UCL Energy Institute

Using retrospective UK power system modeling to inform the scenario choice for the future

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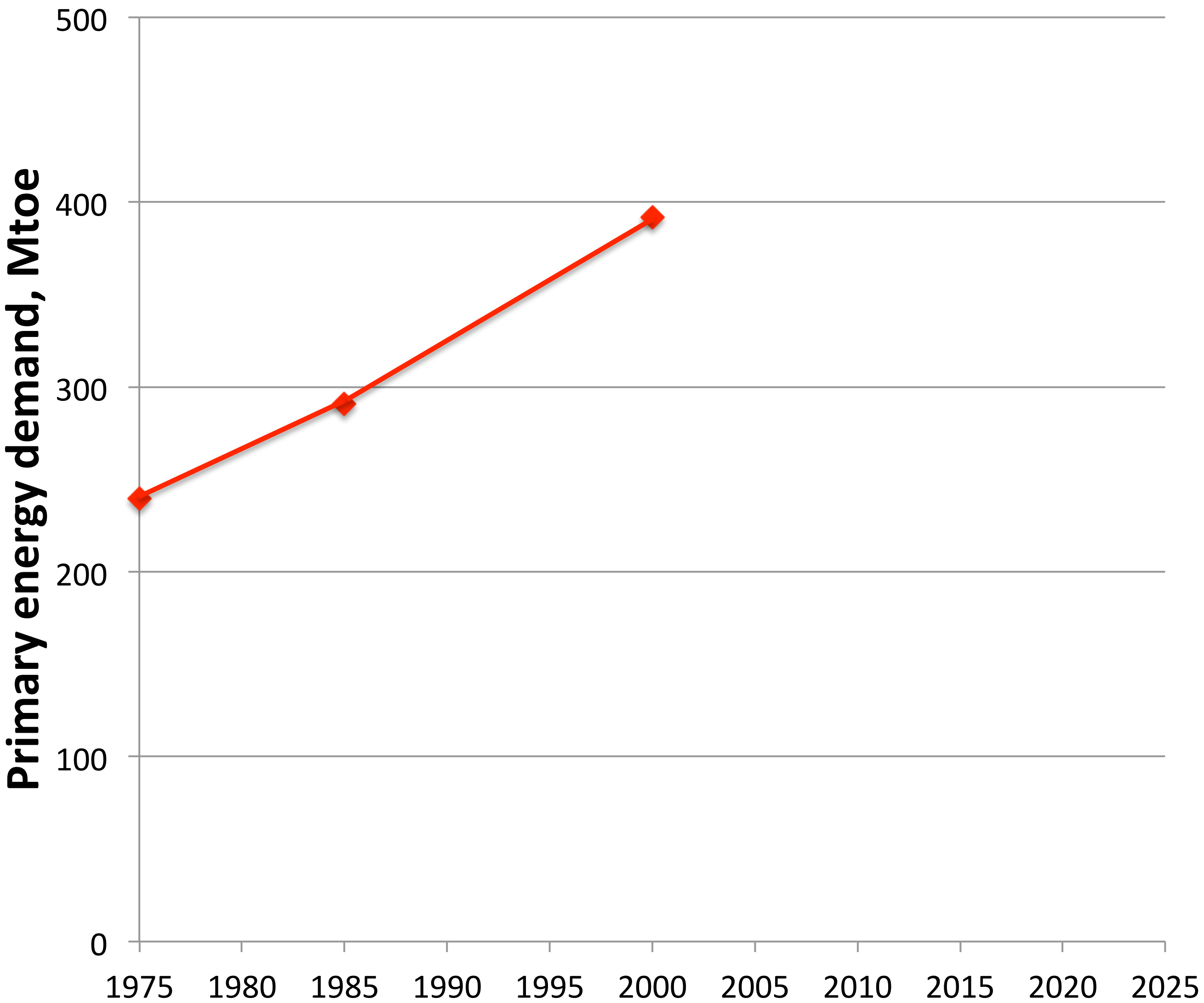
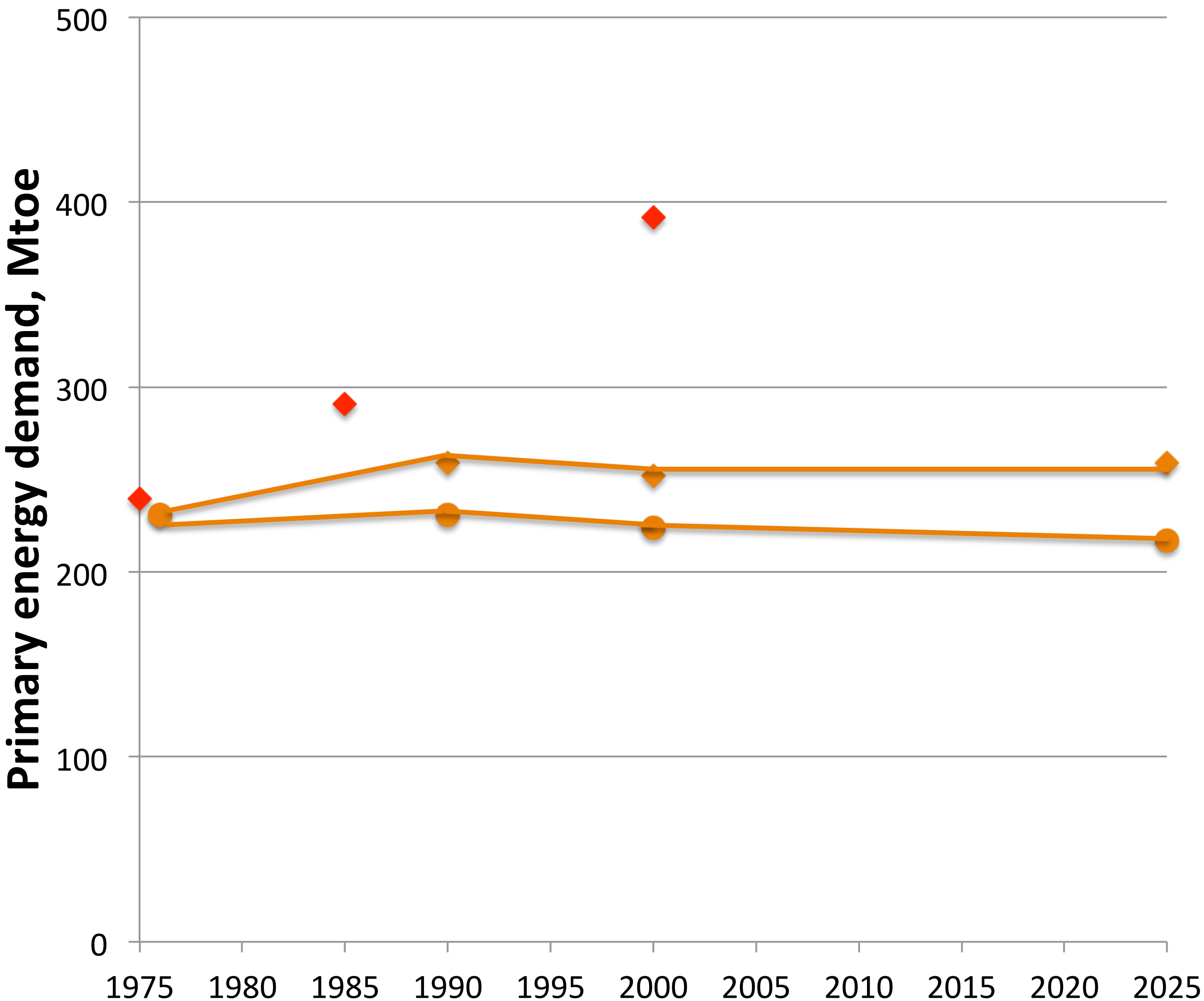
With acknowledgements to Neil Strachan



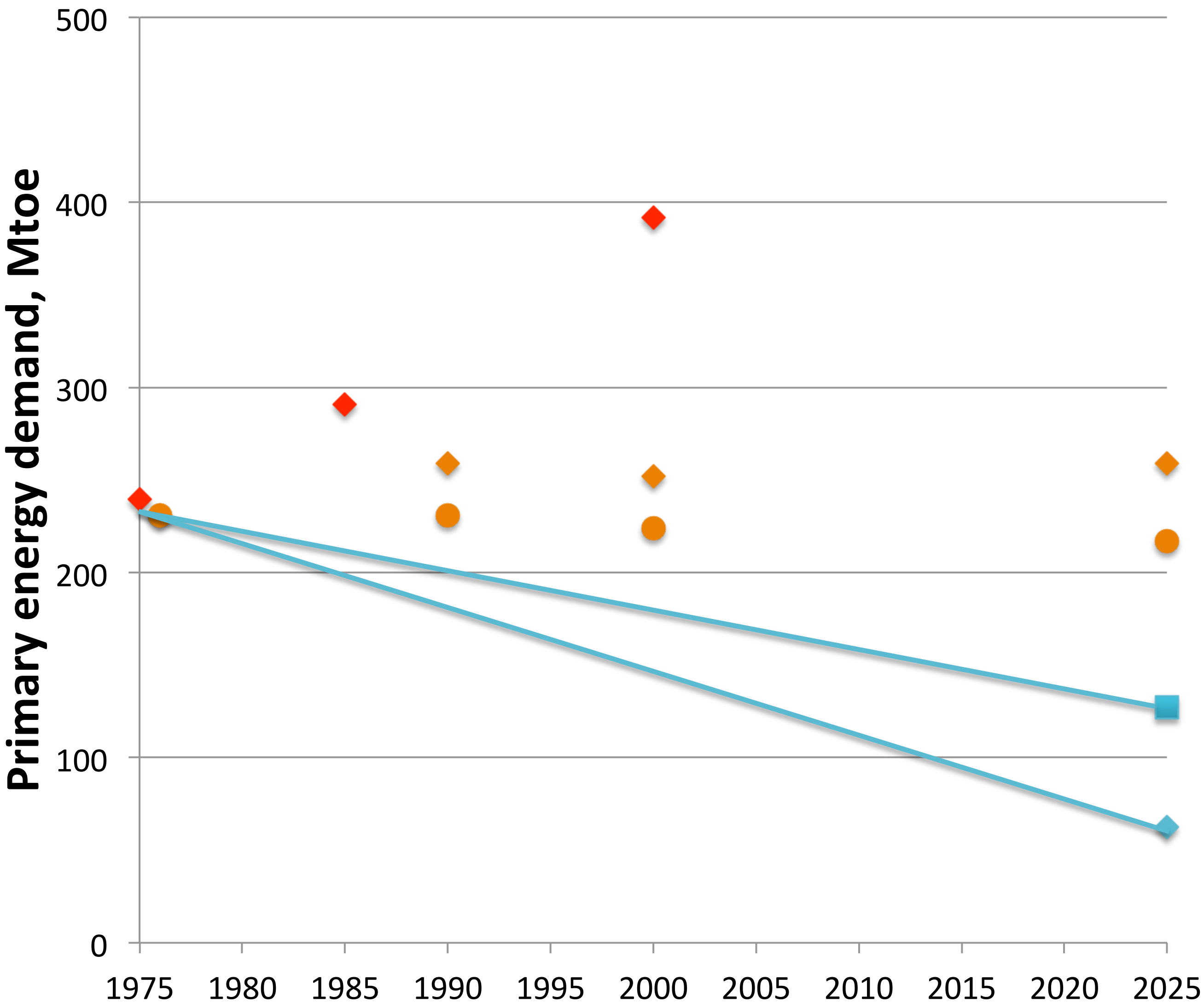
UK Department of Energy, 1978:

"sets out the Government's energy strategy proposal on which we invite to comment"



