The impact of Large-scale Renewable Integration on Europe's Energy Corridors (2030 – 2050)

Gianluigi Migliavacca, RSE
Ozge Ozdemir, ECN

Additional authors: Alessandro Zani, Andrea Grassi (RSE), Karina Veum, Jeroen de Joode (ECN)

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Outline

1. Objectives & Methodology
2. Results for EU electricity markets and infrastructure
3. Results for EU gas markets and infrastructure
4. Interactions between electricity and gas developments
5. Conclusions and recommendations

Objectives

Objective

- Identify required infrastructure investments in both the electricity and gas networks to realize the expected penetration of RES
- Insights into interaction between extensions/changes of gas and electricity infrastructures

Focus presentation:

- What are infrastructure developments in different futures?
- What is the impact of increasing RES on the energy system?

SUSPLAN Storylines

Methodology

Positive public attitude
High environmental focus in population and business.
Reduced energy consumption and demand
for environmentally friendly products

Positive future for high RES integration, but too low technology development rate. Mainly decentralized development

Yellow

Positive future for high RES integration. Both market pull and technology push existing.

Green

Slow tech development
No major technology break-throughs; gradual development of current technologies

Fast tech development
Major break-throughs several technologies, RES, grids, demand side

Red

Difficult future for high RES integration. Few new technologies are available, and low interest to invest. Mainly centralized development with traditional technologies

Blue

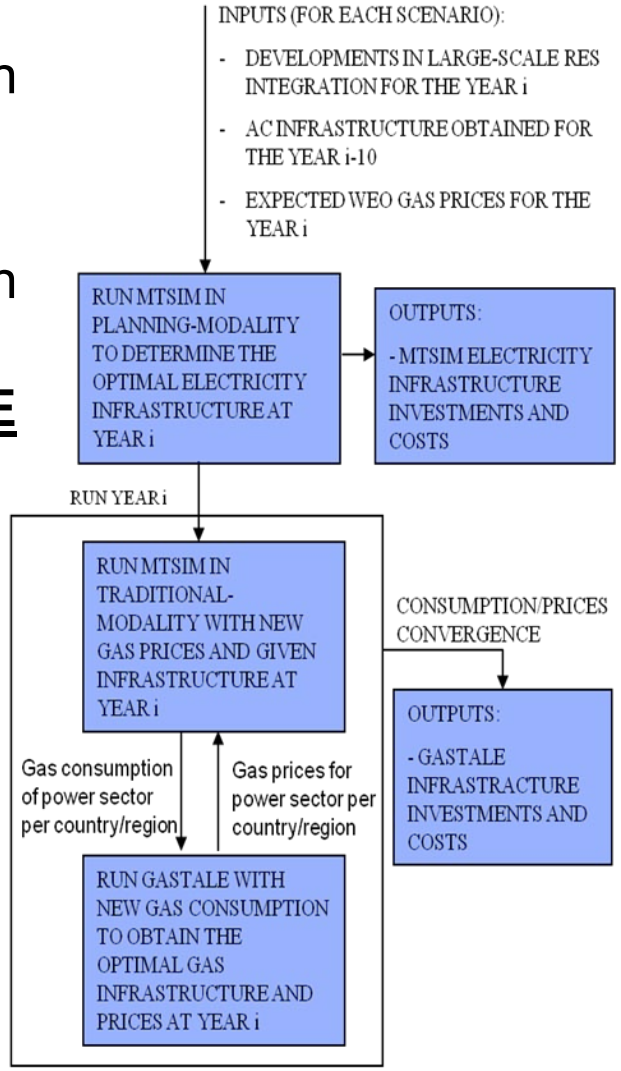
New technologies are available, but low interest to invest and use. Mainly centralized development, but with new technologies.

Indifferent public attitude
Low environmental focus in population and business.
Higher energy consumption and no demand
for environmentally friendly products or services

Summary Approach

Methodology

- Model-based
  - Simulation model representing European **electricity** market and transmission infrastructure: **MTSIM**
  - Simulation model representing European **gas** market and gas infrastructure (transmission, LNG, storage): **GASTALE**
  - Economic optimization
- Interactive analysis
  - Iterations between the two models, both allowing for optimal usage of existing capacity and expansion of capacity
- Long-term perspective
  - **Starting point 2030**, analysis for 2030 - 2050
- Storyline-based

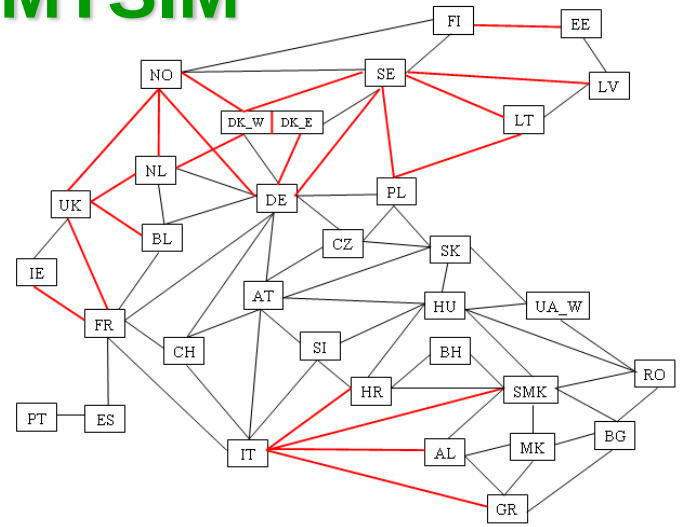


Electricity Network Model: MTSIM

Methodology

The European power system has been modelled with the tool MTSIM as:

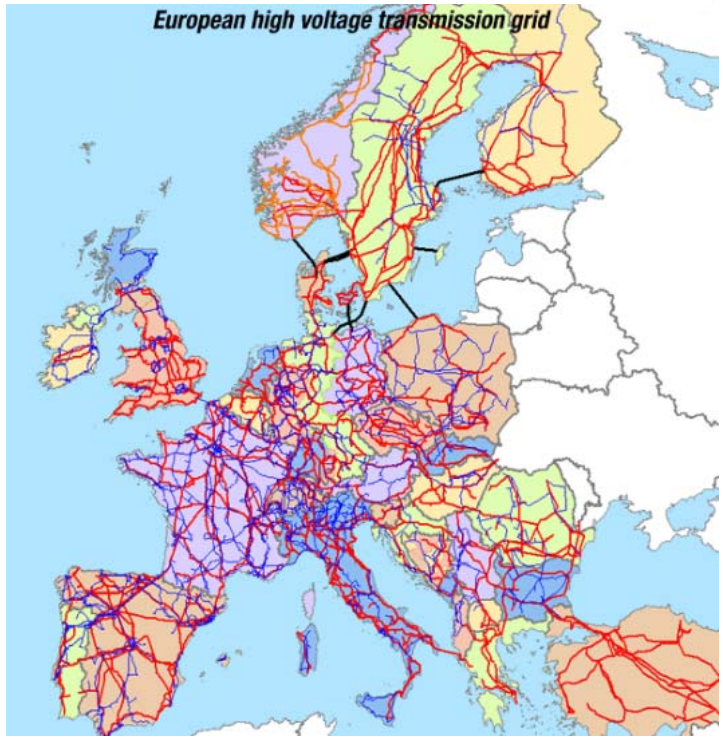
- a set of nodes corresponding to single countries: internal network constraints are not considered
- interconnected by cross-border corridors grouping relevant transmission lines



❑ MTSIM models a meshed day-ahead market calculating system dispatch, energy balances (i.e. fuel consumption, el. prices) and emissions (CO2 and other pollutants).

❑ RES generation is imposed, while the hydrothermal generation dispatch is optimized by the program;

❑ MTSIM can be run in planning modality to calculate the best trade-off between dispatching cost reduction due to new installed capacity and fixed cost increase related to new capacity.



Input: AC corridors expansion (2030-2050)

Electricity Results

Green and Yellow

Capacity expansion (MW)	Type of line
300	220 kV, single circuit
600	220 kV, double circuit
900	1 - 220 kV, single circuit 1 - 220 kV, double circuit
1200	2 - 220 kV, double circuit
1500	400 kV, single circuit
1800	1 - 400 kV, single circuit 1- 220 kV, single circuit
2100	1 - 400 kV, single circuit 1 - 220 kV, single circuit
3000	400 kV, double circuit
3600	1 - 400 kV, double circuit 1 - 220 kV, double circuit
4500	1 - 400 kV, double circuit 1 - 400 kV, single circuit
6000 **Upper limit**	2 - 400 kV, double circuit

Red and Blue

Capacity expansion (MW)	Type of line
300	220 kV, single circuit
600	220 kV, double circuit
1500	400 kV, single circuit
3000 **Upper limit**	400 kV, double circuit

AC expansions cost [€/MW]	30-40	40-50
RED	6158	6158
YELLOW	5969	5843
BLUE	5948	5738
GREEN	5759	5424

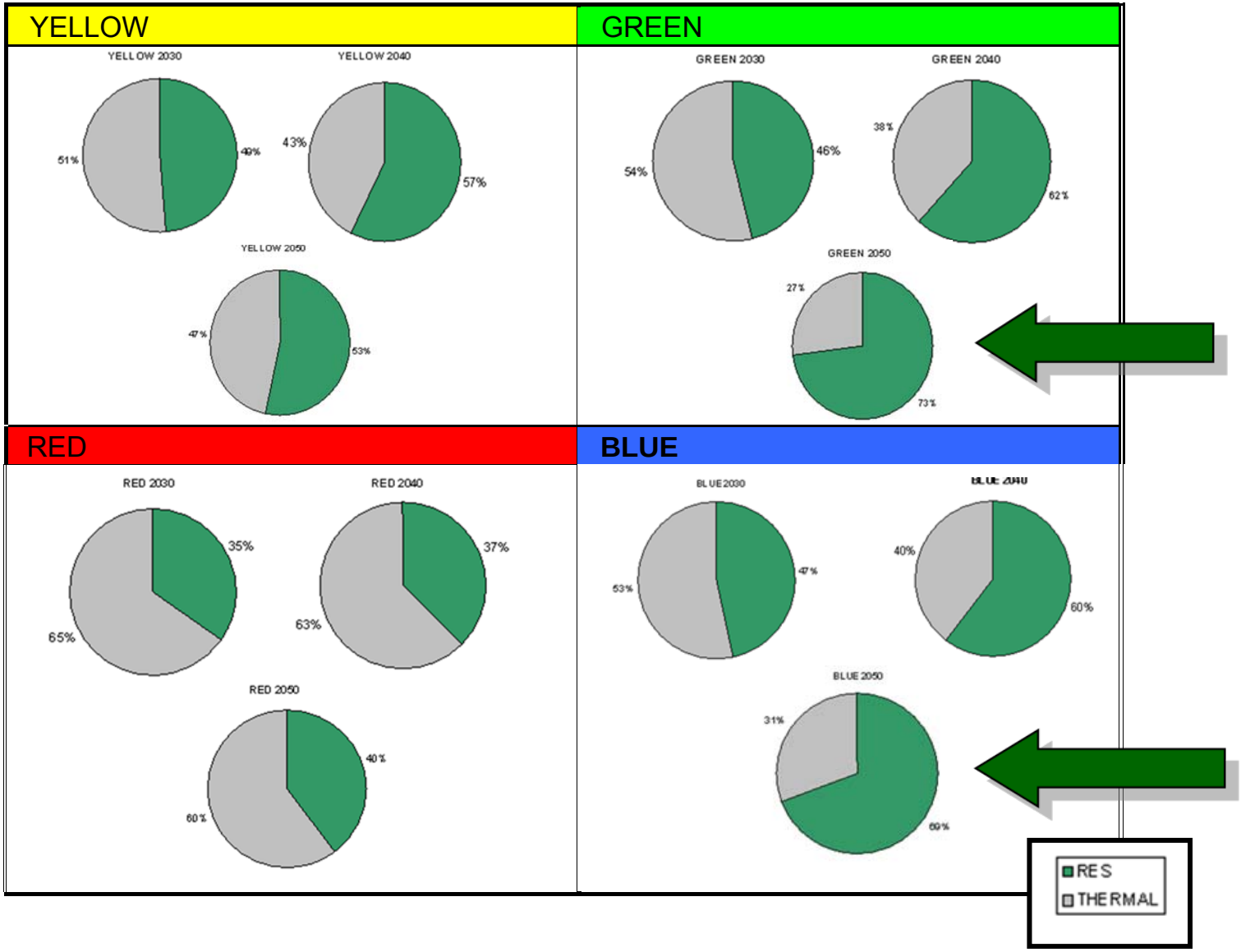
A match is calculated between physical lines and corridors capacity expansion in order to convert the TSO development plans info into a ΔNTC guess, under the two hypotheses:

