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# The effect of policy uncertainty on energy infrastructure deployment: A real option approach for CCS pipeline networks

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**Dr. Joris Morbee**
European Commission
Joint Research Centre

**www.jrc.ec.europa.eu**

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# Introduction: Why $CO_2$ transport networks?

- In order to keep climate change below 2ºC, the European Council reconfirmed in February 2011 the EU objective of **reducing EU greenhouse gas emissions by 80-95% by 2050** compared to 1990, in the context of necessary reductions according to the IPCC by developed countries as a group

- This would require near-complete "decarbonisation" of the power sector: based on the PRIMES EU energy system model, the EU Climate Roadmap 2050 projects **93-99% reduction of $CO_2$ emissions in the power sector** by 2050 compared to 1990

- **Carbon capture, transport and storage (CCS)** is one of the promising technological options for reducing $CO_2$ emissions: the scenarios of the EU Energy Roadmap 2050 project on average **133 GW of CCS power generation capacity by 2050**, which would require capturing and storing around **1 Gt of $CO_2$ per year**

- Large $CO_2$ sinks in Europe are concentrated in few locations (e.g. the North Sea), hence large-scale deployment of CCS across Europe will require the **development of new network infrastructure to transport the captured $CO_2$** from its sources (power plants) to the appropriate $CO_2$ sinks (e.g. depleted oil/gas fields)

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# Introduction: Effect of policy uncertainty

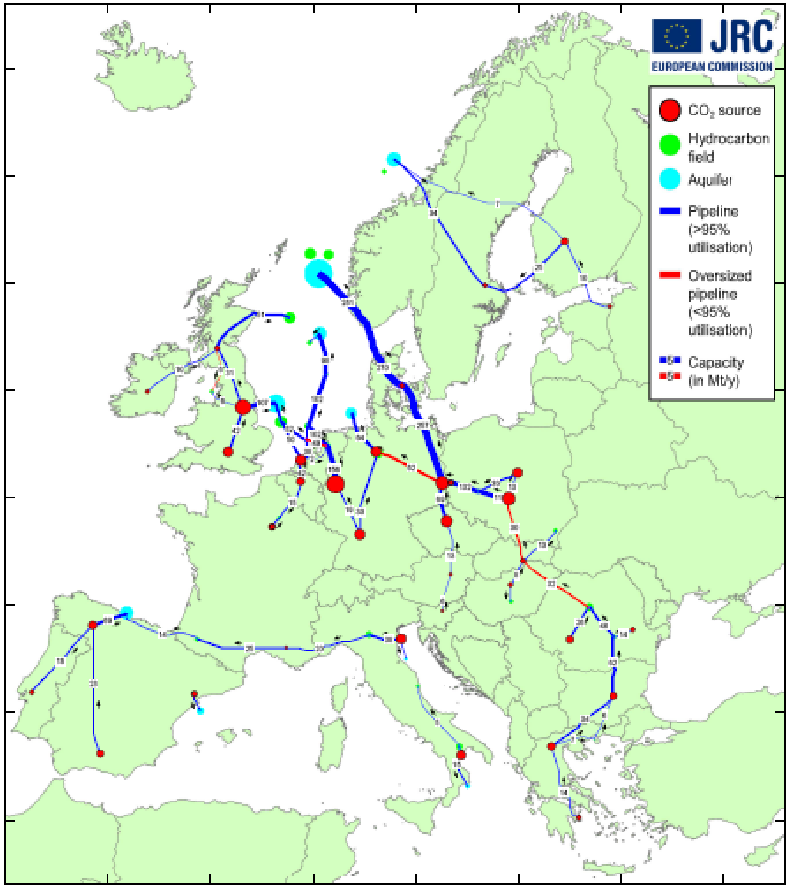
- Earlier work such as Mendelevitch et al. (2010) and Morbee et al. (2012) has shown that an **optimal (cost-minimising) $CO_2$ transport network** will most likely involve a **backbone of large international bulk pipelines** that collect $CO_2$ from multiple sources across Europe

- However, investments in such backbone infrastructure depend on the **anticipation of additional future $CO_2$ flows**, which in turn depend on the evolution of policy support for CCTS

- **As a result of policy uncertainty, investors may prefer to construct small-scale source-sink connections**, rather than more efficient bulk pipelines

**Example:** optimal 2050 network in Morbee et al. (2012)

YEAR 2050 – 16816km network – 33.4 billion EUR cumulative investment

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# Introduction: Research question and approach

**Research question**

- **How would the $CO_2$ pipeline network develop when there is uncertainty** regarding the future level of political support for CCS?
- **How does this compare to an ideal scenario** in which the $CO_2$ pipeline network develops optimally according to a deterministic CCS growth scenario?