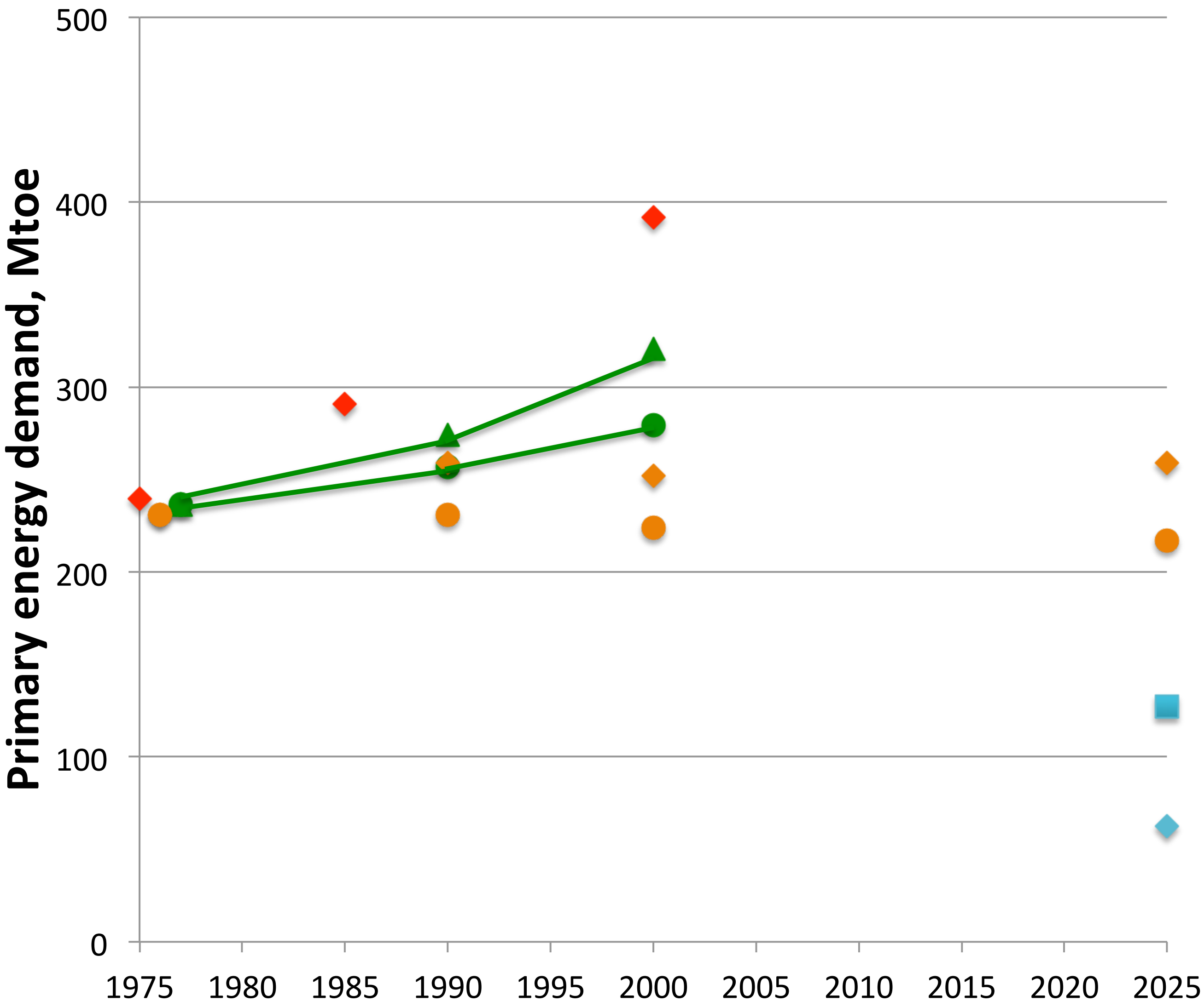
International Institute for Environment and Development, 1979:

"presents a different view of the future"



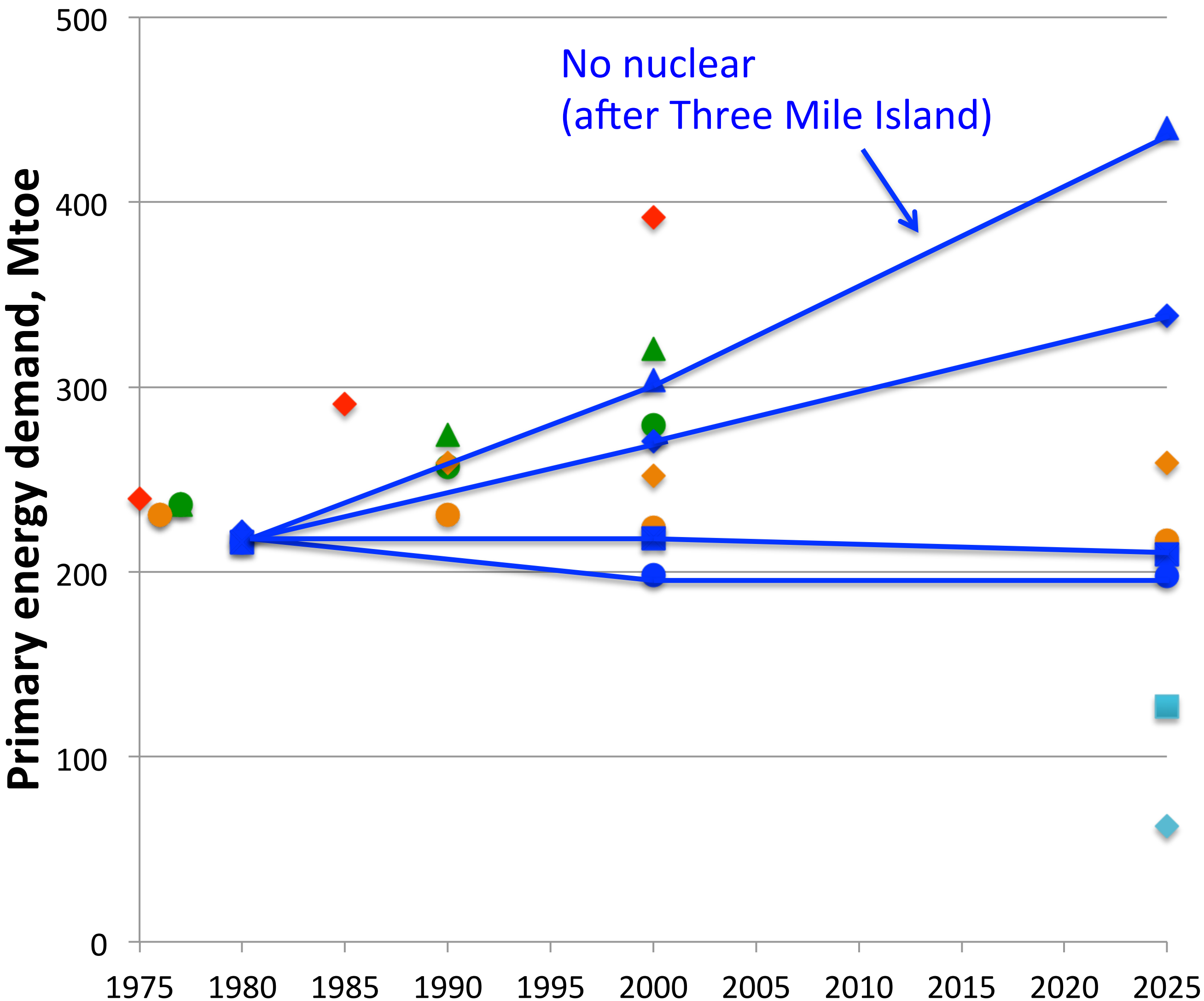
Friends of the Earth

(reproduced from ETSU, 1982)



Update by the UK Department of Energy, 1979:

"intended to provide a broad quantitative framework for the consideration of possible energy futures and policy choices"



Birmingham energy model, 1982:

"designed to calculate and compare optimal strategies"

Scenario “whirlpool”?

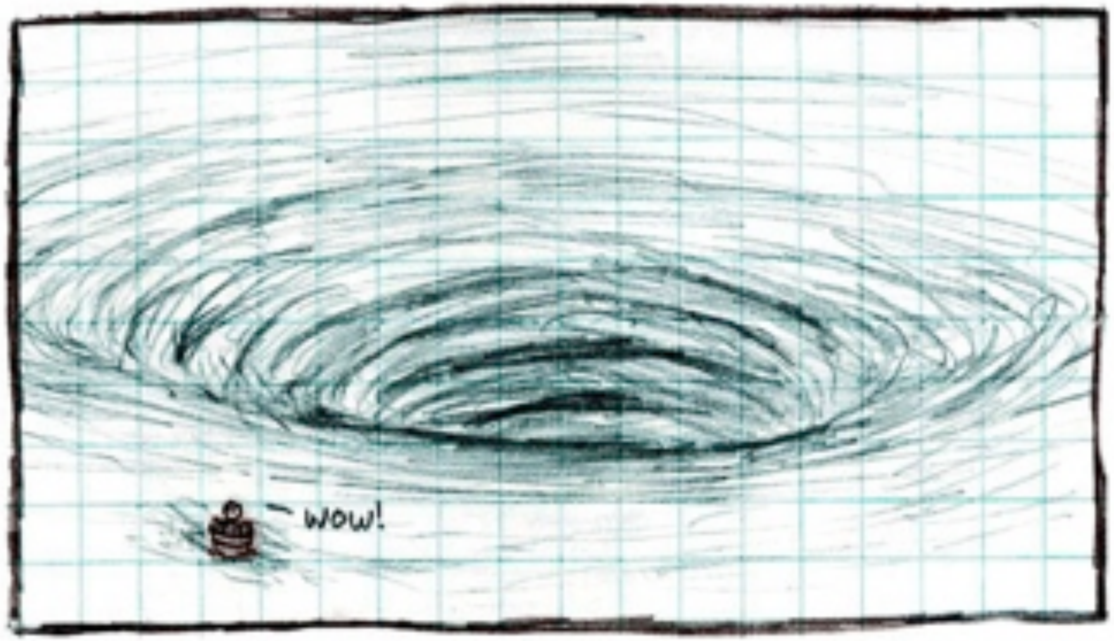
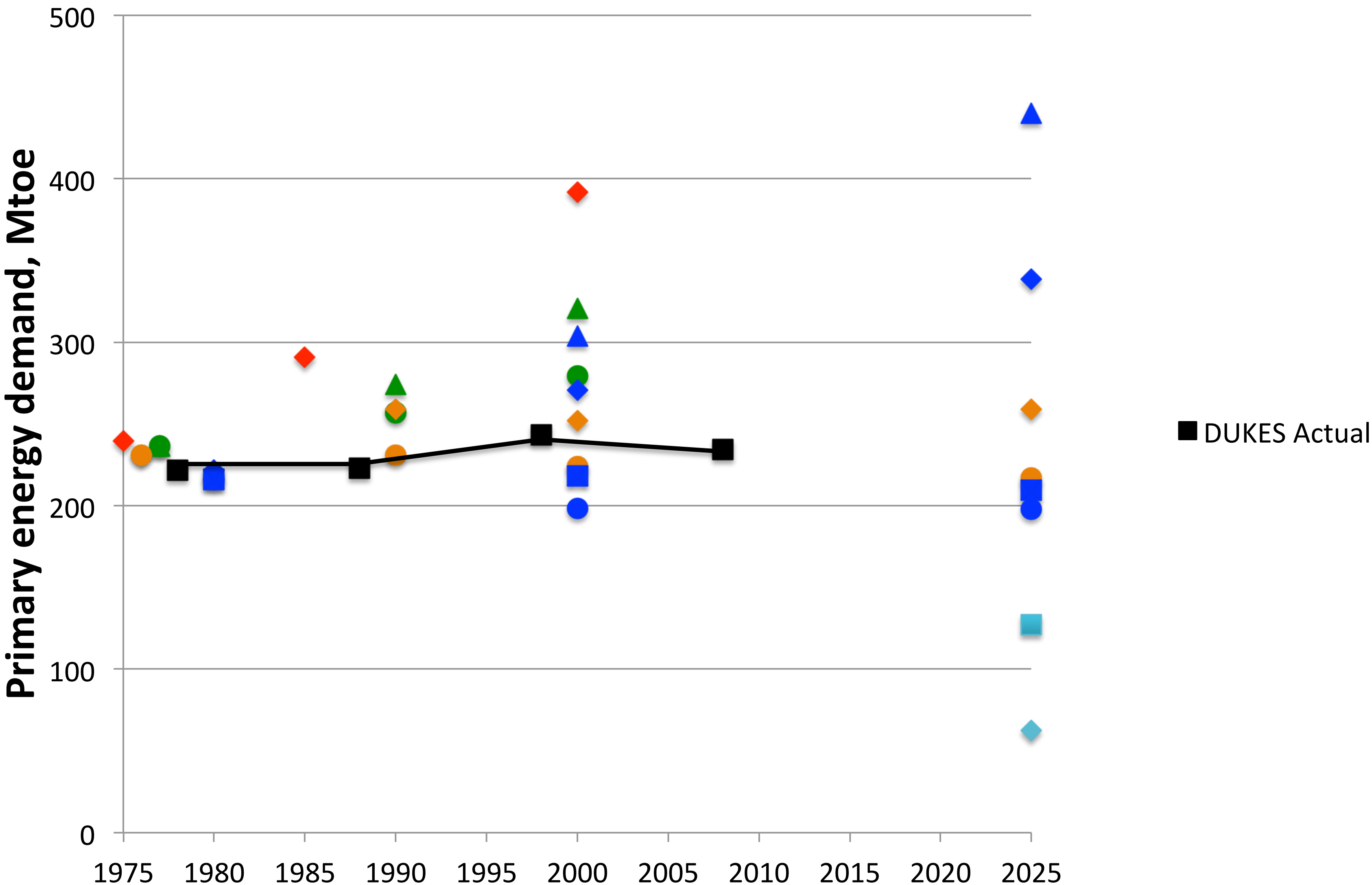
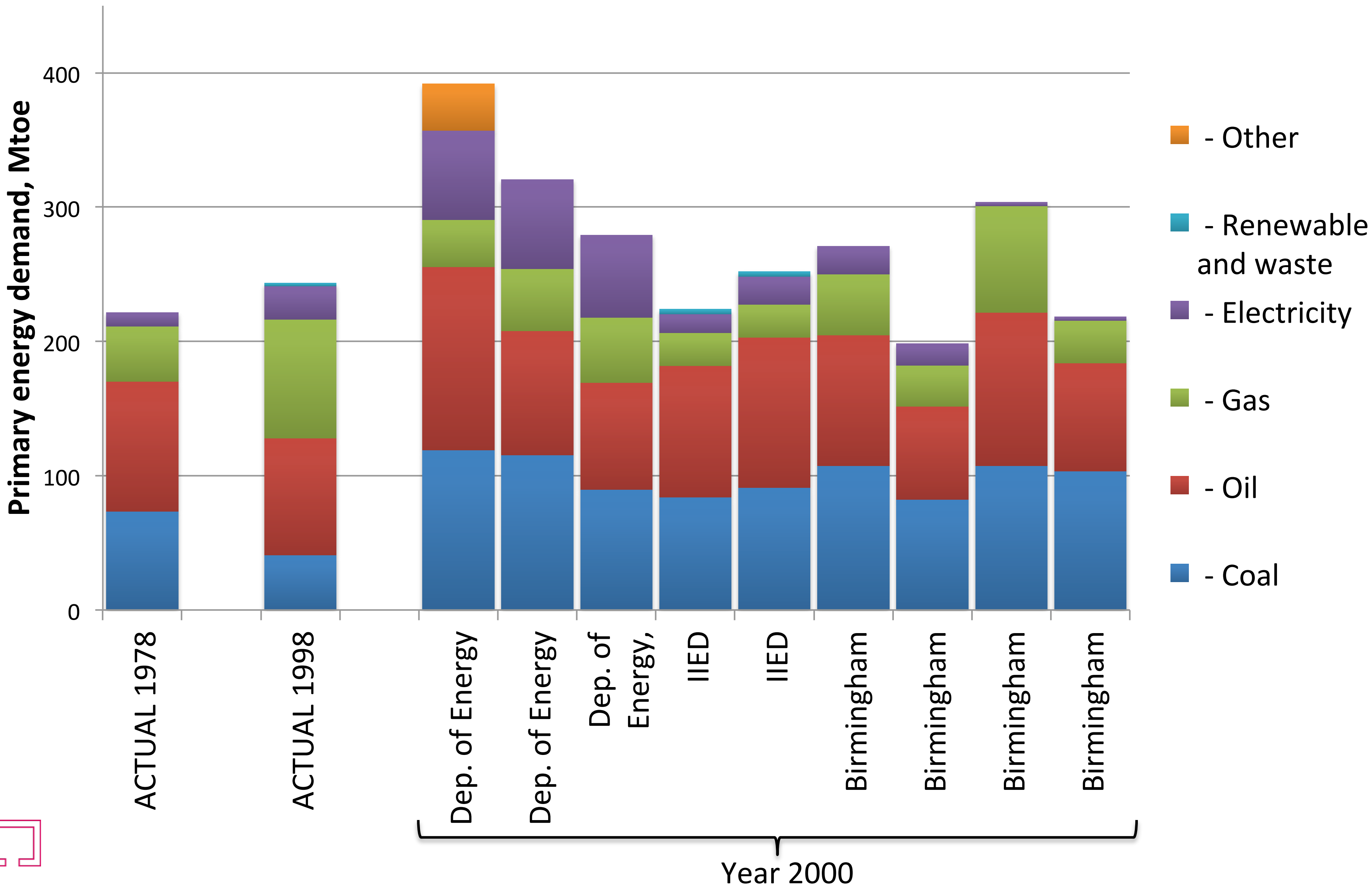
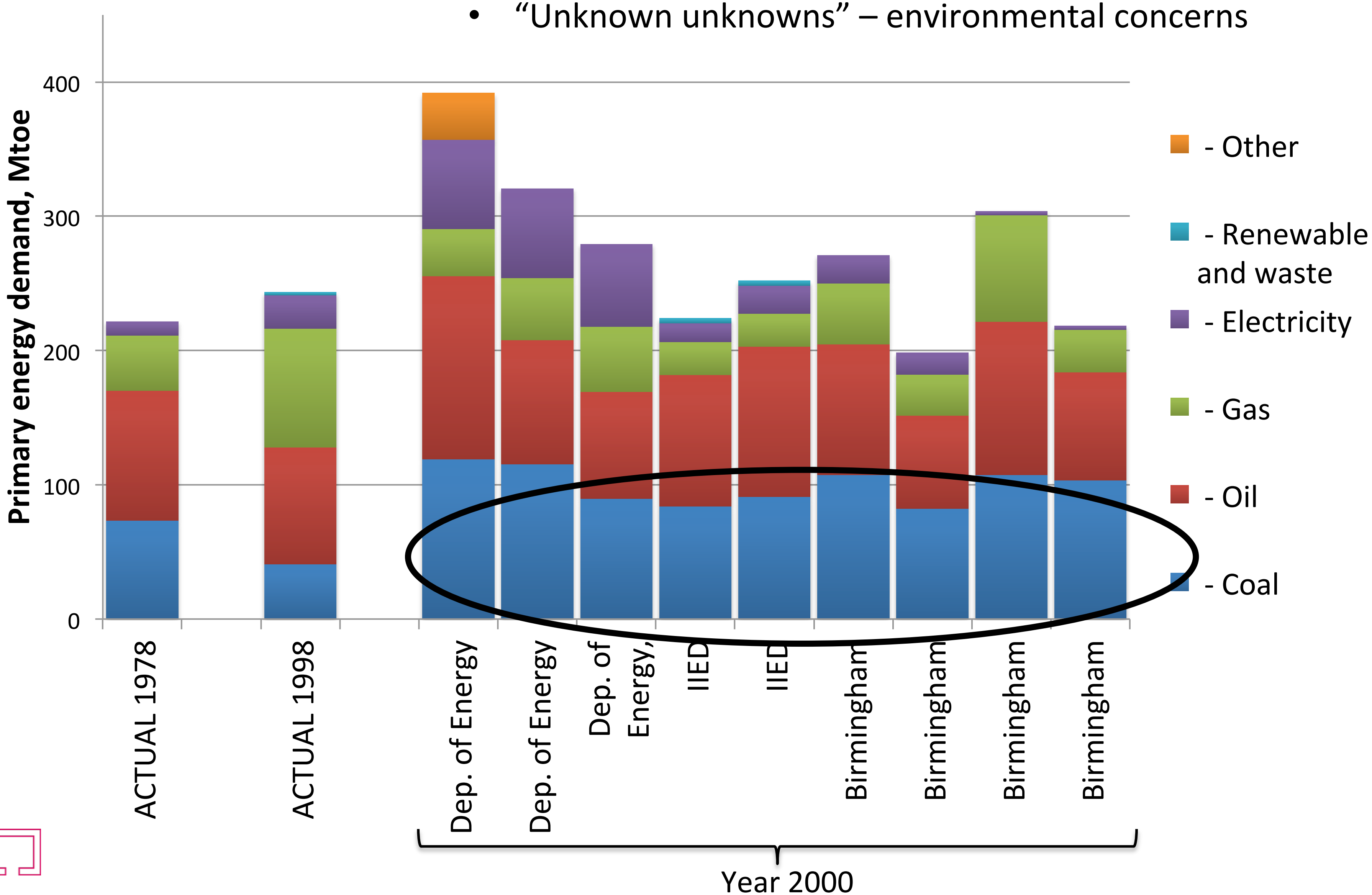


