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Realizing the 1.5^{o}C target: energy transformation and the need of flexibility

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Motivation

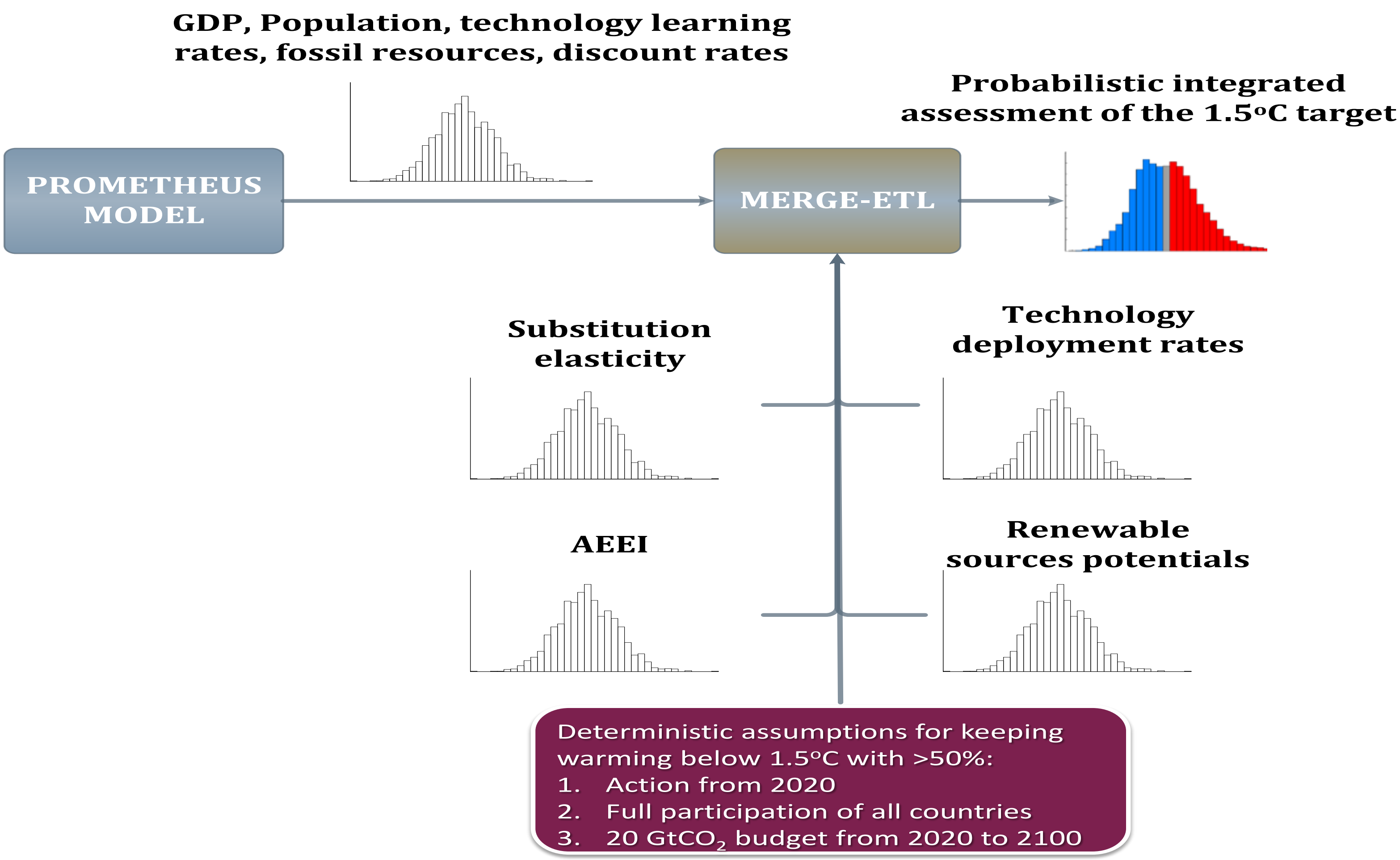
Given the Paris agreement of keeping warming below 1.5^{o}C, we try to answer the following questions:

- Is the 1.5^{o}C target with >50% chance **feasible**?
- If yes at which **cost?**
  - What **technologies** shall be deployed?
  - What level of **energy efficiency** is required?
- If not, what **else shall be deployed**?

We try to answer the above questions by accounting for **uncertainty** in economic, demographic and technological development, resource potentials, discount rates, and technology acceptance (max. deployment rate of technology)

Methodology and modelling framework

- We couple the PROMETHEUS model of ICCS/E3m-lab which quantifies uncertainty in energy-economy-environment system, with the MERGE-ETL integrated assessment model of PSI
- We assess a scenario for keeping warming below 1.5°C with >50% chance, by using a CO2 budget of 380 Gt CO_2 over the period 2011 – 2100 (Rogelj et al., 2015)



Flexibility in MERGE-ETL to cope with 1.5°C target

- Endogenous early capacity retirement when existing capacity has high operating costs, low efficiency and/or high emissions
- Flexible renewable potentials, modelled as logistic functions that increase the specific investment cost according to their level of deployment
- Technology deployment rates are endogenous and correlated with the economic growth (increased FDI, capital flows, technology diffusion)
- Introduction of Fast Breeder Reactors and Direct Air Capture from 2060
- Application of CO_2 capture and storage for synthetic fuels and biofuels production
- Introduction of a back-stop technology (generic geoengineering option) to avoid stopping the Monte Carlo simulation in the case of infeasibilities

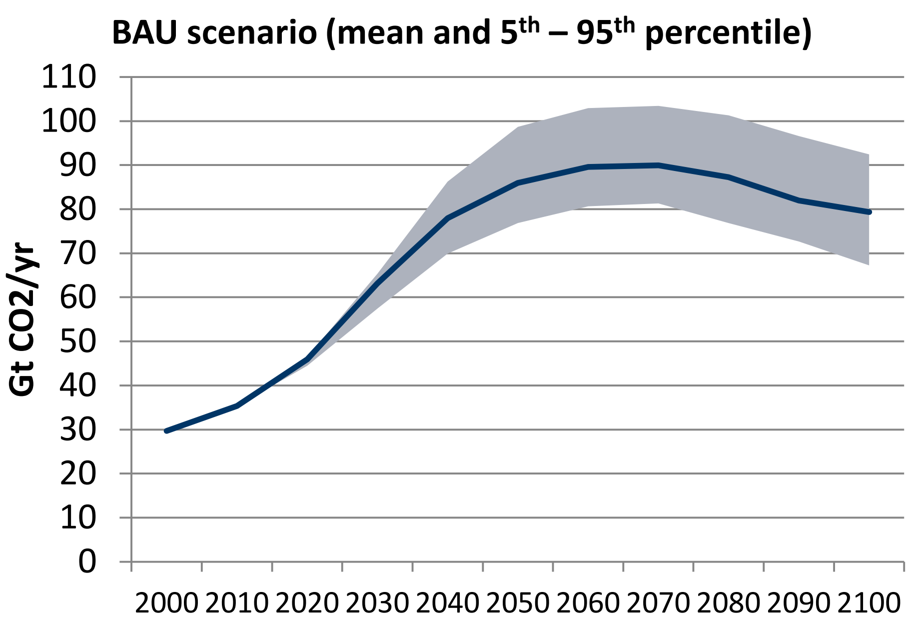
Input probability distributions for Monte Carlo

