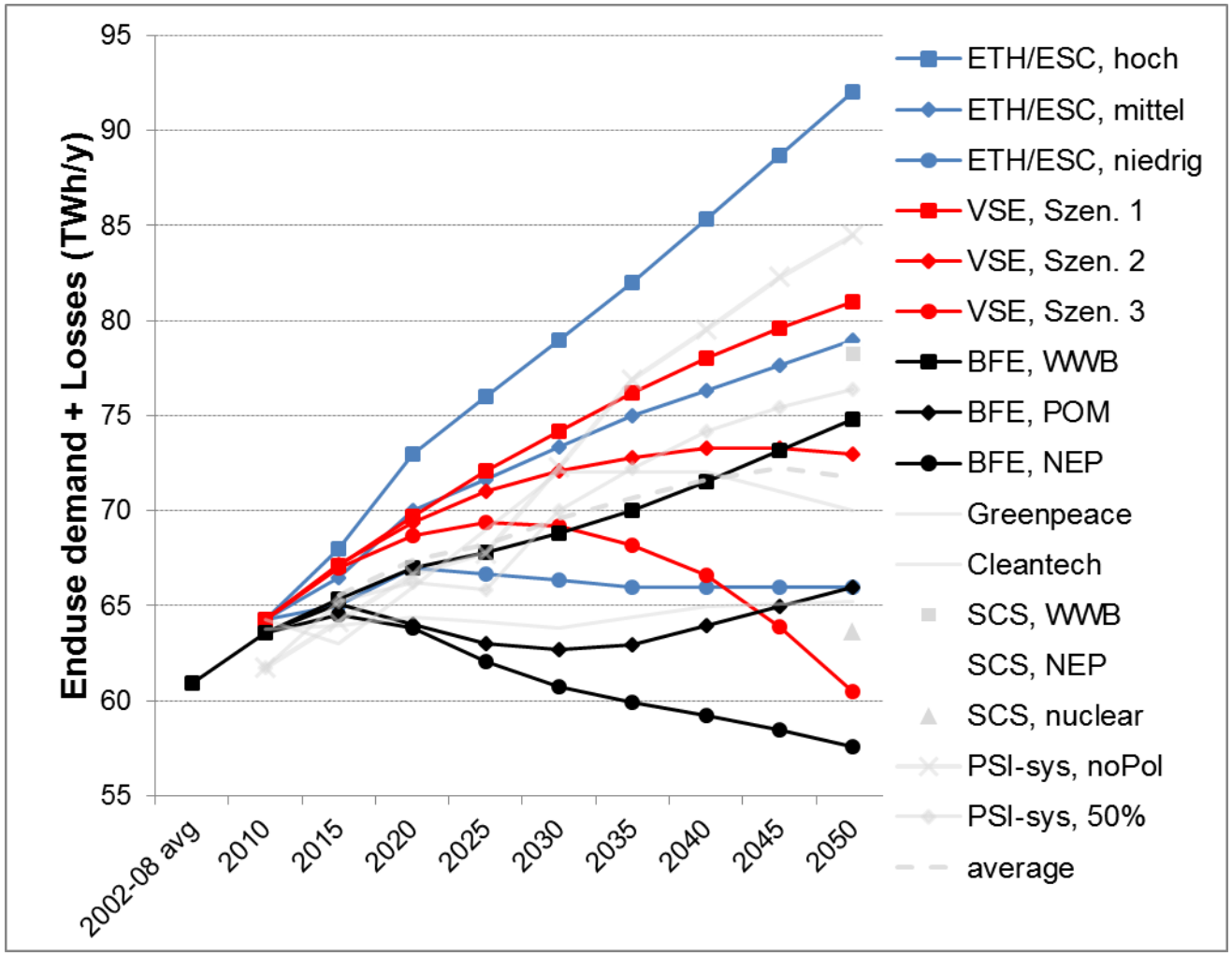
- Production factors (energy, labour, capital), substitutable (partially) in economic sectors
- 3 power generation technologies: nuclear, hydro, renewables (aggregated)
- Output: Energy prices, GPD (→ GDP reduction from nuclear phase-out)

Demand: VSE



- Power system reacts slower than in BFE study
- More demand in Szenario 1 than in WWB despite more efficiency than in WWB (?)

Demand: ETH/ESC



- ETH/ESC-scenario Hoch has population growth according to scenario «Hoch» of the BFS (2010)

SCS, Greenpeace and Cleantech study

SCS

- 8 «example scenarios»: **WWB+C+E, NEP+E, Neue Kernkraftwerke,…**
- Only a **dispatch model (simulation)** for year 2050
- Fixed order of dispatch: 1. batteries, 2. pumped-storage, 3. gas, 4. hydro-storage
- Import/export-trading strategy is determined iteratively (not inside the model)

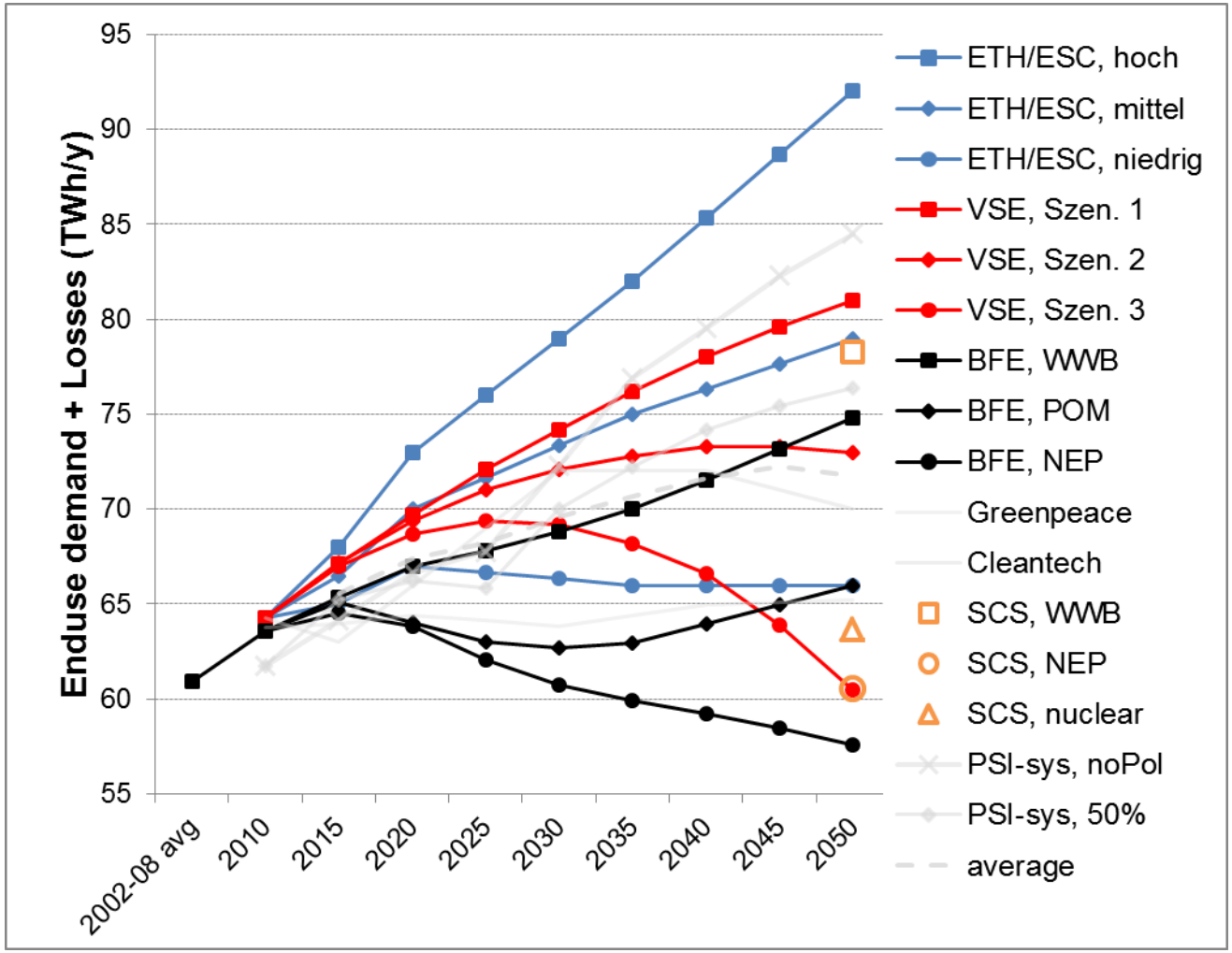
Greenpeace

- **Target scenario:** 95% CO_2-reduction until 2050; 90%+ renewables in 2050 (generation mix pre-determined); annual imports ≥ 0
- **Capacity expansion model (simulation; energy system):**
  - **Input:** Demand, «energy-carrier usage»; **Output**: electricity demand

Cleantech

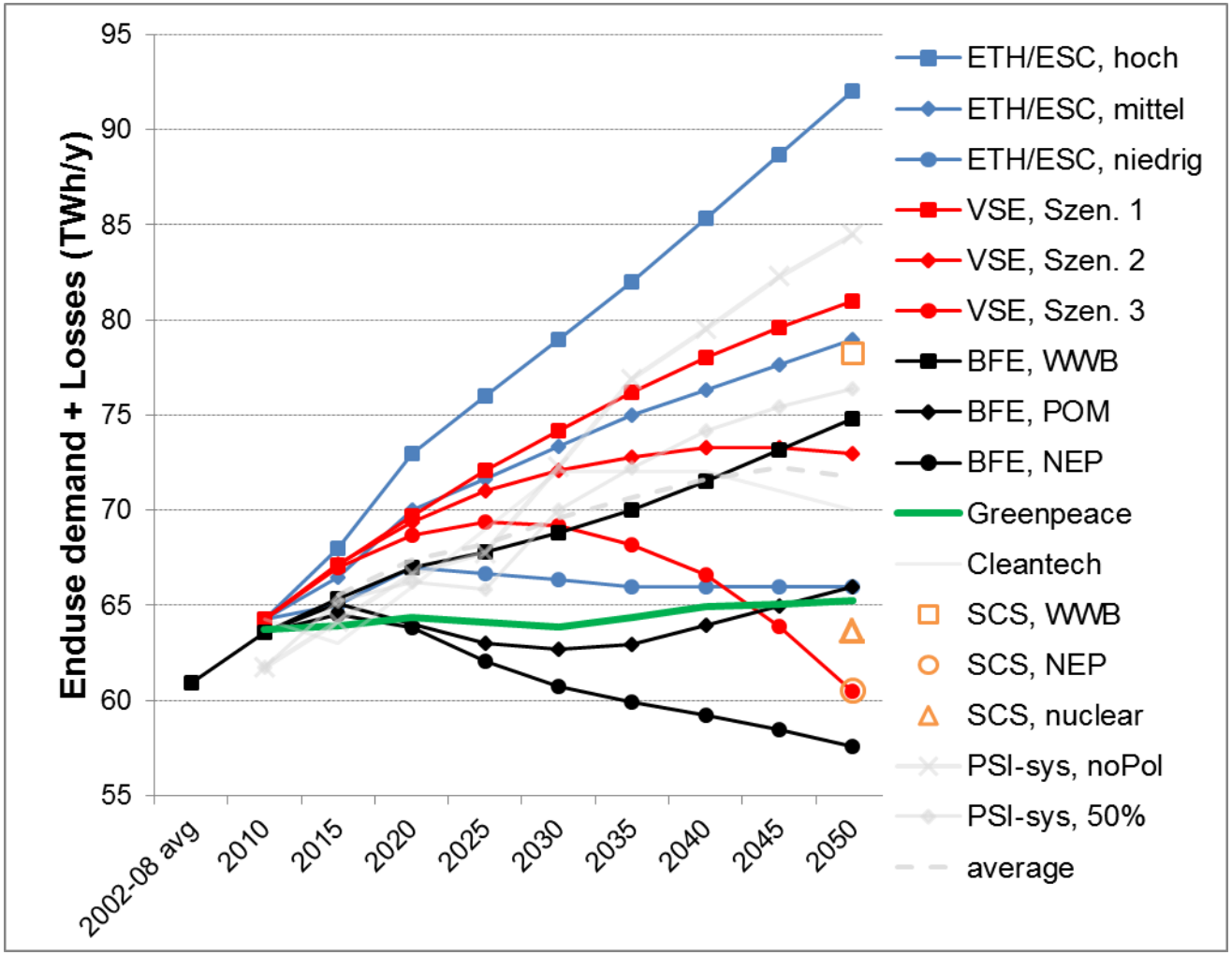
- **Target scenario:** 100% renewables (also in imports) **and** cost-efficient production
- Full cost accounting is considered as the key for efficient markets: Production costs + life-cycle-costs + external costs + insurance premia (no costs are given)
- **Capacity expansion (simulation):** Simplified («over 100 parameters»; “50+ variables”)