Figure from http://www.explainxkcd.com/

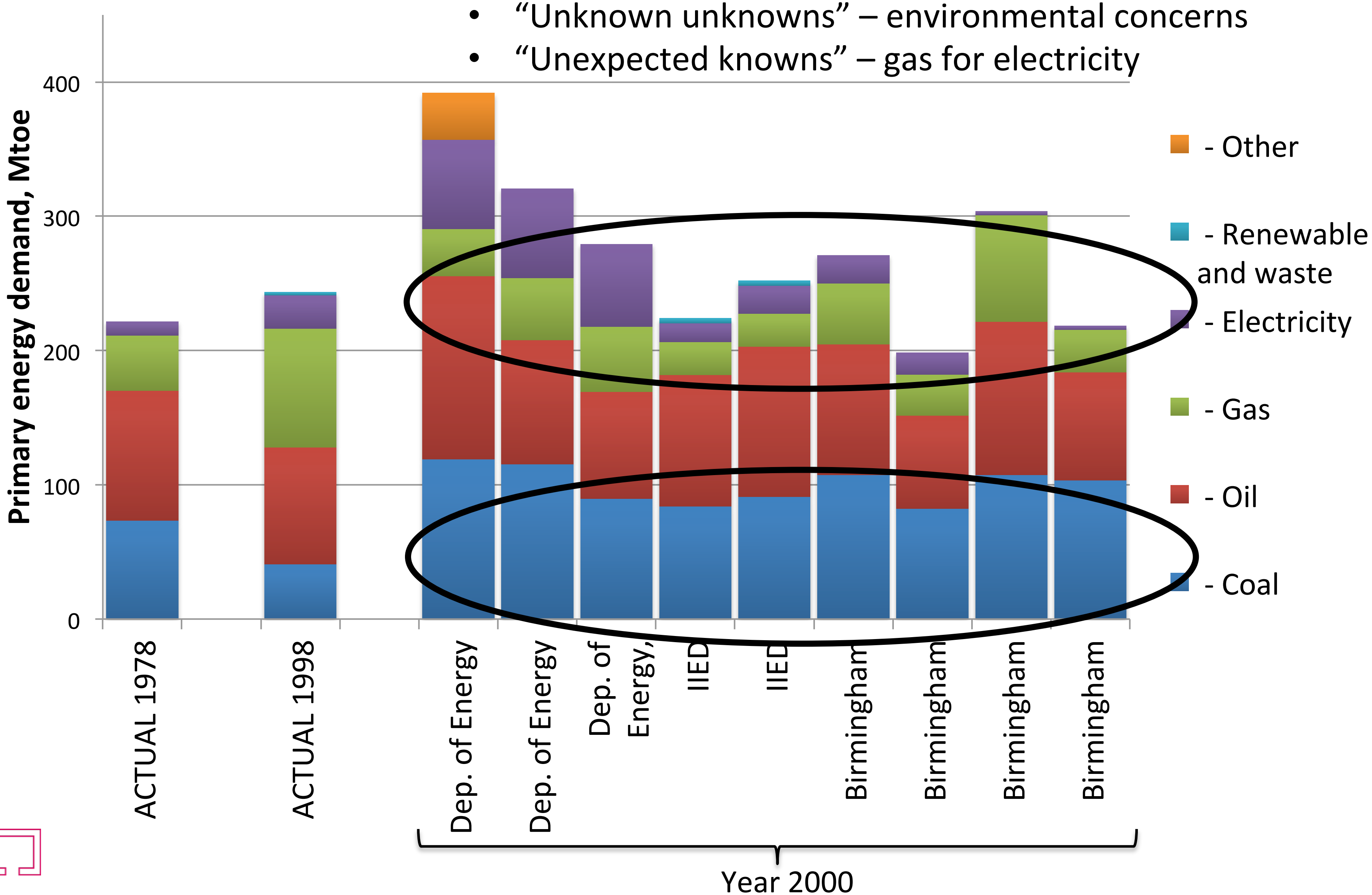

Primary energy demand, Mtoe
500
400
300
200
100
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
DUKES Actual


Primary energy demand, Mtoe
400
300
200
100
0
ACTUAL 1978
ACTUAL 1998
Dep. of Energy
Dep. of Energy
Dep. of Energy,
IIED
IIED
Birmingham
Birmingham
Birmingham
Birmingham
Year 2000
- Other
- Renewable and waste
- Electricity
- Gas
- Oil
- Coal

- "Unknown unknowns" – environmental concerns



- "Unknown unknowns" – environmental concerns
- "Unexpected knowns" – gas for electricity



EXPANSE model

EXploration of **PA**tterns in **N**ear-optimal energy **S**c**E**narios

1. Bottom-up, technology rich, cost optimisation model
   (Ekins et al. 2011; Strachan 2011)

2. Exploration of near-optimal scenarios
   (DeCarolis 2011; Trutnevyte 2013; Trutnevyte et al. 2012a, 2012b)
   - From wedges approach to a dynamic analysis

3. Patterns in a large number of scenarios
   (Guivarch et al. 2013, Lempert 2003; McJeon et al. 2011, Trutnevyte et al. 2011)
   - Maximally-different scenarios

Retrospective UK power system modeling, 1990-2010

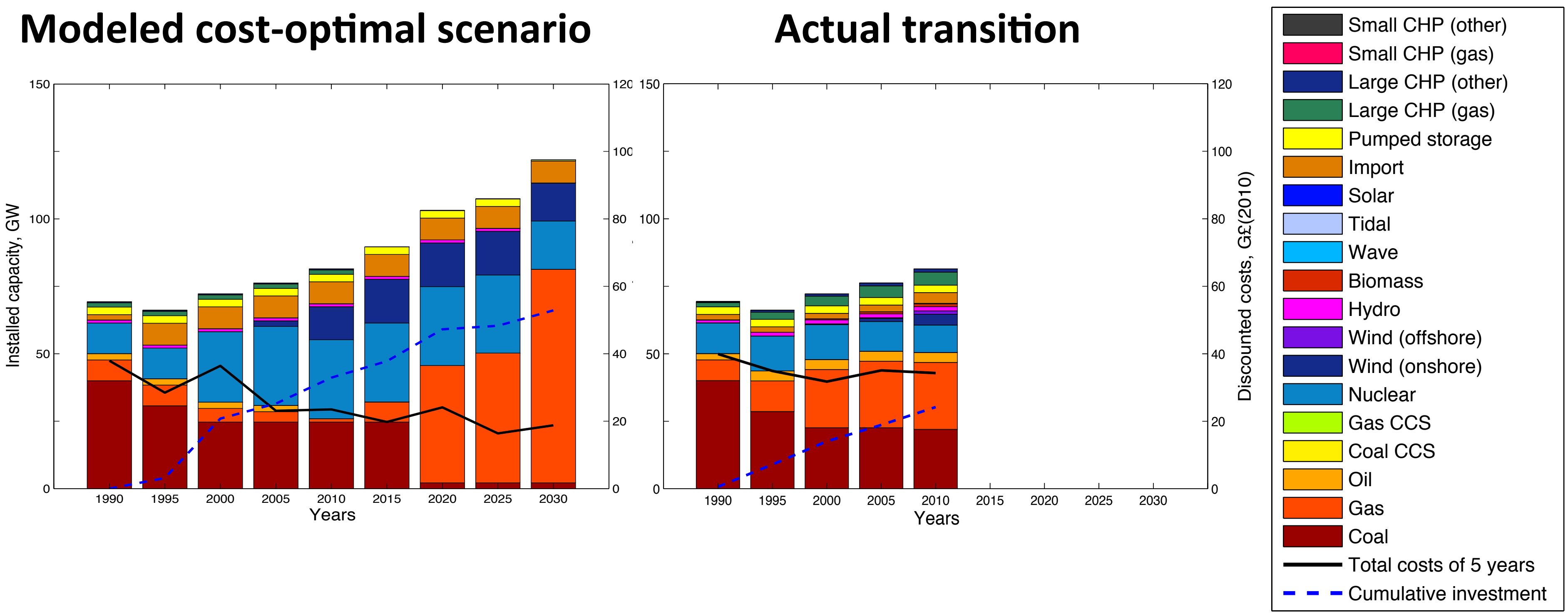
- Timeframe: 40 years (20 actual + 20 future)
- Historical data:
  - Actual electricity demand data
  - Actual plant retirement data
  - Minimized parametric uncertainty in costs
  - Unavailable technologies are not considered, e.g. CCS
- No emission mitigation constraints yet