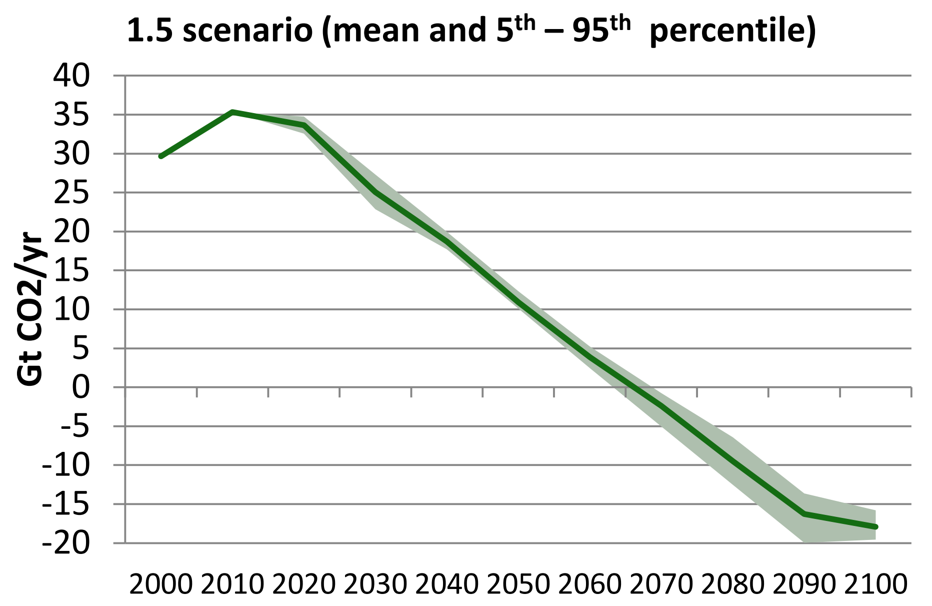
- 1050 Monte Carlo experiments ran with MERGE-ETL
- 90 time-dependent, economic-, resource-, and technology-related parameters are considered as random variables
- Probability distributions obtained from PROMETHEUS for the common parameters
  - For the rest the probability distributions were obtained from (Kypreos, 2007)

Stochastic input parameters to MERGE-ETL (a subset of them)	**Mean**	**Median**	**Min**	**Max**	**Std. dev.**	**Source**
CAGR GWP 2015-2100 (%)	2.30%	2.30%	1.96%	2.74%	0.10%	PROMETHEUS
Global population in 2100 (million)	9298	9273	7387	11870	653	PROMETHEUS
Technology discount rate	5.00%	4.95%	3.03%	7.57%	0.80%	Function of GDP
Oil resources (Gbl)	759	705	193	2553	295	PROMETHEUS
Gas resources (Gtoe)	208	189	37	707	90	PROMETHEUS
Biomass resources in 2100 (EJ)	189	189	152	230	9	Function of income
Seq. potential (Gt CO_2)	1663	1660	1386	2075	81	Function of GDP
CES electric/non-electric	0.45	0.45	0.28	0.65	0.05	Function of income

CO2 emission trajectories in BAU and in 1.5°C cases

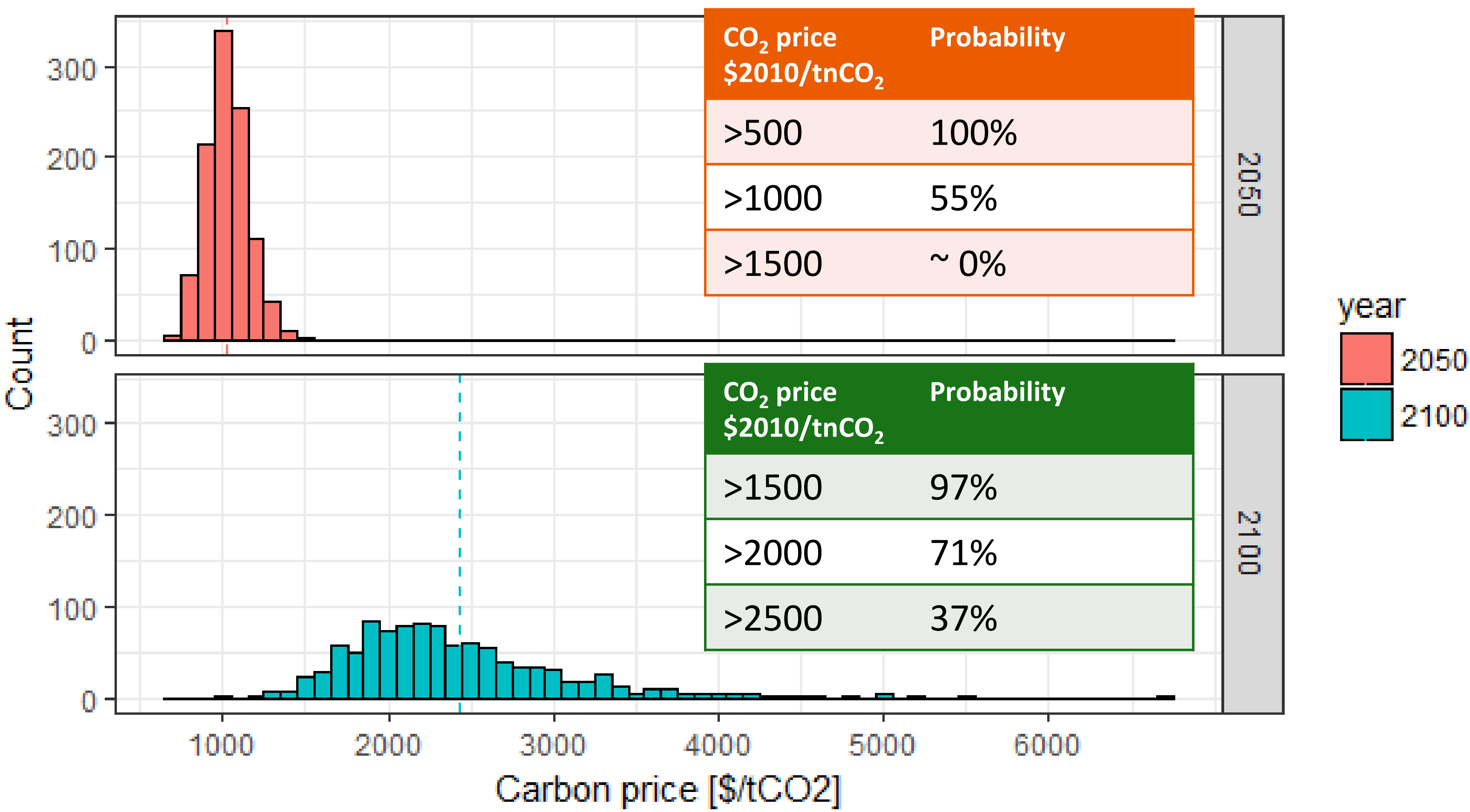
- In BAU scenario : 35% probability that emissions peak before 2060
- In carbon control scenario emissions peak by 2020 and go negative by 2060:
  - Limited flexibility in trajectories due to the stringent budget
  - Probability to have full decarbonization from energy and industrial processes:
    → 2% before 2060, 80% before 2065





