Linking techno-economic modeling of Europe's electricity sector to large-scale CCS infrastructure optimization

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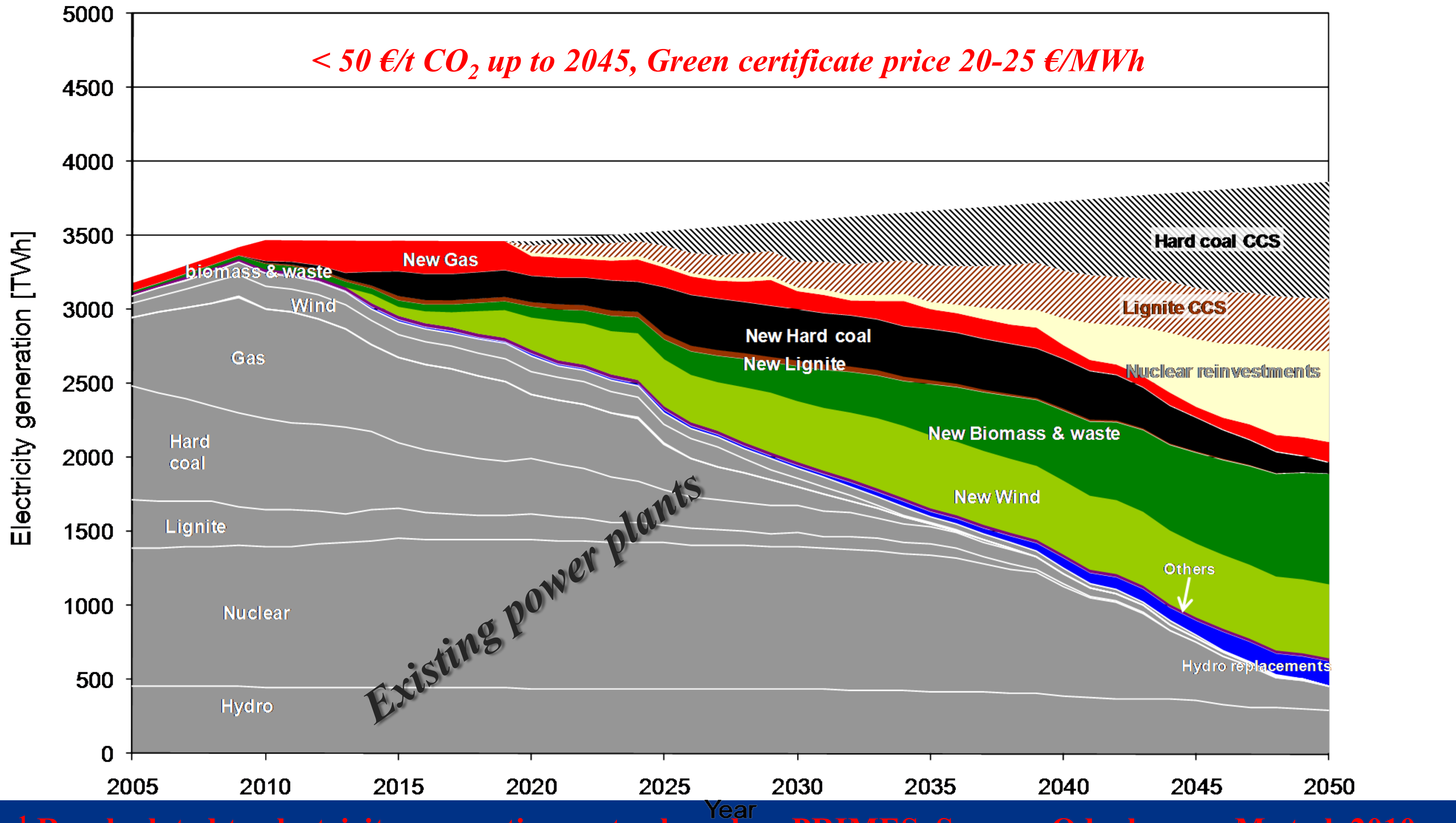
Aim & Methodology

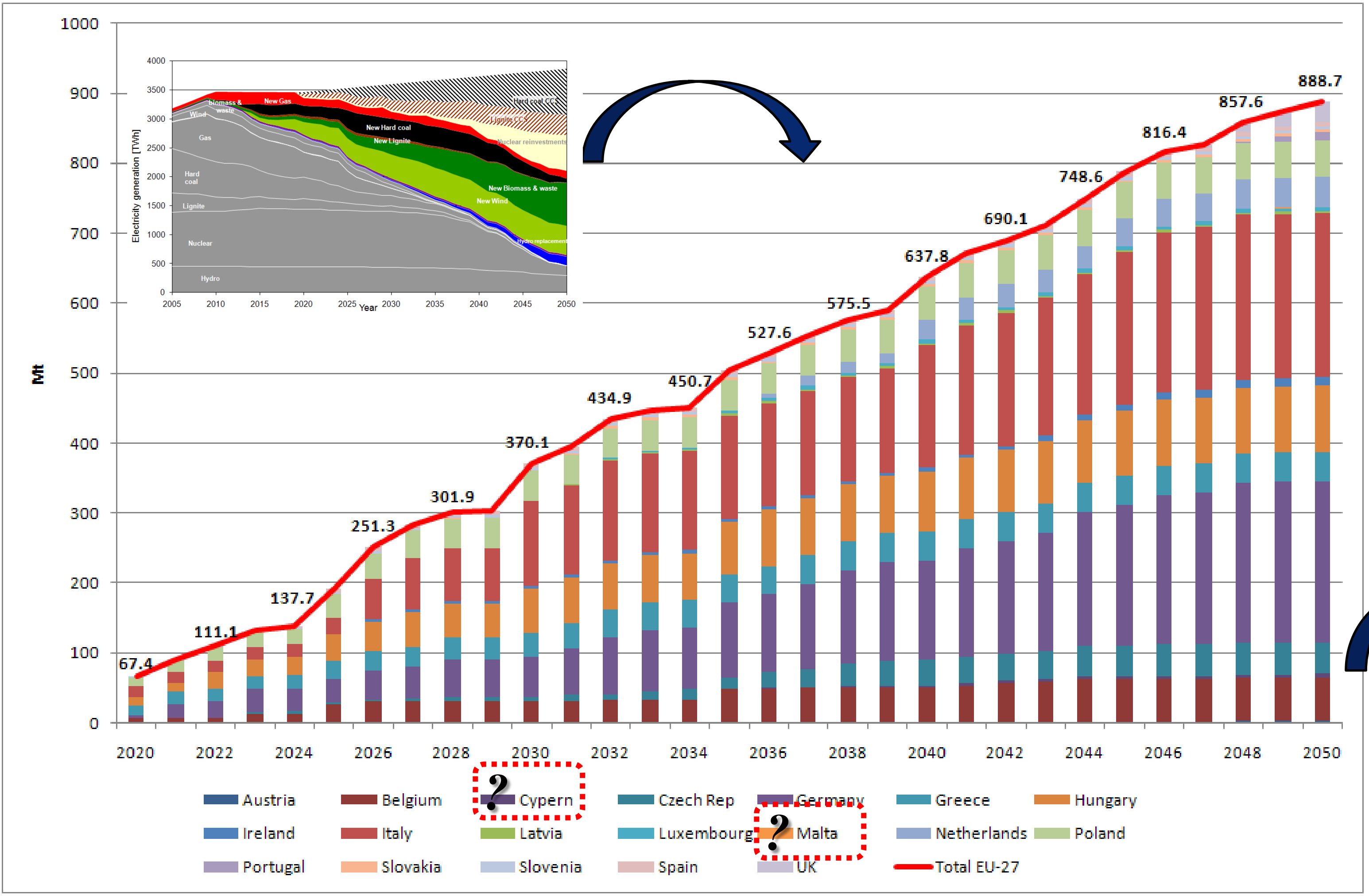
- To investigate implications of introduction of CCS in the European electricity supply system
- To perform a regionalized study, i.e. down to each member state
- To develop a methodology which can link techno-economic modeling in the electricity sector with a CCS infrastructure analysis
- Methodology:
  - Chalmers ELIN: Modeling the electricity sector
  - JRC InfraCCS: Providing bulk CO_2 transport system
  - Chalmers: Developing detailed CO_2 transport system based on InfraCCS providing new input to ELIN and InfraCCS