D-EXPANSE procedure

Cost-optimal pathway

Minimize total system costs

- Annual and peak demand
- Technology data
- Resource bounds
- Costs
- Emission targets
- ***One set of deterministic inputs***

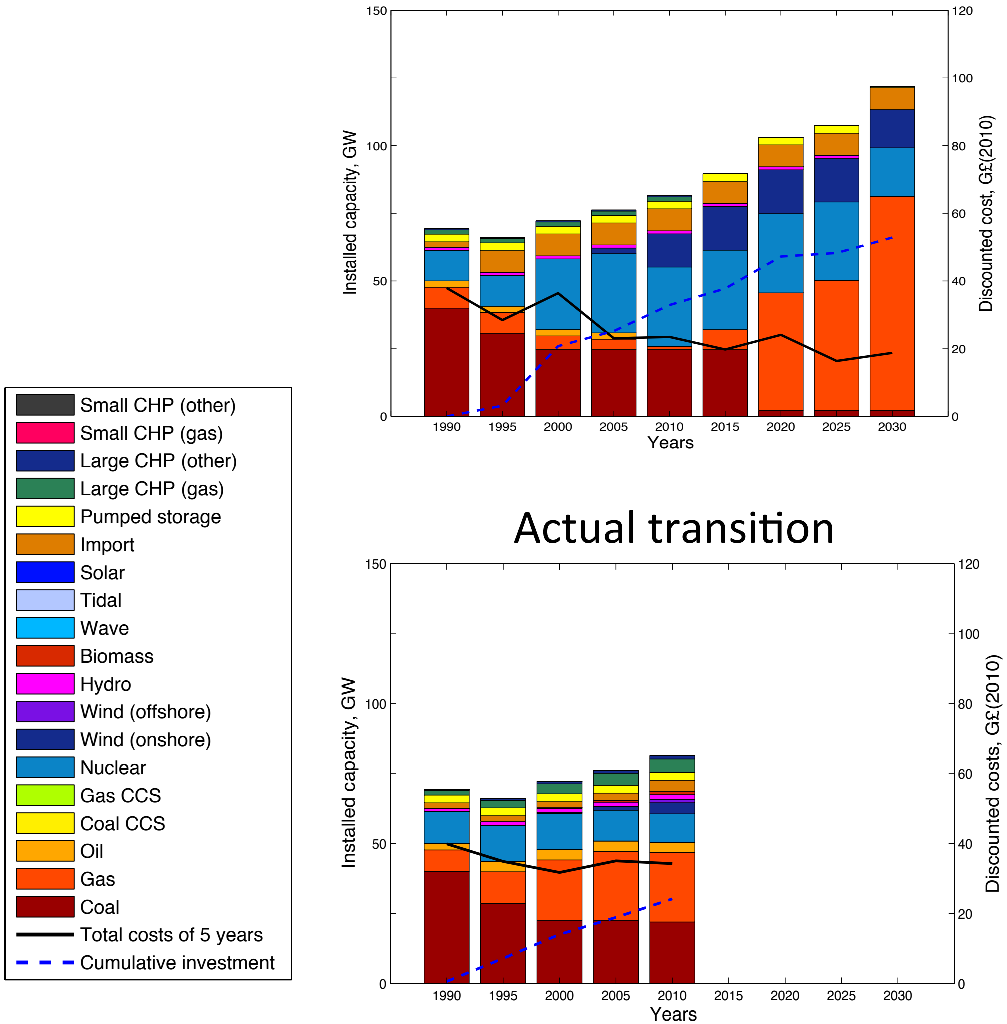


- Total cumulative costs 1990-2010 of the modeled actual transition scenario are 17% higher than of the cost-optimal scenario

Qualitative scenario choices from the past studies

- High oil and gas price ✗
- With/without nuclear ✗
- Low or high renewables ✗

Modeled cost-optimal scenario



Why near-optimal?

- ***Complex system:*** A complex system can hardly be engineered to a single desired state (Ottino 2004)

- ***Unmodeled objectives:*** The cost-optimal pathway may not be the best given the unmodeled objectives (Chang et al. 1982a, 1982b; DeCarolis 2011)

- ***Stakeholders***: Engagement of stakeholders requires alternatives to be posed for discussion (Trutnevyte et al. 2012a, 2012b; Trutnevyte 2013)

➢ ***In D-EXPANSE, costs are optimization constraints rather than objectives***

D-EXPANSE procedure

Cost-optimal pathway → A large number of near-optimal pathways

Minimize total system costs

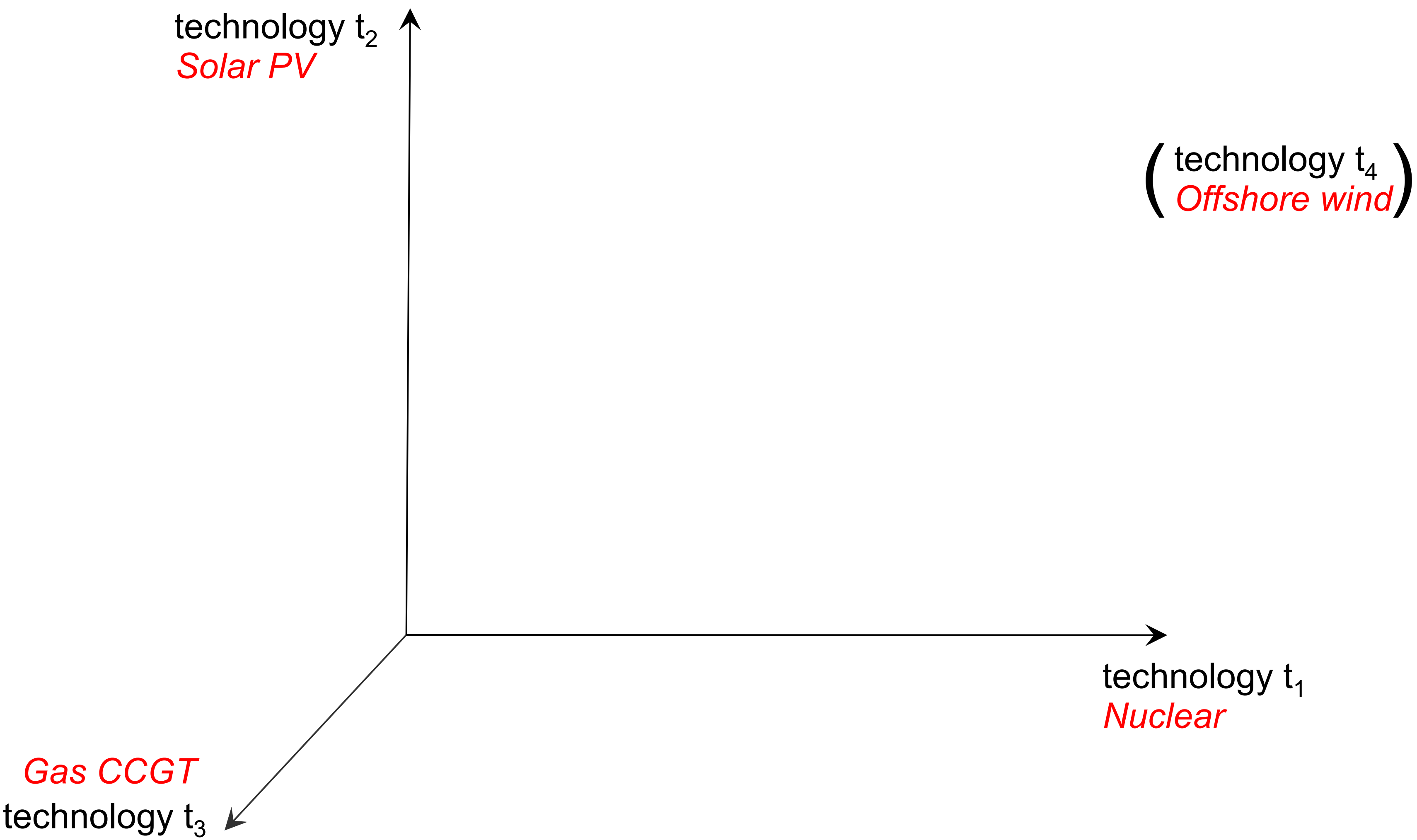
- Annual and peak demand
- Technology data
- Resource bounds
- Costs
- Emission targets
- ***One set of deterministic inputs***
- ***Work in progress***