CO2 emission prices in the 1.5 scenario

- The CO_2 price on average doubles in 2100 compared to 2050
  - But the shape of distribution changes to lognormal from normal denoting probabilities for very high prices
- There is only 0.1% probability to have lower CO_2 price in 2100 than in 2050

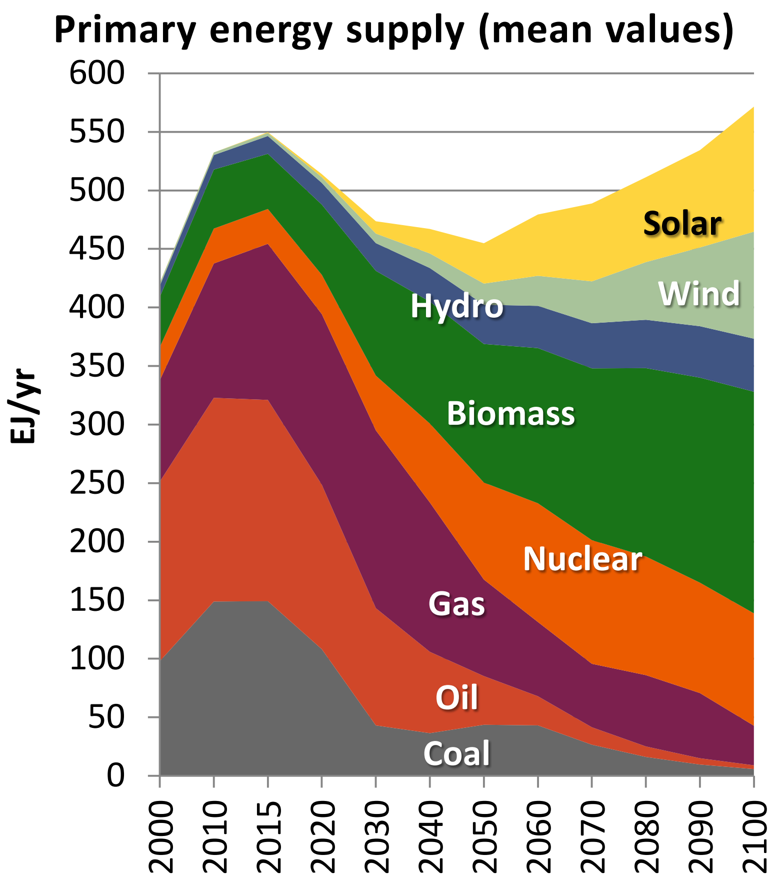


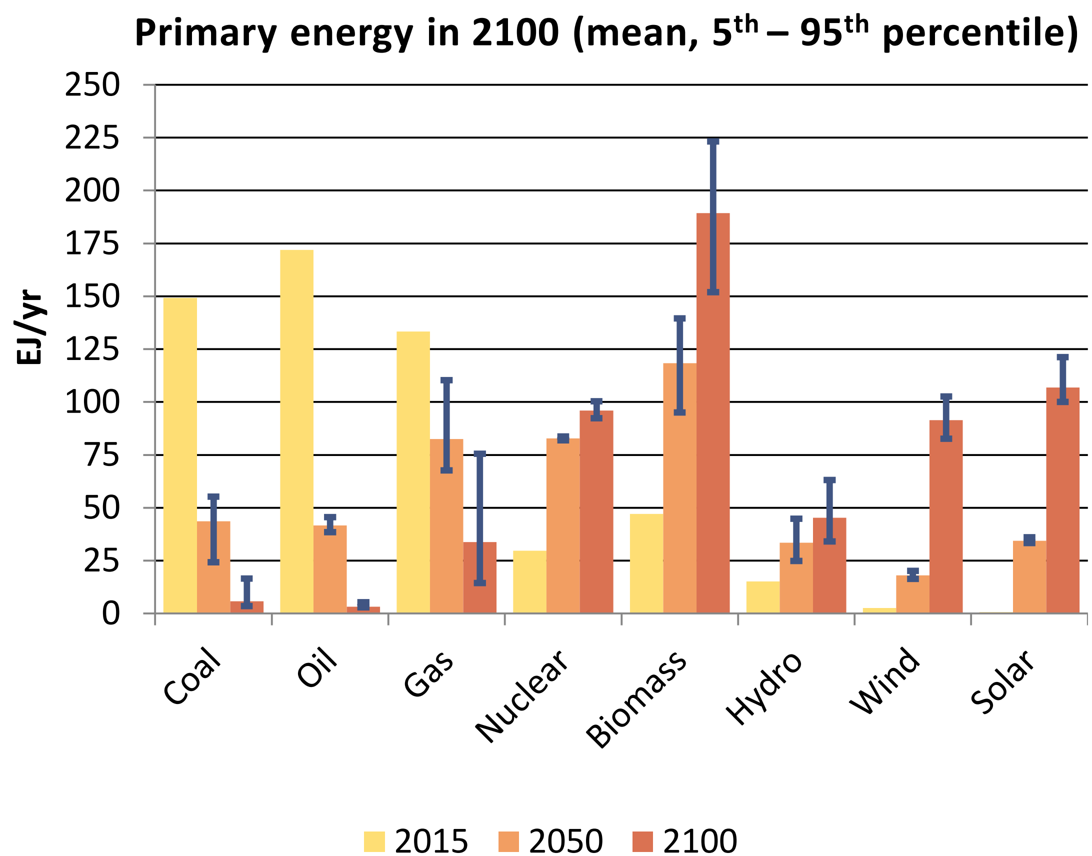
CO_2 price $2010/tn$CO_2$	Probability
>500	100%
>1000	55%
>1500	~ 0%