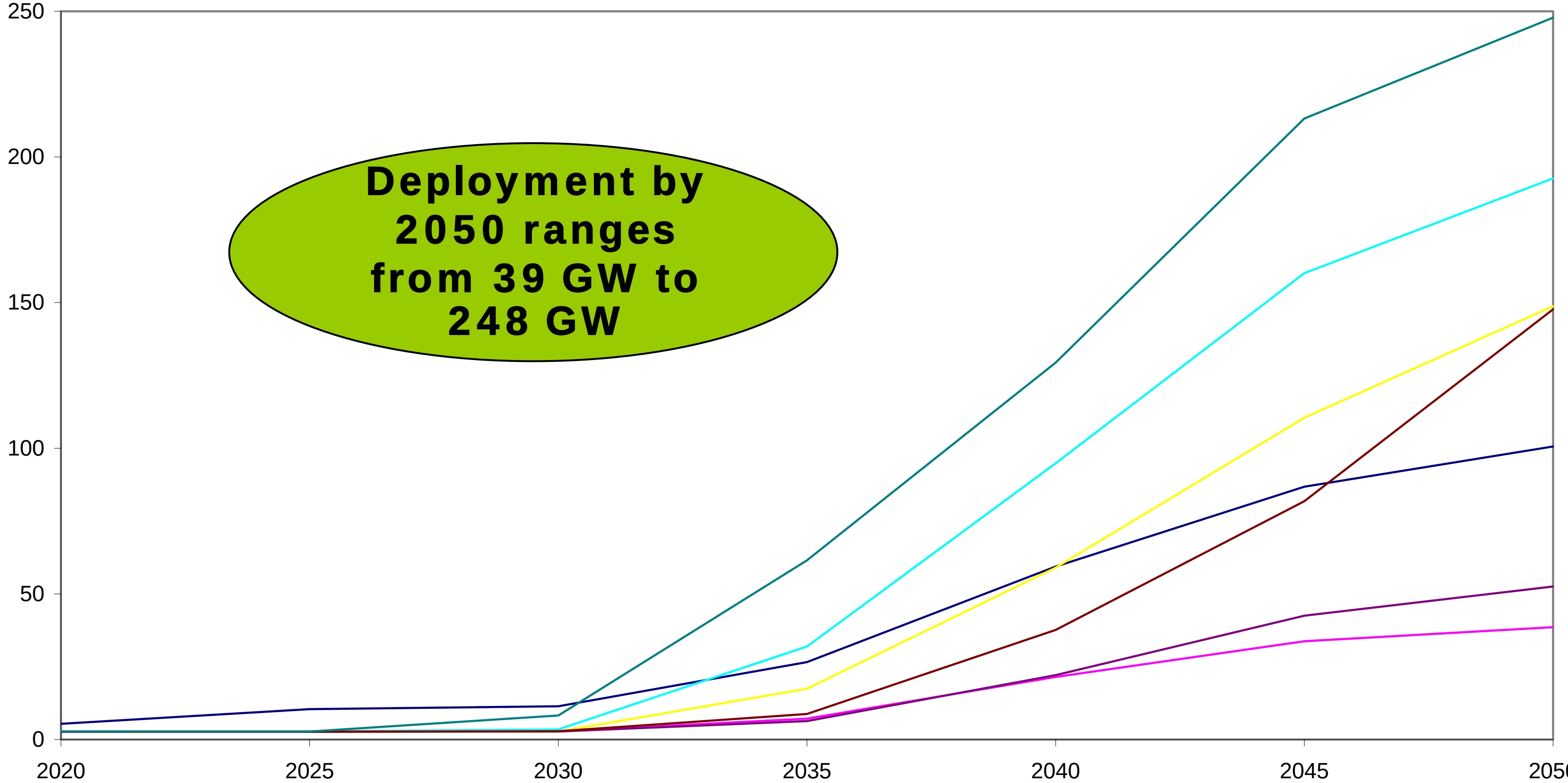
**Approach**

- We modify the **JRC's *InfraCCS* $CO_2$ pipeline network optimisation tool** (Morbee et al., 2012) to take into account an uncertain level of capture plant deployment
- The amount of CO2 captured from 2020 to 2050 is a **stochastic process** (a geometric Brownian motion), which is modelled discretely using a **binomial lattice** with 4 time steps
- The *InfraCCS* is used to determine the **optimal adaptive network investment strategy that minimises expected costs**