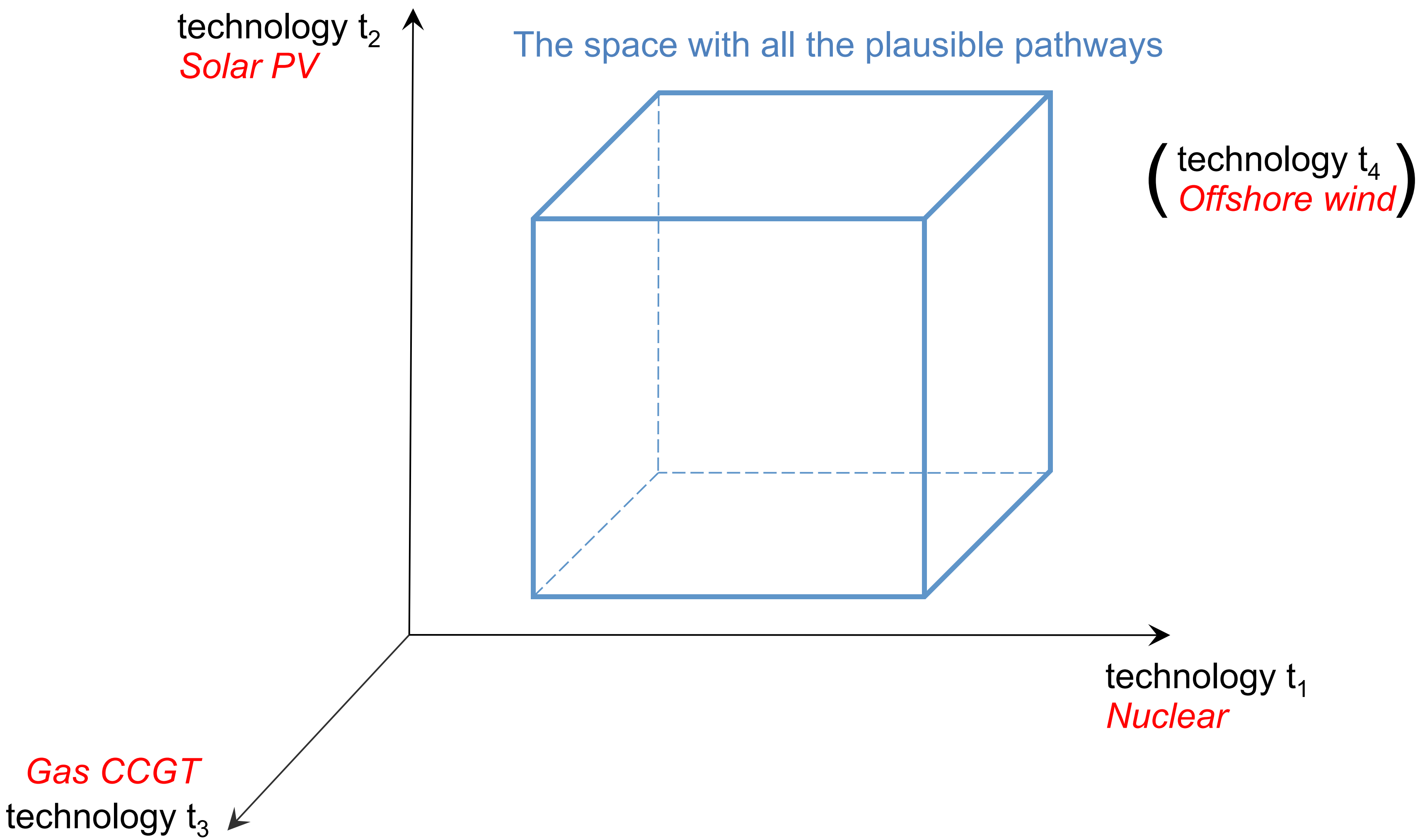
Slack

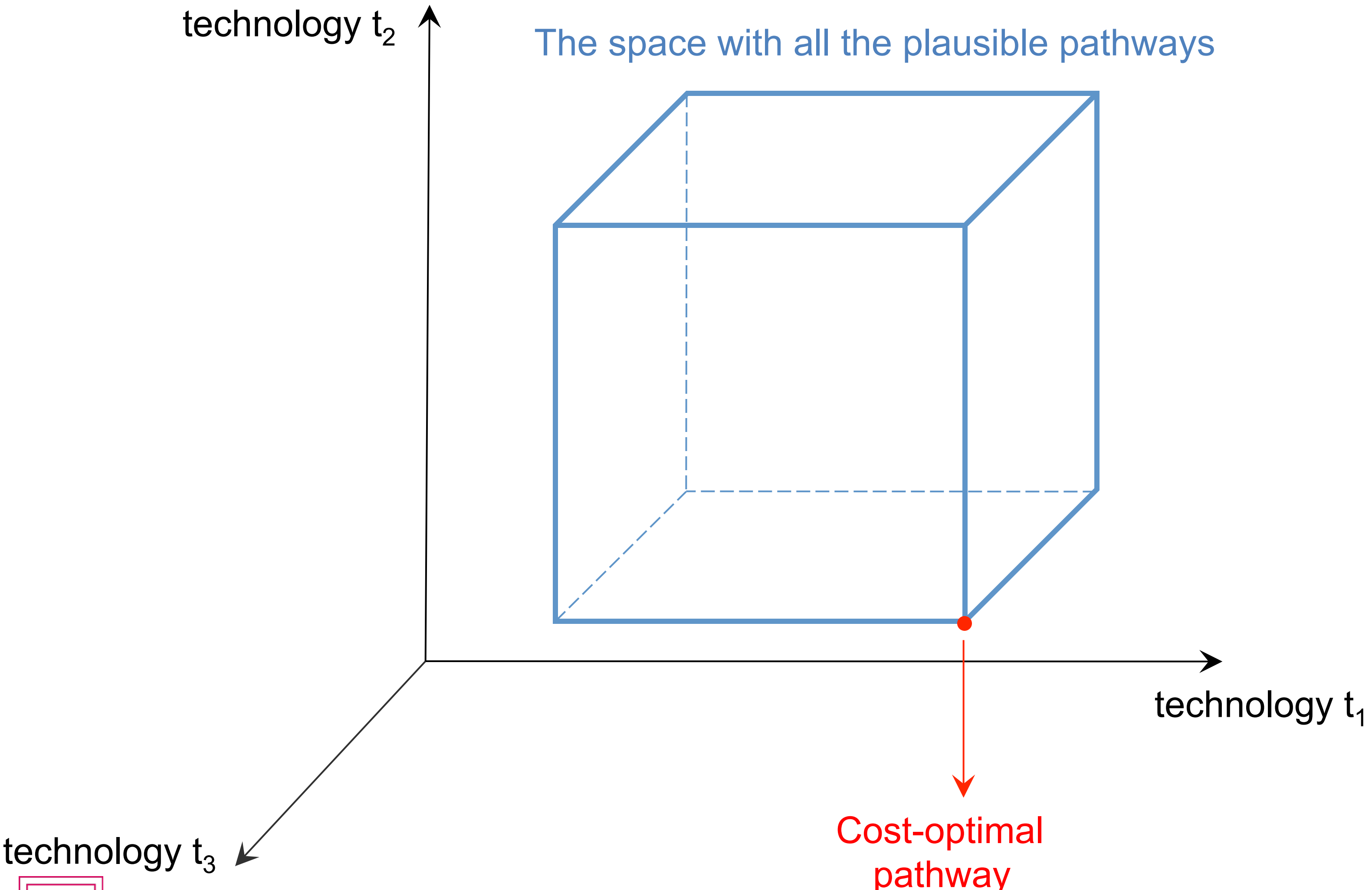
- e.g. 20% on total system costs

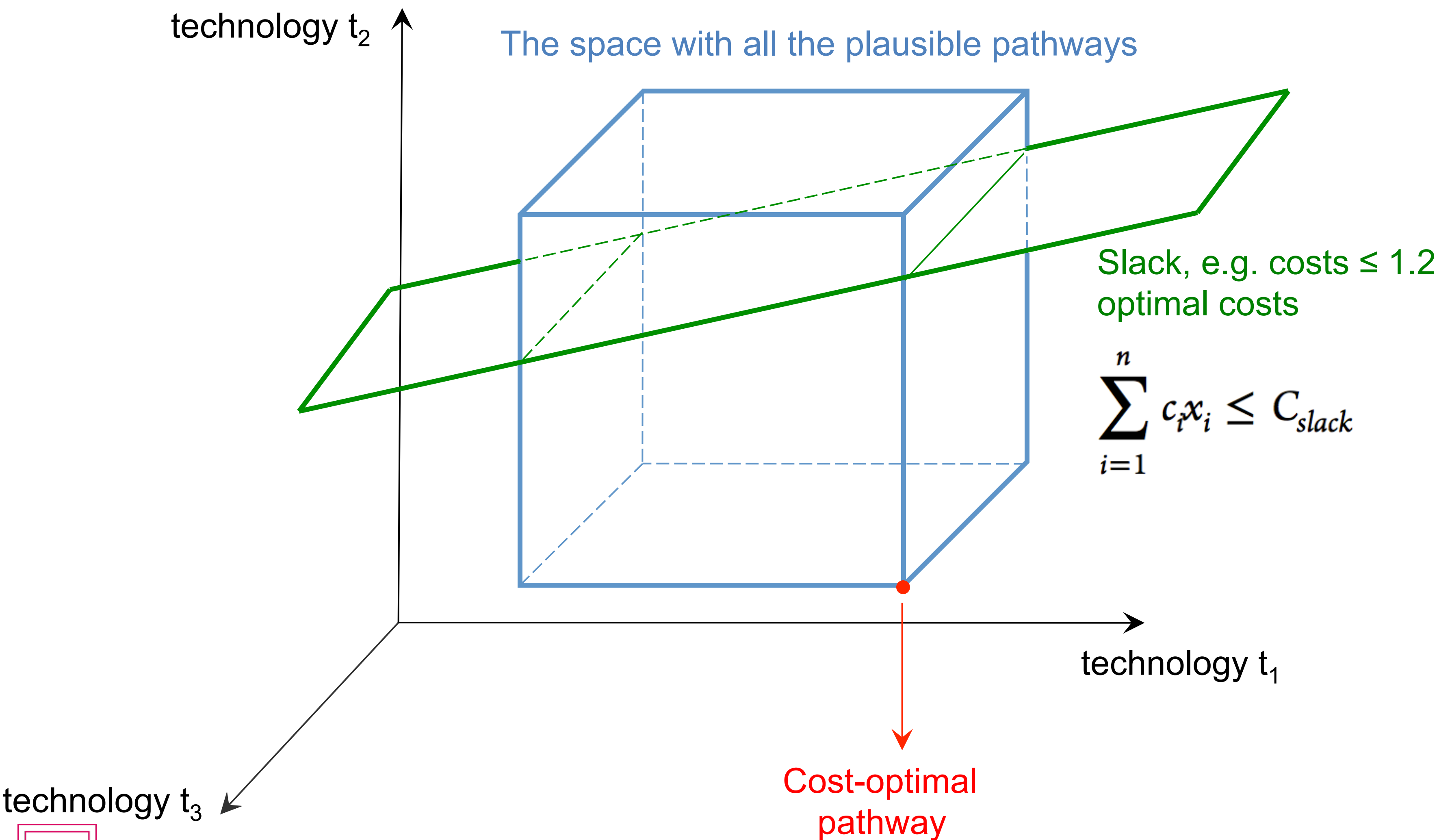
Efficient random generation technique
(Chang et al. 1982a,b)

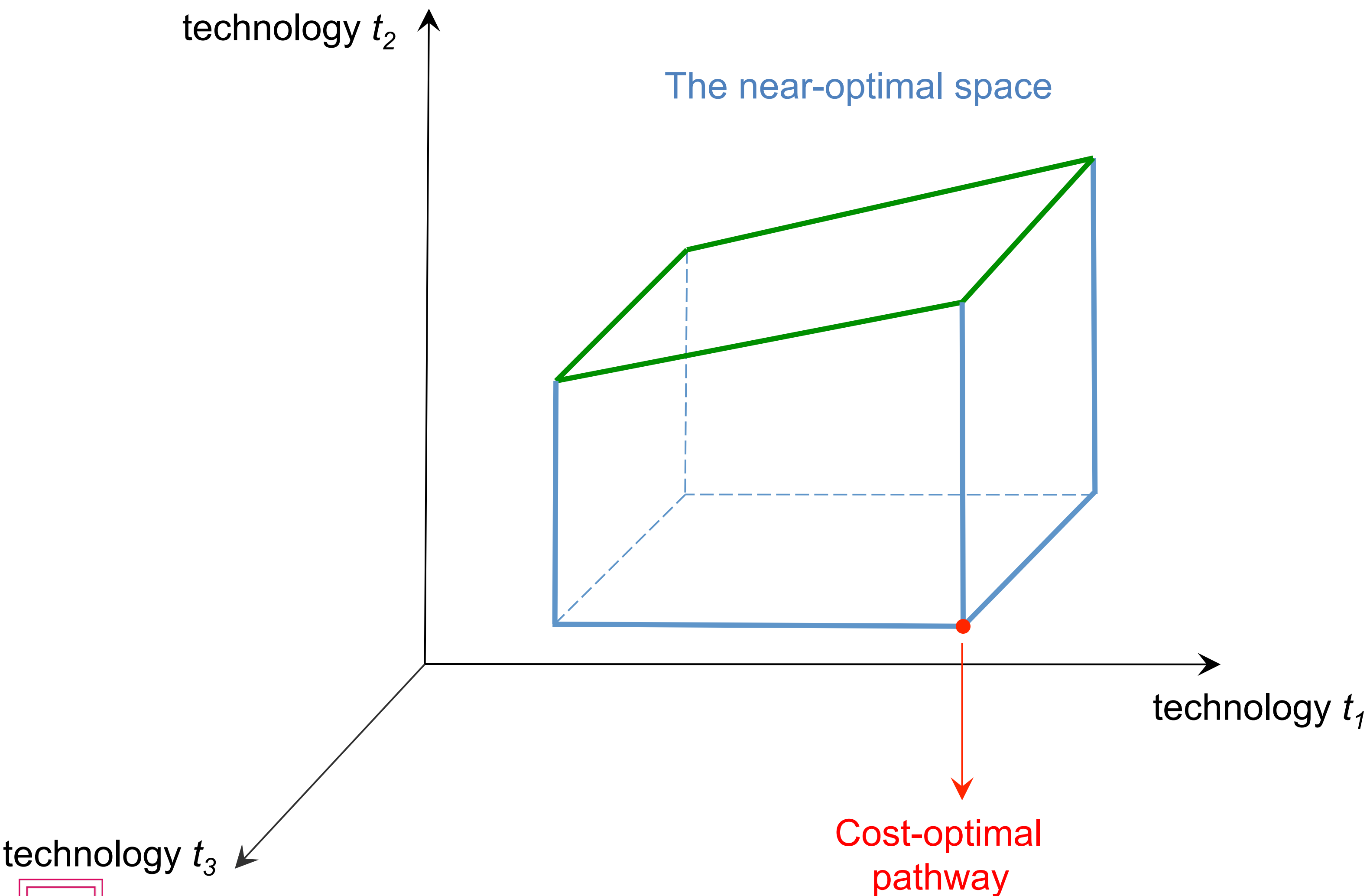
- 1000 pathways

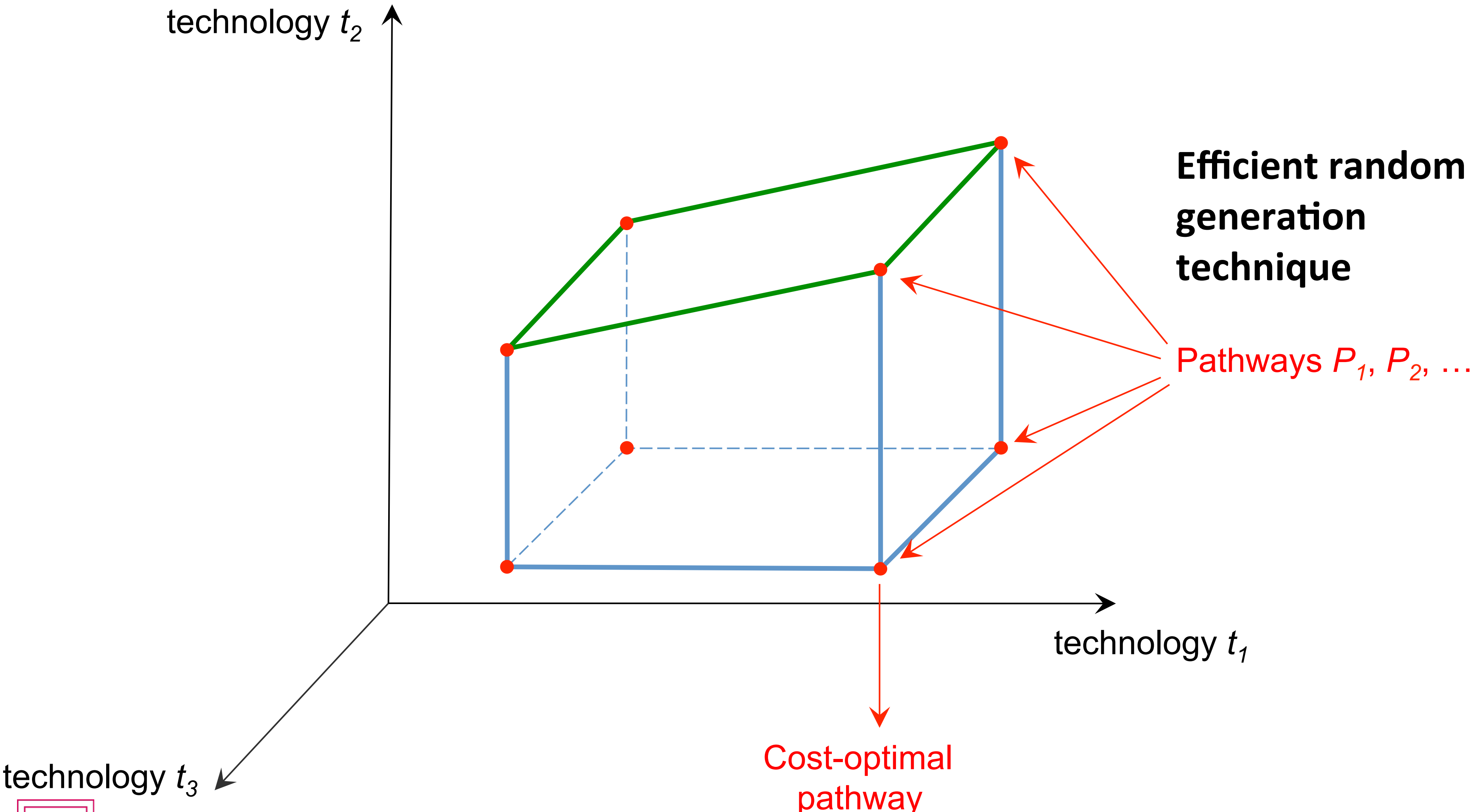

technology t_2
Solar PV
(technology t_4
Offshore wind)
technology t_1
Nuclear
Gas CCGT
technology t_3


technology t_2
Solar PV
The space with all the plausible pathways
(technology t_4
Offshore wind)
technology t_1
Nuclear
Gas CCGT
technology t_3