CO_2 price $2010/tn$CO_2$	Probability
>1500	97%
>2000	71%
>2500	37%

Primary energy supply mix in the 1.5 scenario

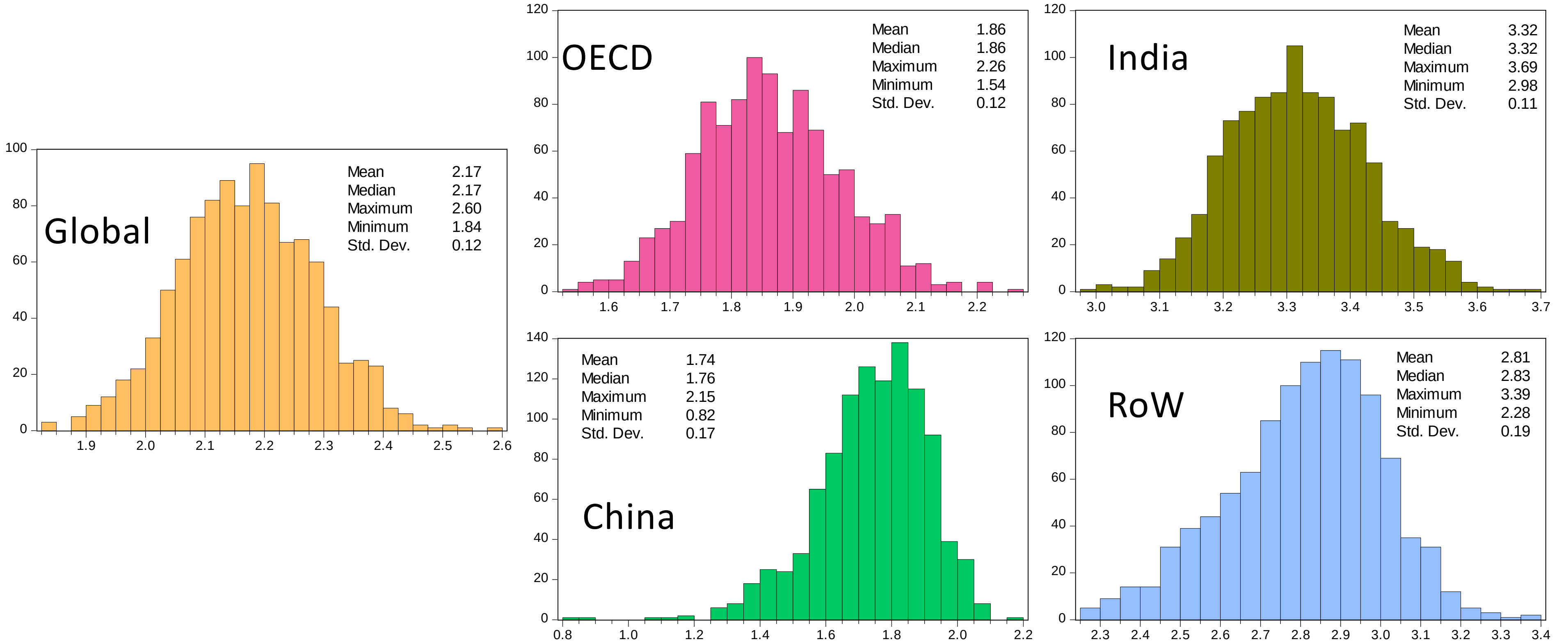
- On average the TPES declines until 2060 and increases thereafter due to BECCS and Direct Air Capture, needed to achieve negative emissions
  - In absolute values there is 3% probability of less TPES in 2100 than in 2015
  - There is 48% probability of less TPES/capita in 2100 than in 1970 (61.5 GJ/cap)





Primary energy intensity in the 1.5 scenario

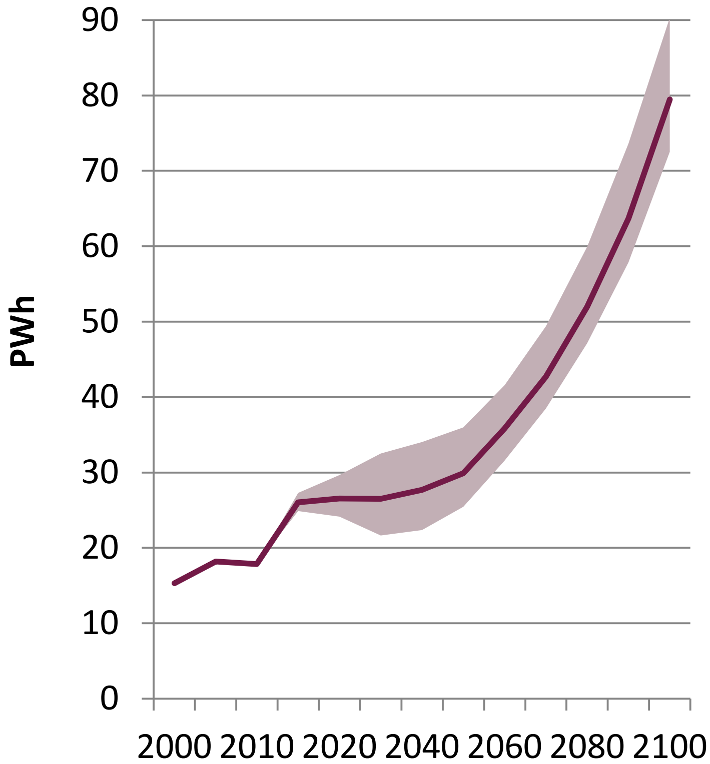
- The primary energy intensity improves in all regions, and on average by 2.1% p.a.
  - Gains are higher in developing regions as they leapfrogging to modern technologies
  - In all regions except China the energy intensity gains exceed the historical 1970-2015
- Left-skewed distributions denote regions with large potential for high gains
  - e.g. China has 20% probability to have higher gains than OECD