Demand: SCS (merely an input-parameter)



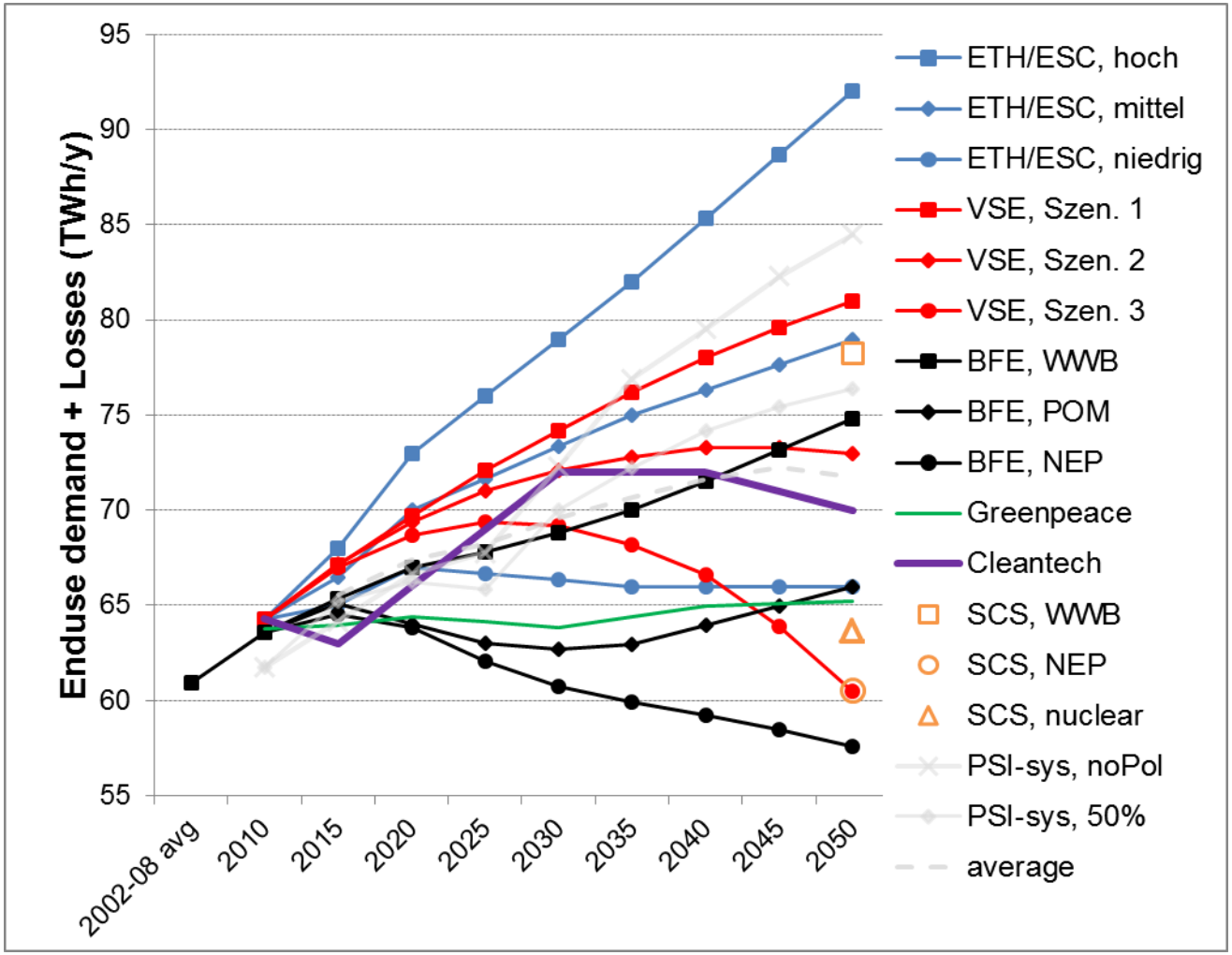
Demand in the SCS-scenarios **WWB** and **NEP** seem not to match BFE (?); losses may not be subtracted

Demand: Greenpeace



Shown demand is without H_2-production: Power-to-gas to store PV- and wind-power with H_2-electrolysis (no costs given)

Demand: Cleantech



PSI-sys and PSI-elc studies

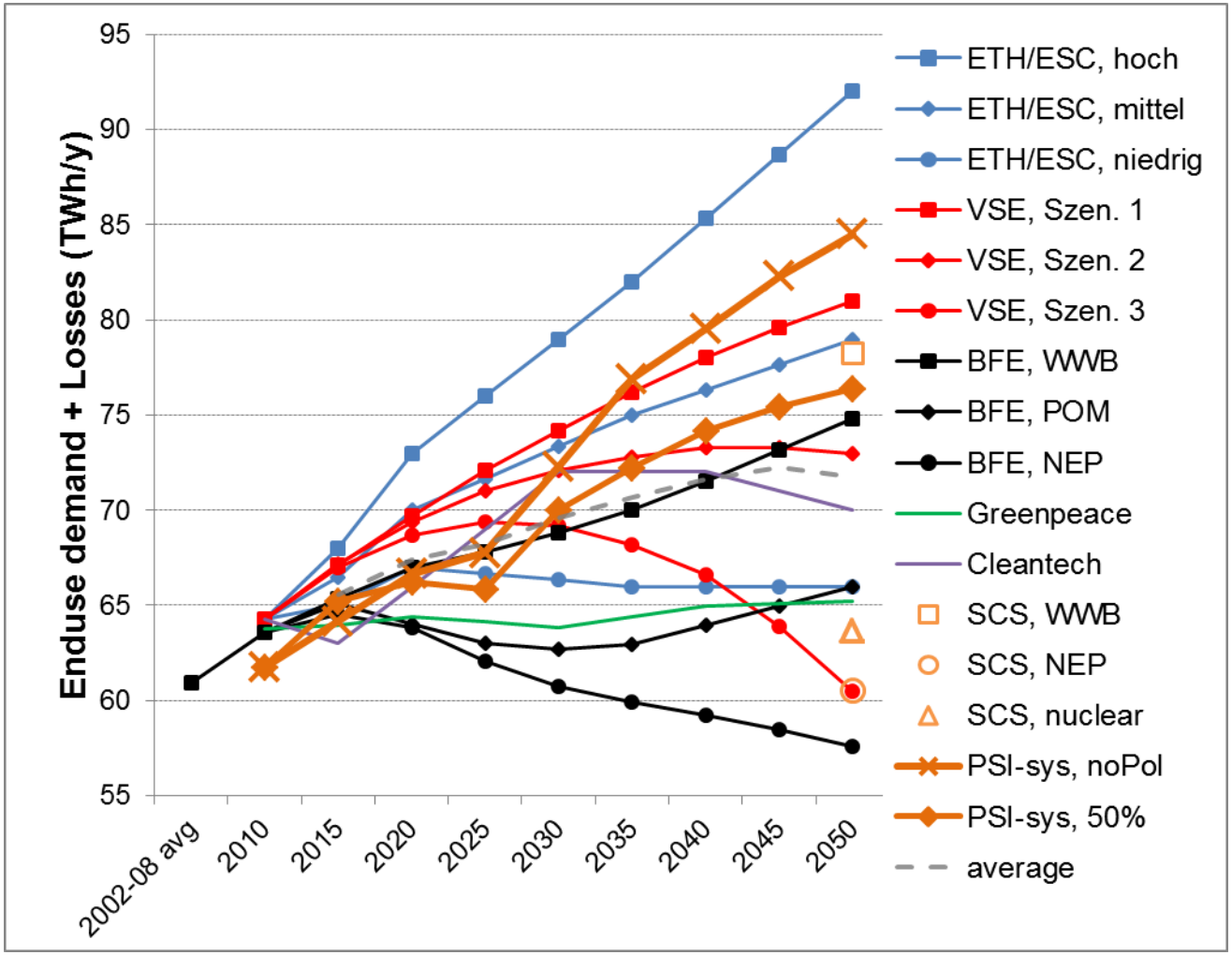
PSI-sys ("Swiss MARKAL" energy-system model)

- **Scenarios: noClimPol (**no additional climate policy); **-50% CO_2 (**on whole energy system)
- **Capacity expansion model (Optimization, incl. CO2-costs):**
  - 6 demand- and supply profiles: (winter, summer, spring/autumn) × (high-, low tariff time)
  - Input: Energy services (light, heat, driven distance etc.); amounts similar to BFE
  - Output (among others): Energy demands (e.g. demand of electricity)

PSI-elc ("Swiss TIMES" electricity model)

- **Scenarios:** WWB+Gas, WWB+Imp, WWB+Nuc, POM+Gas,…
  - Demands and CO_2-prices from BFE (WWB, POM, NEP)
  - Gas: Gas plants allowed, annual import = 0
  - Imp: Gas plants not allowed, annual import ≥ 0
  - Nuc: New nuclear plants allowed, annual import = 0
- **Integrated capacity expansion and dispatch model (Optimization, incl. CO2):**
  - 288 demand-and supply profiles:
    (winter, spring, summer, autumn) × (workdays, Saturday, Sunday) × (1,…,24th hour).

PSI-sys: Demand

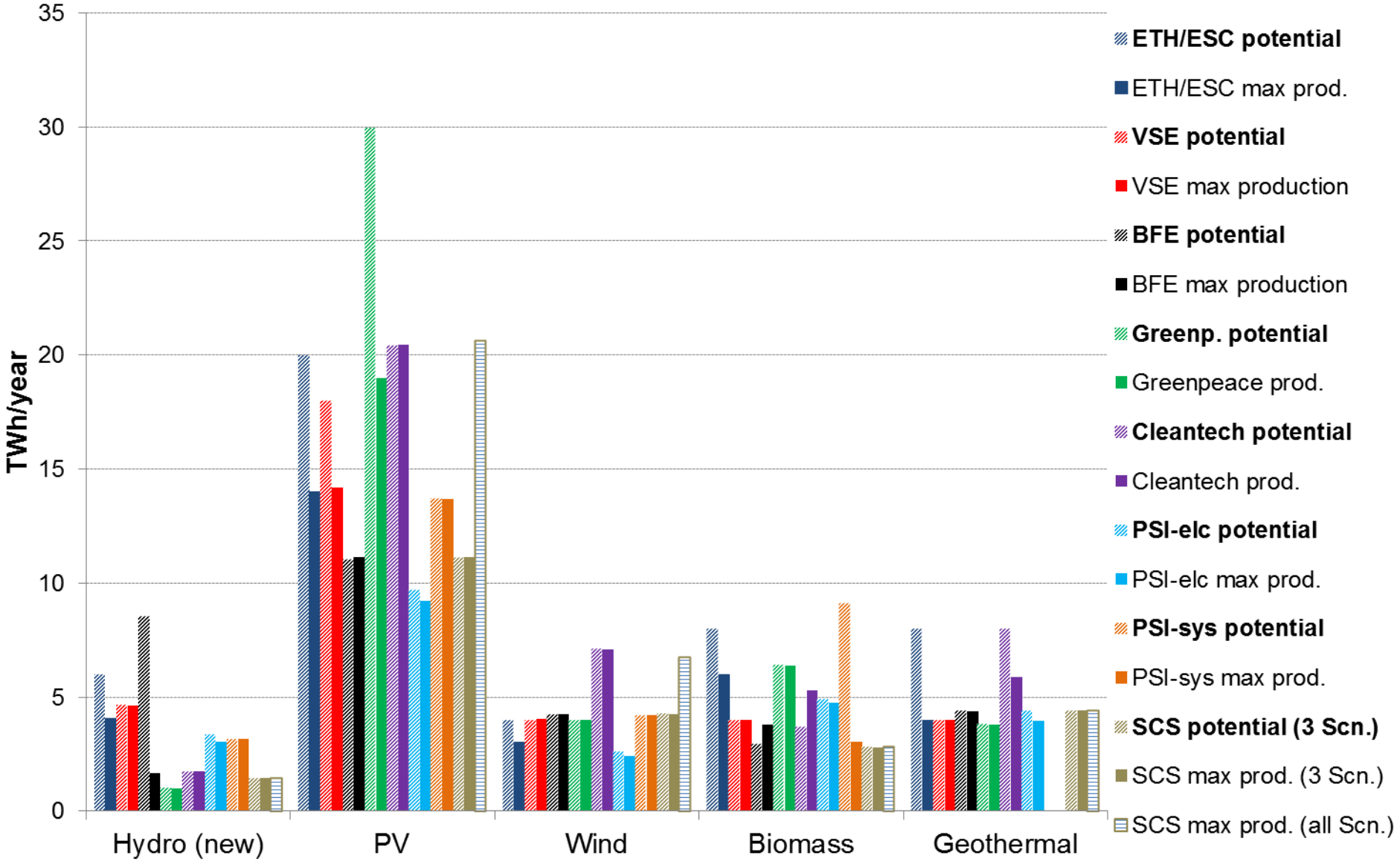


- Demand is optimized by minimizing the system cost
- High demand even in the 50%-CO_2-reduction scenario