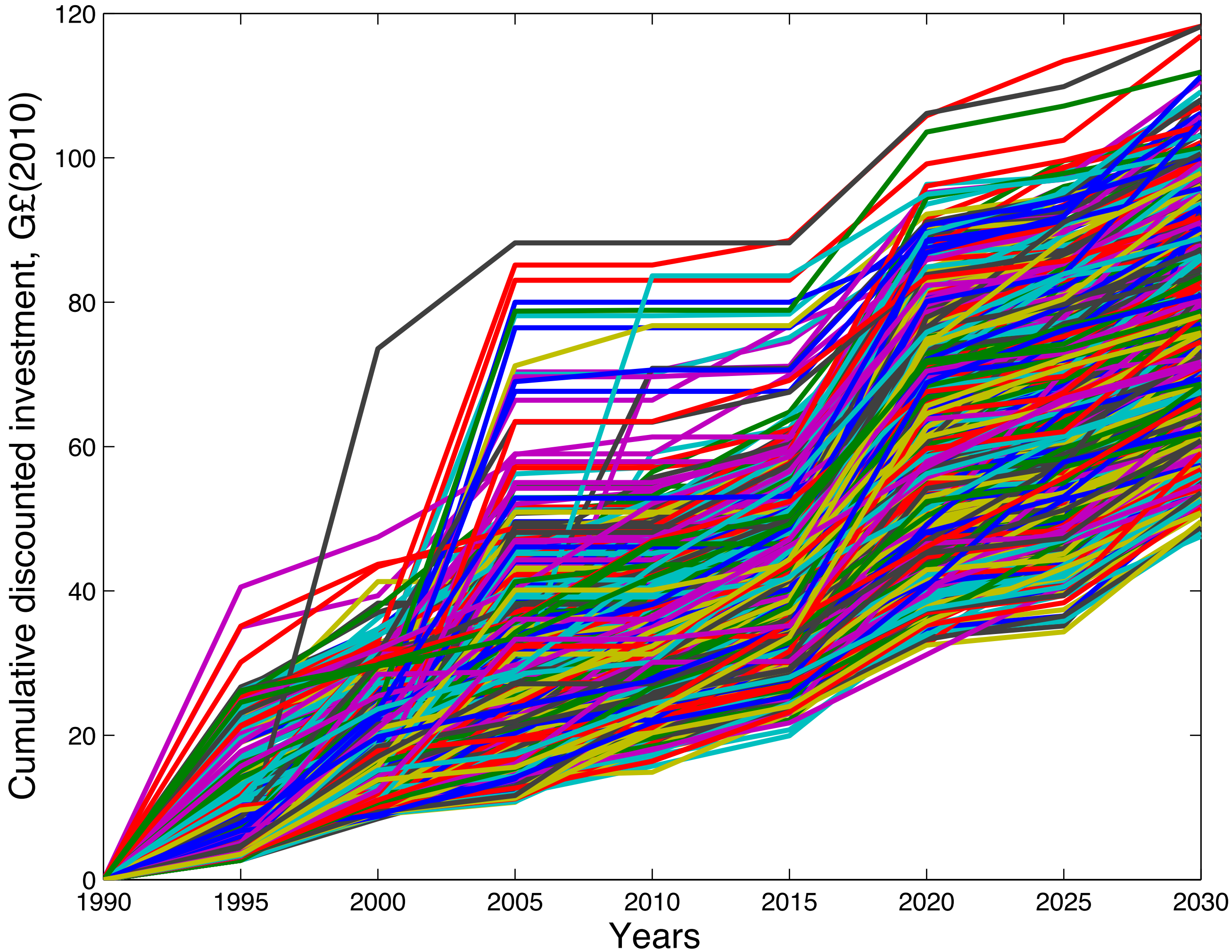

technology t_2
The space with all the plausible pathways
technology t_1
technology t_3
Cost-optimal
pathway


technology t2
The space with all the plausible pathways
Slack, e.g. costs ≤ 1.2 optimal costs
$\sum_{i=1}^{n} c_i x_i \leq C_{slack}$
technology t1
technology t3
Cost-optimal pathway


technology t_2
The near-optimal space
technology t_1
technology t_3
Cost-optimal
pathway


technology t_2
technology t_1
technology t_3
Efficient random generation technique
Pathways P_1, P_2, …
Cost-optimal pathway

Multiple near-optimal scenarios



D-EXPANSE procedure

Cost-optimal pathway → A large number of near-optimal pathways → Maximally-different pathways

Minimize total system costs

- Annual and peak demand
- Technology data
- Resource bounds
- Costs
- Emission targets
- ***One set of deterministic inputs***
- ***Work in progress***

Slack

- e.g. 20% on total system costs

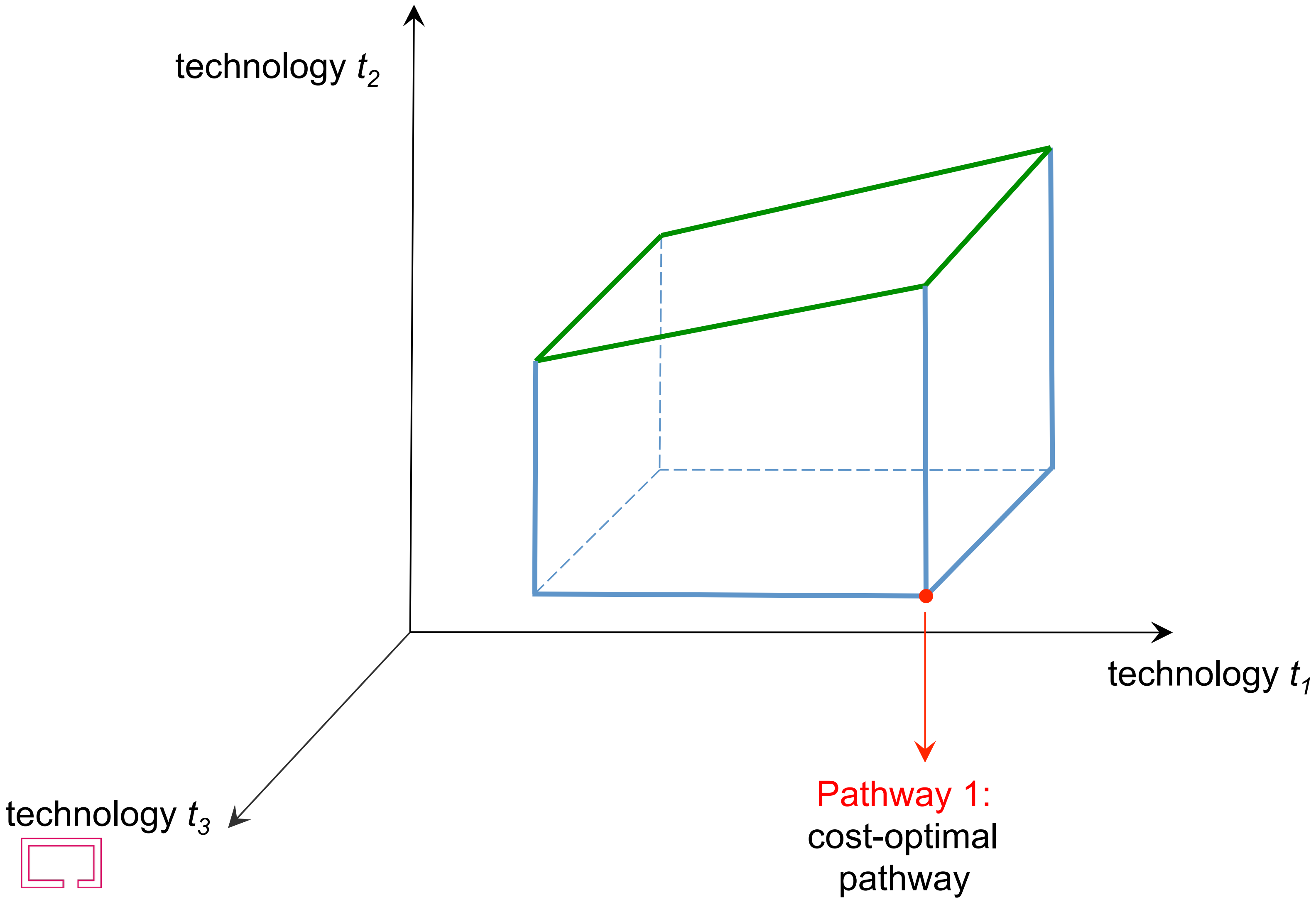
Efficient random generation technique

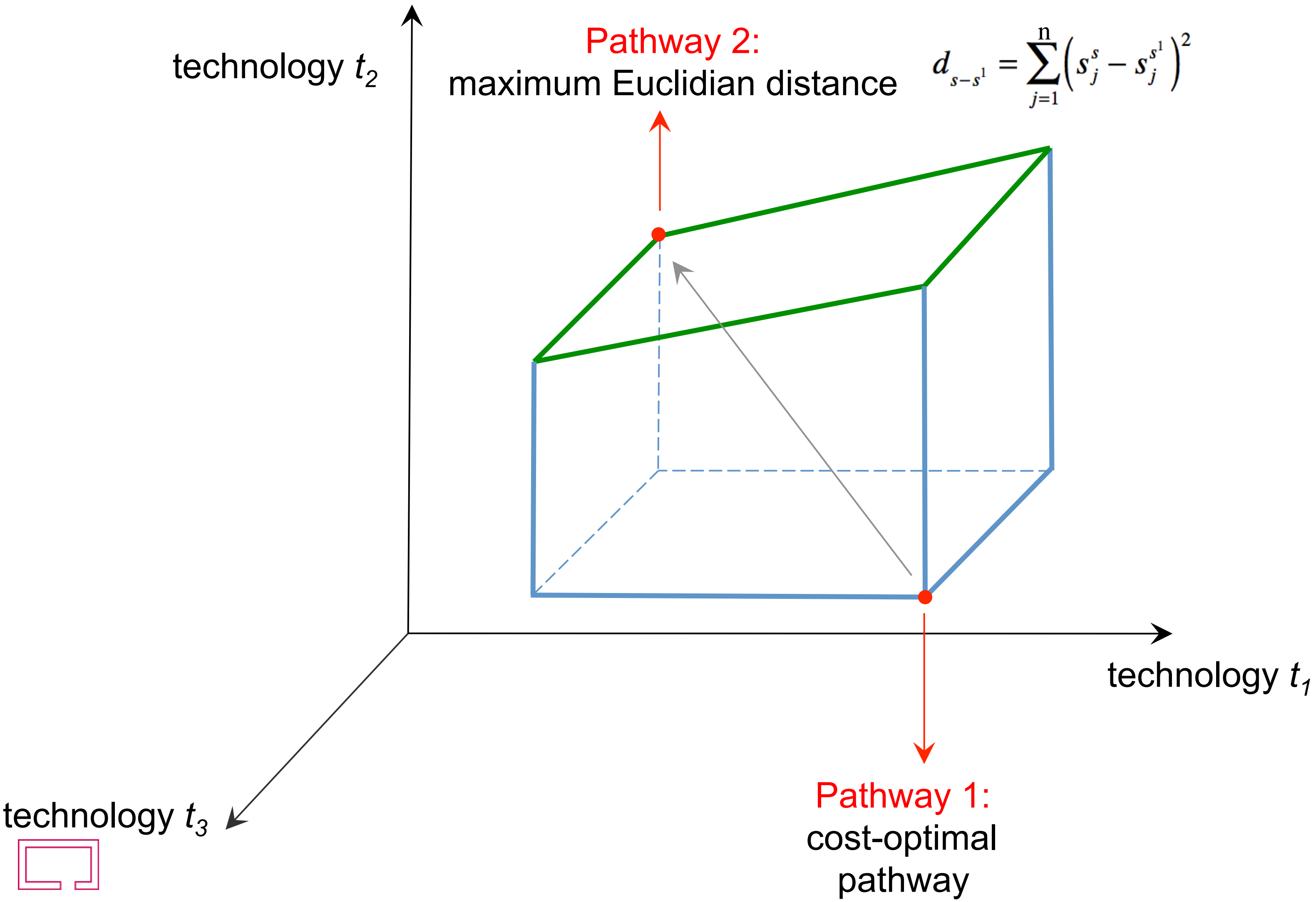
(Chang et al. 1982a,b)