- **Lines expansions (MW) are assumed to be reflected by an equal amount of NTC increase (after 2030 the role of cross-border bottlenecks is supposed limited)**

- **National transmission systems, not represented, are supposed to expand correspondingly and not to constitute a limitation to the trans-national flows**

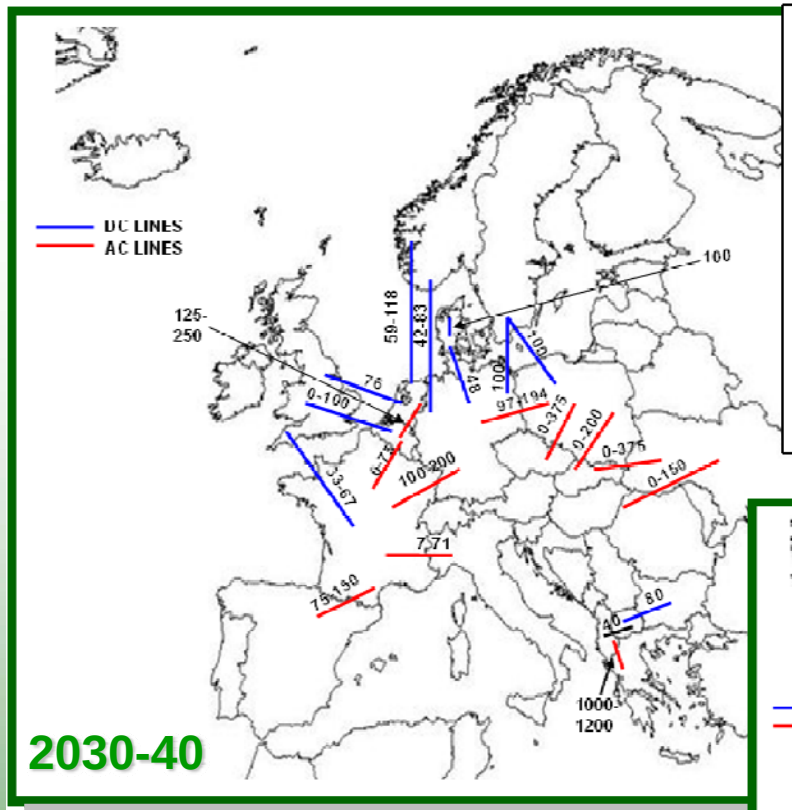
Share of RES in electricity mix

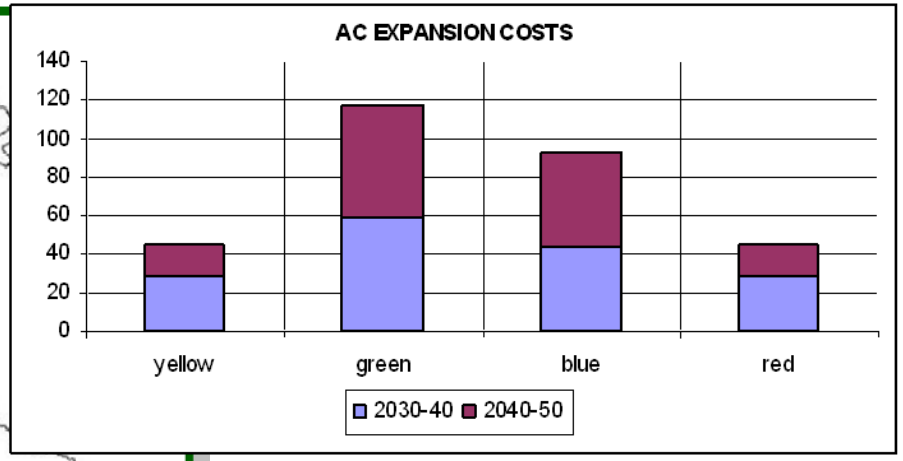
Electricity Results

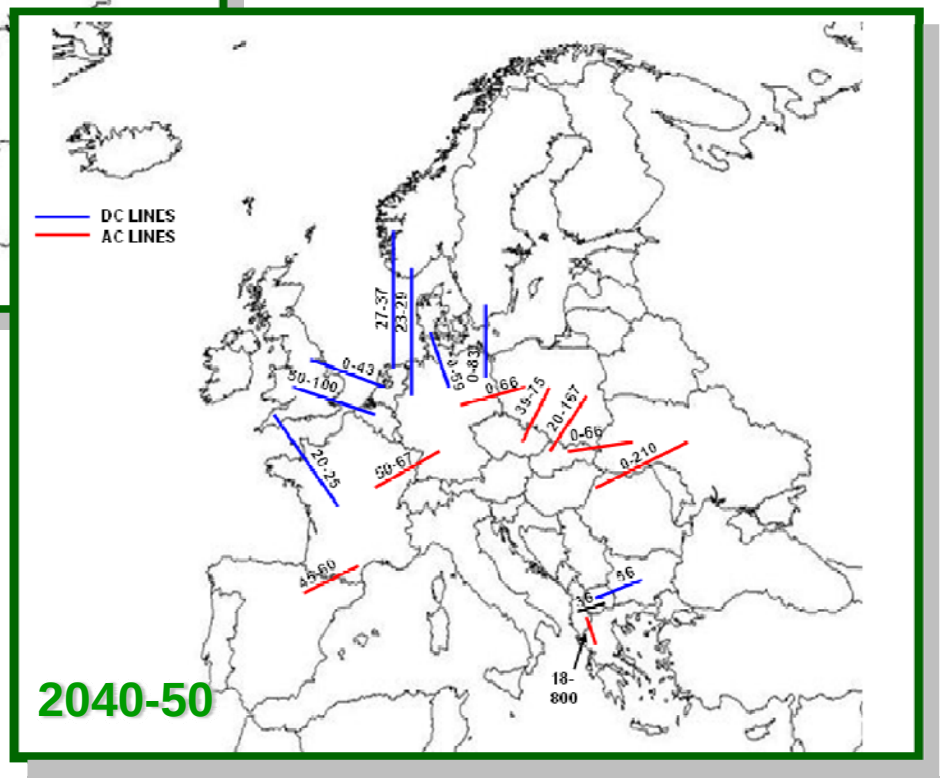


AC-DC corridors expansions

Electricity Results





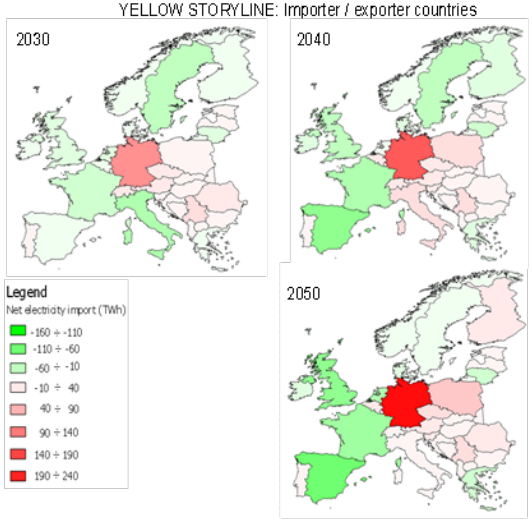


Importer/Exporter Countries

Electricity Results

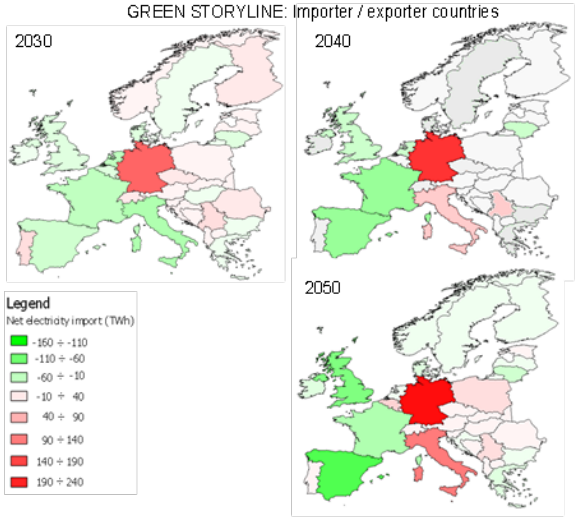
YELLOW

YELLOW STORYLINE: Importer / exporter countries



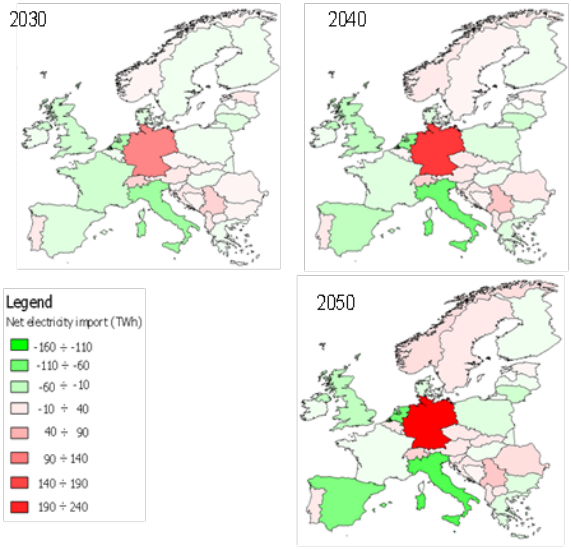
GREEN

GREEN STORYLINE: Importer / exporter countries