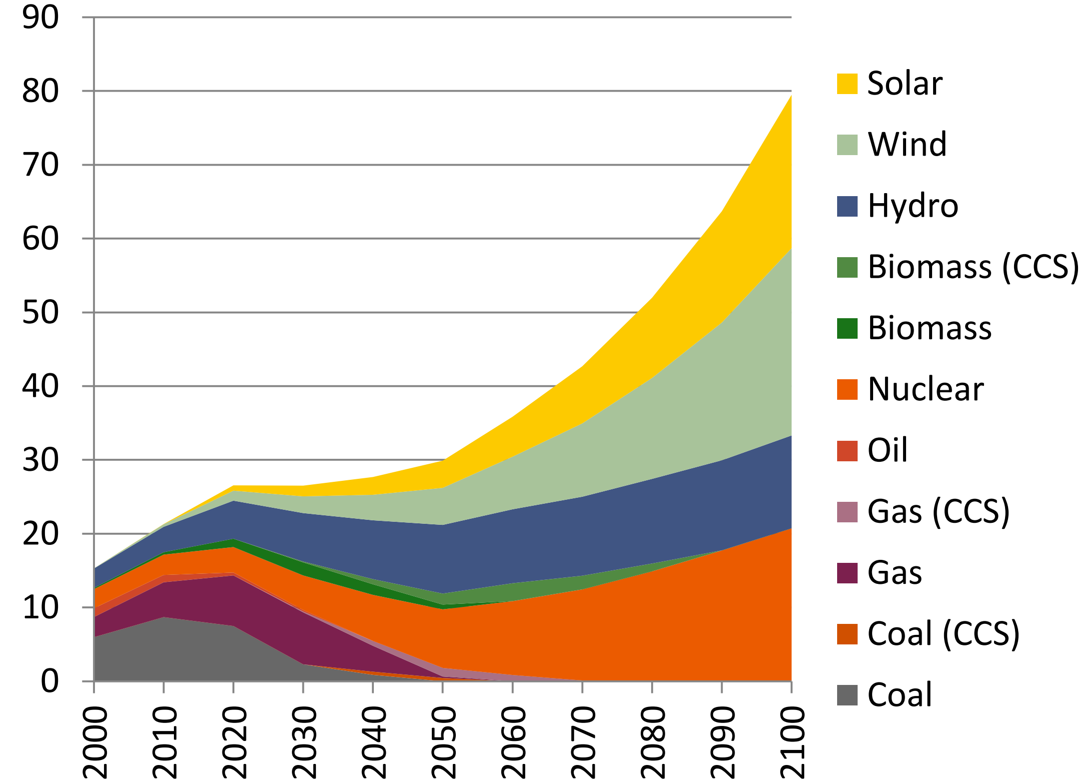
Electricity generation mix in 1.5 scenario

- Rapid electrification after 2050, facilitates efficiency and decarbonisation
- After 2050, electricity generation is non-fossil based
  - However, biomass is used solely for biofuels production

Total global electricity generation (mean, 5th – 95th percentile)

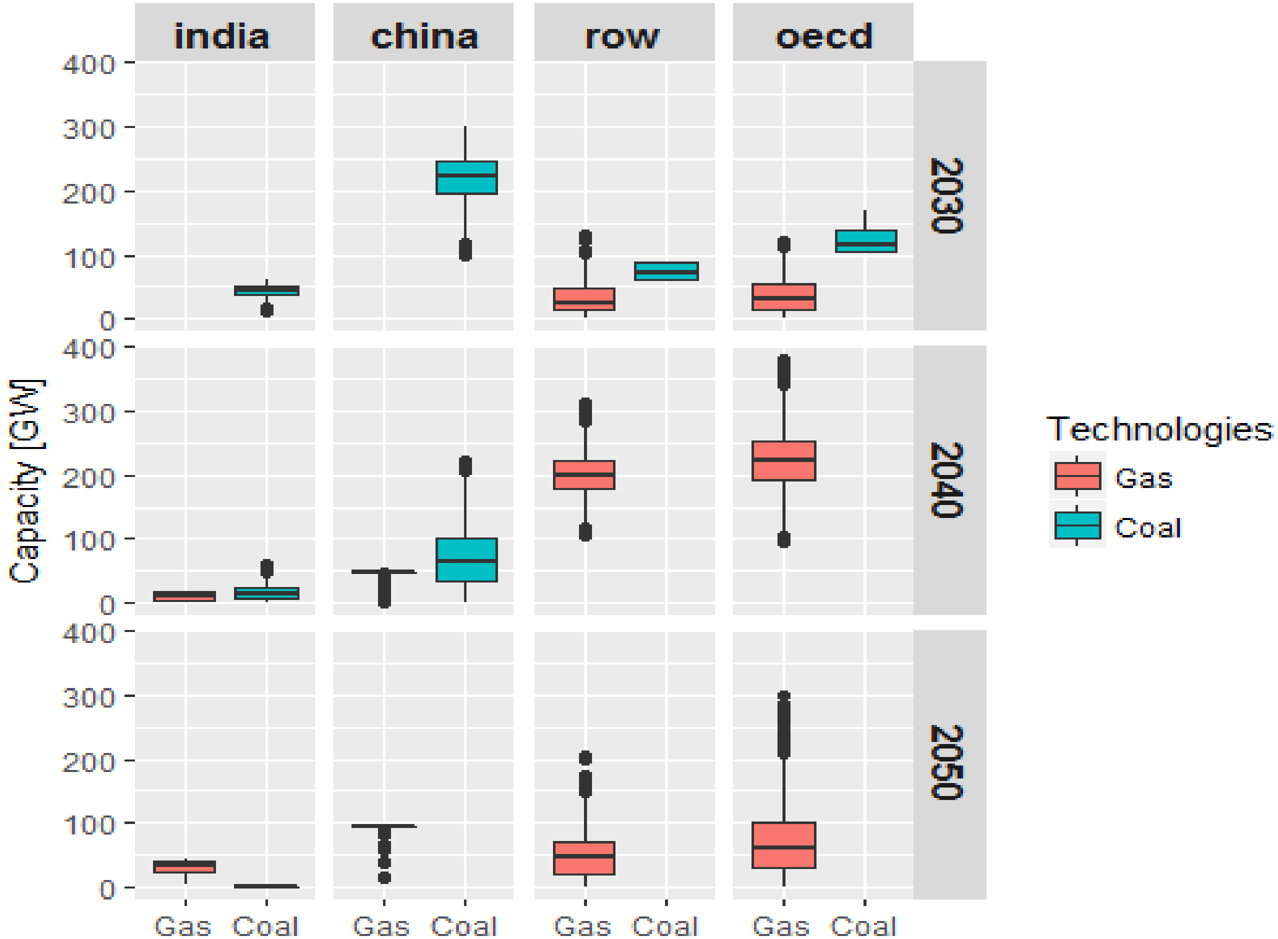


Global electricity generation by technology (mean)