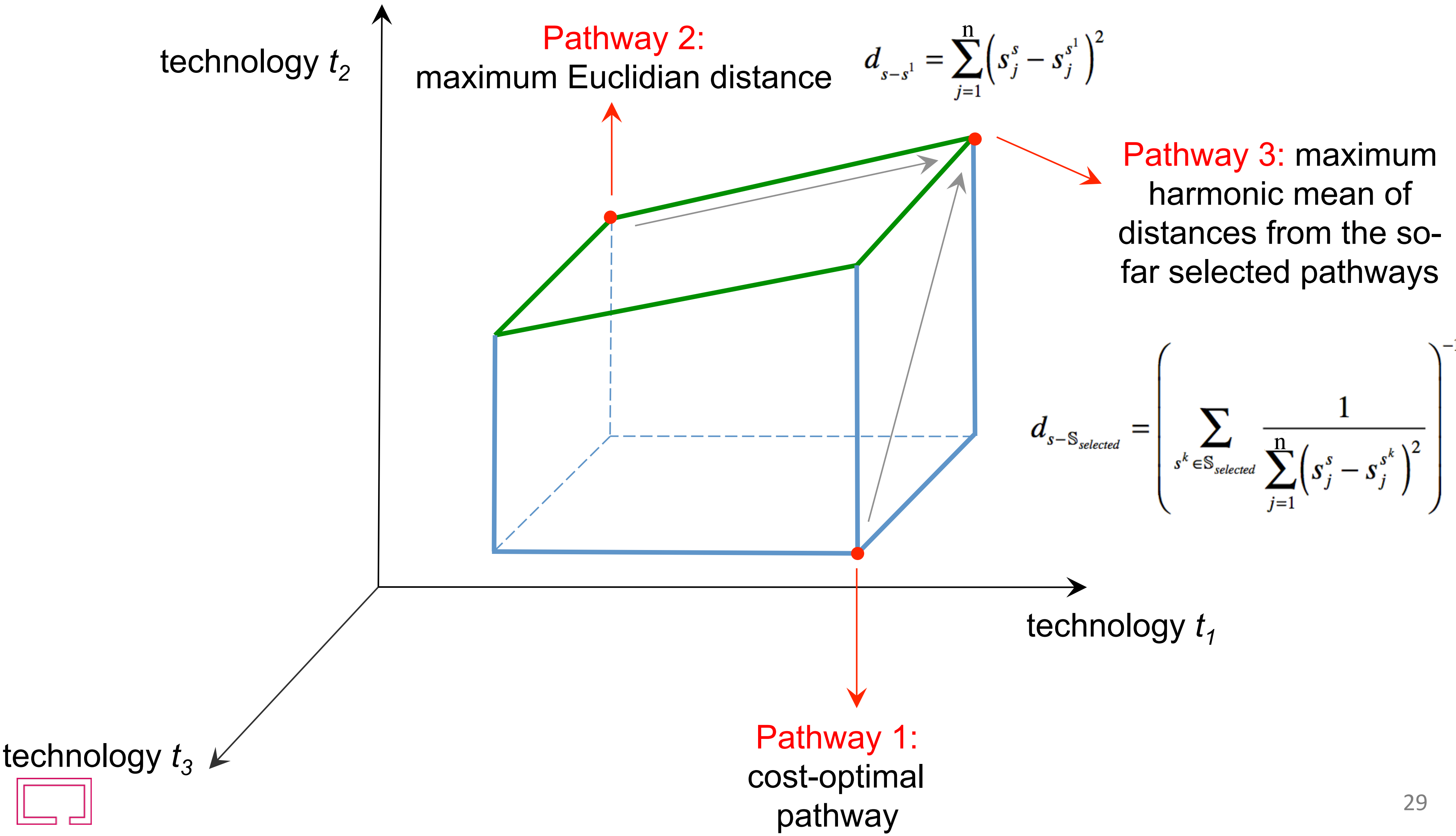
- 1000 pathways

Adapted distance-to-selected technique

(Tietje 2005; Trutnevyte et al. 2012)

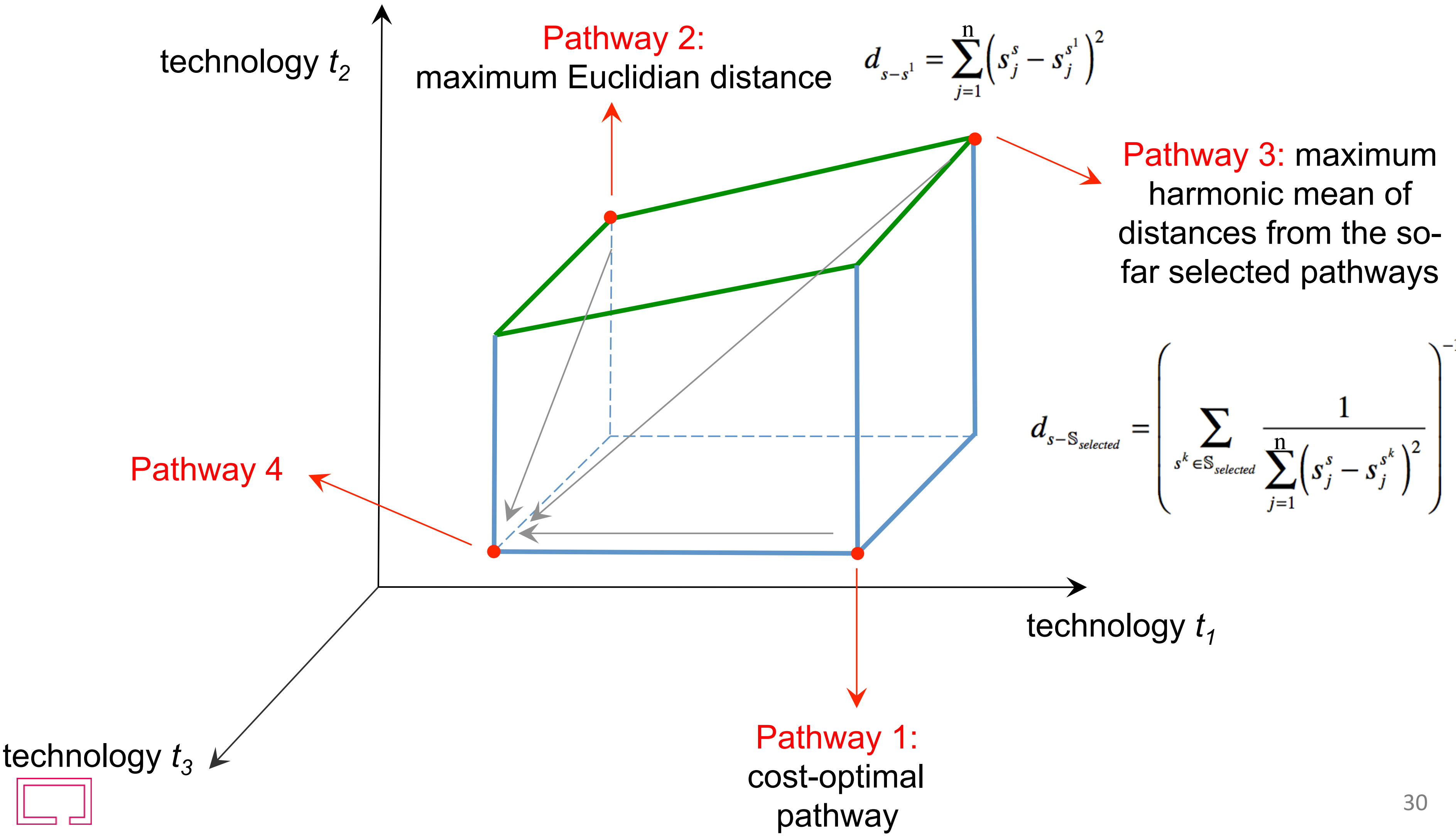

technology t_2
technology t_1
technology t_3
Pathway 1:
cost-optimal
pathway


technology t_2
Pathway 2:
maximum Euclidian distance
$d_{s-s^1} = \sum_{j=1}^{n} \left(s_j^s - s_j^{s^1} \right)^2$
technology t_1
technology t_3
Pathway 1:
cost-optimal
pathway



$$d_{s-s^1} = \sum_{j=1}^{n} \left(s_j^s - s_j^{s^1} \right)^2$$

$$d_{s-\mathbb{S}_{selected}} = \left(\sum_{s^k \in \mathbb{S}_{selected}} \frac{1}{\sum_{j=1}^{n} \left(s_j^s - s_j^{s^k} \right)^2} \right)^{-1}$$