Techno economic modeling by ELIN for EU-27 (plus Norway) EU 20-20-20 target[1] by 2020, 85% CO_2 reduction by 2050



[1] Recalculated to electricity generation sector based on PRIMES. Source: Odenberger, M et al, 2010

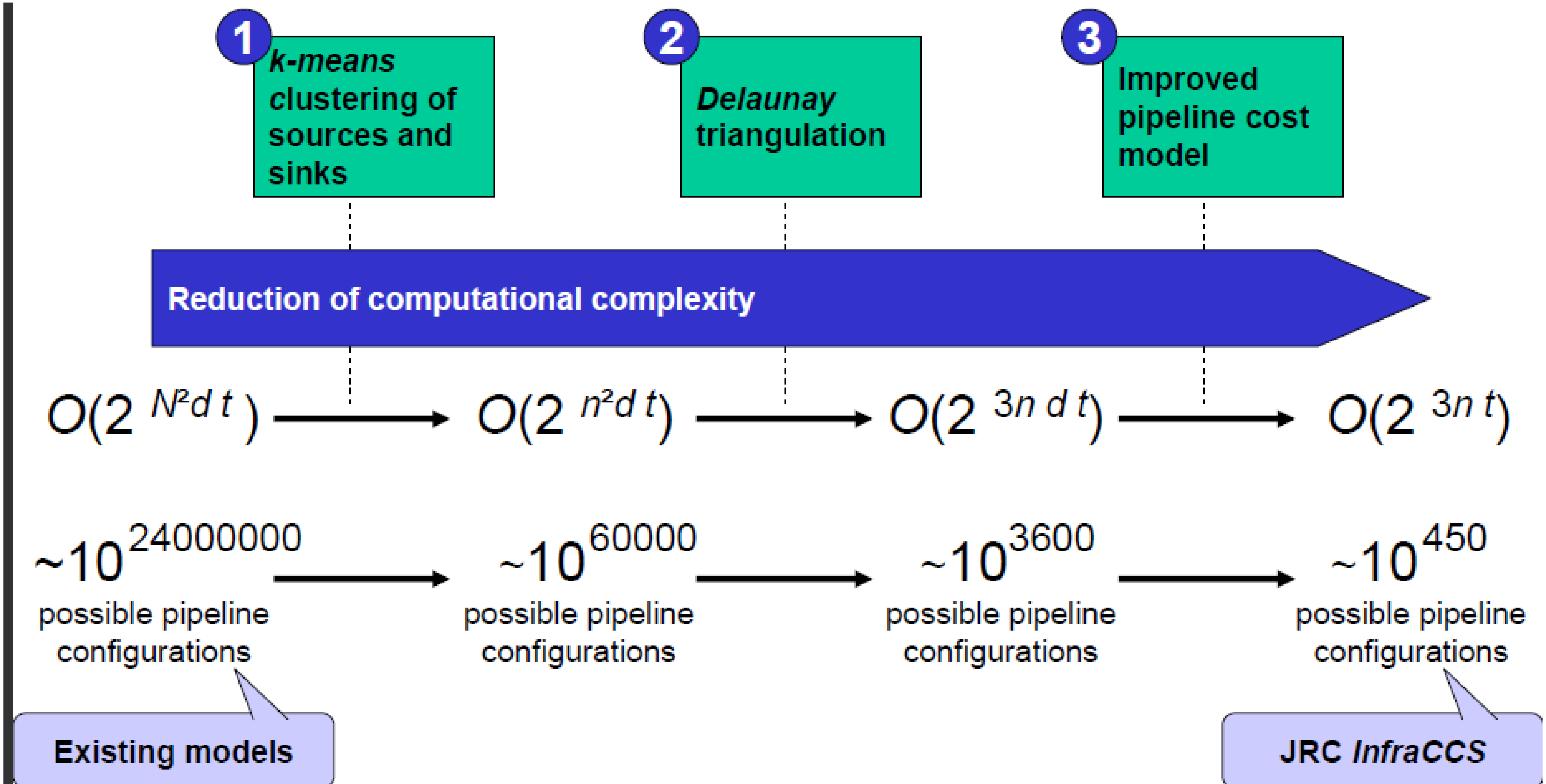
ELIN model provides annual CCS capacity and CO_2-flow by **fuel and by country**