Early retired electricity capacity in the 1.5 scenario

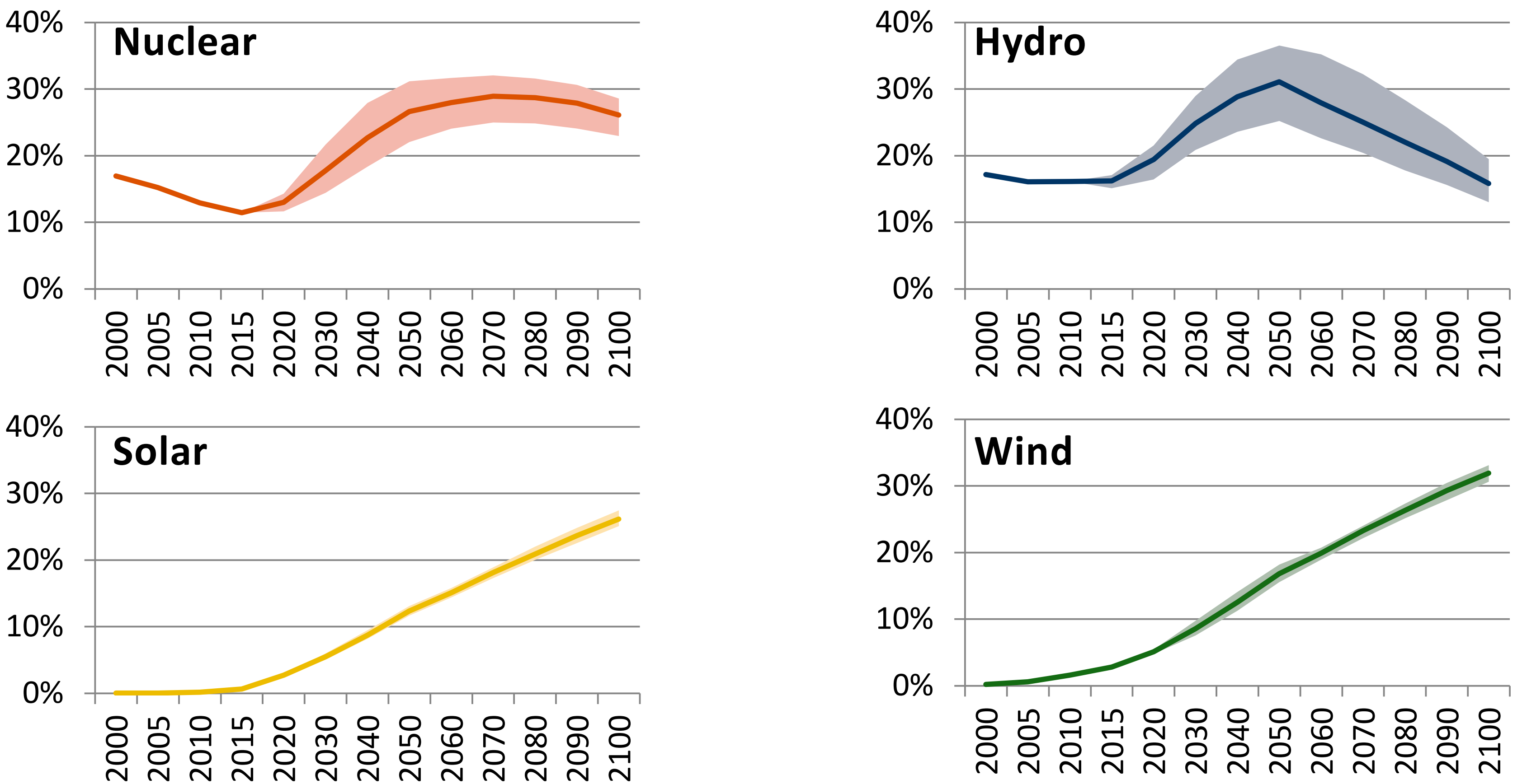
- Fossil-based capacity is prematurely retired by 2050, creating “stranded assets”
  - China and India retire by 2030 about 1/3 of today’s coal capacity
  - In ROW and OECD gas is used as transition technology till 2030-2040



Shares of key power generation technologies

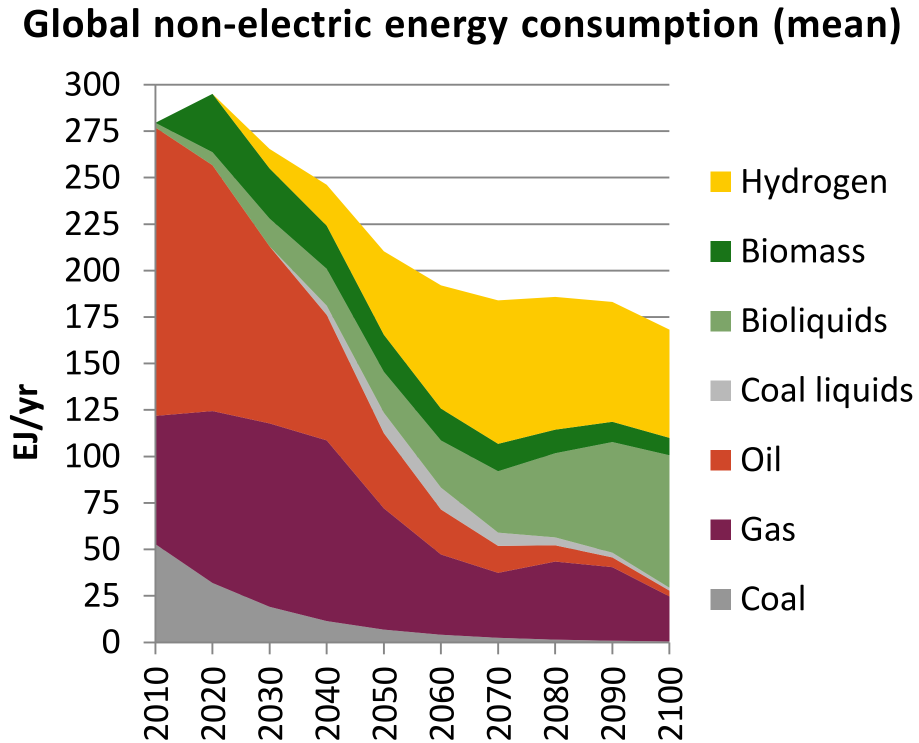
- High variation in nuclear and power, denotes challenges in its deployment
- Low variation in wind and solar, implying we “have-to-deploy-them”