# Methodology: We start from the 7 scenarios of the EU's Energy Roadmap 2050

**CCS deployment in EU-27, in 7 scenarios of the Energy Roadmap 2050**

GW installed capacity



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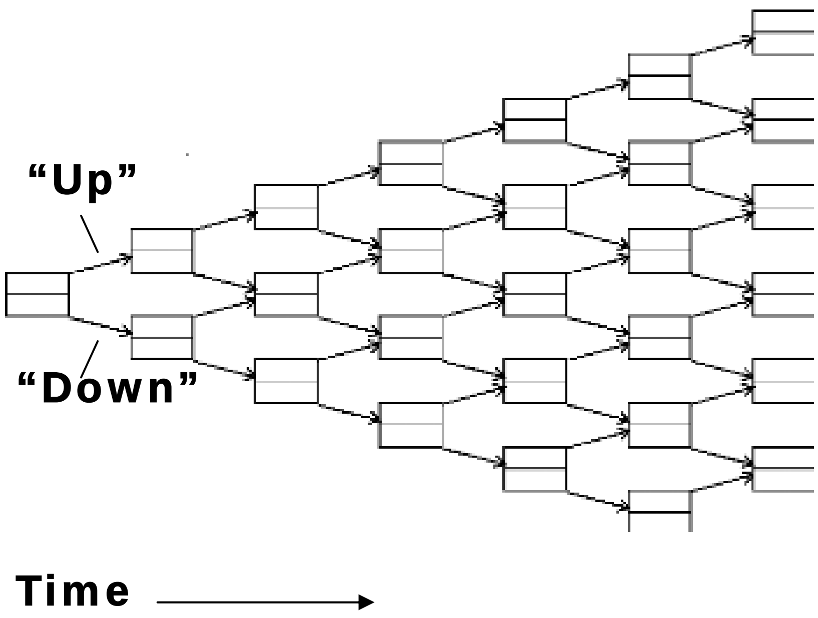
# Methodology: We create a binomial lattice, as in Cox-Ross-Rubinstein (1979) for option pricing