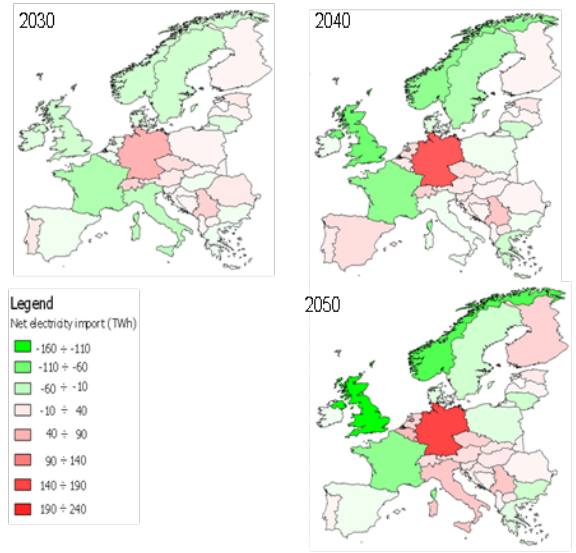
RED

RED STORYLINE: Importer / exporter countries



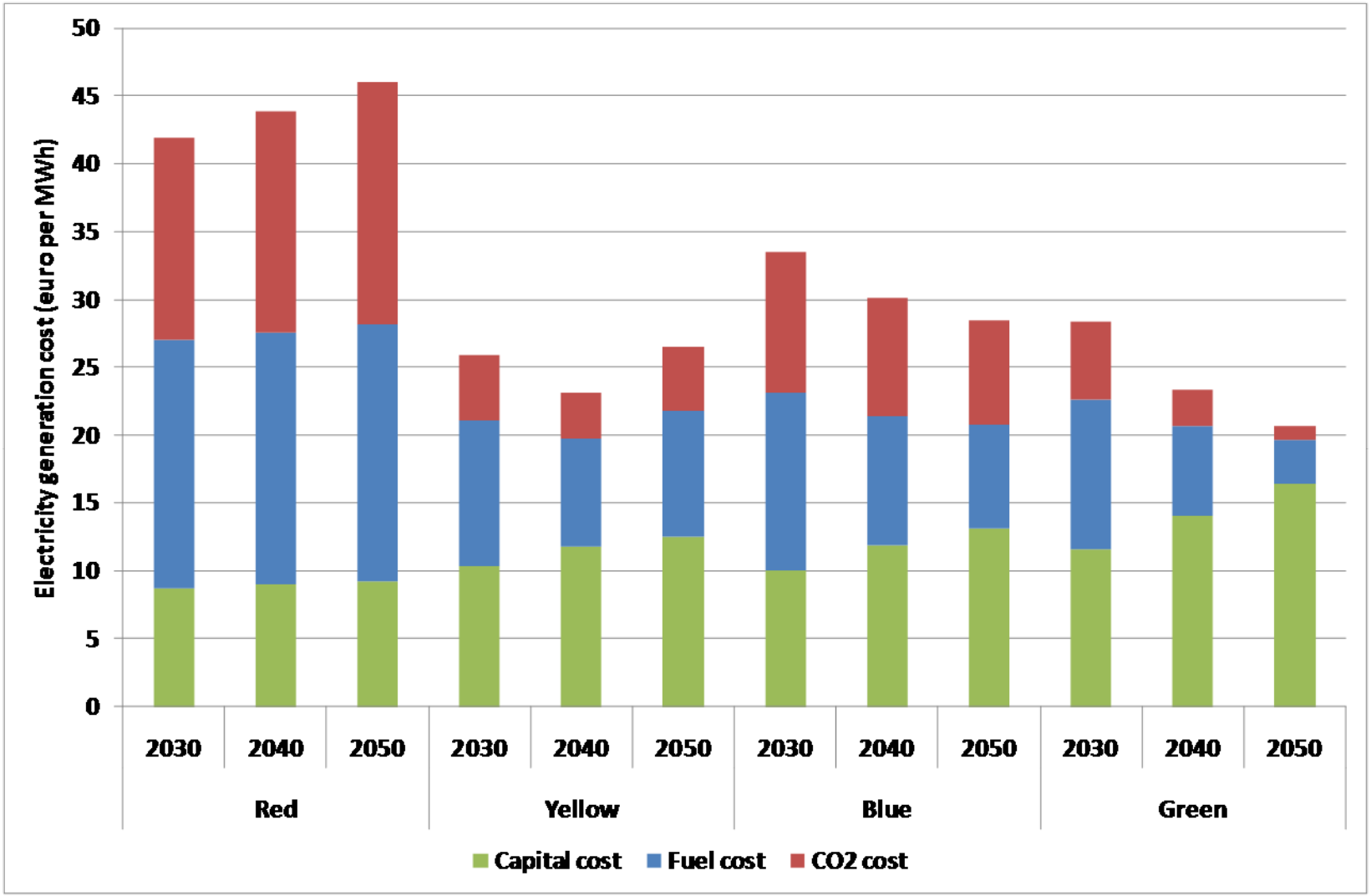
BLUE

BLUE STORYLINE: Importer / exporter countries



Electricity generation cost

Contrast between capital & operational cost impact



Electricity Results

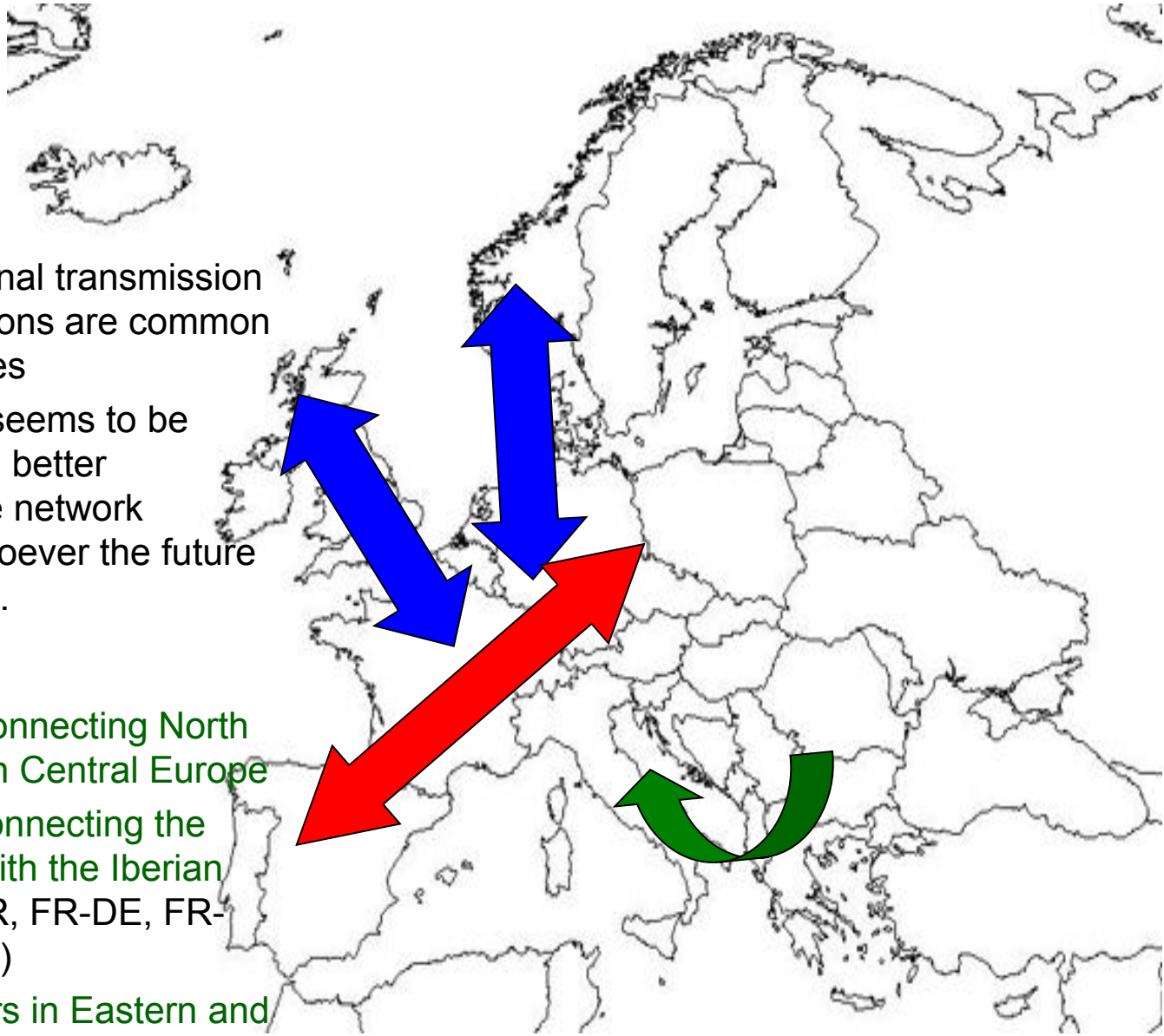
Conclusions

Some trans-national transmission corridors expansions are common to all the Storylines

Their expansion seems to be fundamental for a better exploitation of the network potentiality whatsoever the future system scenarios.

In particular:

- DC corridors connecting North and UK/EIRE with Central Europe
- AC corridors connecting the Central Europe with the Iberian Peninsula (ES-FR, FR-DE, FR-BL, FR-IT, DE-PL)
- DC/AC corridors in Eastern and South-Eastern Europe (AL-GR, RO-UA_W and SK-UA)