Overview of models

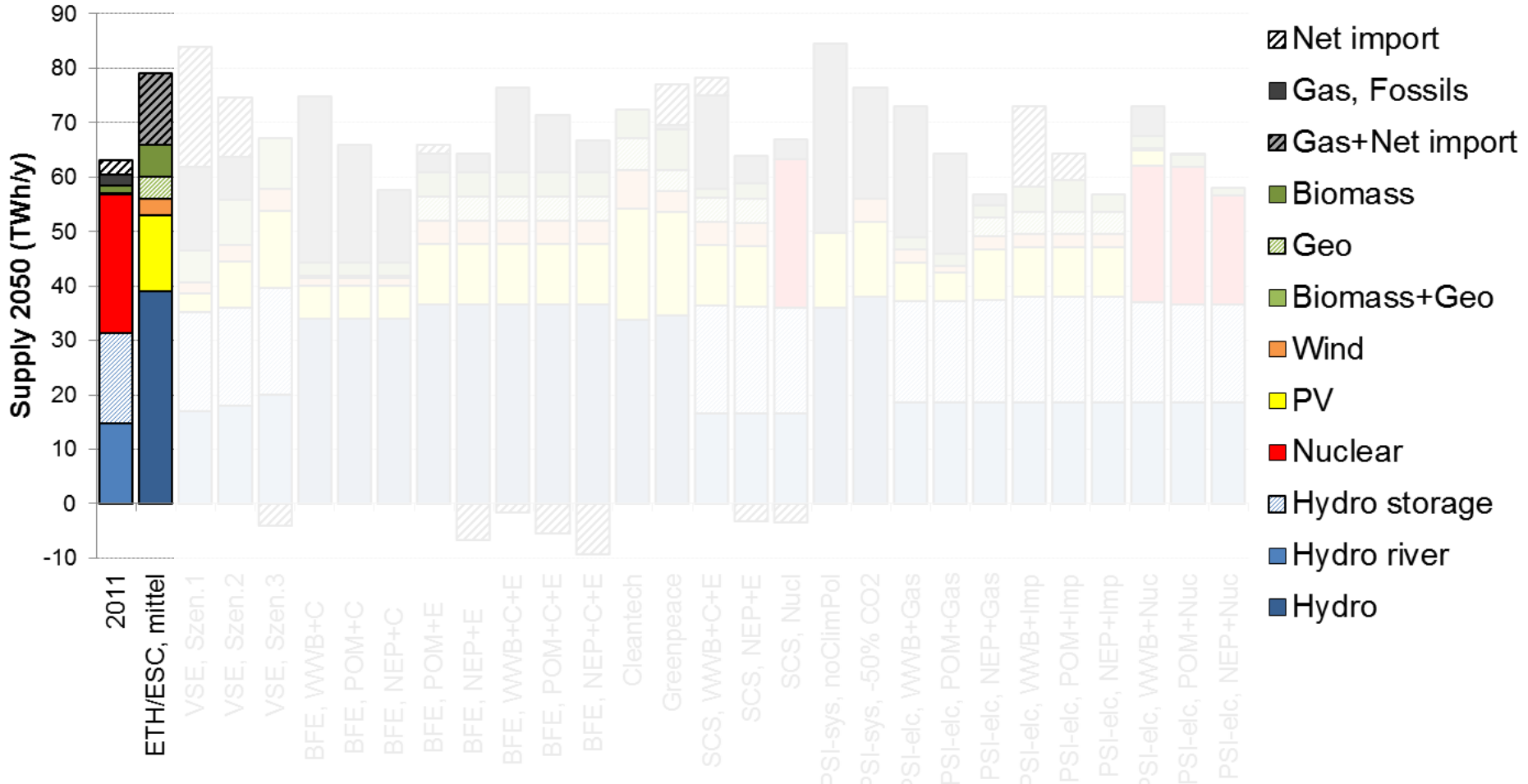
Study (electricity only)	Electricity demand model (if no model: data from)	Capacity expansion model	Dispatch model	Modelling of energy system network	Speciality
BFE	Simulation	Simulation	Simulation	na	
VSE (elc)	Simulation	**Optimization**		na	Cap./Disp. model also **for neighbouring countries**
ETH/ESC	Simulation	Simulation	na	na	3rd model used for the whole economy (labour, capital, energy)
SCS (elc)	(from BFE)	na	Simulation	na	Model is only for year 2050
Greenpeace	Simulation	Simulation	(from SCS)	yes	Electricity demand is endogenous (?)
Cleantech	Simulation	Simulation	na	na	**no costs** (not even ex-post)
PSI-sys	**Optimization**		na	yes	Electricity demand is endogenous
PSI-elc	(from BFE)	**Optimization**		na	«typical hour» for dispatch

Potentials and max. production of renewables



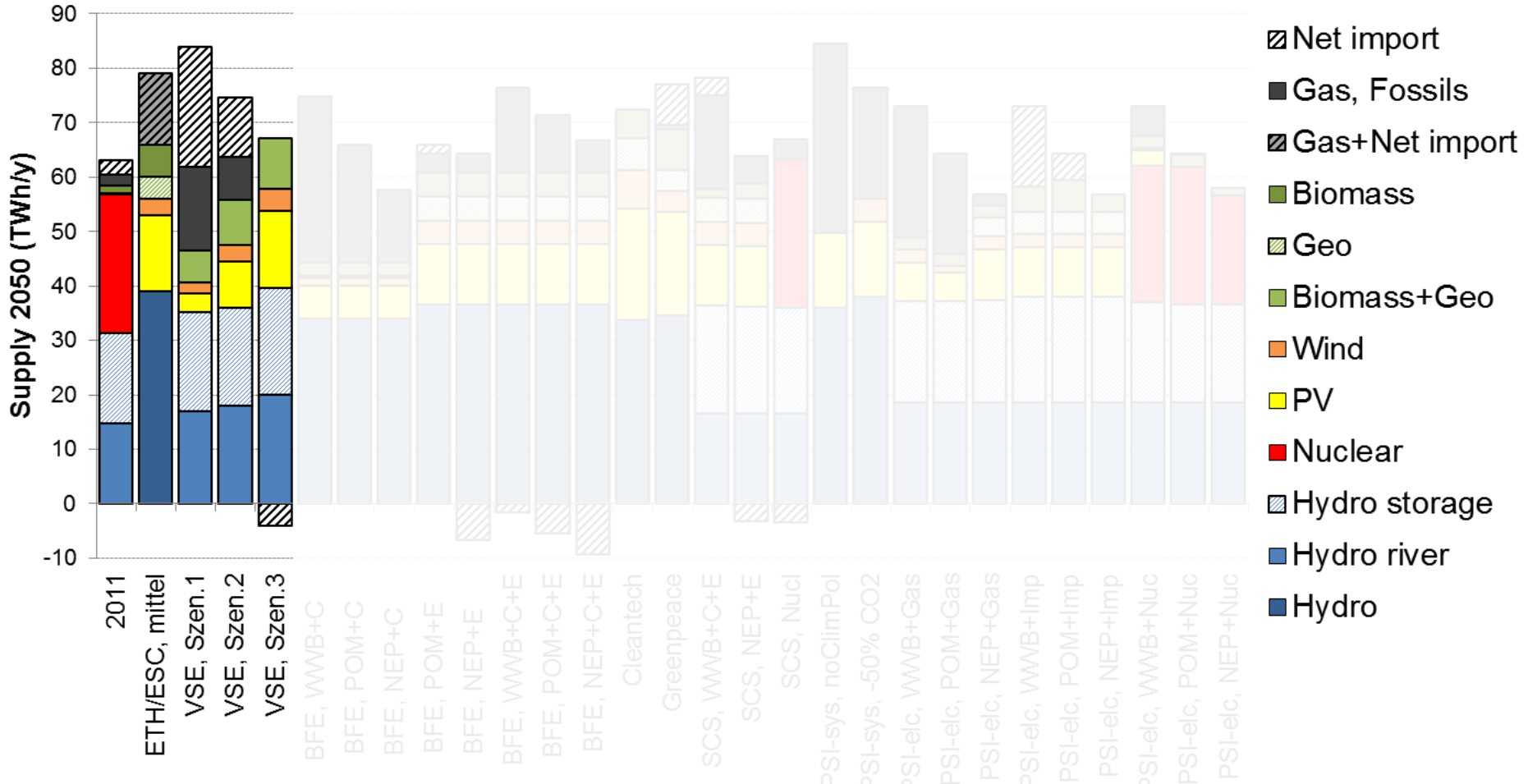
Germany 2013: PV: 30 TWh/y, Wind: 47 TWh/y, PV Potential is 10x higher = 160 TWh/y (IEA-study)