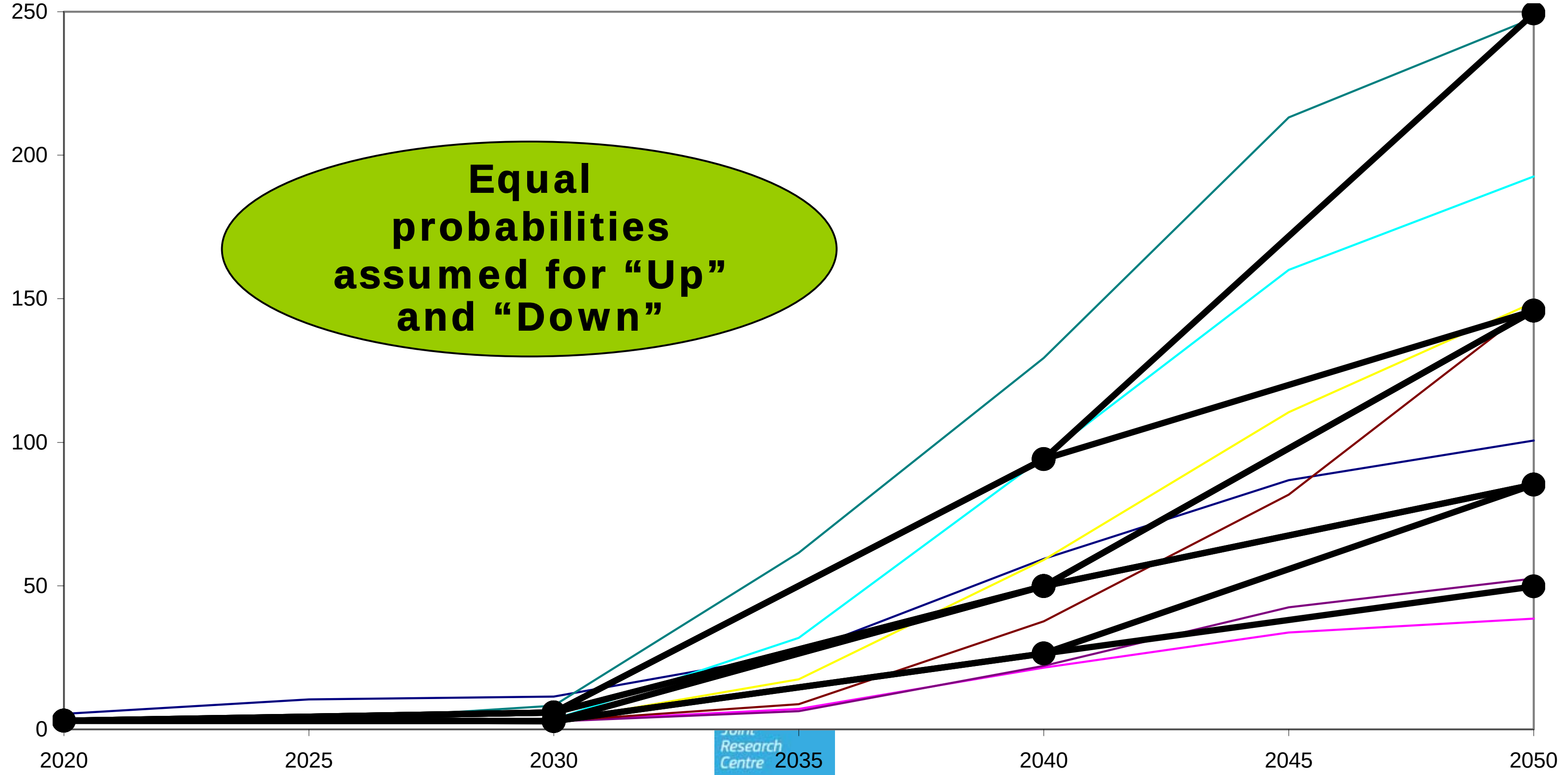
**Binomial lattice for stock option pricing**




- This binomial lattice is a **discretisation of the geometric Brownian motion**
- In stock option pricing, the “Up” and “Down” **steps are chosen based on the volatility** of the underlying stock
- Here, we choose the up and down steps such that at every time step, the **95% confidence interval** of the geometric brownian motion corresponds to the **range of the EU Energy Roadmap scenarios**

# Methodology: Comparison of EU scenarios, with the binomial lattice

**CCS deployment in EU-27, in 7 scenarios of the Energy Roadmap 2050** versus **binomial lattice** [GW installed capacity]



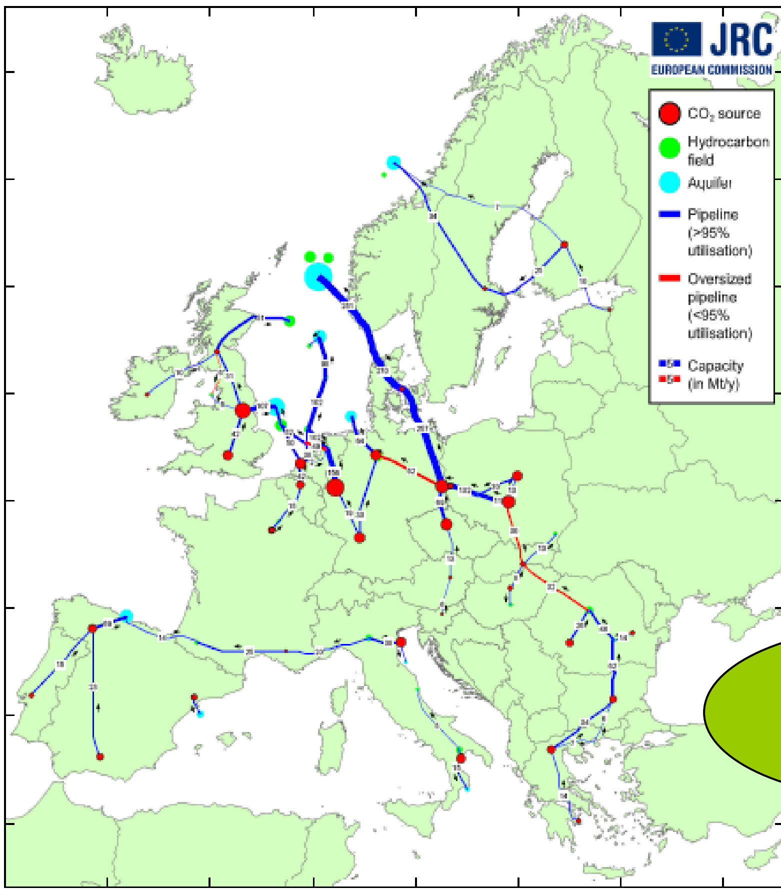
# Methodology: We apply the *InfraCCS* pipeline network optimisation tool