Natural gas market model: GASTALE

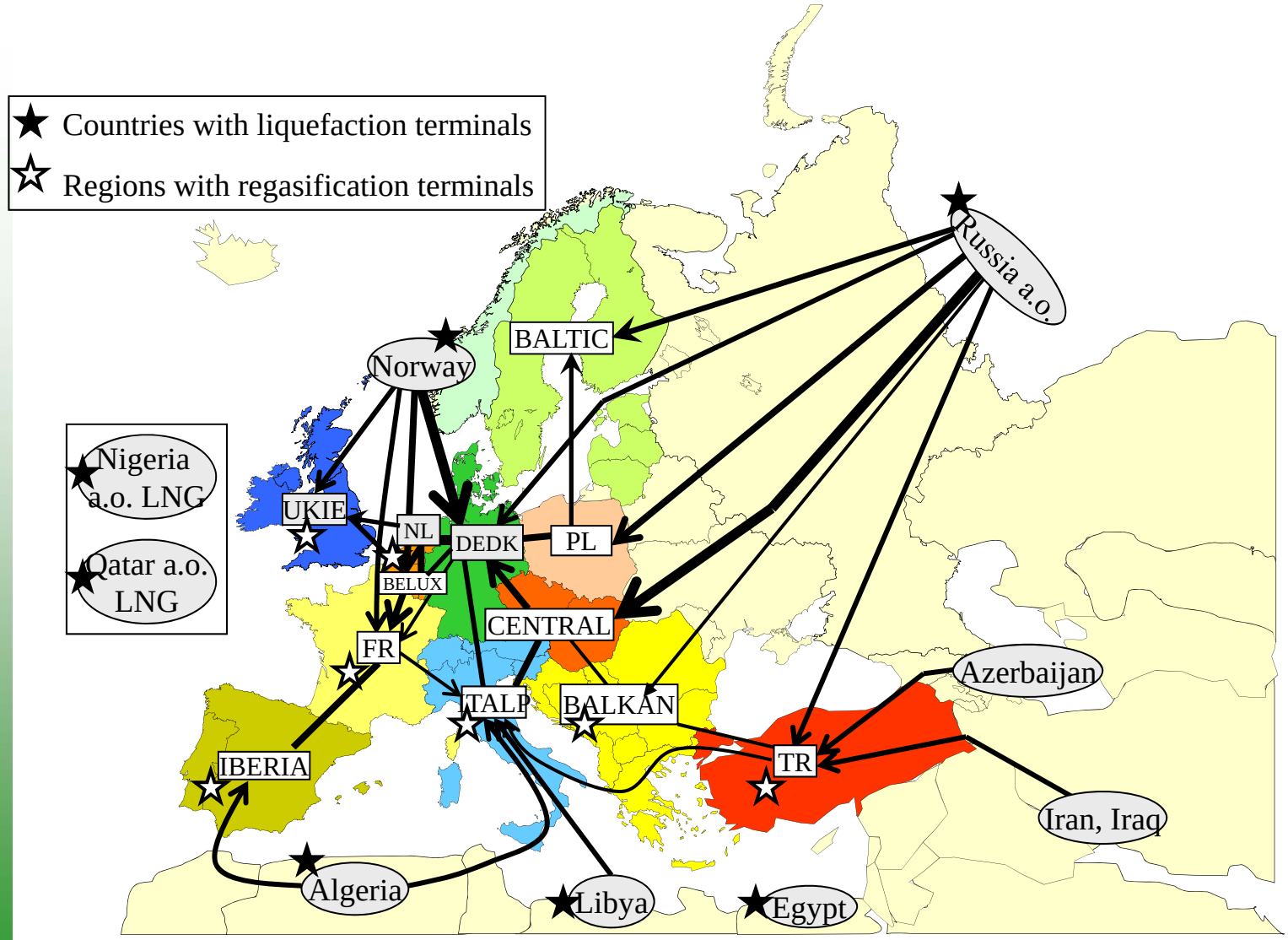
Methodology

- **Game-theoretic equilibrium model of EU gas markets:**
  - Economic equilibrium model
  - Mixed-complementarity problem formulation
  - Market power representation

- **Market actors:**
  - **Producers** with market power: decide on production, transport to country border, earning a border price.
  - **Transmission system operators** (TSO): regulates transport through pipeline network & LNG shipping.
  - **Arbitragers** without market power: trade gas among power generation, industries, residents & storage.
  - **Storage system operators** (SSO): regulates injection during the warm season and extraction from storage facilities during the cold season.
  - **Consumer prices** clear the market

- **Endogenous investment:**
  - Storage, pipeline, liquefaction and regasification

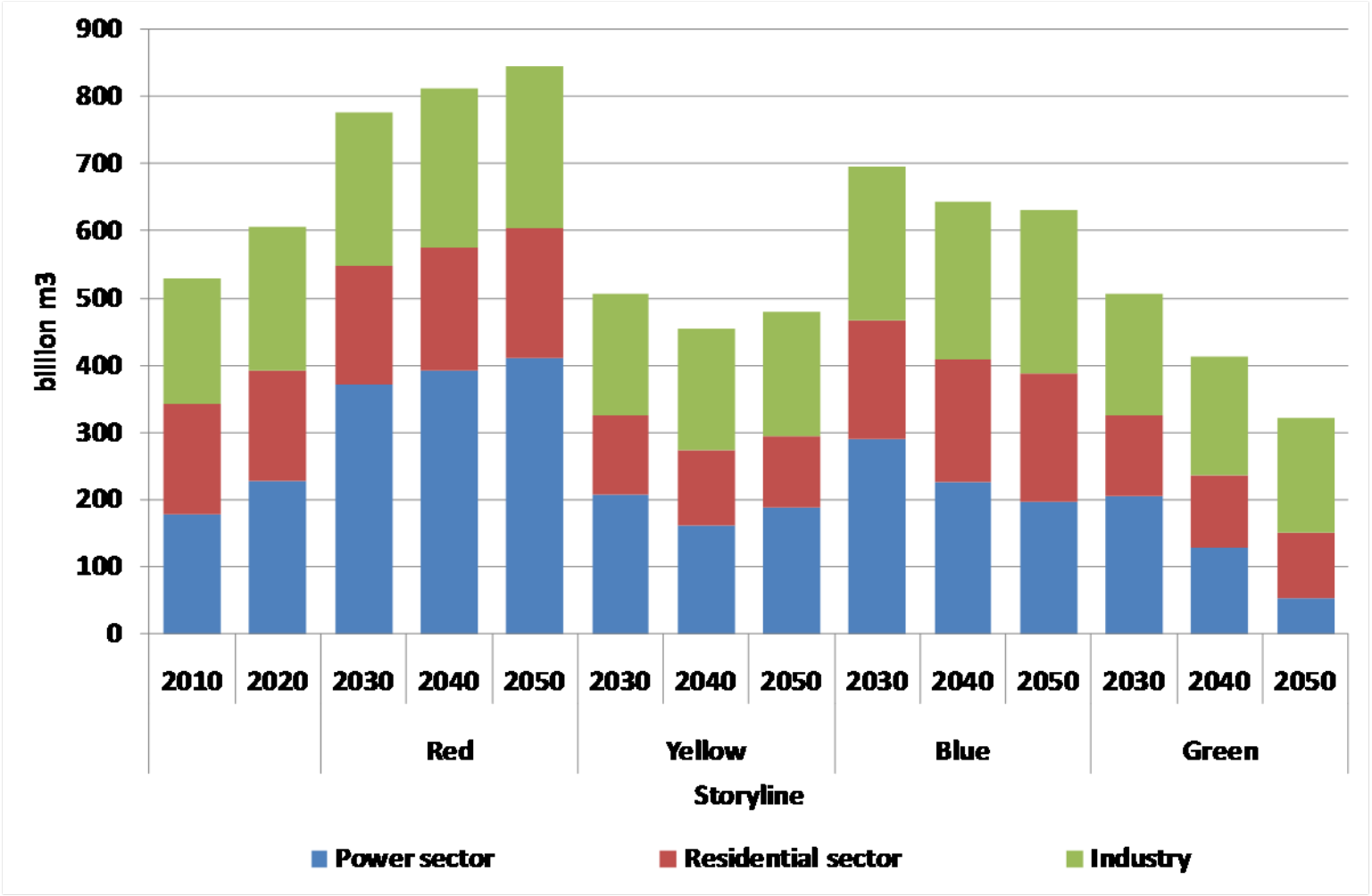
Geographical coverage GASTALE



Methodology

Input: EU Natural gas demand

Gas Results



SUSPLAN

Change in gas demand 2010 - 2050

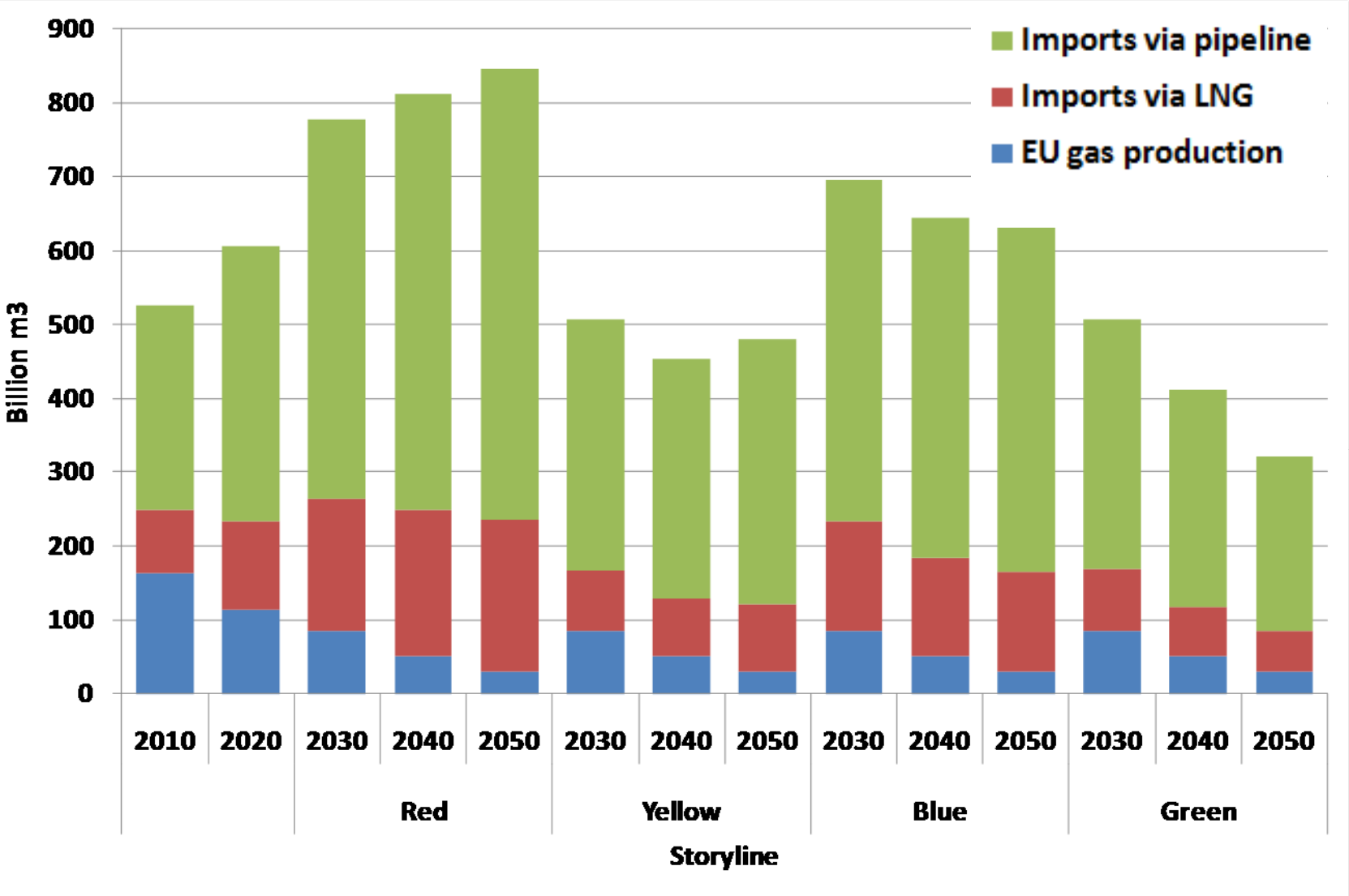
(billion m3)

Results

- -69 to -50
- -49 to -30
- -29 to -10
- -9 to 10
- 11 to 30
- 31 to 50
- 51 to 70
- 71 to 90