Annual supply mix 2050

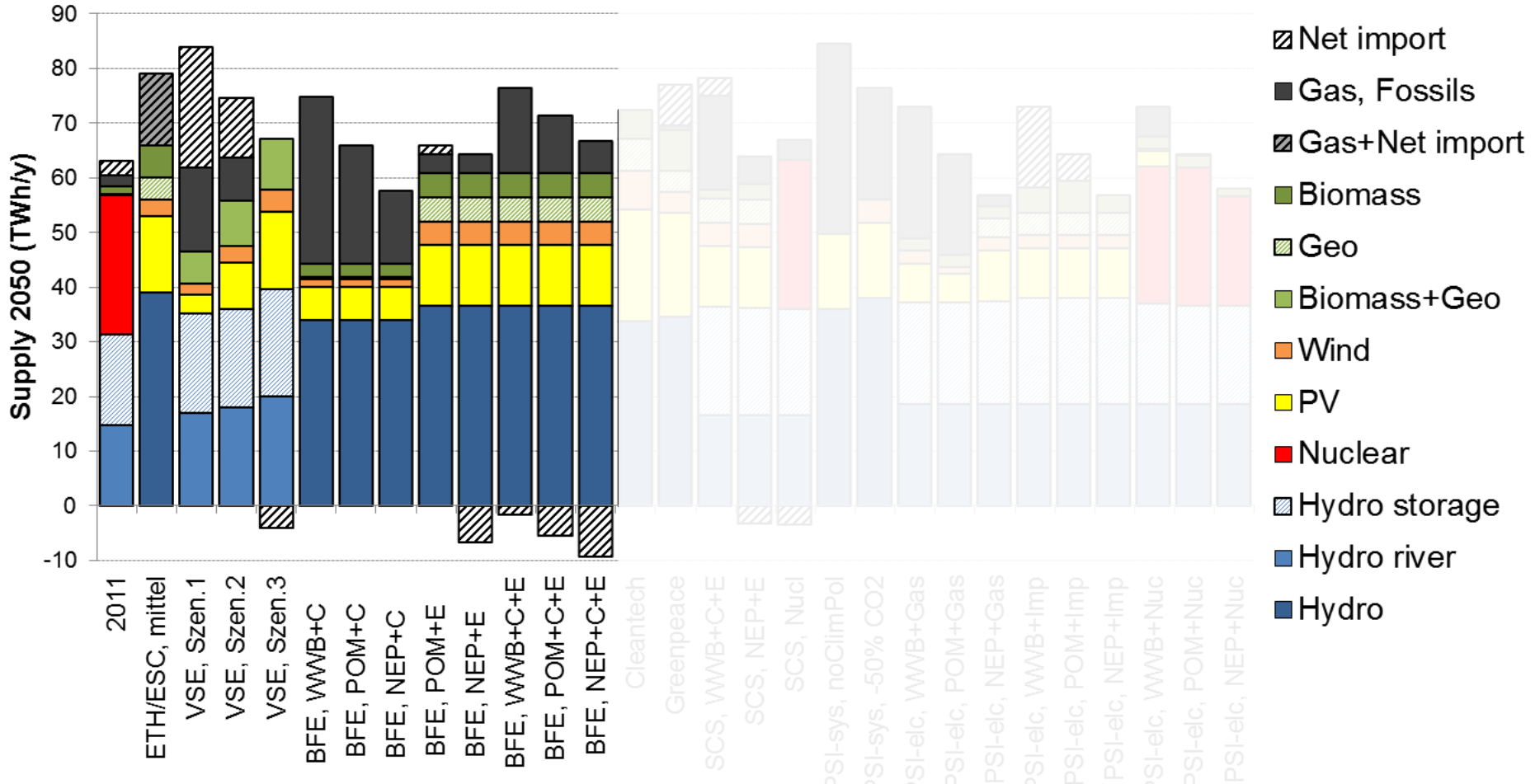


ETH: supply gap = gas plants «**and/or**» imports

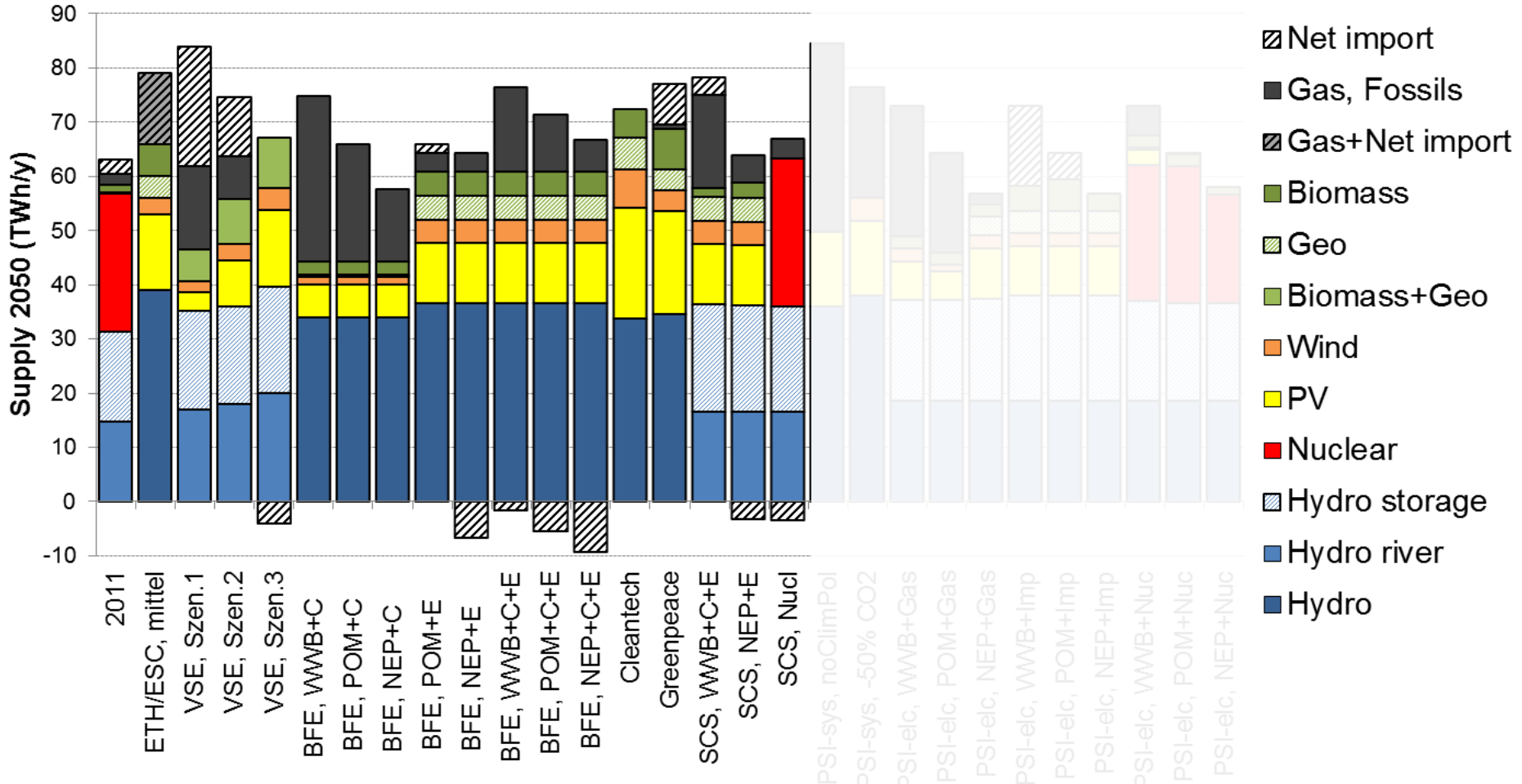
Annual supply mix 2050



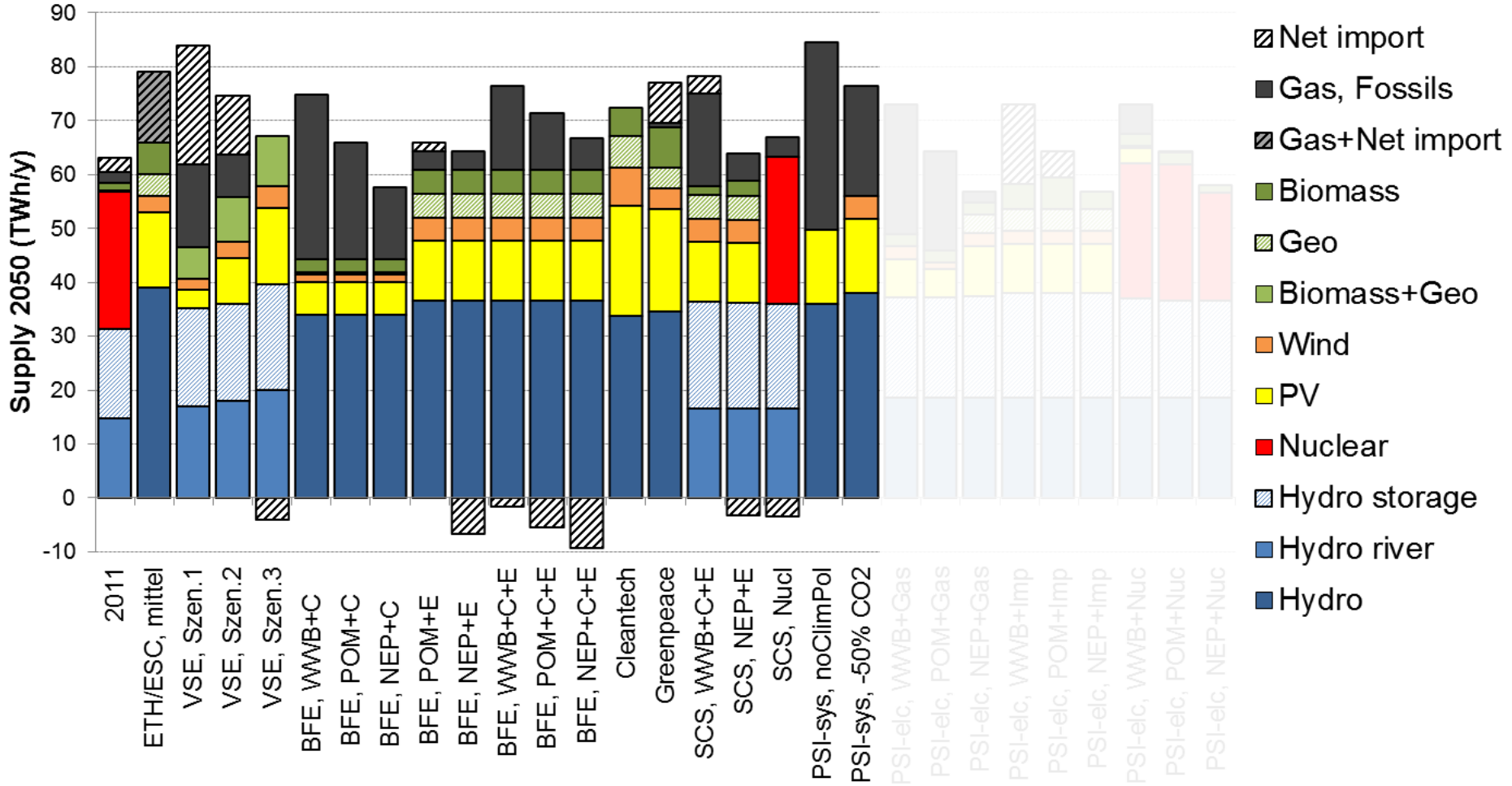
Annual generation mix 2050



Annual supply mix 2050

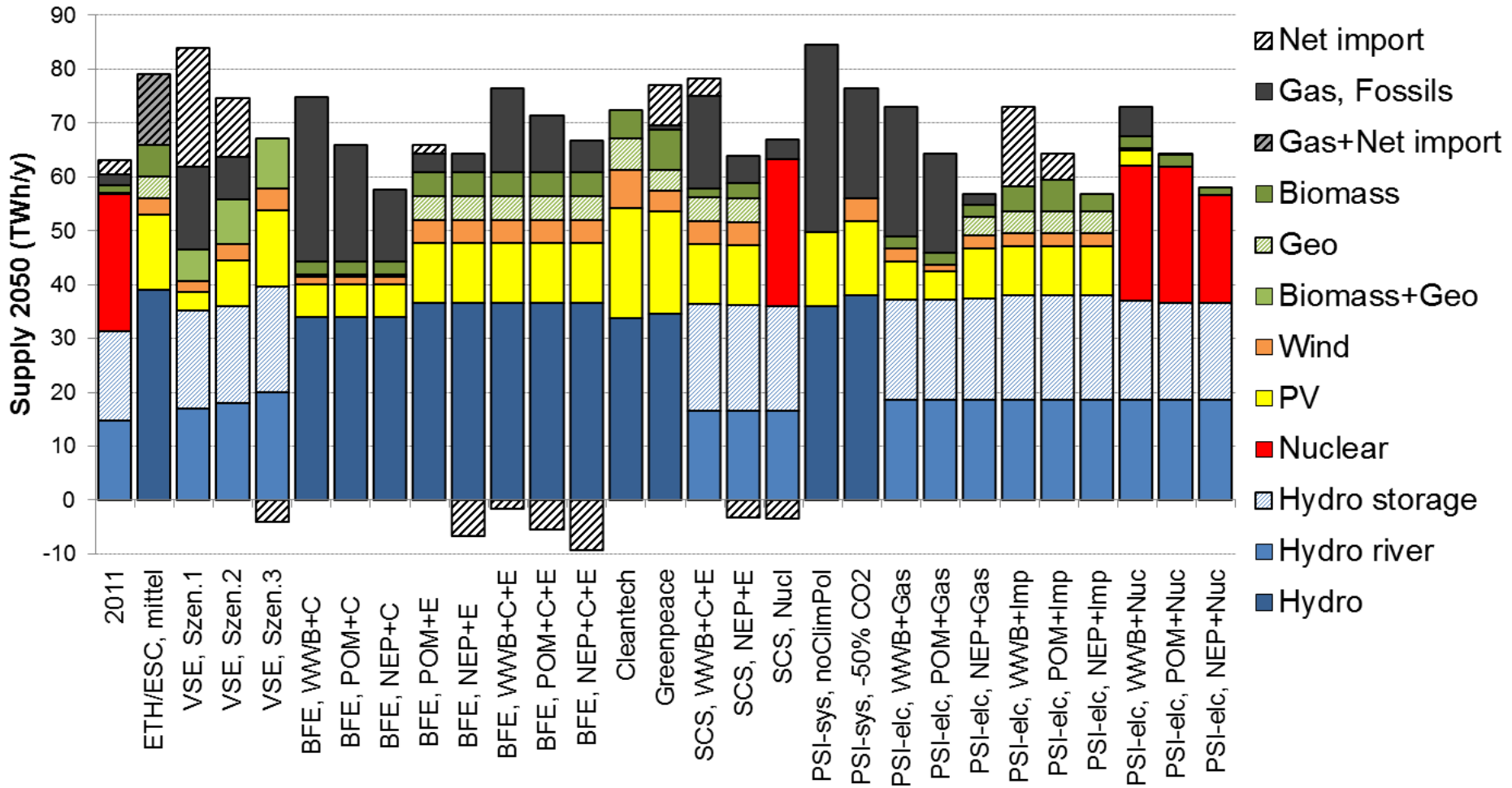


Annual supply mix 2050



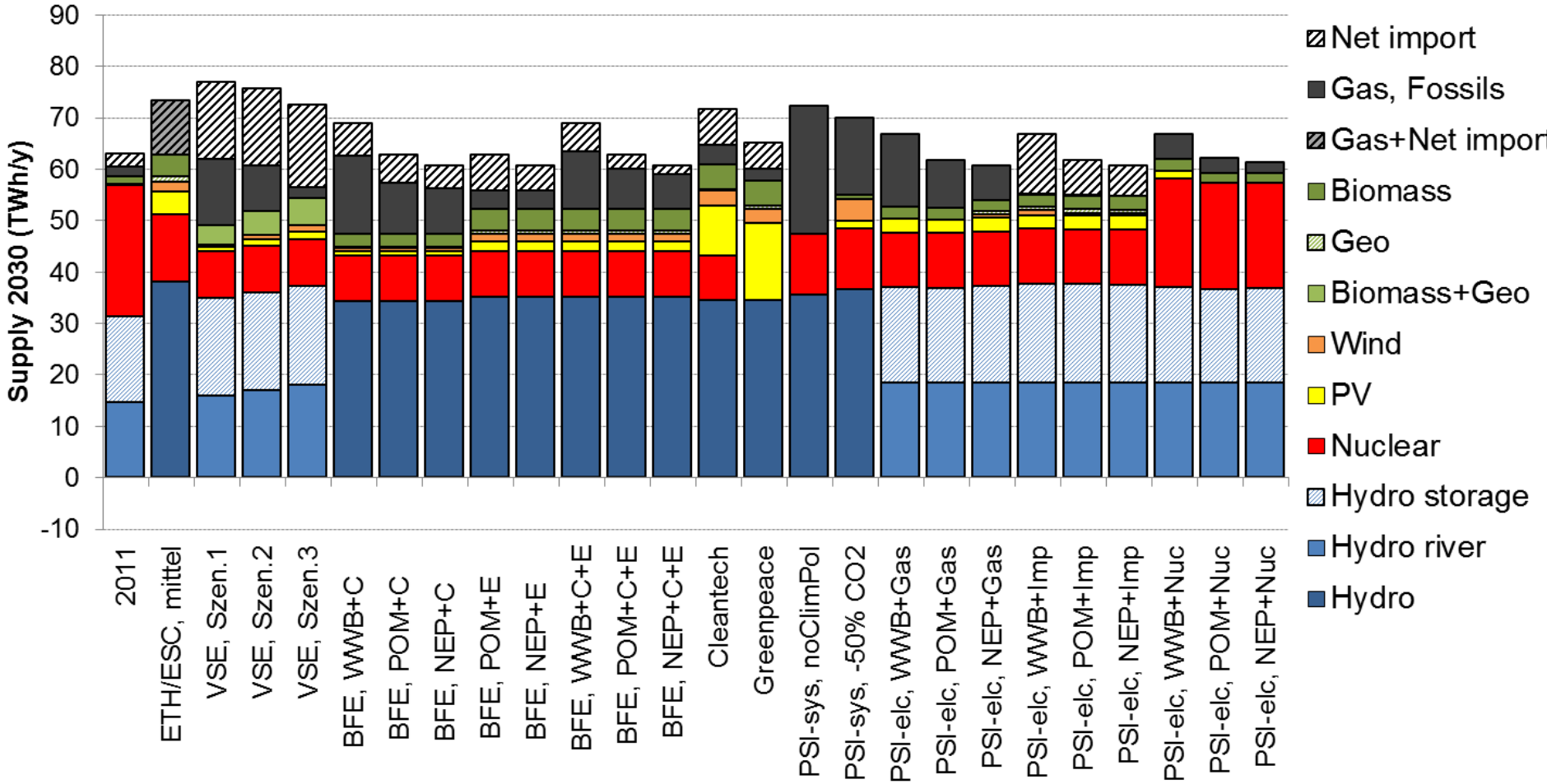