CO_2 stored 2020-2050: 15.2 Gt

InfraCCS

The InfraCCS model optimizes a bulk CO_2 pipeline network

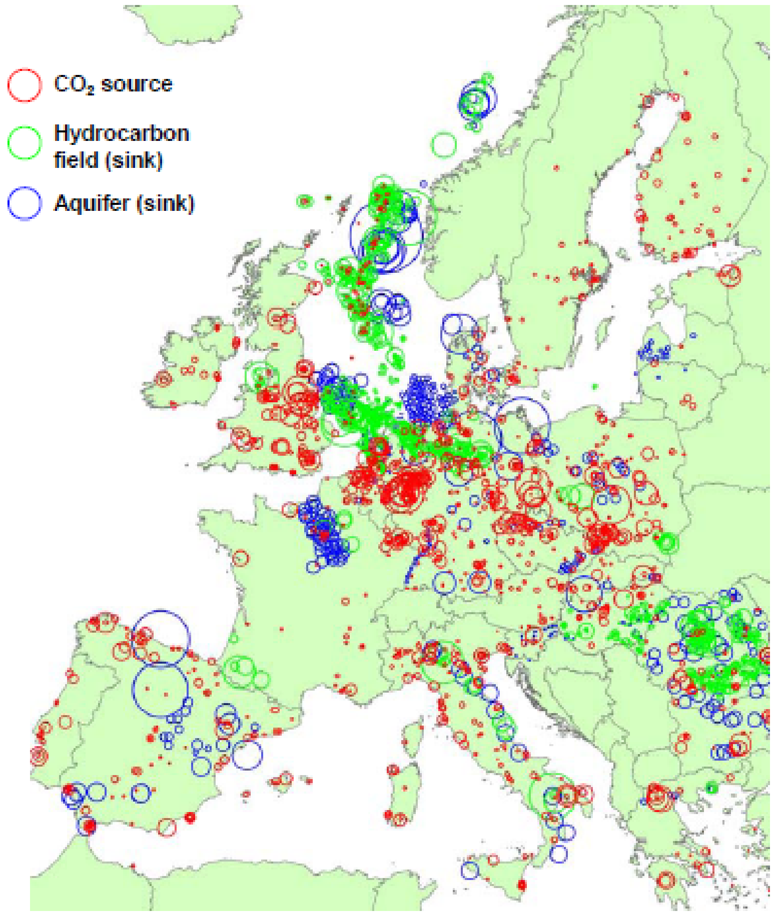


N : total number of sources and sinks
n : number of nodes (after clustering sources and sinks)
d : number of possible pipeline diameters
t : number of time steps

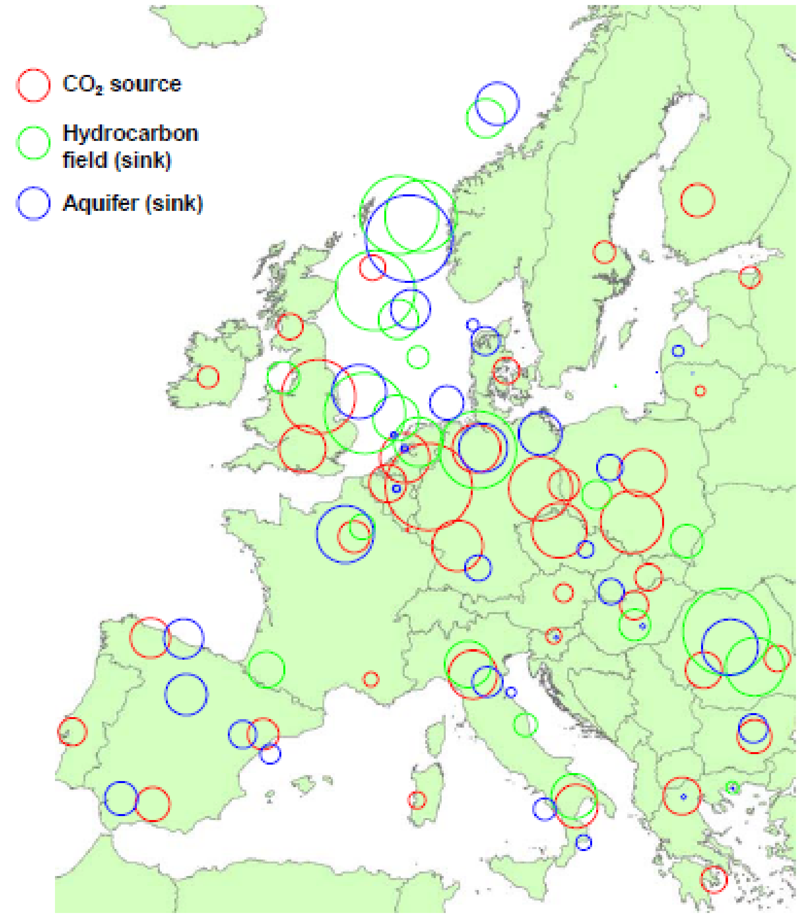
Can be solved on a standard laptop!

"k-means" clustering of sources and sinks

All CO_2 sources and sinks (3191 points)

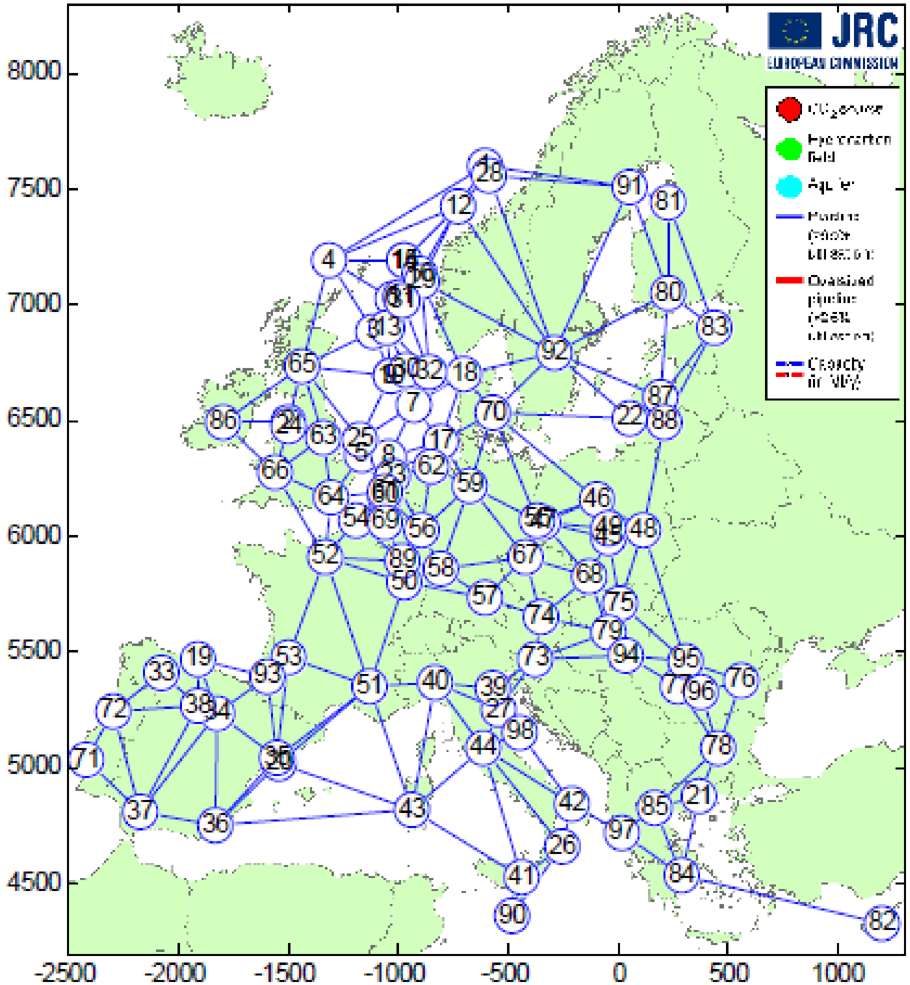


Clusters identified by *k-means* (101 nodes*)