SEVENTH FRAMEWORK PROGRAMME

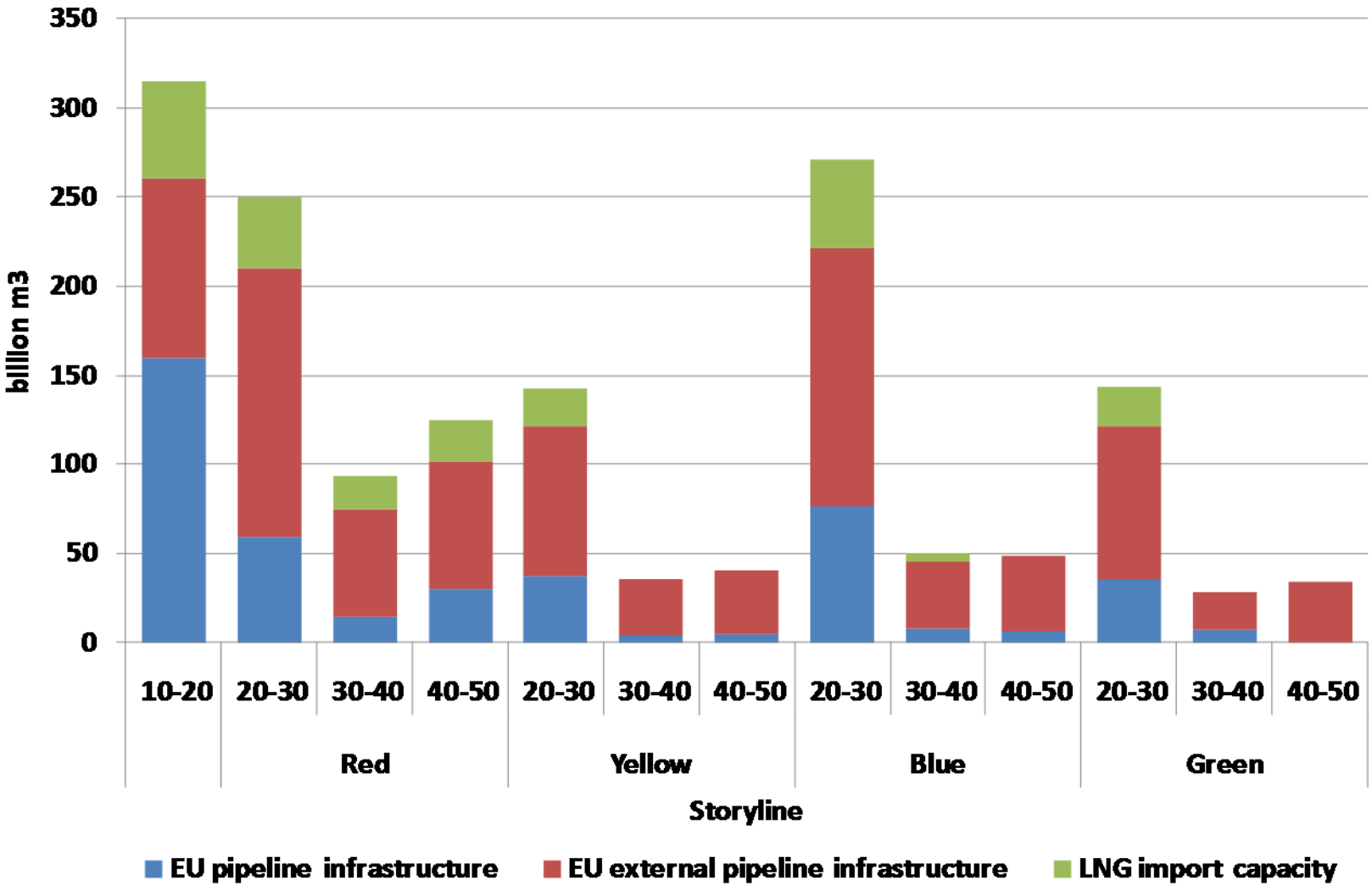
EU gas supply sources



Gas Results

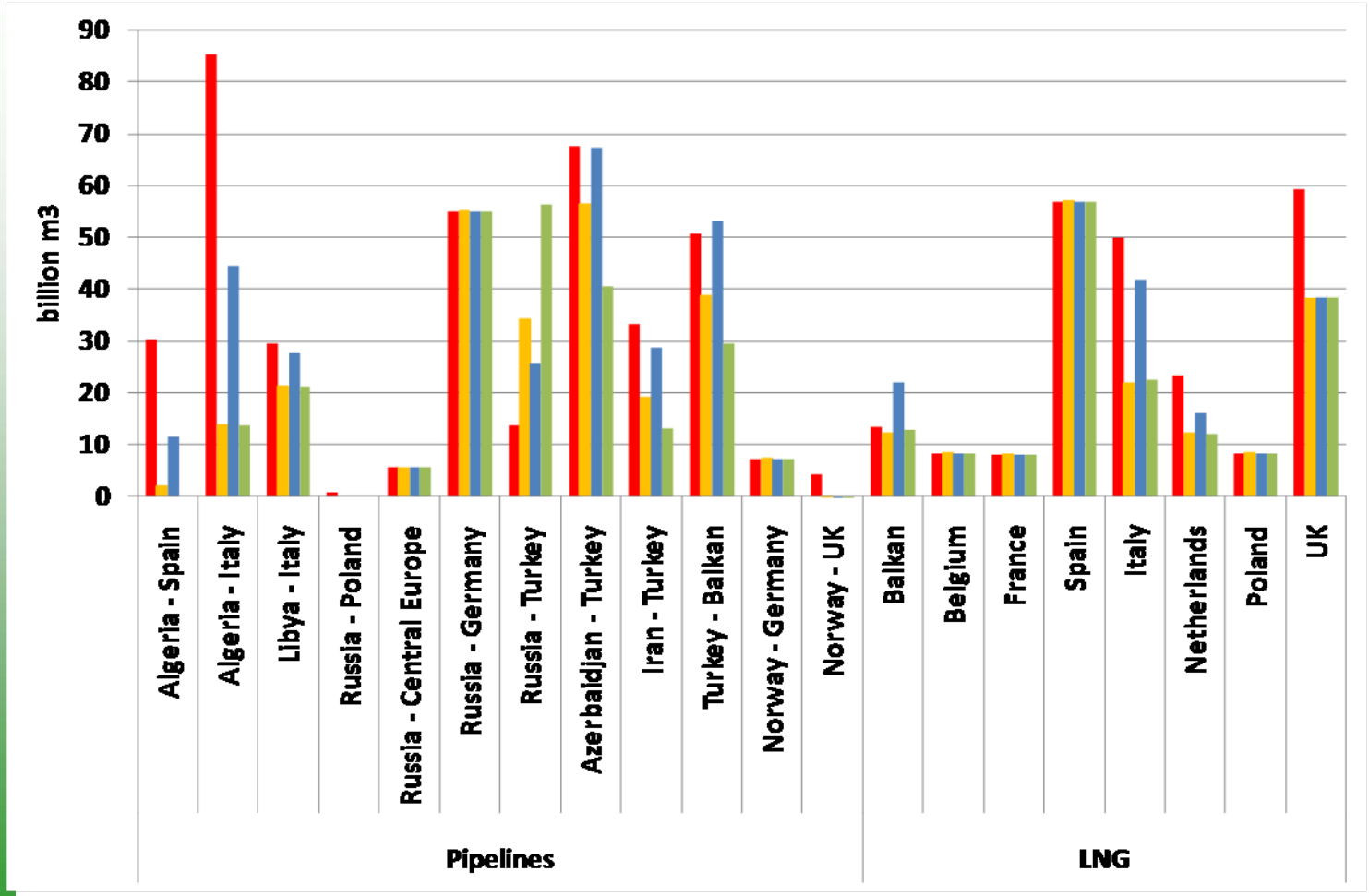
Investment in gas infrastructure

Gas Results



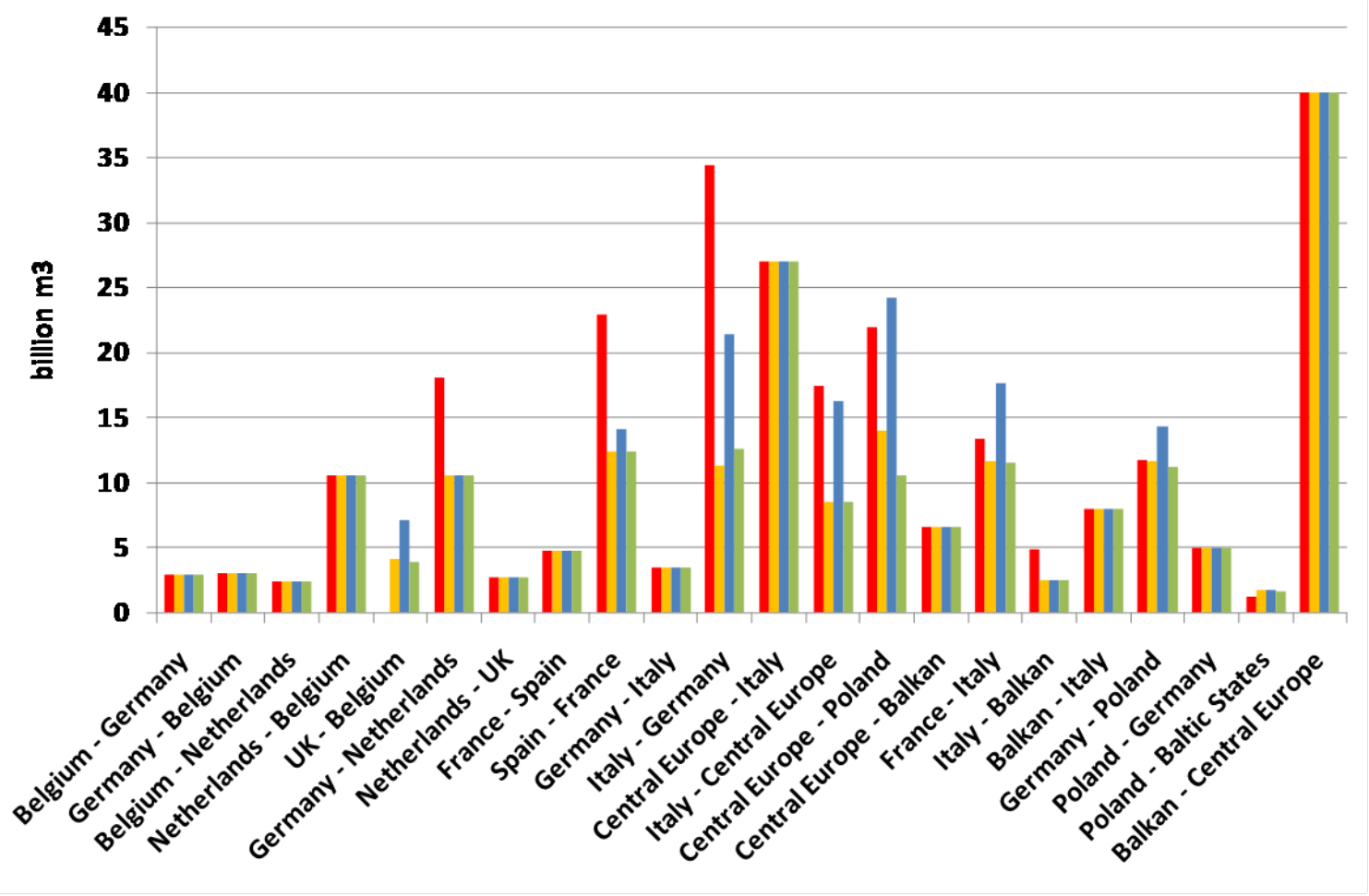
Investment in EU external supply lines

Gas Results



Investment in EU internal capacity

Gas Results



Main observations on gas corridors and hubs

Conclusions

- Turkey – Southeastern Europe strong corridor in all storylines
  - Including downstream expansions in region
- Depletion of gas reserves in the UK and the Netherlands->Limited infra expansion in Northwestern Europe
- Most important storyline differences occur in South and Southwestern Europe
  - Pipeline imports North Africa – Spain / Italy
  - LNG imports in Italy & Spain
  - Italy as gas hub in high demand storylines, triggering pipeline expansion downstream (region)