PSI-sys (by assumptions): Annual import = 0, no geothermal

Annual supply mix 2050



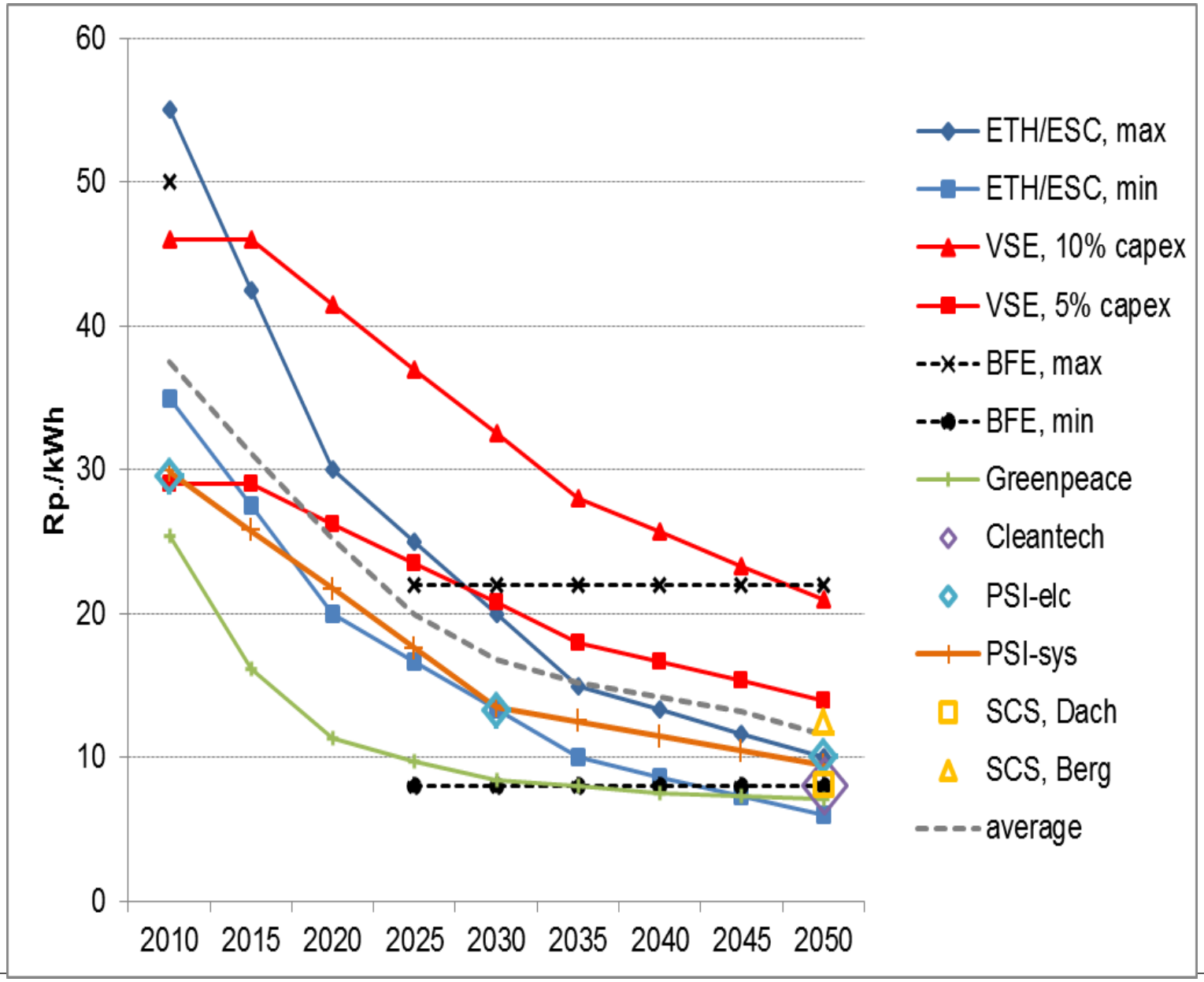
2050: If demand is low or gas plants are allowed → No annual imports

Annual supply mix 2030

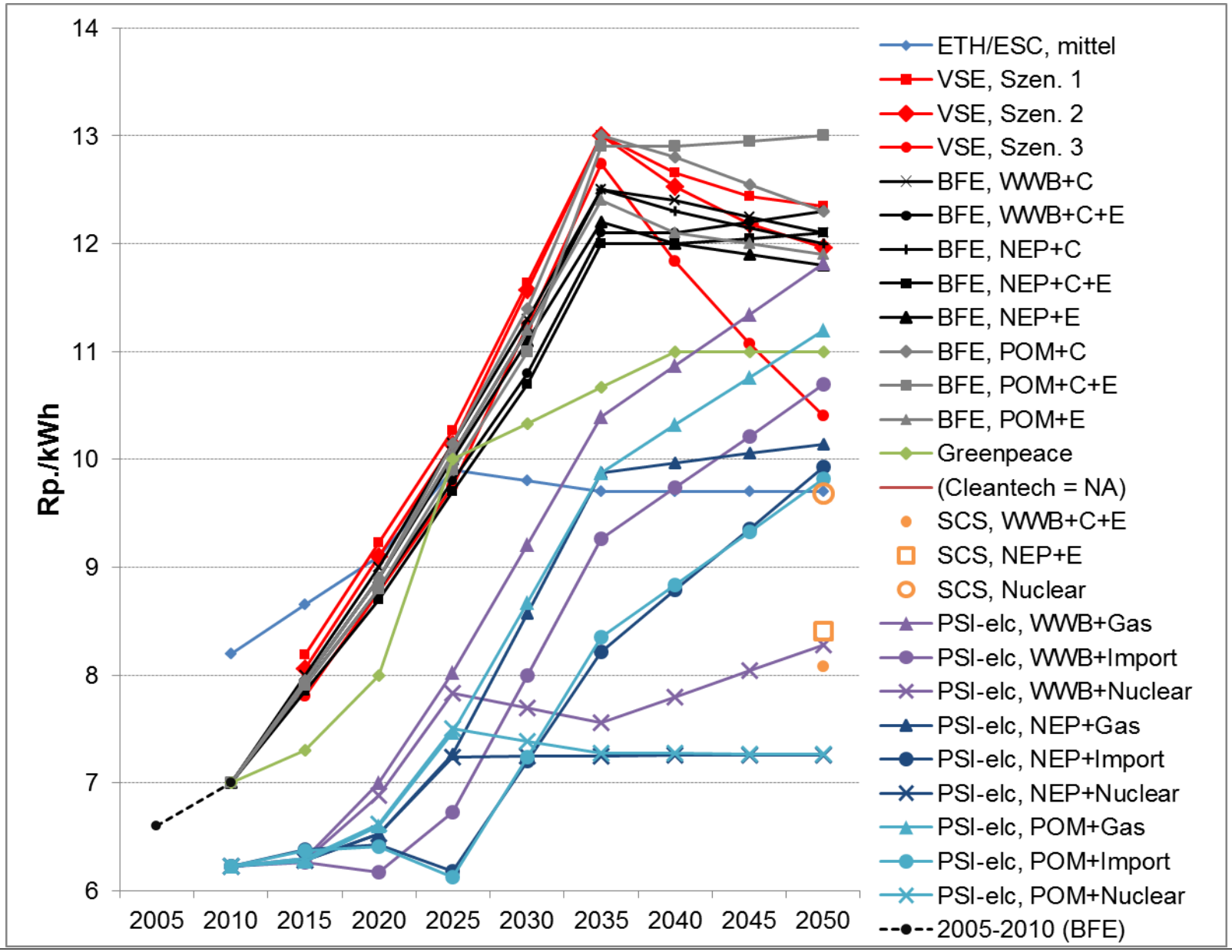


2025-2035 are critical: In contrast to 2050, more annual imports in more scenarios

PV: Production costs (without additonal system cost)