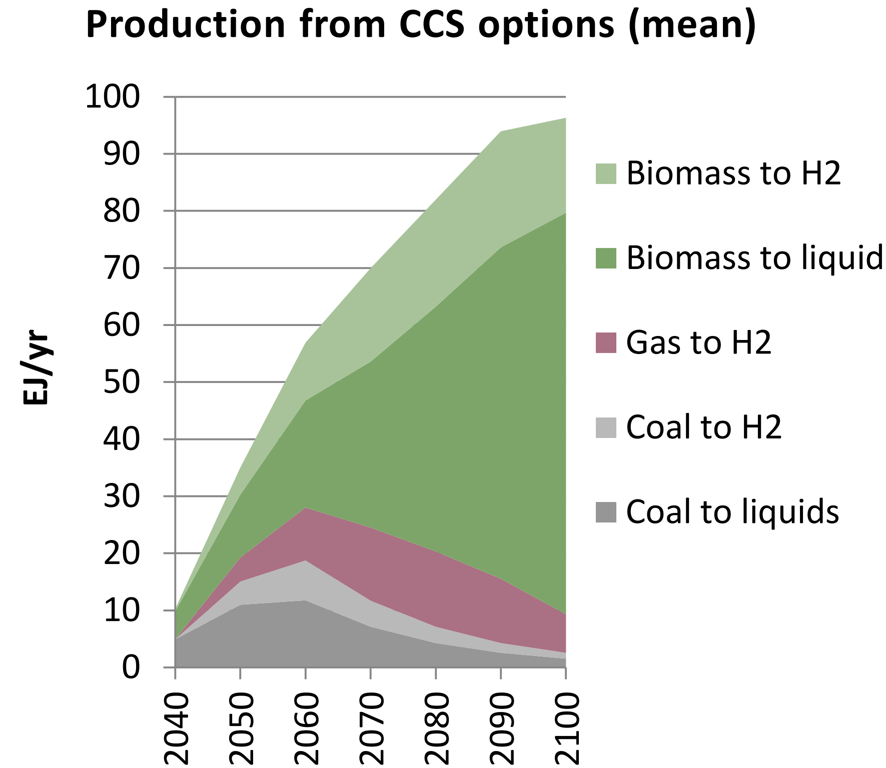
Share in global electricity production (mean, 5th – 95th percentile)



Non-electric energy consumption in the 1.5°C case

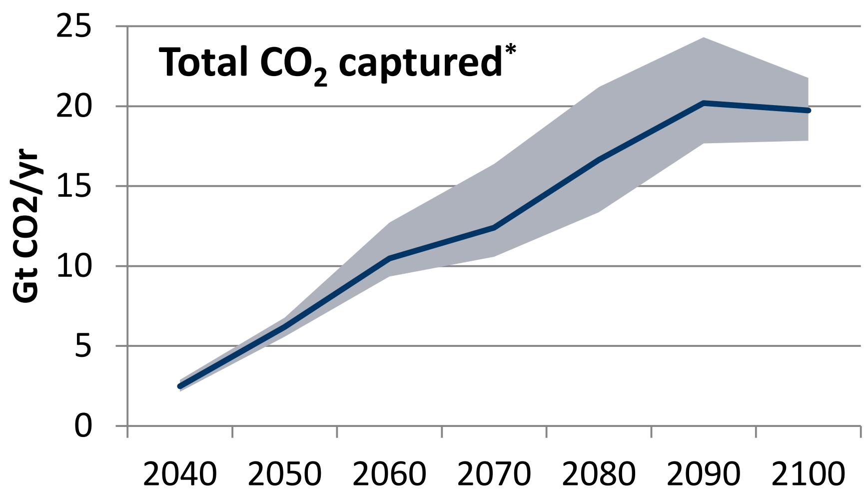
- Non-electric consumption moves to low-carbon synthetic fuels
- On average the contribution of CCS options in producing H2 and liquids increases from 18% in 2050 to 60% in 2100
  - – BECCS account for 50% of the CCS-produced fuels in 2050 → 90% in 2100

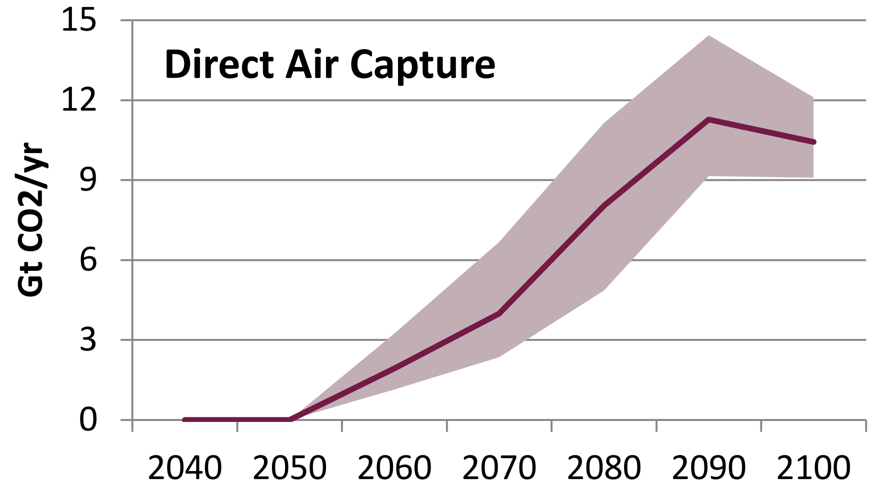


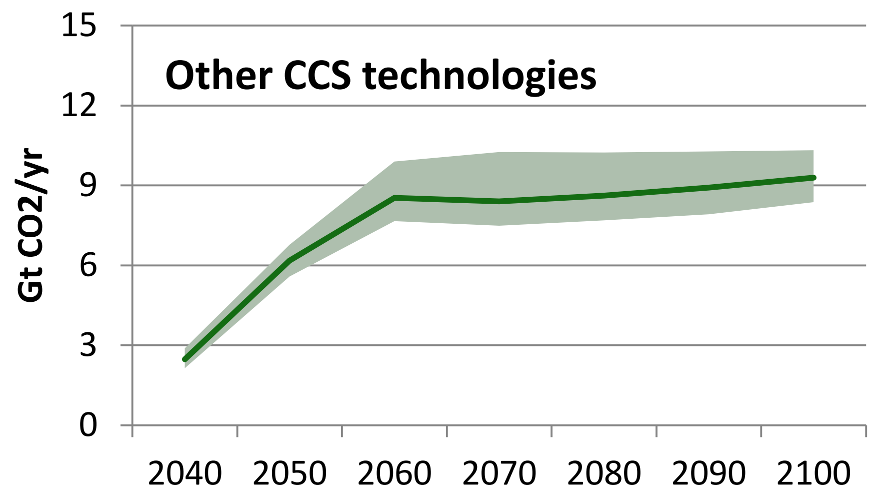


CO2 capture and storage by technology in the 1.5 scenario

- Fossil-based CCS are deployed until 2050
- Till 2070 significant penetration of BECCS
- After 2070 DAC gains share for negative emissions
- Correlation between DAC and other options is slightly positive (0.12)