Summary across storylines

Electricity consumption vs RES share

Yellow

		2030	2040	2050
Electricity consumption	PWh	4.2	4.2	4.2
Renewable electricity generation	PWh	2.1	2.4	2.3
	%	50%	58%	54%
Gas consumption	Billion m3	507	455	480
Gas imports	Billion m3	422	403	449
Electricity infrastructure expansion	GW		55	22
Gas pipeline expansion	Billion m3	142	35	41
CO2 emissions electricity sector	Megaton	468	264	321

Green

		2030	2040	2050
Electricity consumption	PWh	4.2	4.2	4.2
Renewable electricity generation	PWh	2.0	2.6	3.0
	%	48%	62%	71%
Gas consumption	Billion m3	507	412	321
Gas imports	Billion m3	422	361	291
Electricity infrastructure expansion	GW		72	65
Gas pipeline expansion	Billion m3	143	28	34
CO2 emissions electricity sector	Megaton	556	210	66

Red

		2030	2040	2050
Electricity consumption	PWh	4.8	5.1	5.3
Renewable electricity generation	PWh	1.8	2.0	2.2
	%	37%	39%	41%
Gas consumption	Billion m3	777	812	846
Gas imports	Billion m3	692	761	815
Electricity infrastructure expansion	GW		36	20
Gas pipeline expansion	Billion m3	250	93	125
CO2 emissions electricity sector	Megaton	893	830	798

Blue

		2030	2040	2050
Electricity consumption	PWh	4.9	5.1	5.4
Renewable electricity generation	PWh	2.4	3.2	3.8
	%	49%	62%	70%
Gas consumption	Billion m3	696	644	631
Gas imports	Billion m3	611	593	601
Electricity infrastructure expansion	GW		56	56
Gas pipeline expansion	Billion m3	271	50	48
CO2 emissions electricity sector	Megaton	627	451	347

Conclusions

Main Conclusions

- Increasing RES has large consequences for investment requirements in trans-national electricity infrastructure (AC and DC)
- Power sector main driver for gas market developments
  - Differences across Europe → corridors and LNG hubs
- Increase in RES has positive impact on operational costs, but negative impact on generation asset costs, net impact is likely to be positive with increasing RES share.
- Higher electricity infrastructure requirements may partly be compensated by lower gas infrastructure requirements

Recommendations

- Further support for focused infrastructure policy, with particular attention for some corridors (i.e. EU infrastructure package)
- Need for adequate policy signals regarding long-term CO2 price, since it is a major uncertainty in shaping of electricity generation mix
- Electricity infrastructure affects gas infrastructure (and vice versa), so energy policy should not focus on one sector in isolation
  - What is the future role of gas in the EU energy mix?

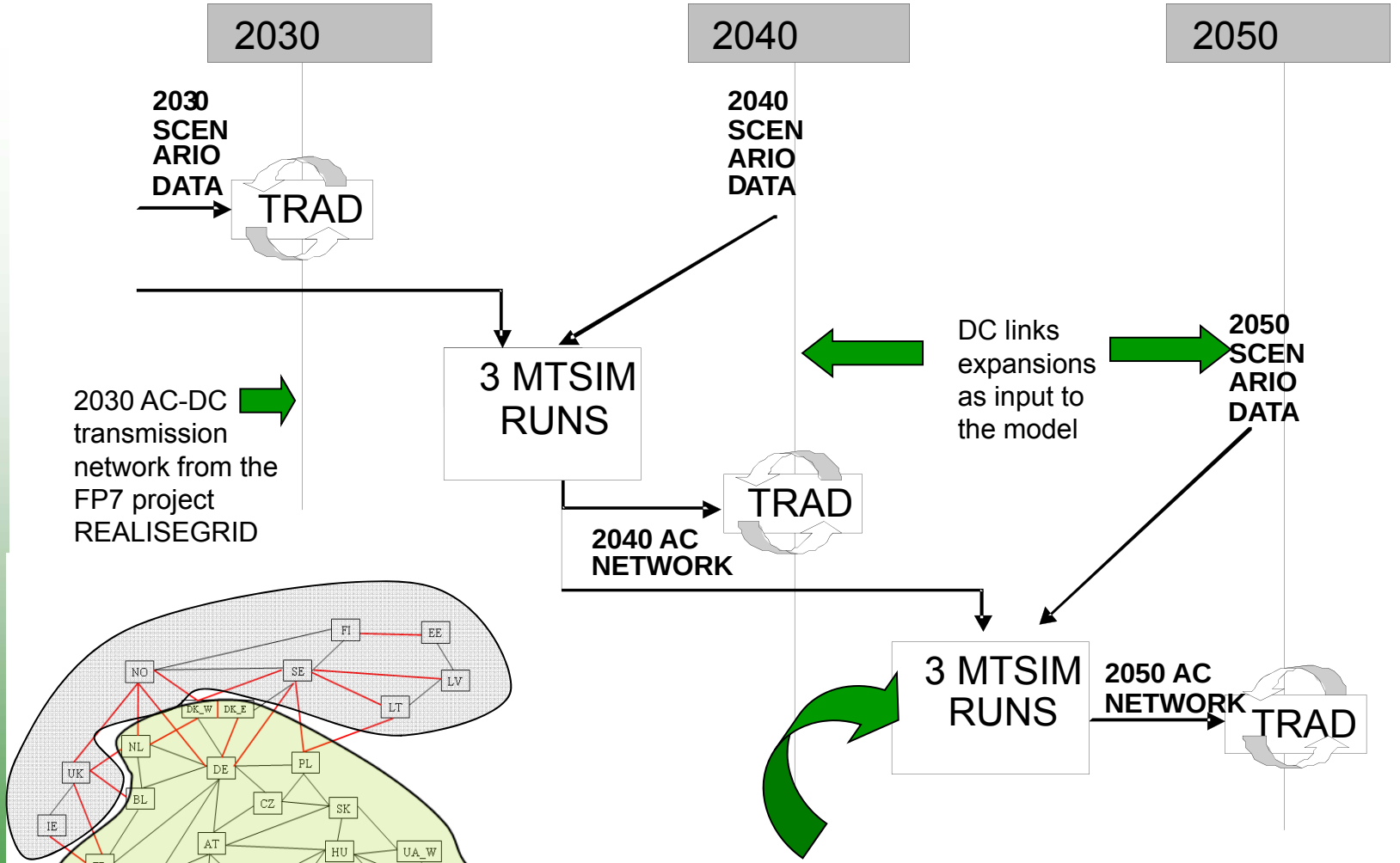
Thank you for your attention!

ozdemir@ecn.nl
Gianluigi.Migliavacca@rse-web.it

Additional Slides

MTSIM loop for assessing AC expansions

Methodology



- One traditional run (non planning) to calculate DC flows
- Two runs (UCTE, NORDEL+UK+EIRE) in planning

Gas Infrastucture Invesments

Assumptions

- Expansion of pipeline (TSO), storage (SSO), LNG capacity

- Short-sighted view: Economically optimal expansion of pipeline, LNG, and storage capacities for each ten year period

- **Assumption:** Infrastructure investors do not behave strategically to increase prices:

KKT condition: The investor (i.e. the network operator, LNG terminal operator, gas storage operator) invests until the expected additional income (discounted scarcity rent) from next decade is sufficient to cover X% (hurdle rate) on top of its long run unit cost of investment.

Gas demand

Assumptions

- Represented by 3 different market sectors and 3 seasons:

  Market sectors (**M**) : Power generation, Industry, and Residential

  Seasons (**T**): Low demand season (summer)
  Medium demand season (autumn/spring)
  High demand season (winter)

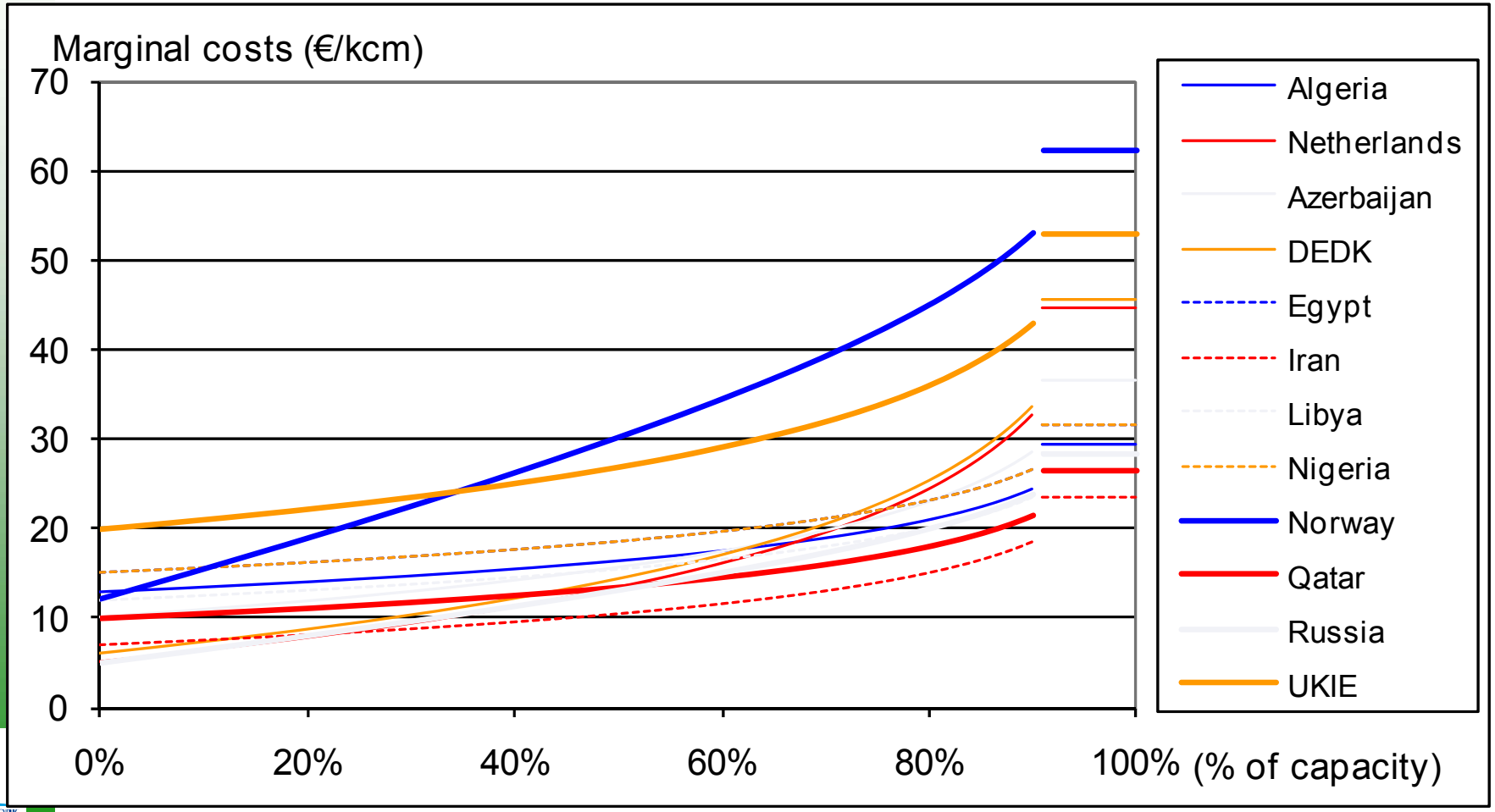
- Residential and industrial sectors respectively shows large and no seasonal variation