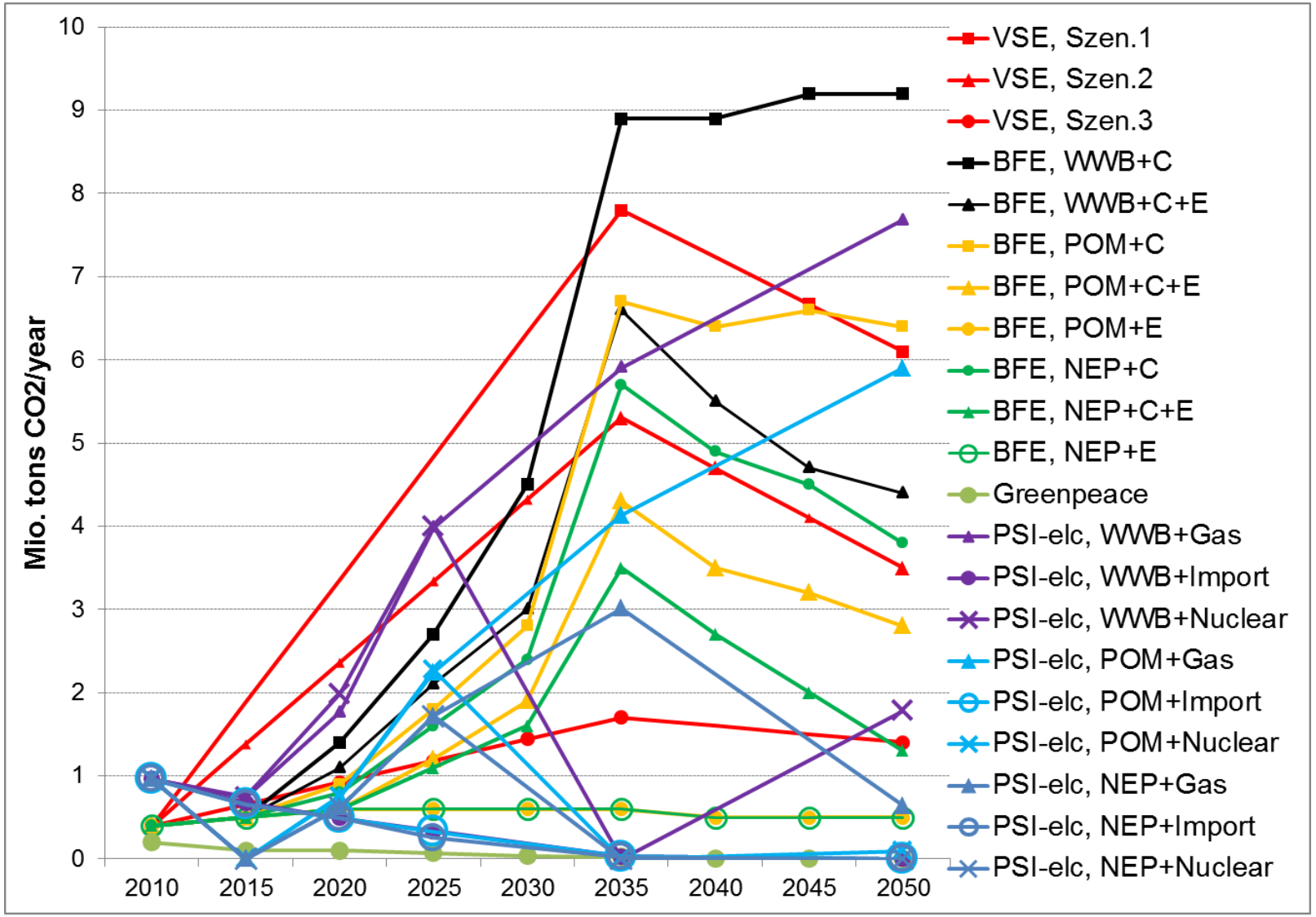
Production cost of generation mix



System costs

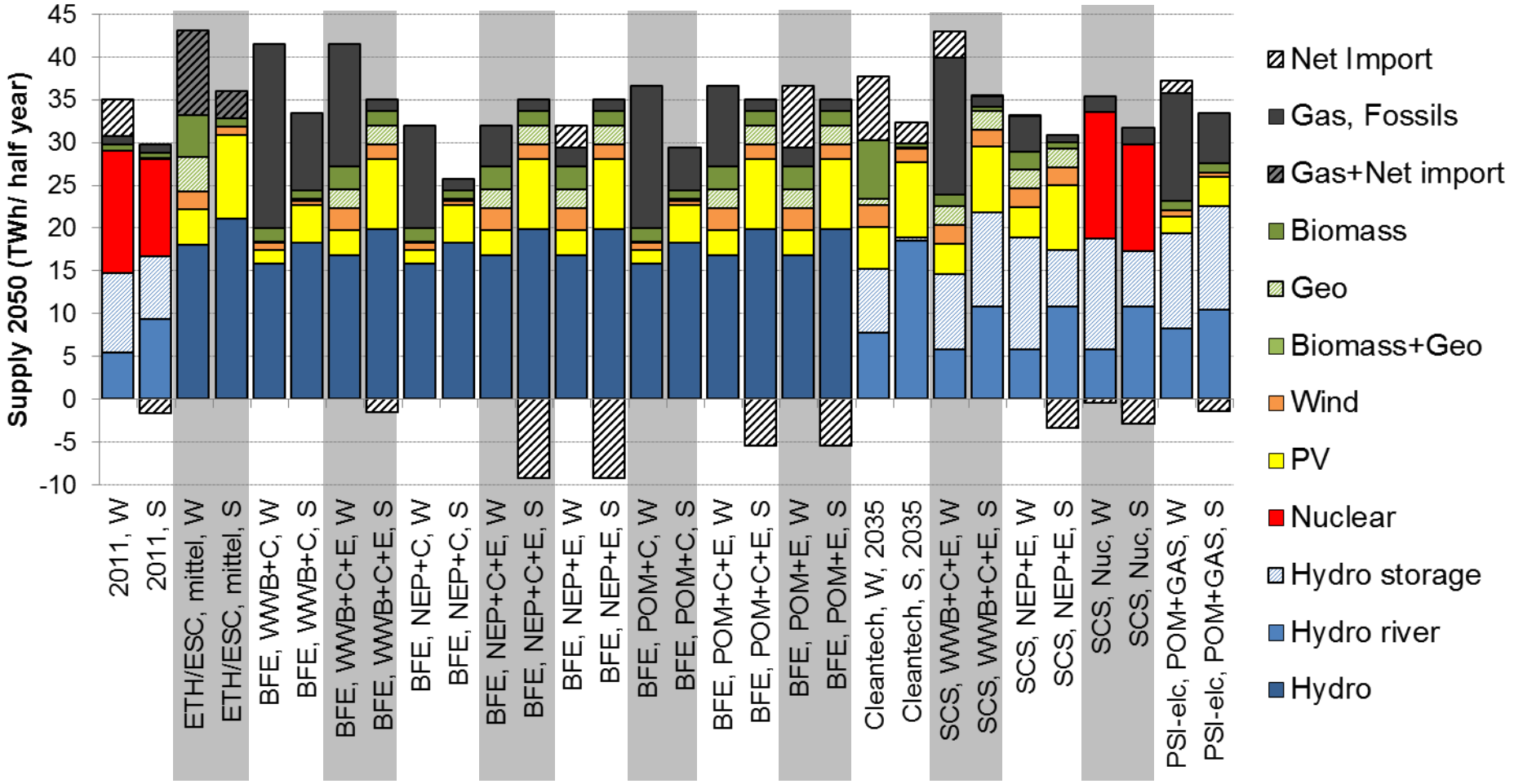
Study	Cumulated cost until 2050	Old or new?	Discounted?	Scenarios	Costs (Billion CHF)
Greenpeace	Investment cost of production	old+new	no	-	90
Cleantech	Investment cost of production	old+new	no	-	80
VSE	Investment cost of production	old+new	no	Szenario 1	50
				Szenario 2	70
				Szenario 3	80
		old	no	all	30
	Investment cost of grid **(from Consentec study)**	new	no	Szenario 1	5
				Szenario 2	8
				Szenario 3	12
	Investment cost of grid	old	no	all	60
	Investment costs of transmission grid	new	no	all	3
BFE	Total cost of production	new	yes	WWB+C, POM+C+E	70
				WWB+C+E	80
				NEP (all), POM+C, POM+E	60
		old	yes	all	130
PSI-elc	System cost of production (without trading profit)	old+new	no	WWB+Imp	240
				WWB+Gas	230
				POM+Imp	200
				POM+Gas	190
				WWB+Nuc, NEP+Gas, NEP+Imp	170
				POM+Nuc	130
				NEP+Nuc	120

CO_2-emissions form power sector (without imports)



- **Comparison:** CO_2 from energy sector (+transport) today: ~40 Mio. tons/Jahr
- **BFE, NEP+E** and **BFE, POM+E** have same domestic emissions, but POM-E has more imports

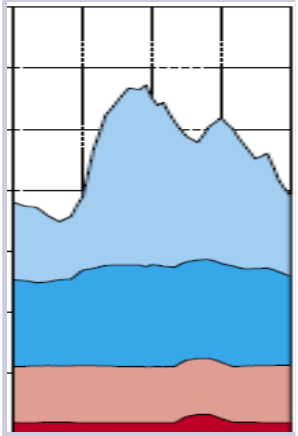
Winter/summer supply 2050

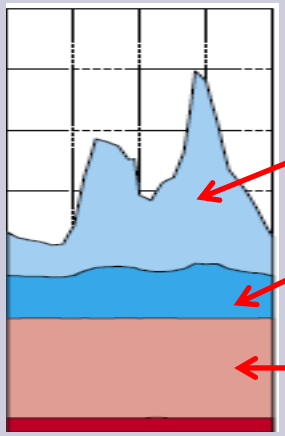


- In case of high PV share, then net-export in summer (exception: Cleantech, SCS-WWB)
- Hydro-storage also in summer (exception: (!) Cleantech)
- More biomass- and geothermal-power (!) in winter

Dispatch in 2012 und 2050 (Example: BFE)

Summer day (20.6.2012)	Winter day (19.12.2012)	GW / 0h-24h

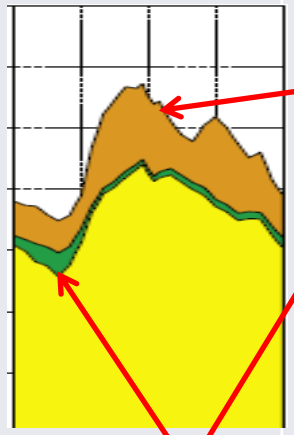


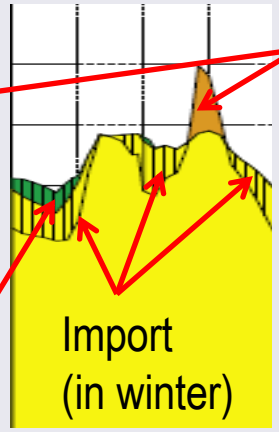


Hydro-storage

Run-of-river

Nuclear





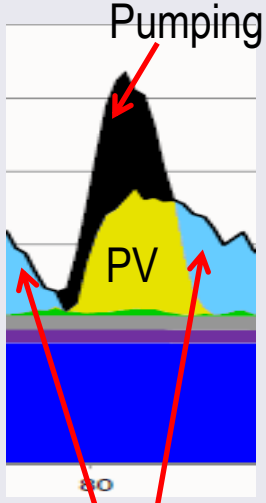
Export (primarily in summer)

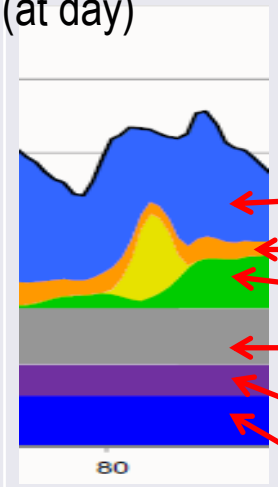
Import (in winter)

Pumping primarily in the night, summer and winter

BFE, scenario NEP+C+E , year 2050

Summer day	Winter day	





Hydrostorage (without Pump.)

Gas, Bio (flex)

Wind

Gas, Geo, Bio

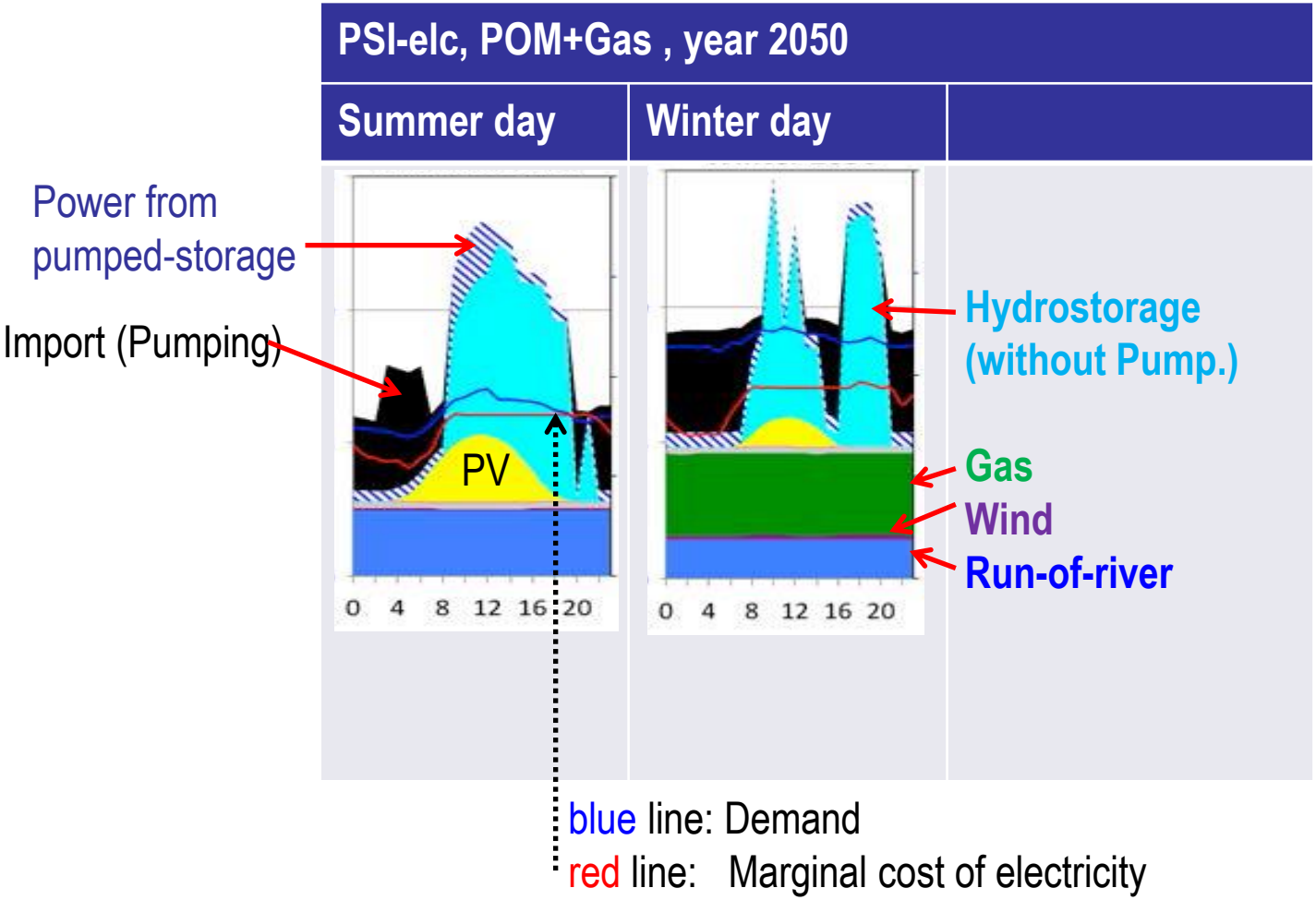
CHP

Run-of-river

Power from pumped-storage in the night

- total depletion of the storages every nights (after days with sunshine)
- No pumping in winter?
- Import/export in 2050?