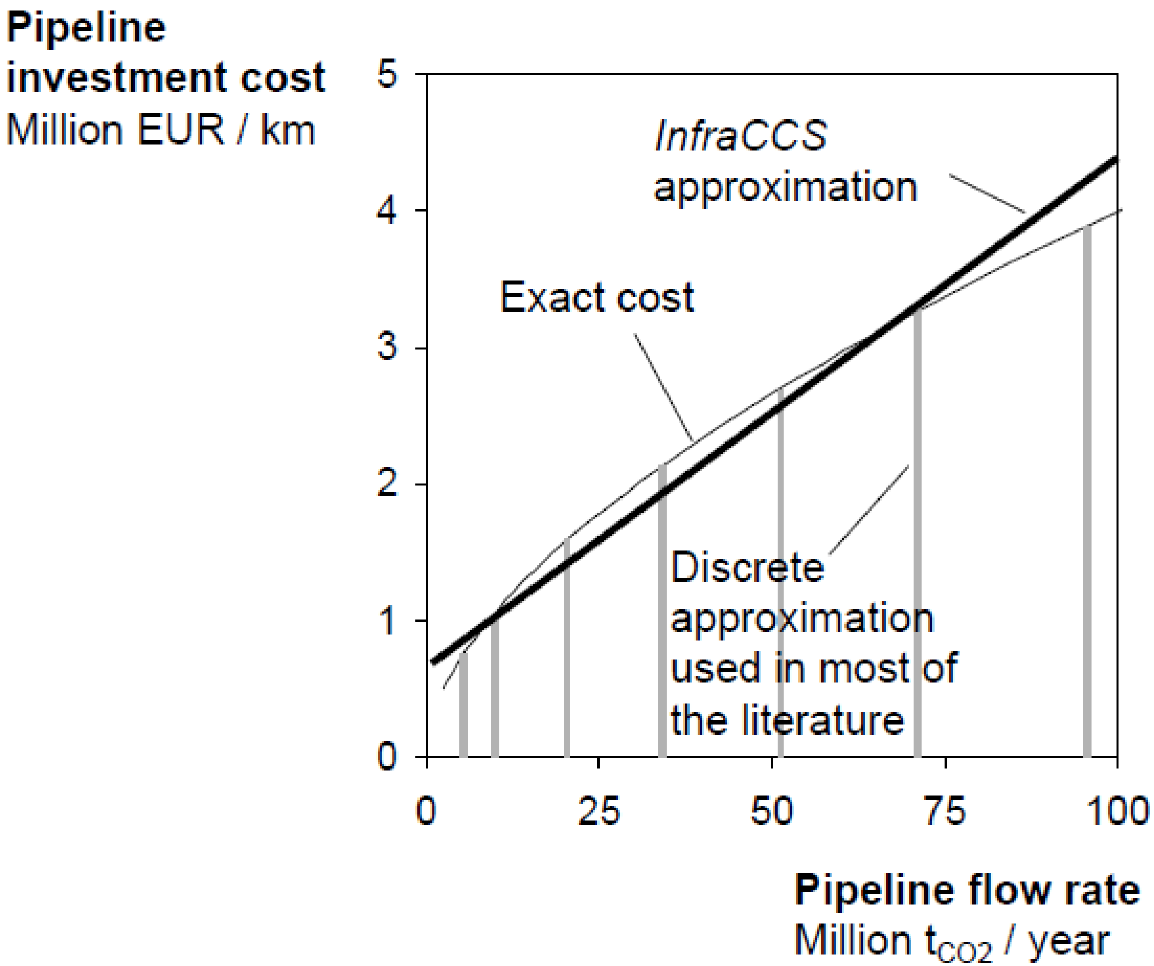
* The number of clusters (nodes) is chosen such that CO_2 sources and sinks are on average less than 75km away from the nearest cluster centre

Delaunay triangulation



- **Previous research** (e.g. Middleton & Bielicki, 2009, and van den Broek et al., 2009a/b) considers **possible connections between all sources and all sinks**, which leads to excessive computational complexity
- The *InfraCCS* model uses the *Delaunay* triangulation algorithm in order to **connect each node only to its natural neighbours**