- Power sector demand for each season is taken from MTSIM

Gas supply

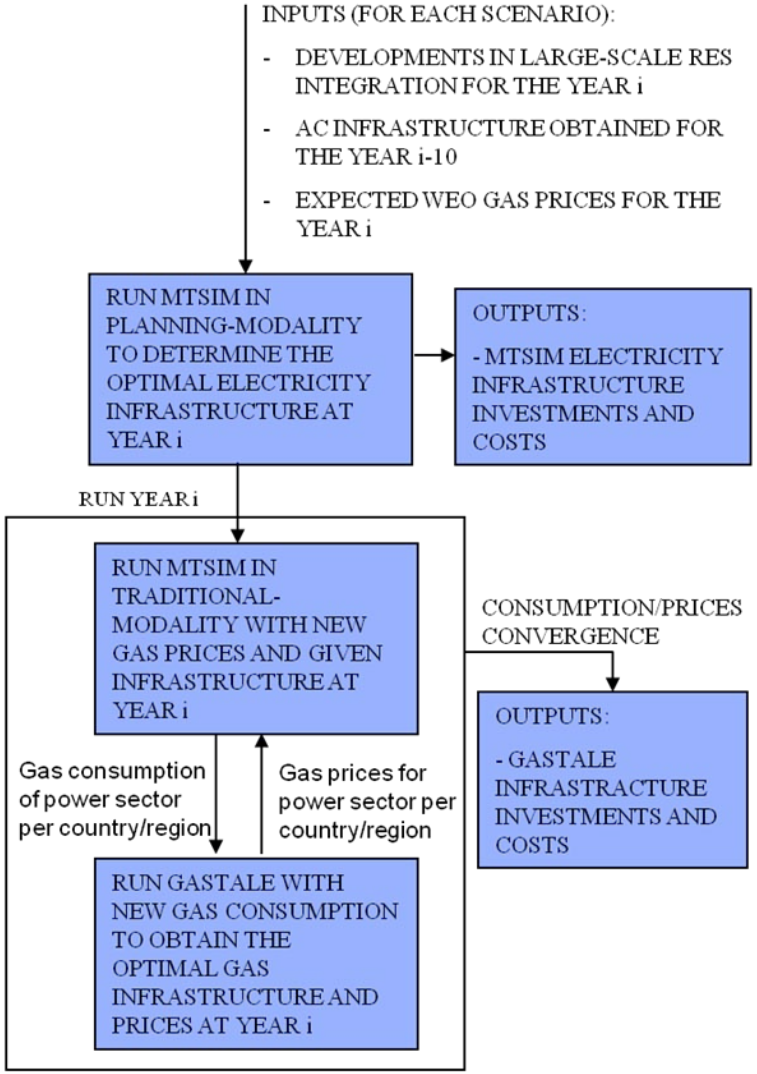
- A single marginal production cost function per producer/region (aggregated over all active fields)

Assumptions



Overview of interaction of electricity and gas market models

Methodology

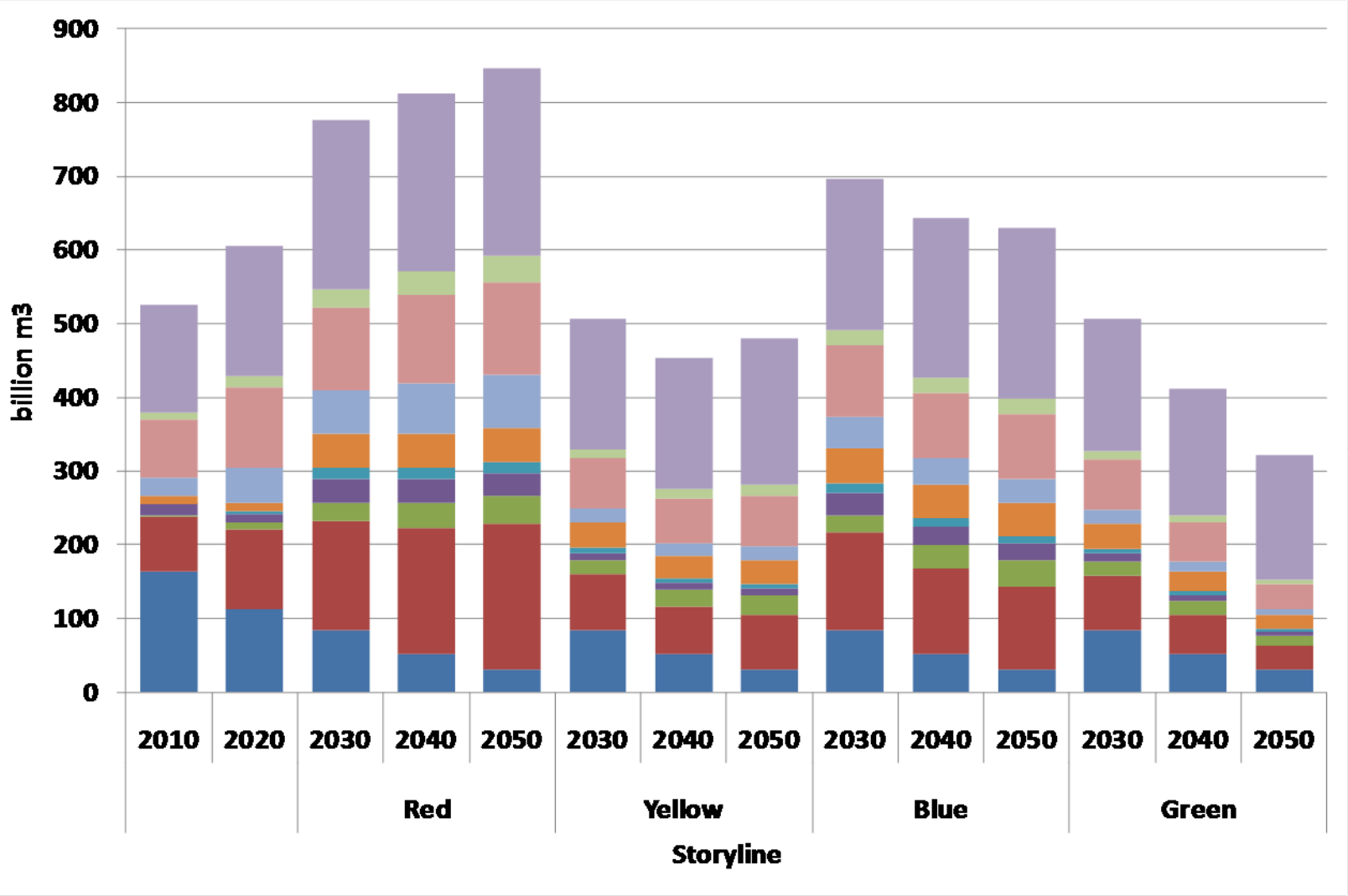


Electricity and gas infrastructure developments up to 2030

- Electricity Infrastructure developments between 2010-30
  - ENTSO-E's 10 year development plan (2010-2019)
  - Own analysis. The information and the data contained in several public sources regarding existing interconnection projects (ongoing, planned, under study, potential) in Europe have been taken into account
  - Results of the FP7 project REALISEGRID are used as an input on the transmission network developments till 2030, starting year for the SUSPLAN analysis.

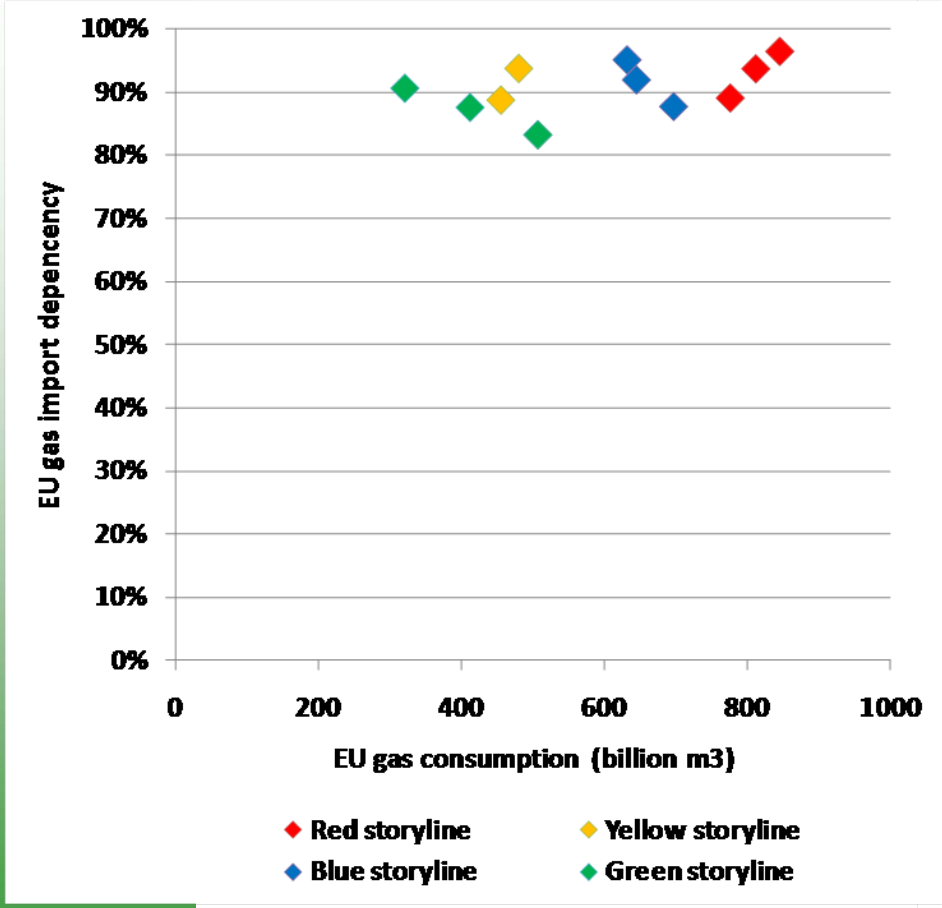
- Gas Infrastructure developments between 2010-30
  - ENTSO-G's 10 year development plan (2010-2019)
  - Own analysis. Projects like Nabucco, South stream (moderate estimation), Nord stream, ITGI-Poseidon, GALSI, Baltic pipeline, and the extension of the Transmediterranean project have been added as far as they were not yet included in ENTSO-G figures
  - For developments between 2020-30, the GASTALE model was run under each storyline