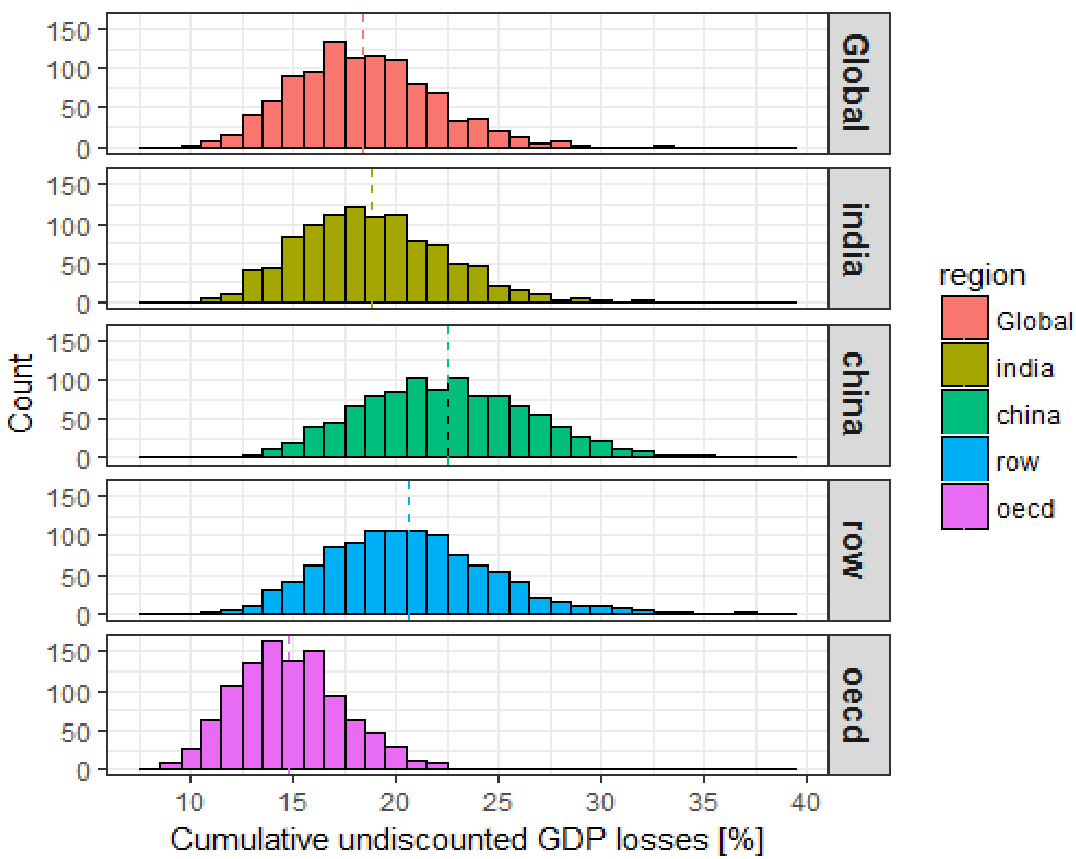




*** Mean and 5th – 95th percentile**

Results: Undiscounted GDP losses 2020 - 2100

- The undiscounted GDP losses are signficant in all regions
- The probability that at a global level the losses exceed:
  - 2 times the losses occured in the 2°C case is 90%
  - 3 times the losses occured in the 2°C is 20%



Probability to exceed losses of:

	>10%	>20%	>25%
Global	100%	84%	30%
India	100%	87%	34%
China	100%	98%	71%
ROW	100%	93%	54%
OECD	98%	45%	3.1%

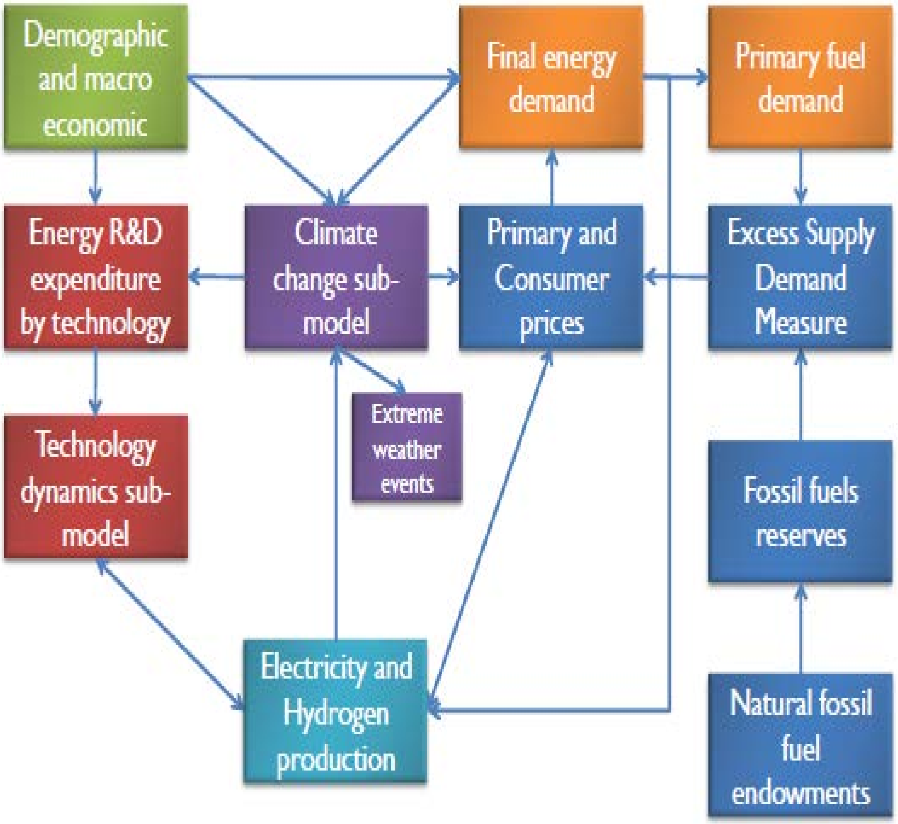
Conclusions

- The 1.5°C target is **technically feasible** but it requires fast and global commitments in every aspect of the problem: global coordination, technology development, governance and WTP
- Global coordination requires **early actions** even from 2020
- **All available low carbon options** need to be explored and deployed:
  - BECSS, Direct Air Capture and New Nuclear Designs are part of the solution
  - Untapped potential of wind, solar, hydro needs to be exploited
  - Existing (or in advanced planning) investments in fossil-based technologies will need to be retired earlier, within the next 20 years → challenge to avoid "stranded assets"
- High shadow prices of energy stimulate **significant efficiency gains** at unprecedented rates
- All the above result in **high costs to economy** (GDP losses), with high probabilities to be 2 or even 3 times higher than the GDP losses for the 2°C case, which raise **issues of financing**
- … all these with the caveat that this is a work in progress and there are still issues to be tackled: e.g. demand technologies for assessing efficiency gains requirements, stochastic CO_2 budgets

Thank you very much for your attention!

The PROMETHEUS model of ICCS/E3m-lab

- World energy stochastic model, with full coverage of uncertainties associated with the evolution of the energy-economic-environment system
- Simulates market-based formation of energy prices
- Includes endogenous technology learning



The MERGE-ETL model of PSI

- Integrated Assessment model maximising the global social welfare
- Bottom-up description of the energy system with endogenous technology learning
- Top down description of the economy (Ramsey type)