Dispatch 2050 (Example: PSI-elc)



If PV production is limited, then the dispatching of pumps as of today stays **cost-optimal**

Average of multiple models = Forecast ?

Side-by-side comparison of scenarios:

Silberglitt et al. (2003) *US energy scenarios: Meta-scenarios, pathways, and policy*
Dale (2012) *Meta-analysis of non-renewable energy resource estimates*
Schmid et al. (2013) *Renewable electricity in Germany: A meta-analysis of mitigation scenarios*
Cochran et al. (2014) *Meta-analysis of high penetration renewable energy scenarios*
… … …

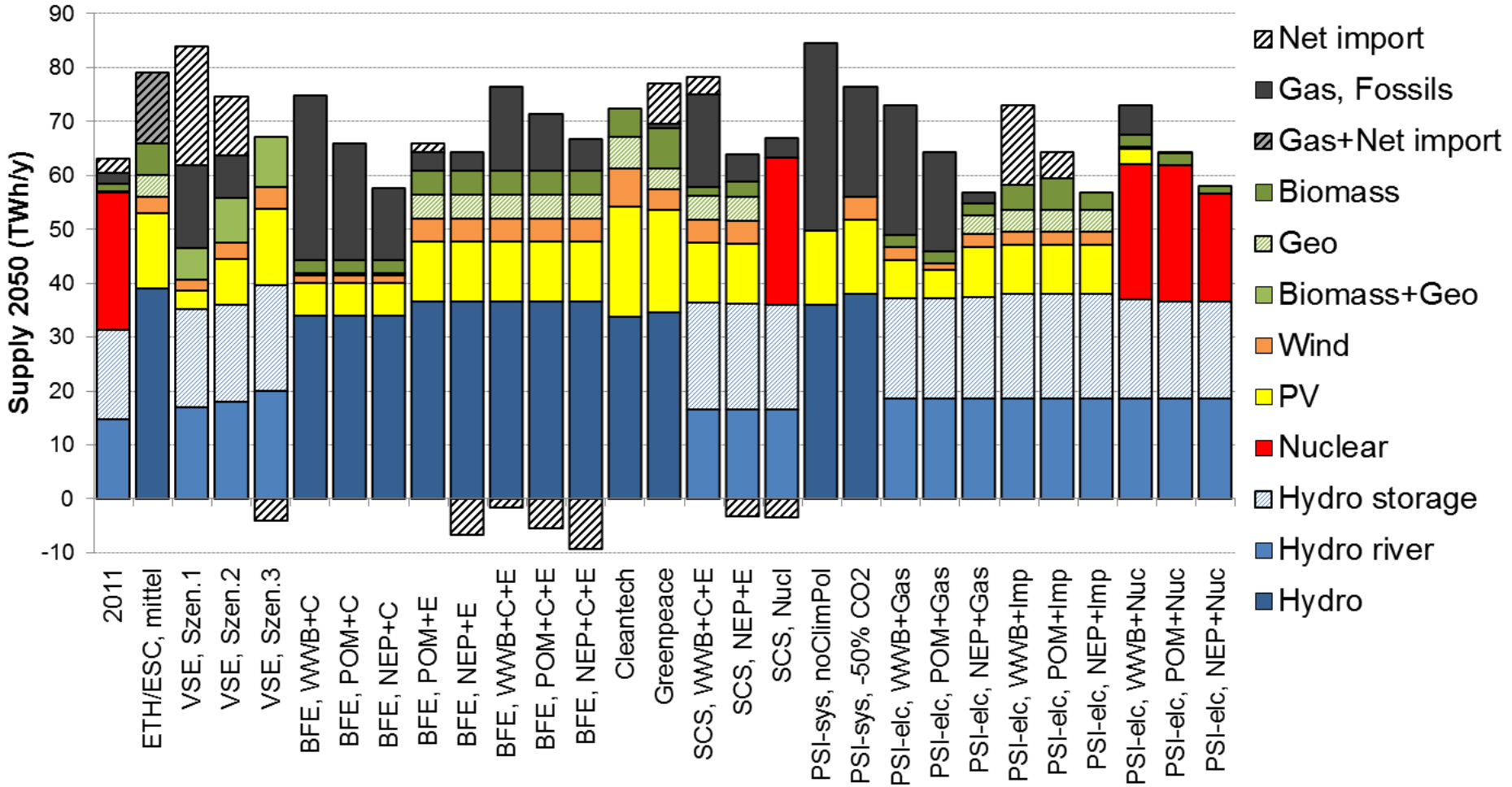
Is the (statistical) averaged result of multiple models a result of a valid model?

Knutti et al. (2010) *Challenges in combining projections from multiple climate models:*

"An average of multiple models may show characteristics that do not resemble those of any single model, and some characteristics may be physically implausible."

→ Pragmatic analysis of "variability" of the scenarios

Annual supply mix 2050: 26 “realizations” of a vector



PCA of the supply mix 2050

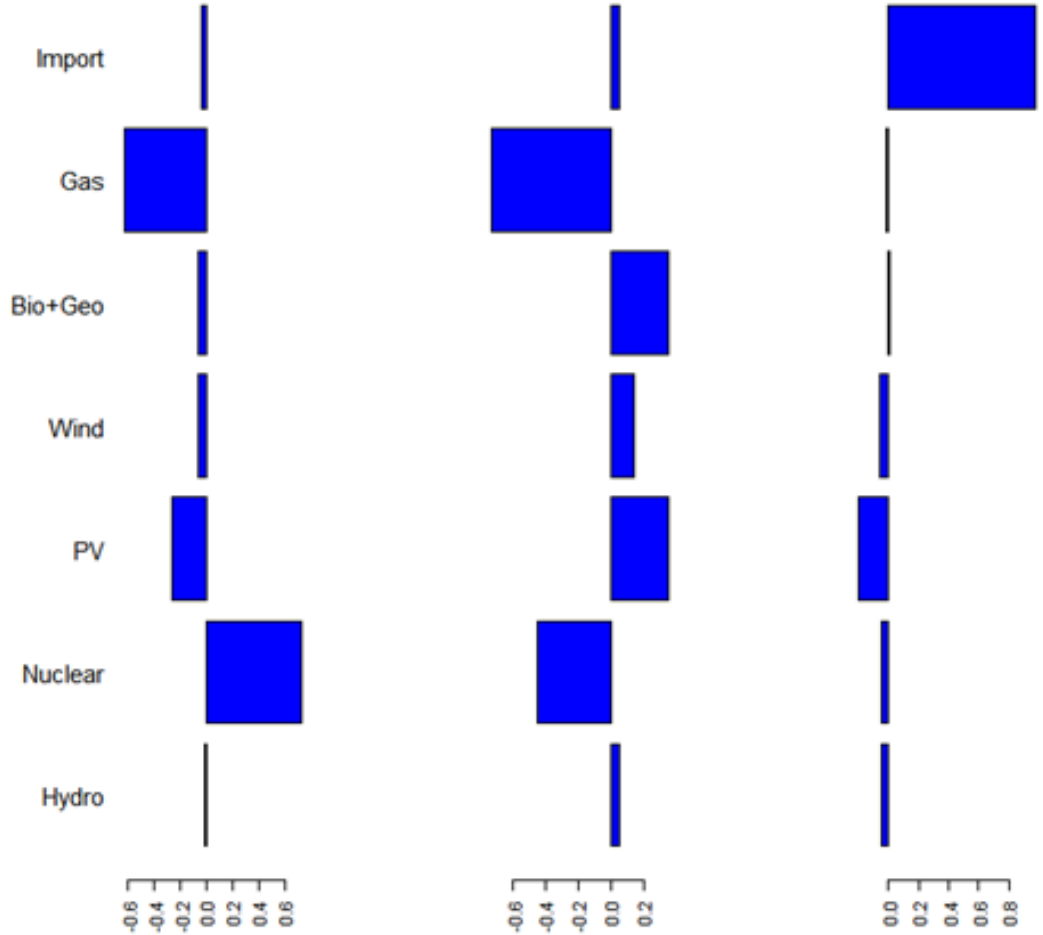
Principal Component Analysis of covariance matrix of supply mix:

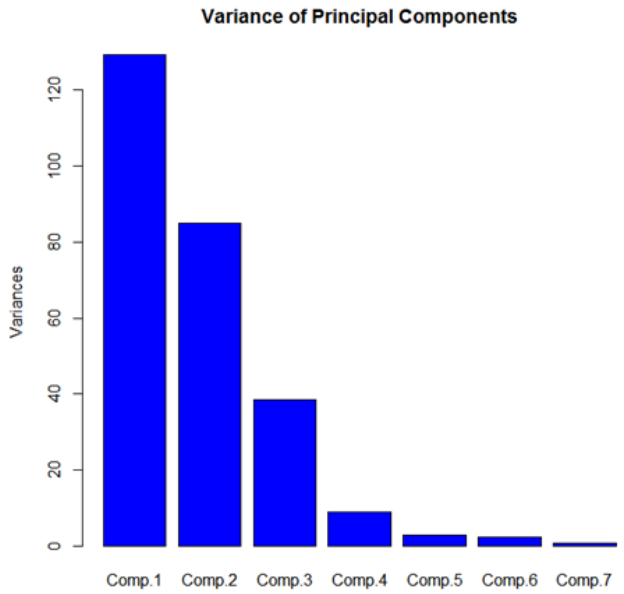
1st comp.
(+) nuclear, (-) all others

2nd comp.
(+) renewables, (-) central

3rd comp.
(+) import, (-) all others

← **Main energy policy decisions**





Central planning in liberalized market environment?

(**Pumped-)storage hydropower** has pivotal role in many scenarios (if high PV: daily pumping and selling at night to empty reservoirs); **gas power** (if allowed) becomes important in winter.

So why has the company Repower shelved the pumped-storage project Lagobianco?
Why should Swiss power producers,

- who have already flexible capacity (hydropower),
- and profitable price-peaks have disappeared (by PV-infeed in Germany and Italy),

invest in more flexible capacity (i.e. gas plants) or in PV?

Investment risk of power producers is caused by market and policy uncertainties

- CO_2-price policy, Dates of nuclear phase-out
- Demand in 2050, Gas market price
- Uncertain investment decisions of other non-cooperative producers and countries
- Degree of future market liberalization (EU-agreement)
- Blind auctions of power markets, Market power of large players
- Physical uncertainties: Weather, water inflow

Assumption in all studies:

- Perfect competition (central planner under perfect foresight)
- The «invisible hand» of the market keeps prices low

Conclusions

- The height of **demand of electricity in 2050** is uncertain (range of ~58–90 TWh/y)
- In some target-scenarios the demand-reduction is an input, und the required **efficiency measure (or behavioural change)** is a result. Is the efficiency gain feasible?
- **Production cost** of mix may stay below a doubling ☺ (without grid or efficiency cost)
- **Costs of efficiency measures** are not considered (exception: PSI-sys)
- **Comparison of costs** across studies is difficult: Are costs of efficiency measures included? What is the discount rate?
- **Cost-optimization versus (non-cost) simulation**: Costs should enter decision making
- **Storage.** With high PV- and wind-power, **hydro (pumped-) storage plants** are heavily operated in daily cycles.
  - Modelling of all storage plants as a single basin may overestimate flexibility
  - Modelling of **battery** and **power-to-gas storage** should be improved (incl. the costs)
- **Neglected:** Grid, neighbouring countries (exception: VSE), investment risk, market aspects