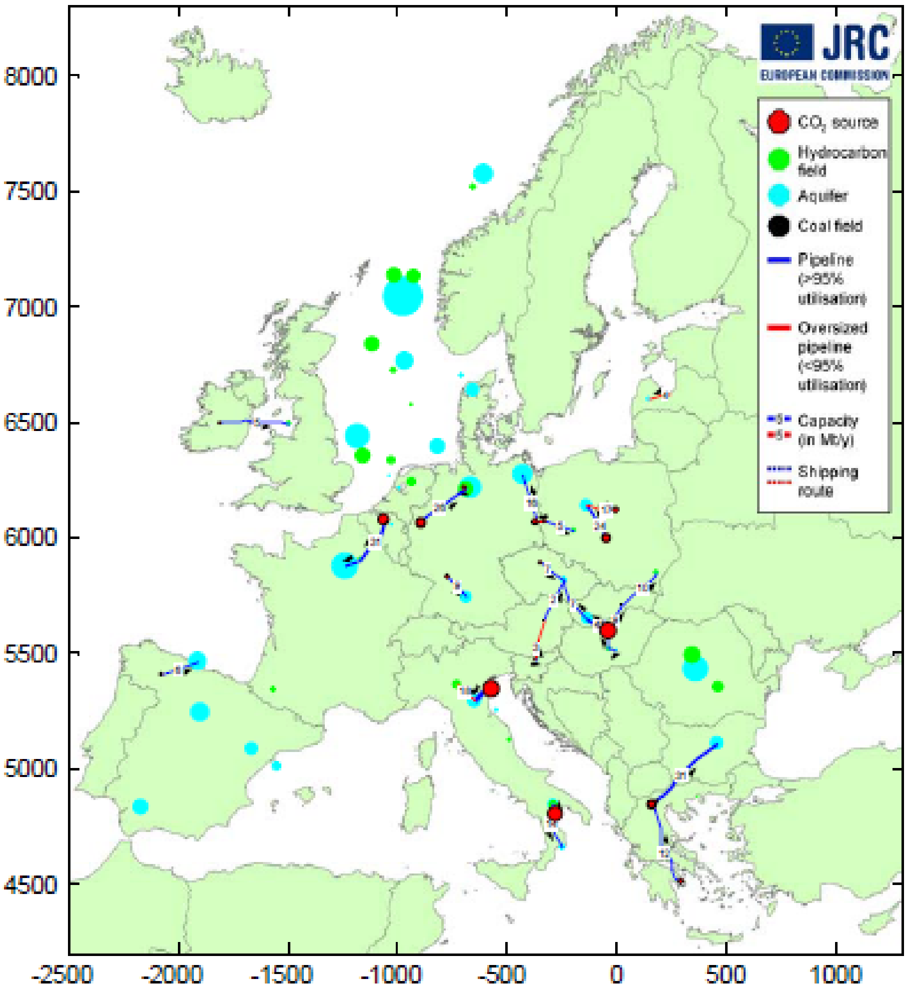
Pipeline costing model



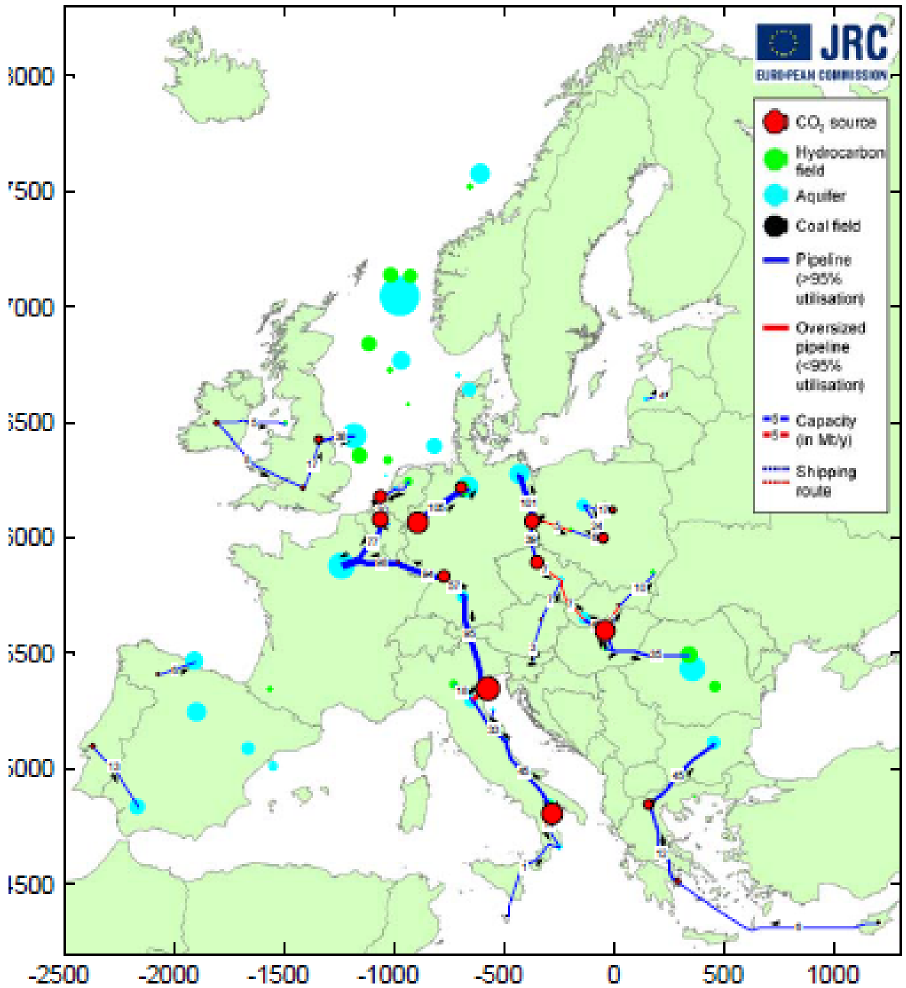
- Previous literature considers a **discrete set of possible pipeline diameters**, which may create artifacts and leads to computational complexity
- The pipeline costing model in *InfraCCS* allows a **continuous set of possible diameters**
- The **linear approximation** provides an accurate fit, while allowing for simplified optimisation model formulation