- In the binomial lattice, the uncertainty of capture plant deployment is **gradually resolved** over time. E.g. in 2040, more is known about the capture plant deployment scenario than in 2030
- We run the ***InfraCCS* model, a mixed-integer programming model** that computes the optimal (cost-minimising) pan-European pipeline network for a given capture plant deployment scenario
- The *InfraCCS* model is adjusted so that it **optimises the network investment decisions at each time step**, in order to minimise expected total pipeline network investment cost (risk-neutrality assumption)
- The optimal strategy is **adaptive**: pipeline network investment decisions are dependent on how CCS deployment develops over time (i.e., which path in the binomial lattice is followed)
- Note that the tree is **non-recombinant**: the optimal decisions in each point depend also on which route was taken to arrive at that point

# Results: Network structure

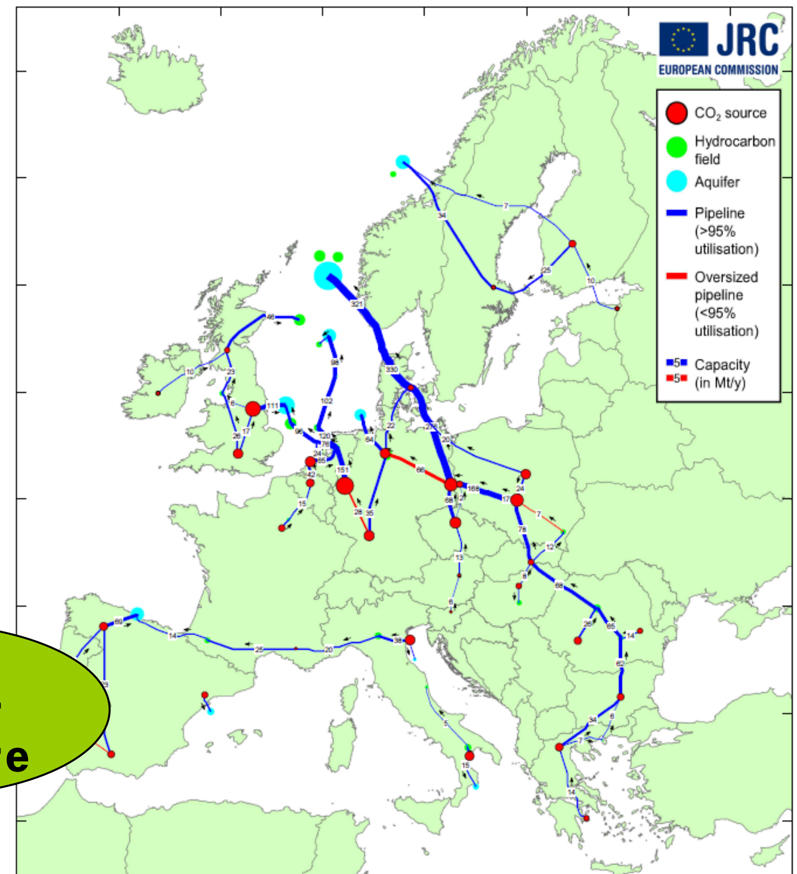
**Network by 2050, when "Up" has happened at every node on the way**