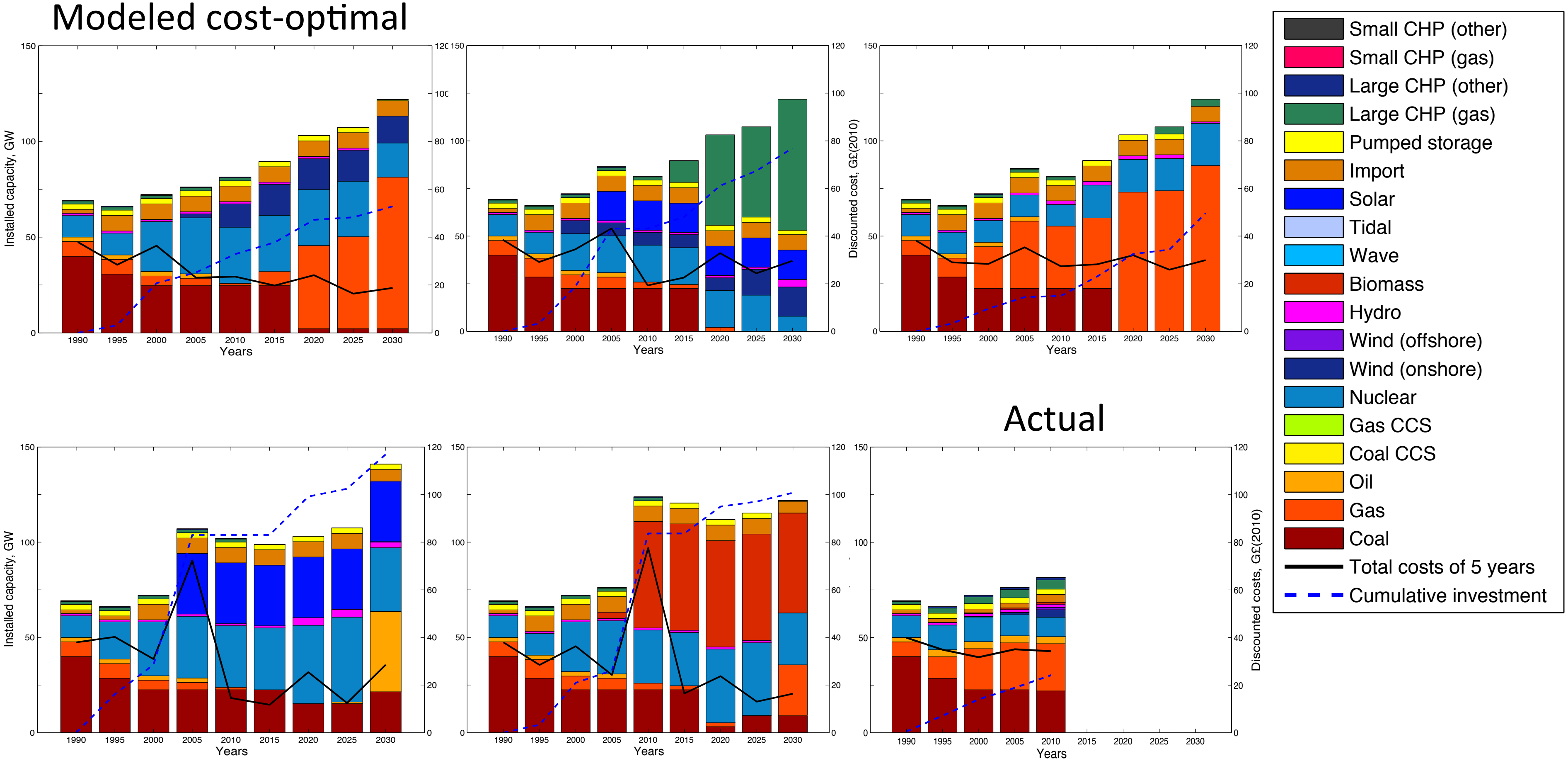


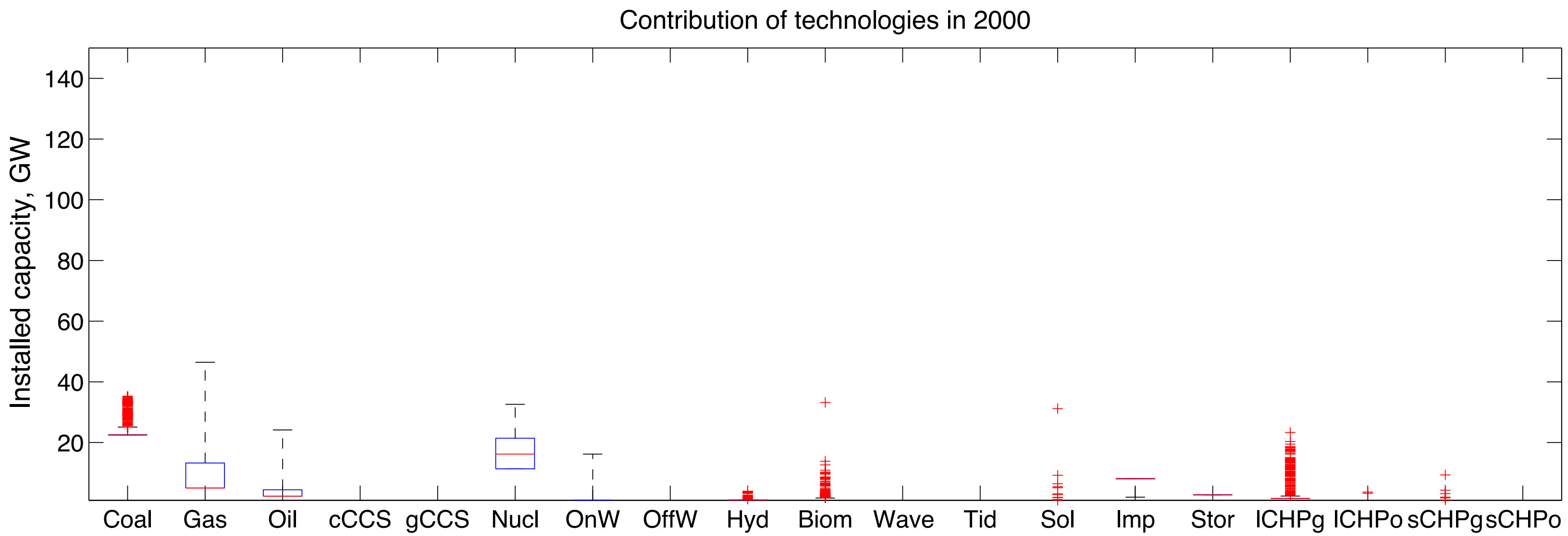
$$d_{s-s^1} = \sum_{j=1}^{n}\left(s_j^s - s_j^{s^1}\right)^2$$

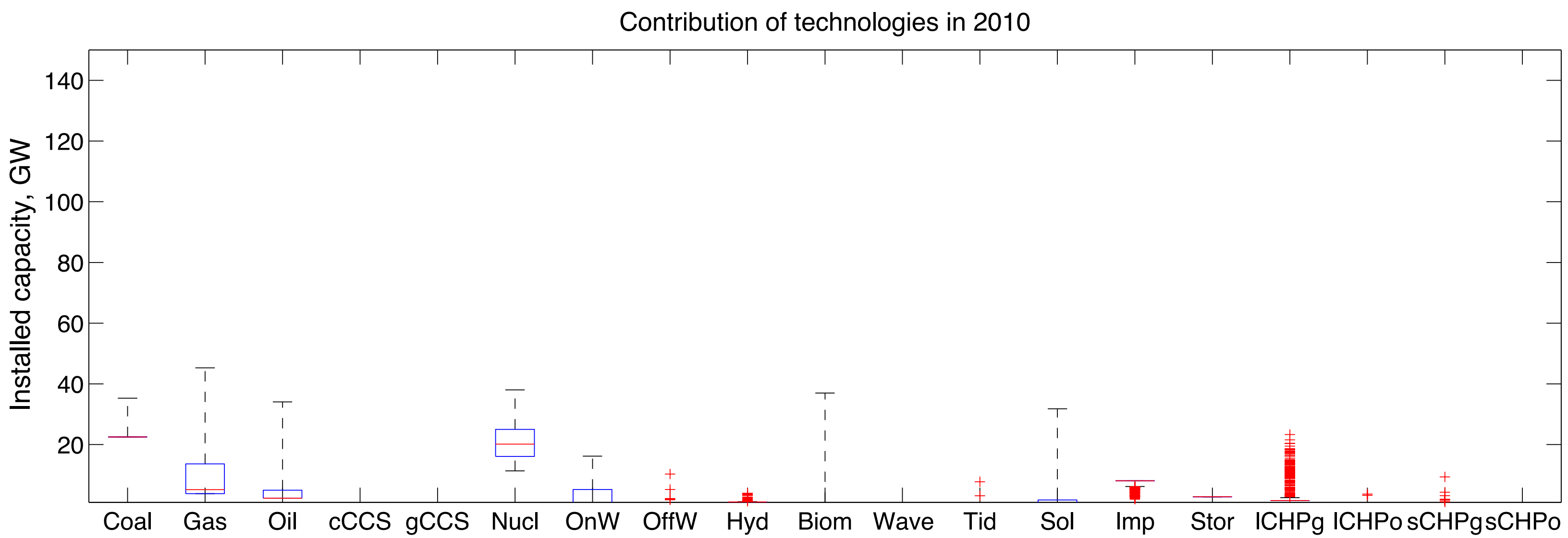
$$d_{s-\mathbb{S}_{selected}} = \left(\sum_{s^k \in \mathbb{S}_{selected}} \frac{1}{\sum_{j=1}^{n}\left(s_j^s - s_j^{s^k}\right)^2} \right)^{-1}$$

Maximally different near-optimal scenarios

Modeled cost-optimal




Contribution of technologies in 2000
Installed capacity, GW
140
120
100
80
60
40
20
Coal
Gas
Oil
cCCS
gCCS
Nucl
OnW
OffW
Hyd
Biom
Wave
Tid
Sol
Imp
Stor
ICHPg
ICHPo
sCHPg
sCHPo


Contribution of technologies in 2010
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Coal
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OnW
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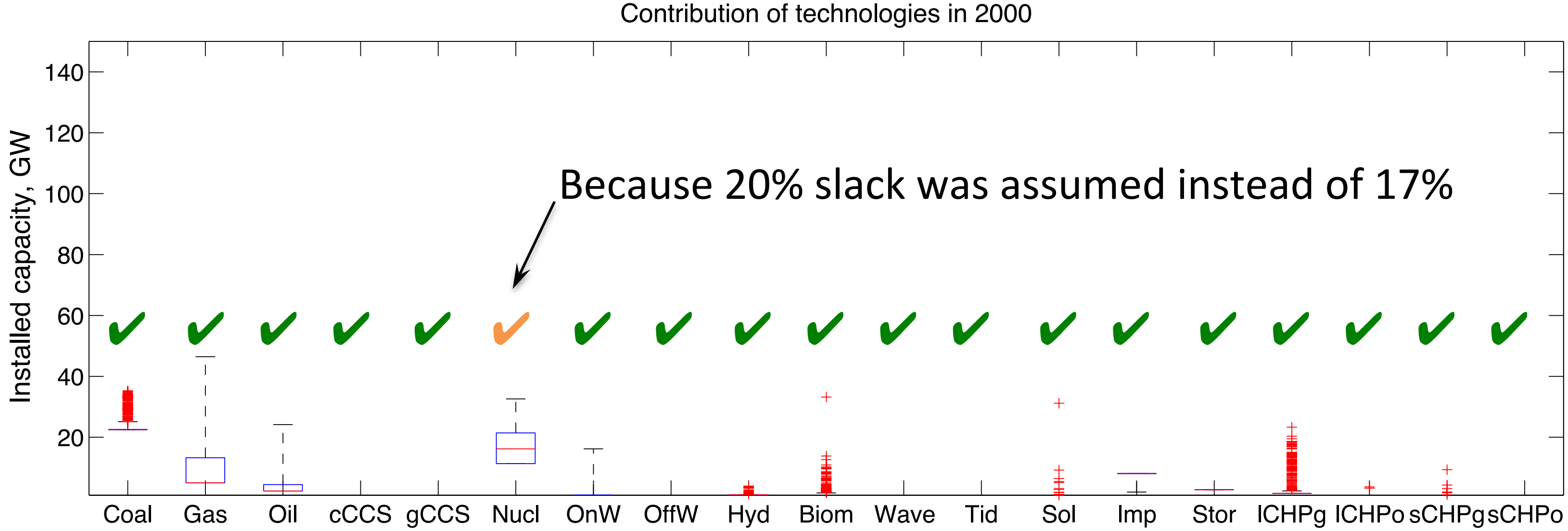
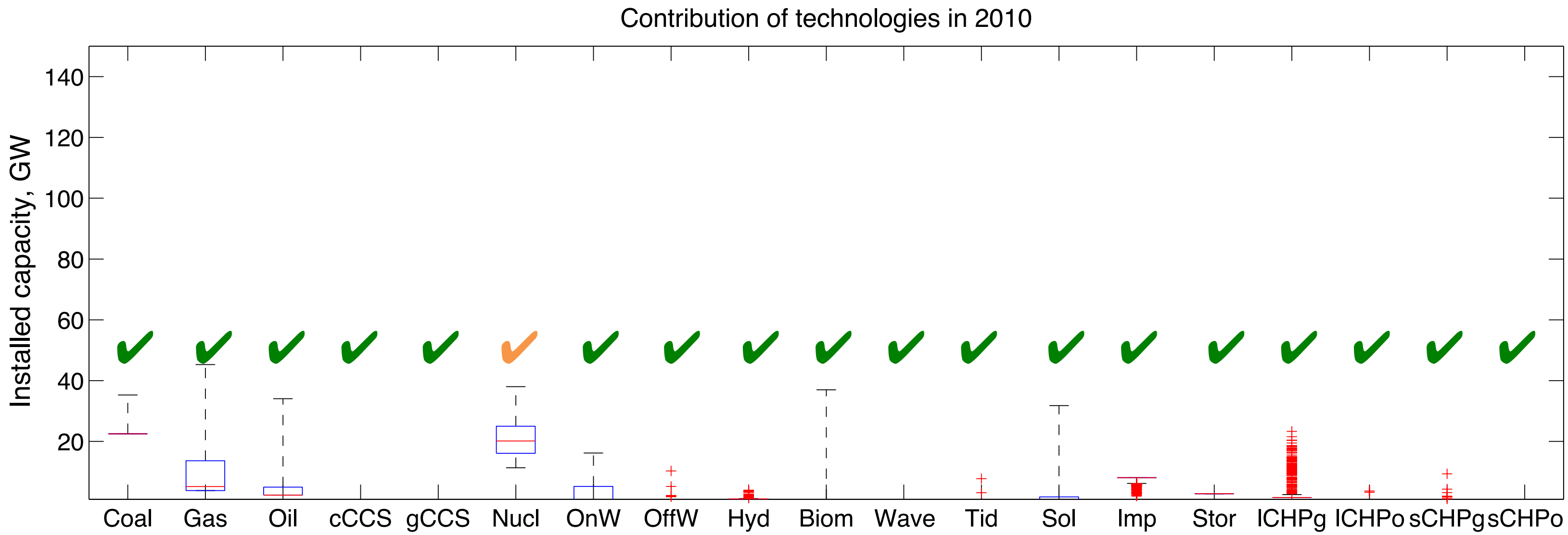
Hyd
Biom
Wave
Tid
Sol
Imp
Stor
ICHPg
ICHPo
sCHPg
sCHPo


Contribution of technologies in 2000
Installed capacity, GW
140
120
100
80
60
40
20
Because 20% slack was assumed instead of 17%
Coal Gas Oil cCCS gCCS Nucl OnW OffW Hyd Biom Wave Tid Sol Imp Stor ICHPg ICHPo sCHPg sCHPo


Contribution of technologies in 2010
Installed capacity, GW
140
120
100
80
60
40
20
Coal Gas Oil cCCS gCCS Nucl OnW OffW Hyd Biom Wave Tid Sol Imp Stor ICHPg ICHPo sCHPg sCHPo

Key messages for future scenario choice

- Need to look beyond the cost-optimal scenarios
  - Cost optimization does not necessarily approximate the real world transition
  - Relatively high deviation, e.g. 17% in total costs in 20 years
  - Near-optimal scenarios can be poles apart

- Qualitative scenario choices may not be enough
  - "Unknown unknowns" are challenging to capture, but "unexpected knowns" could be dealt with to some extent

- The actual transition could be encapsulated by the EXPANSE maximally-different scenarios
  - But EXPANSE scenarios are at extremes

Future research needs

Historical analysis:

- Improve precision of historical data
- Model with cost expectations rather than out-turn costs

EXPANSE model:

- Explore further metrics for selecting maximally different scenarios
- Explore alternative definitions of deviation from the cost-optimal scenarios
- Explore overlaps with parametric uncertainty analysis
- Needs better system representation

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Please get in touch with questions and comments

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REALISING TRANSITION PATHWAYS

Read more:

- Trutnevyte E., 2014. The allure of energy visions: are some visions better than others? Energy Strategy Reviews 2(3-4), 211-219.
- Trutnevyte E., 2013. EXPANSE methodology for evaluating the economic potential of renewable energy from an energy mix perspective. Applied Energy; 111; 593-601.
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- Trutnevyte E, Stauffacher M, Scholz RW, 2011. Supporting energy initiatives in small communities by linking visions with energy scenarios and multi-criteria assessment. Energy Policy; 39:7884–95.
- Trutnevyte E, Stauffacher M, Scholz RW, 2012b. Linking stakeholder visions with resource allocation scenarios and multi-criteria assessment. European Journal of Operations Research; 219: 762-772.