InfraCCS result 1 – storage in onshore aquifers allowed

YEAR 2030 - 4528km network - 4.0 billion EUR cumulative investment

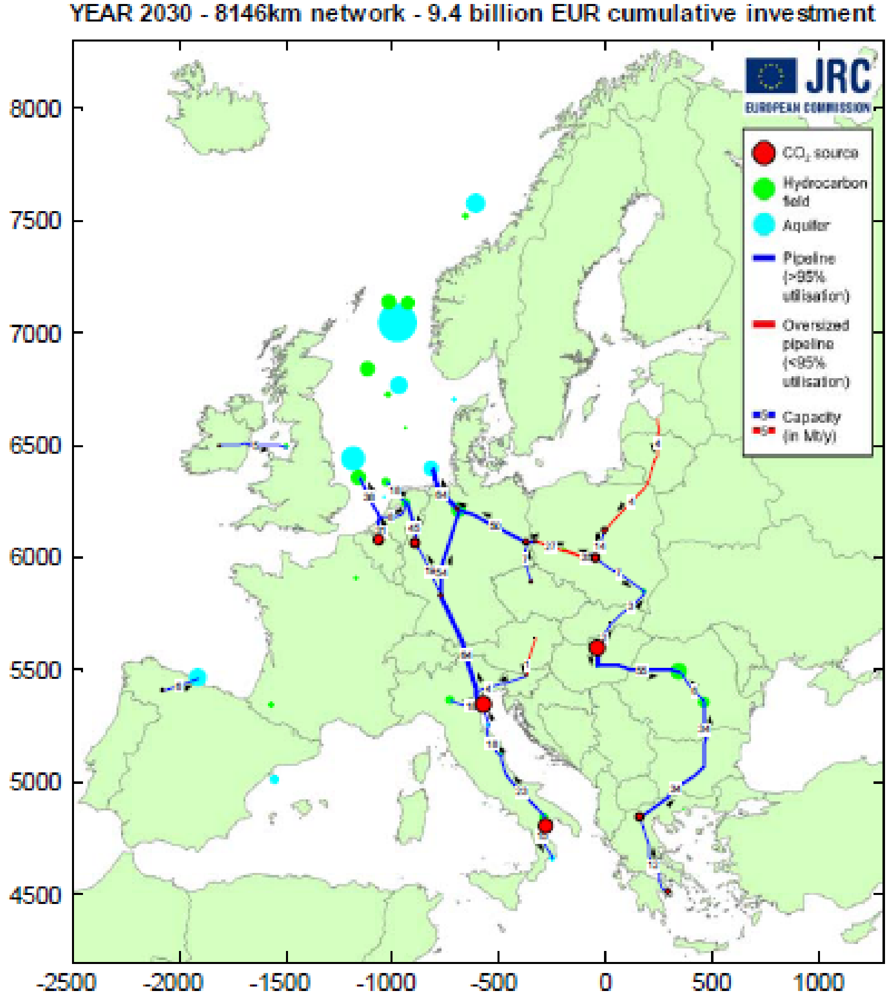


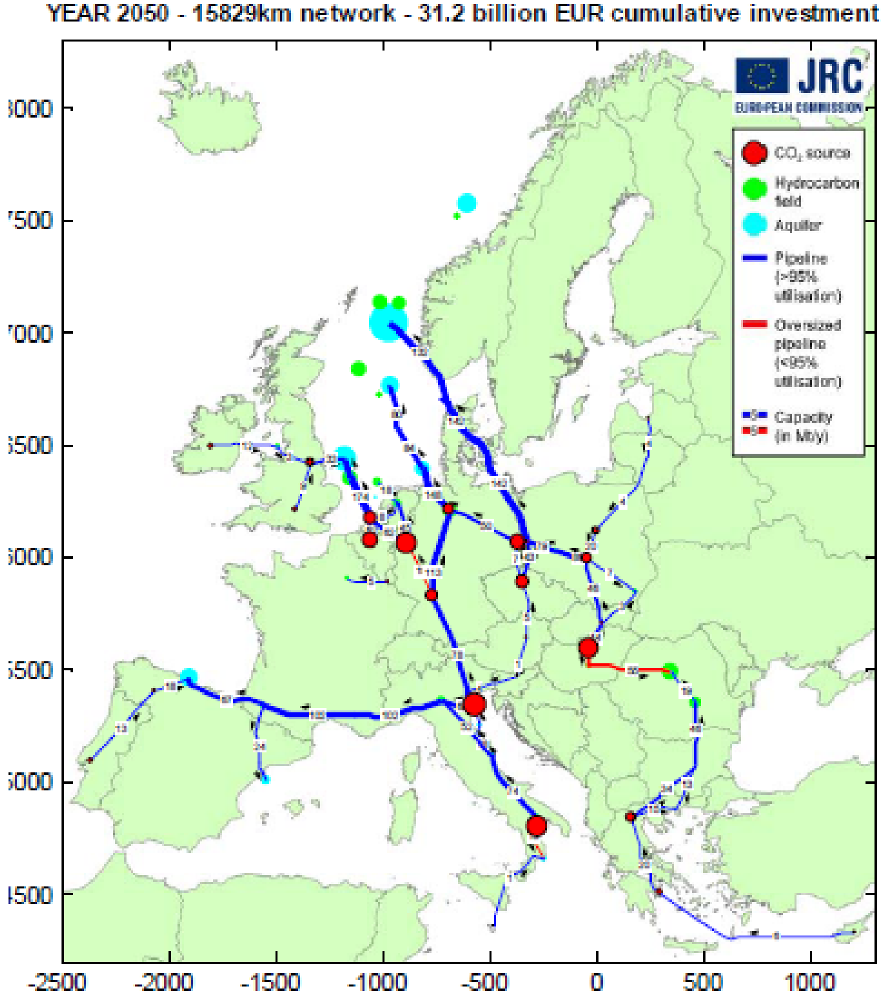
YEAR 2050 - 10302km network - 13.7 billion EUR cumulative investment