CO2, Transparency; PSI's Model Extensions

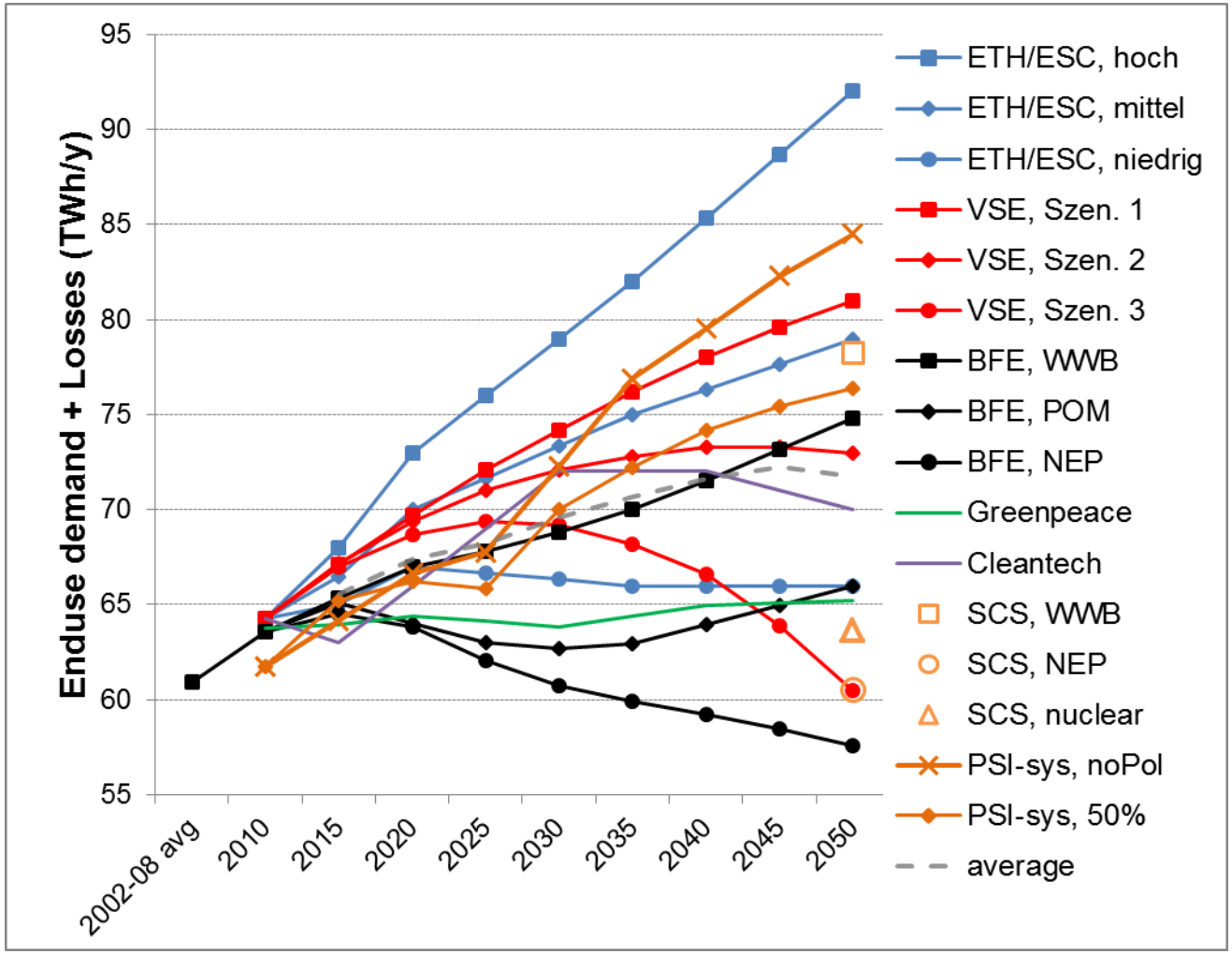
- **Direct CO_2-emissions** are sometimes included in the cost-objective function
  - **CO_2-emissions from import** are not fully integrated (i.e., calculated a posteriori, if at all)
  - 7.2 ton CO_2-eq/capita from direct emission inside Switzerland in year 2004
  - 12.5 ton CO_2-eq/capita from total consumptions of goods in 2004 [BAFU, 2007]
  - **Stringent CO_2-reduction target over the whole energy sector**...
    ...can lead cost-optimally to more CO_2 from electricity (see PSI-sys)
    ...accelerates outsourcing of CO_2–intensive production of goods into other countries
- **Transparency** is sometimes minimal. Desirably, a consensus should be reached on the set of reported basis assumptions and central calculation steps.

→ **Model extensions at PSI:**

- Extension on neighbouring countries (**"CROSSTEM"-Model)**
- Extension on entire energy system in Switzerland (**"STEM"-Model)**
- New model on market power and investment risk

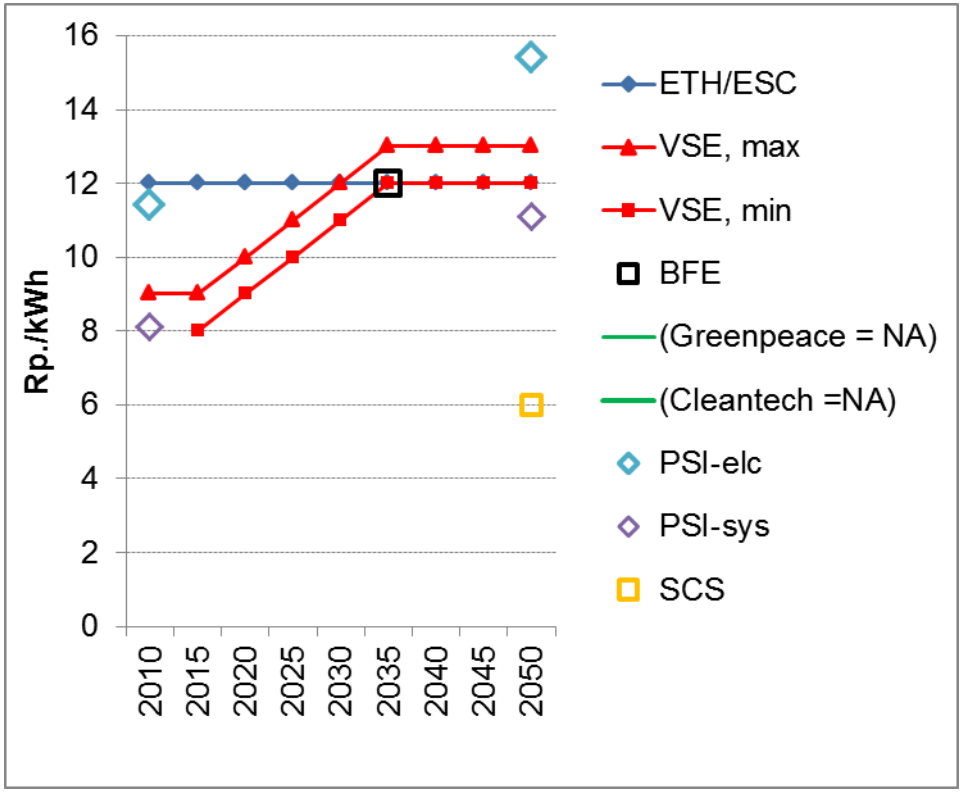
Thanks to the audience, and to the initiator Prof. Wokaun.

Demand (all scenarios)

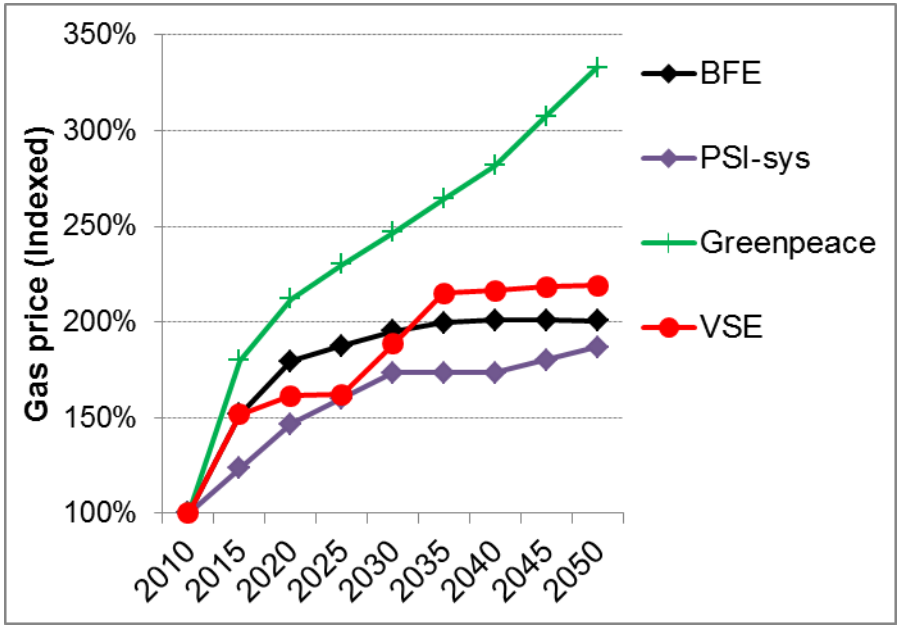


Gas power plants (CCGT)

Production costs:



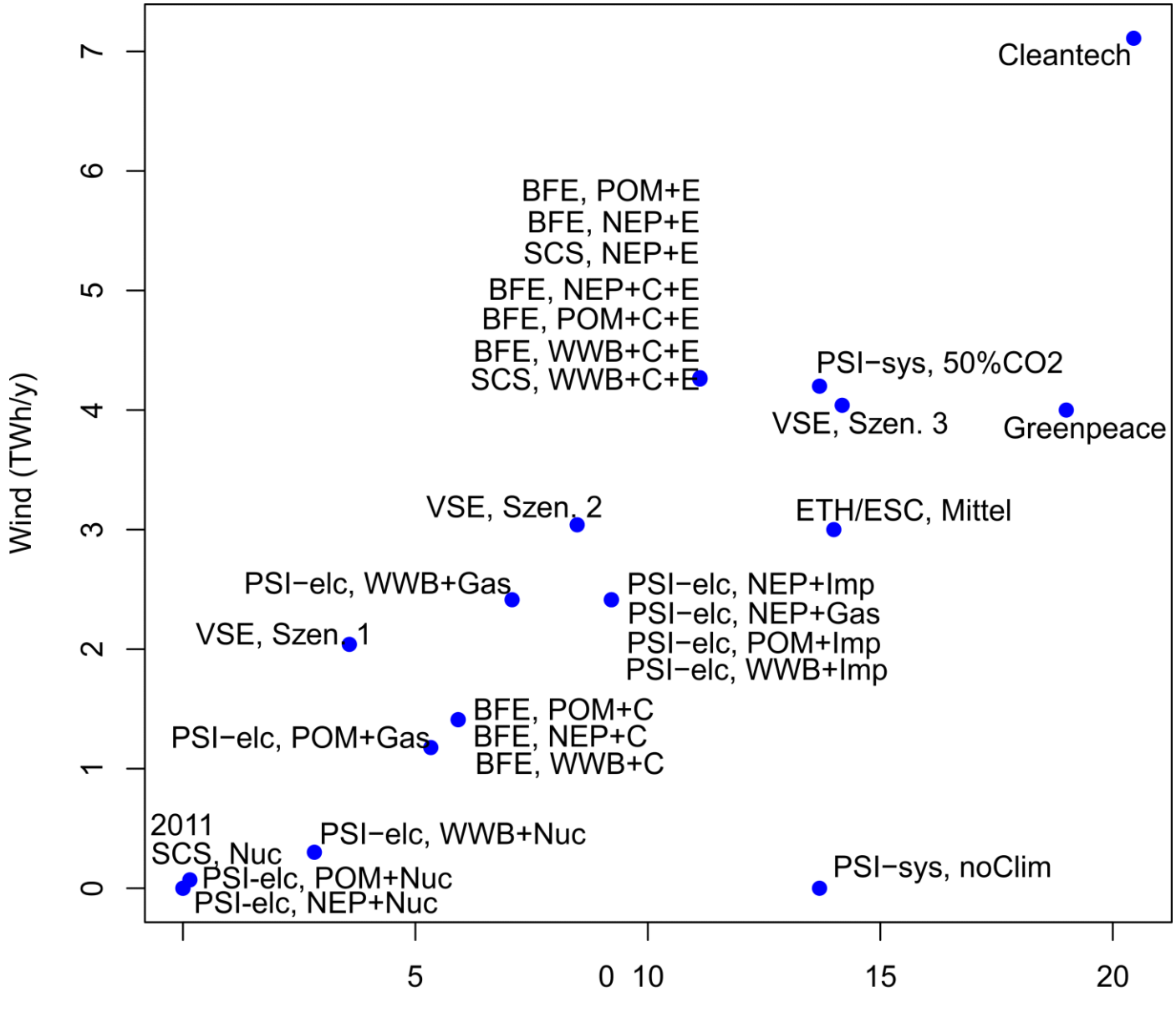
Gas price (indexed):



for studies that report time series of gas prices

- **2025-2035:** Gas power plants in full/medium-load operation in many scenarios
- **2035-2050:** Partial- and low-load operation in winter in many scenarios

Correlation between PV and wind power in 2050



The studies

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