YEAR 2050 – 16816km network – 33.4 billion EUR cumulative investment




**Network when same path is followed deterministically**

YEAR 2050 – 18312km network – 37.5 billion EUR cumulative investment




**Very similar structure**

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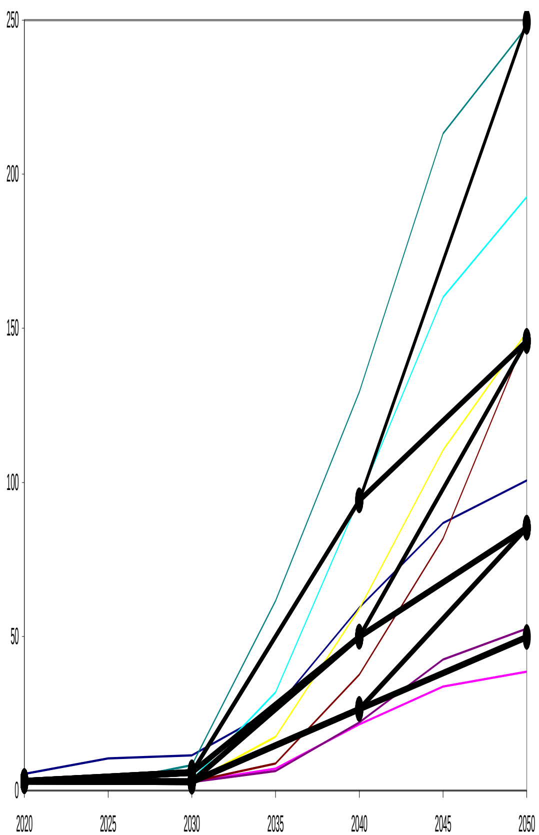
(X) Difference

# Results: Uncertainty leads to extra cost…

Billion euro




| Total network cost when this end point is reached | Difference | Cost when same path is followed deterministically |
|---|---|---|
| 37.5 | **4.1** | 33.4 |
| 20.2 – 20.6 | **~2.9** | 17.2 – 17.9 |
| 12.3 – 12.5 | **~1.5** | 10.6 – 11.2 |
| 9.6 | **1.4** | 8.2 |

Policy uncertainty makes the network **~15% more expensive** (10% in NPV terms)

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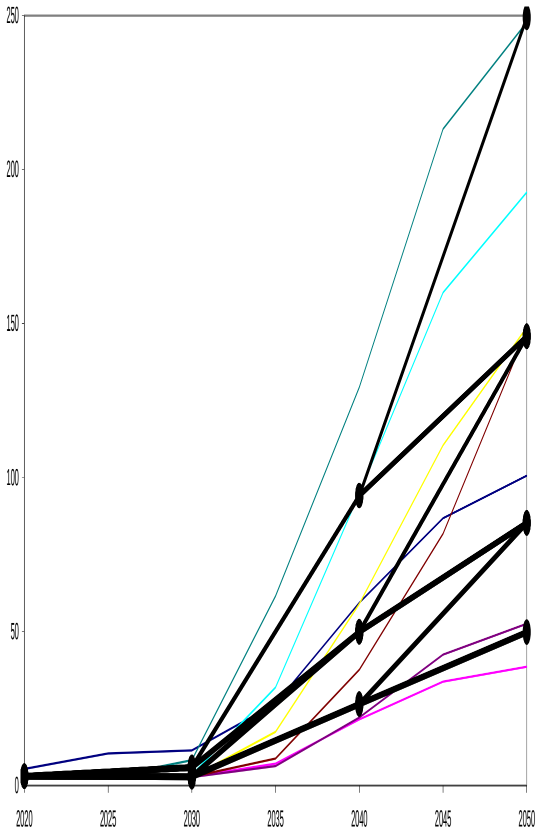
(X) Difference

# … and additional pipeline kilometers

Thousand km




| Total pipeline km when this end point is reached | Difference | Km when same path is followed deterministically |
|---|---|---|
| 22.4 | **2.7** | 19.8 |
| 18.0 – 18.9 | **~2.1** | 16.1 – 16.8 |
| 14.3 – 14.6 | **~1.8** | 12.3 – 13.1 |
| 13.3 | **2.4** | 11.0 |

Policy uncertainty makes the network **~14% longer** (many small pipelines in parallel, instead of 1 bulk pipeline)

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# Conclusions

- We simulate the effect of CCS policy uncertainty on the optimal (or sub-optimal) development of a $CO_2$ transport pipeline network
- We run the *InfraCCS* pipeline optimisation model on a binomial lattice of capture plant deployment scenarios
- We find that policy uncertainty:
  - Increases total network cost by 15%
  - Increases the NPV of total network cost by 10%
  - Increases the total length of pipelines constructed by 14%
- In the most optimistic case of CCS deployment, total network cost may be increased by more than 4 billion euro compared to the deterministic case

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