→ ***detailed modelling***

InfraCCS result 2 - no storage in onshore aquifers



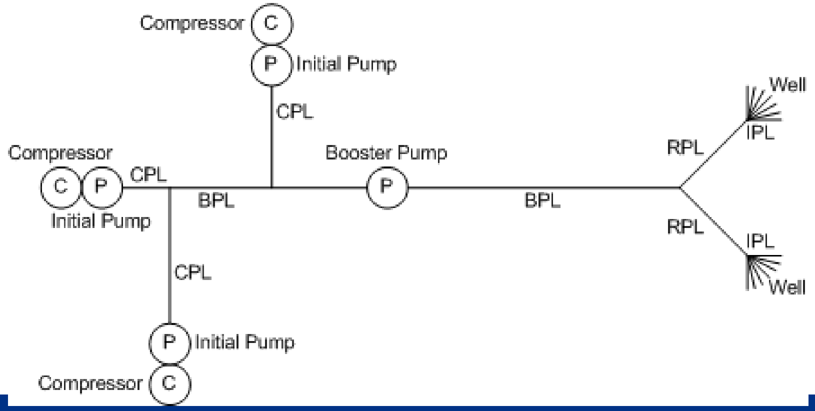


→ ***detailed modelling***

Detailing the bulk CO_2 network provided by InfraCCS

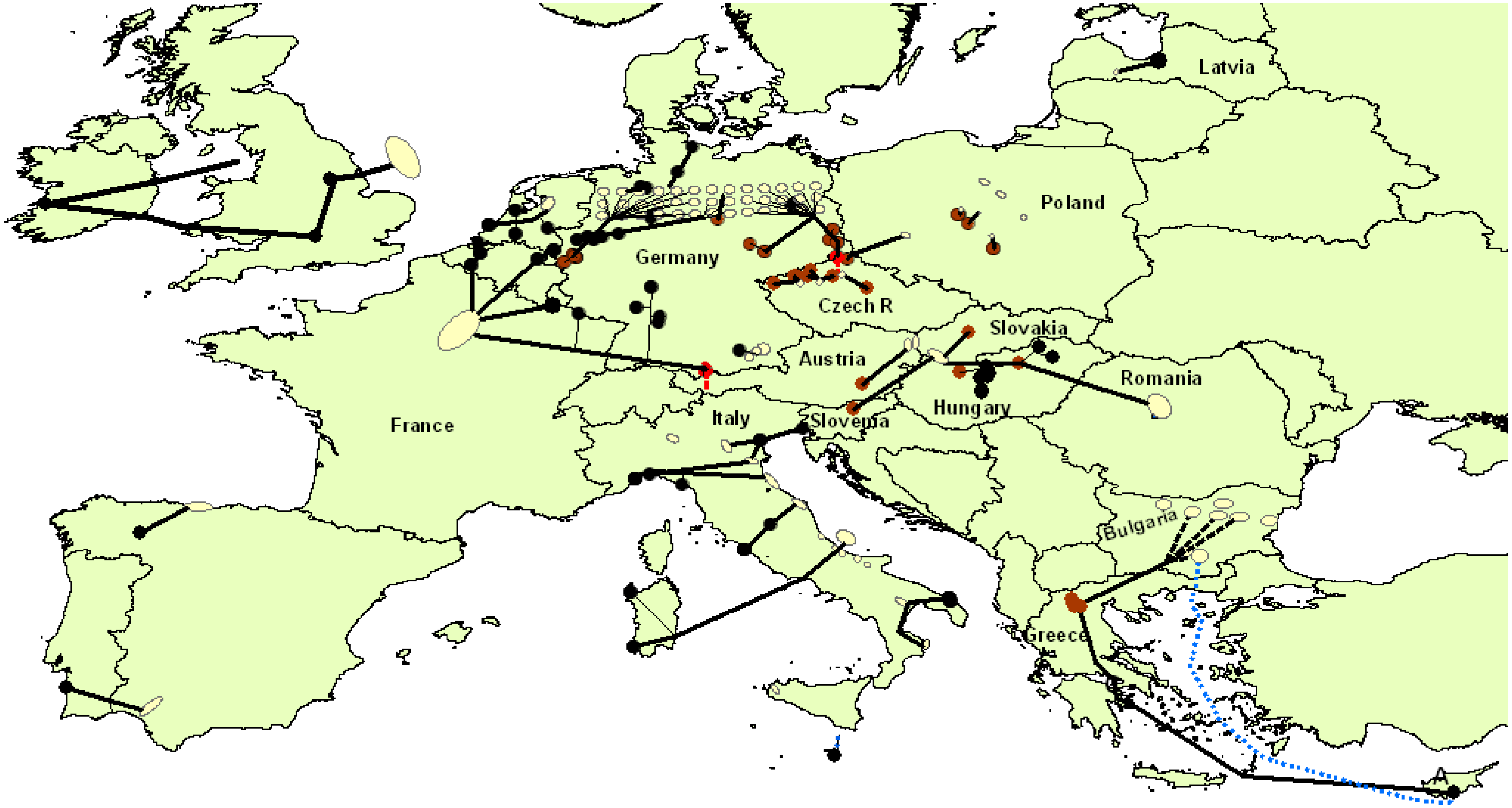
- ELIN provides _annual_ CO_2-flow by _fuel_ and by _country_
- Existing plants replaced by CCS plants based on age – this gives the geographical distribution of sources.
- Capture sites together with Chalmers CO_2 storage database define the transport network.
- 4 Pipeline modes; Collection Pipelines, Bulk Pipelines, Reservoir Pipelines, Injection Pipelines*.
- Cost calculated based on 2 equations updated according to IHS CERA UCCI; IEA 2005 and IEA 2007 (2007 based on in-house data from AMEC).

- System boundary:
  - ✓ Compression included in capture cost
  - ✓ Well included in storage cost



* Depends on injectivity - Chalmers applies 1 Mtpa per well

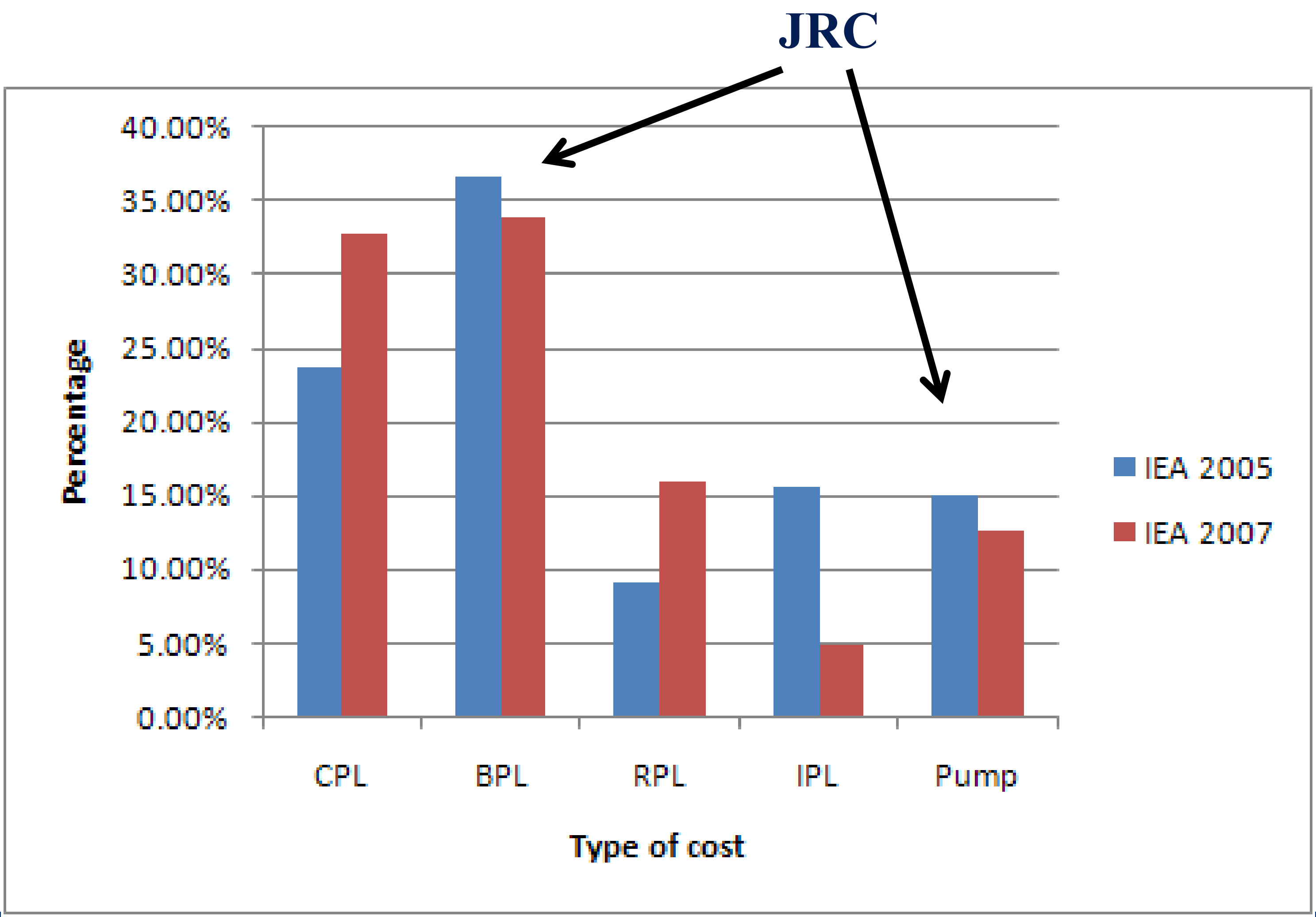
Detailed network - Storage in onshore aquifers allowed



- Network length: 14,900* – 15,800 km (ship*/no ship) (InfraCCS bulk only: 10,300 km)
- Total Investments: € 26.8 - € 36.2 billions (InfraCCS € 13.7 billion)
- System Specific Cost: € 4.43 - € 5.45 per ton CO_2
- Country specific cost (excl Cyprus/Malta): € 1.5 - € 25.9 per ton

*** In addition 1,200 km boat trip Cyprus-Bulgaria**

Distribution of System Specific Cost



Collecting network and a storage distribution system account for 50-55% of total cost.

Main issues

- ”Erroneous” model results
- Injectivity
- Geographic distribution of storage sites and storage capacity

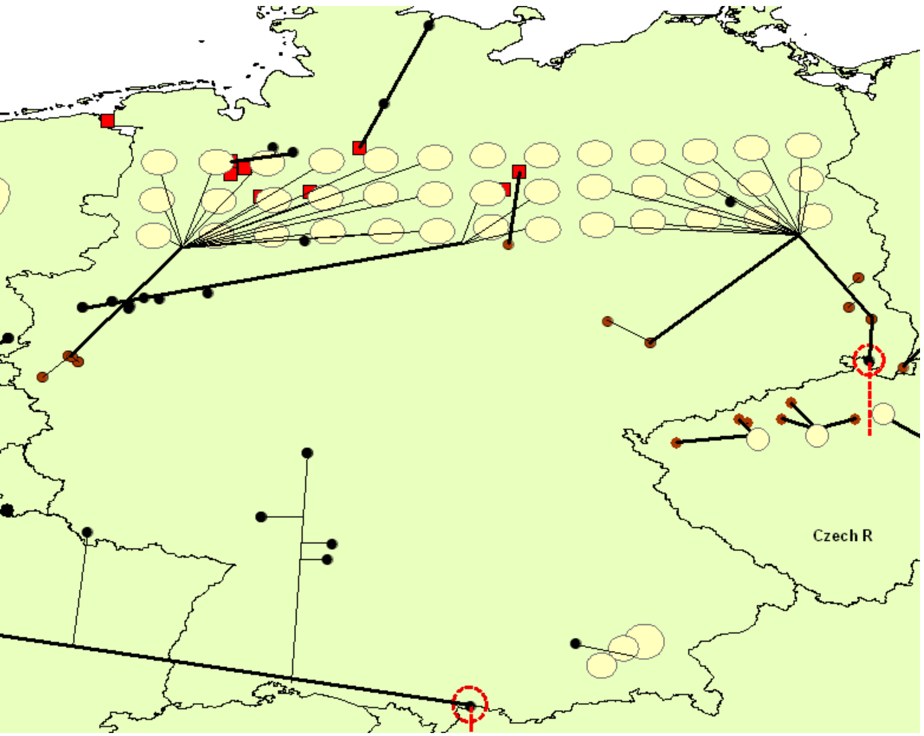
Injectivity – example Italy

How much CO2 can maximum be injected annually into any specific aquifer?

That is, how many wells can you drill?

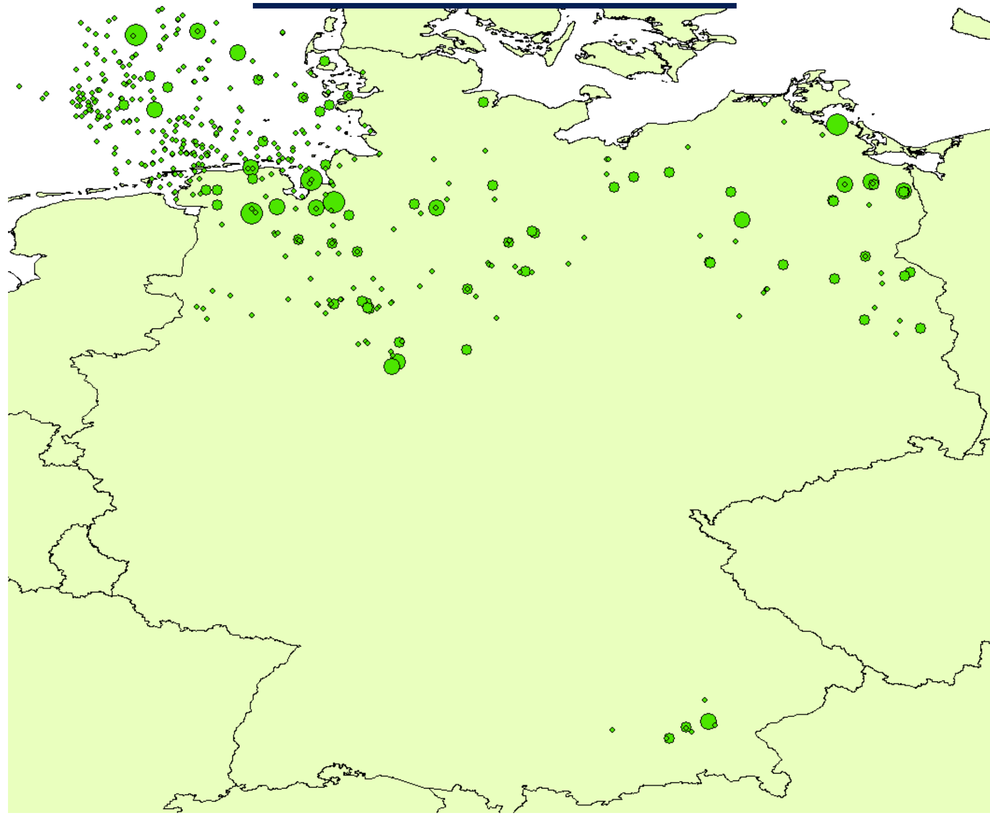
Distribution of storage sites/capacity – example Germany

Applied distribution



Assumed storage capacity of 100 Mt per reservoir

”Real” distribution



74 aquifers > 49 Mt capacity, combined capacity 10.7 Gt (36 aqf > 99 Mt, 8 Gt)

Source: BGR 2010, Greenpeace 2011

Conclusions

- The exercise has so far proved useful to validate and improve the models.
- Although storage capacity in EU appears to be large, accurate capacity figures are lacking and storage capacity is unevenly distributed among countries and onshore/offshore location – but distribution of appropriate storage capacity will to large extent decide the network.
- Reservoir injectivity key for design of a transport and storage infrastructure and thus also vital with regard to cost
- Assuming no storage in onshore aquifers will raise total investments by almost 130% for the bulk (backbone) system alone.
- Collecting systems and distribution networks account for roughly 50% of total transport cost
- Specific cost for the entire system range between € 4.4 and 5.5 while specific cost by country range from € 1.5 to € 25.9

Future work

- Models will be adjusted to exclude ”erroneous” results.
- Models will be further improved and developed based on future results
- Germany will be recalculated based on known distribution of storage sites.
- The “injectivity” problem will be resolved and transport networks adjusted accordingly.
- The case of “no storage in onshore aquifers” will be calculated