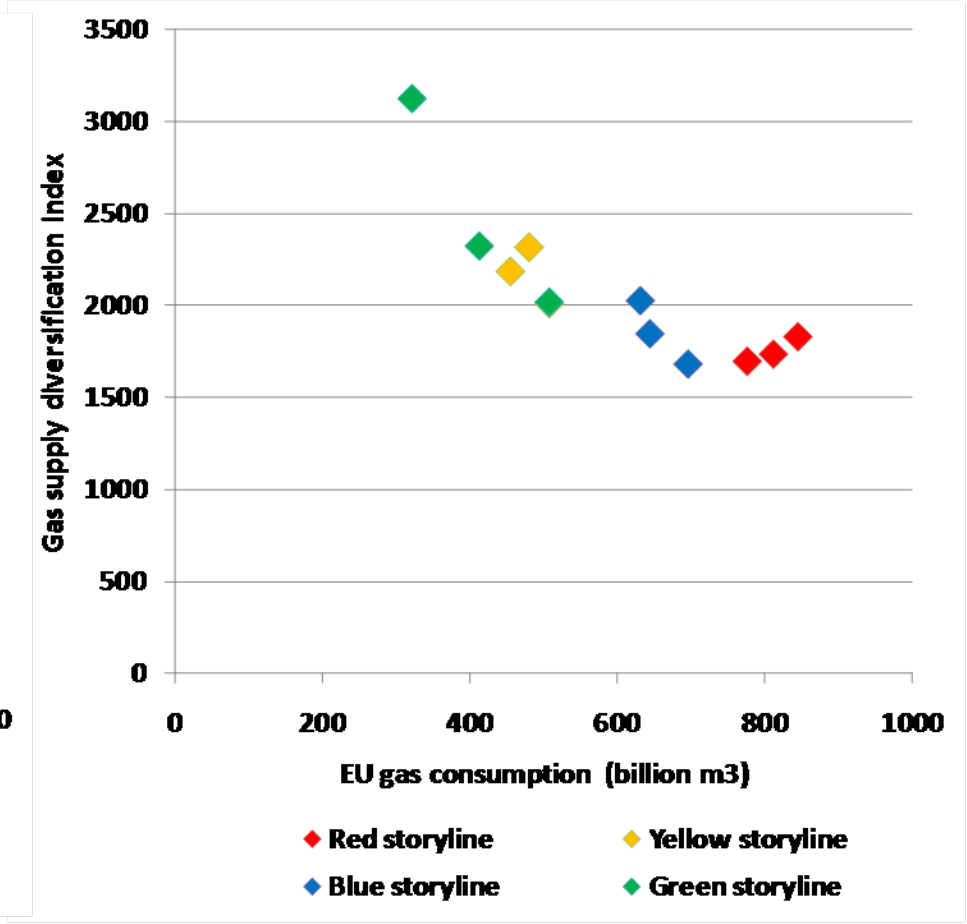
EU gas supply sources



Security of gas supply

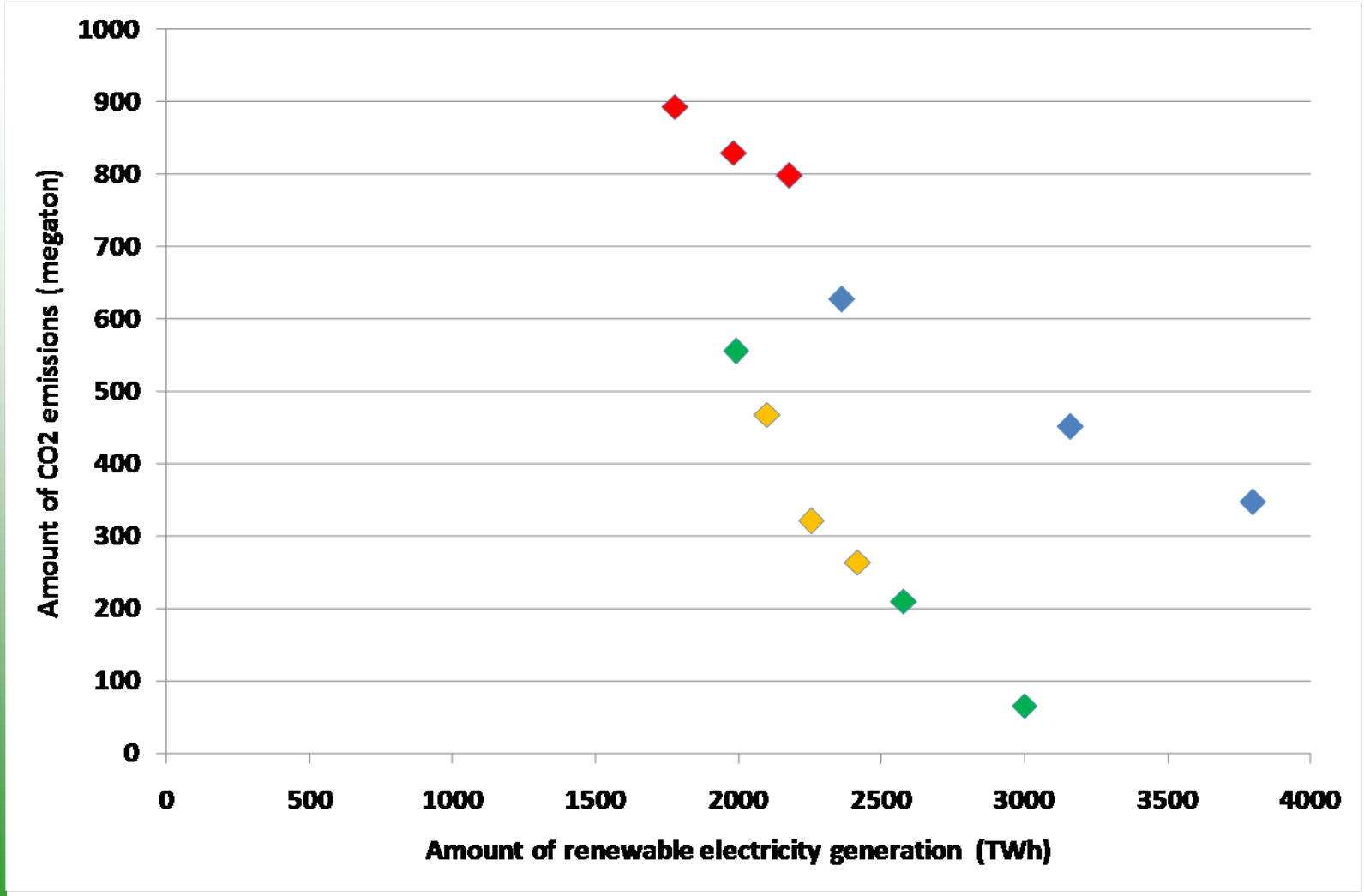
Import dependent, but more or less diversified





CO_2 emissions decrease in all storylines

Electricity Results



Results for electricity infrastructure

Results

Corridor-oriented model of the pan-European power system

Aim: assessing how transnational transmission corridors should be upgraded for:

- integrating the maximum share of RES in Europe in the timeframe 2030-2050
- ensuring security of electricity supply while keeping into account the impact on electricity production costs and CO_2 emissions

Load shedding and energy in excess

Results

RES Increase

Demand Increase

YEL	Load shedding	Energy In Excess
2030	-	ES: 622 GWh IE: 415 GWh PT: 608 GWh UK: 902 GWh
2040	-	ES: 1708 GWh IE: 55 GWh PT: 587 GWh UK: 49 GWh
2050	-	ES: 1035 GWh PT: 267 GWh

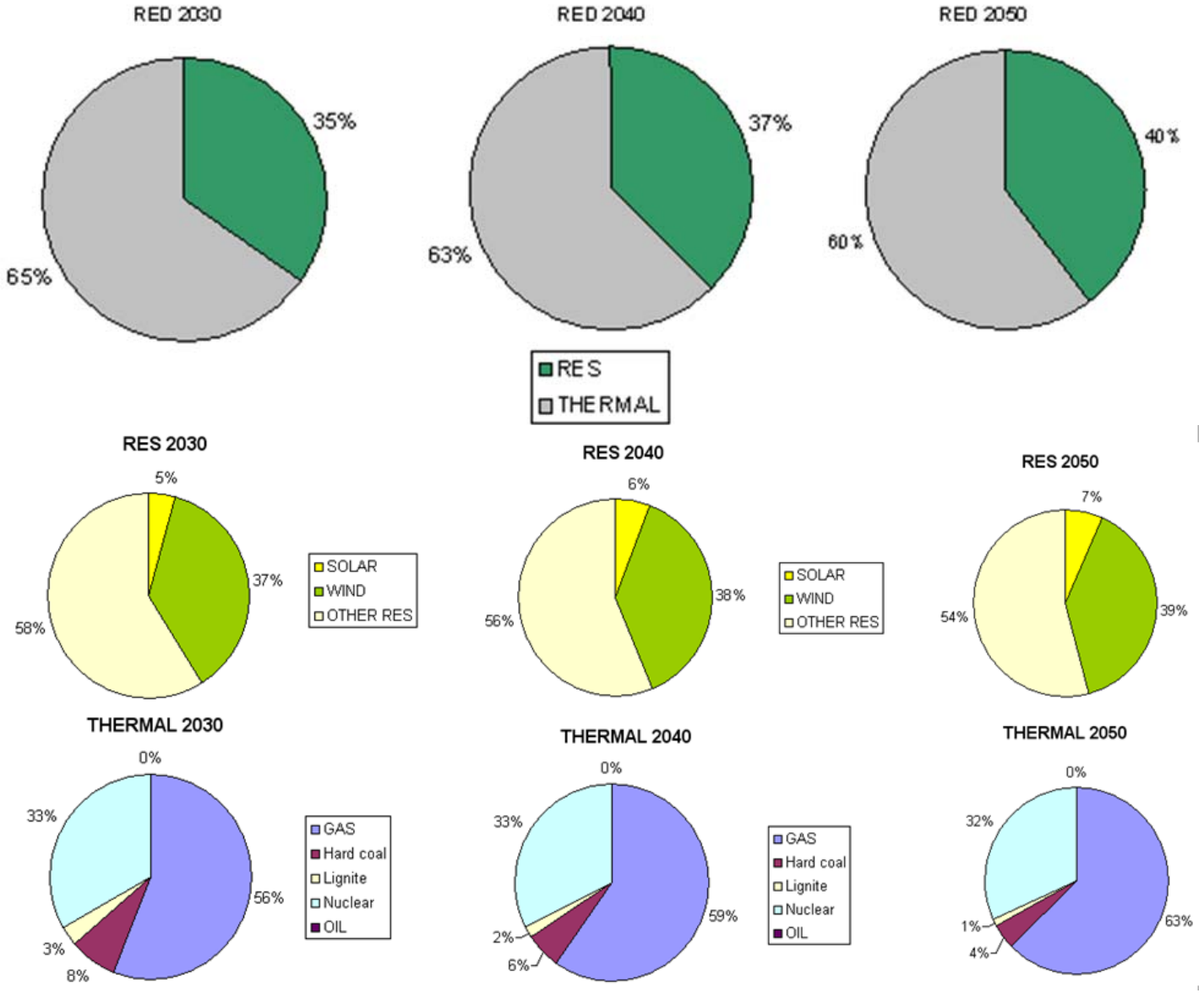
GREEN	Load shedding	Energy In Excess
2030	BL: 168 GWh CH: 0,2 GWh DE: 447 GWh	ES: 1548 GWh IE: 65 GWh PT: 826 GWh UK: 105 GWh
2040		ES: 11784 GWh GR: 7 GWh IE: 168 GWh PT: 2436 GWh UK: 207 GWh
2050		ES: 38376 GWh GR: 6 GWh IE: 490 GWh PT: 4870 GWh UK: 655 GWh

Winter: peak load, RES + import are insufficient

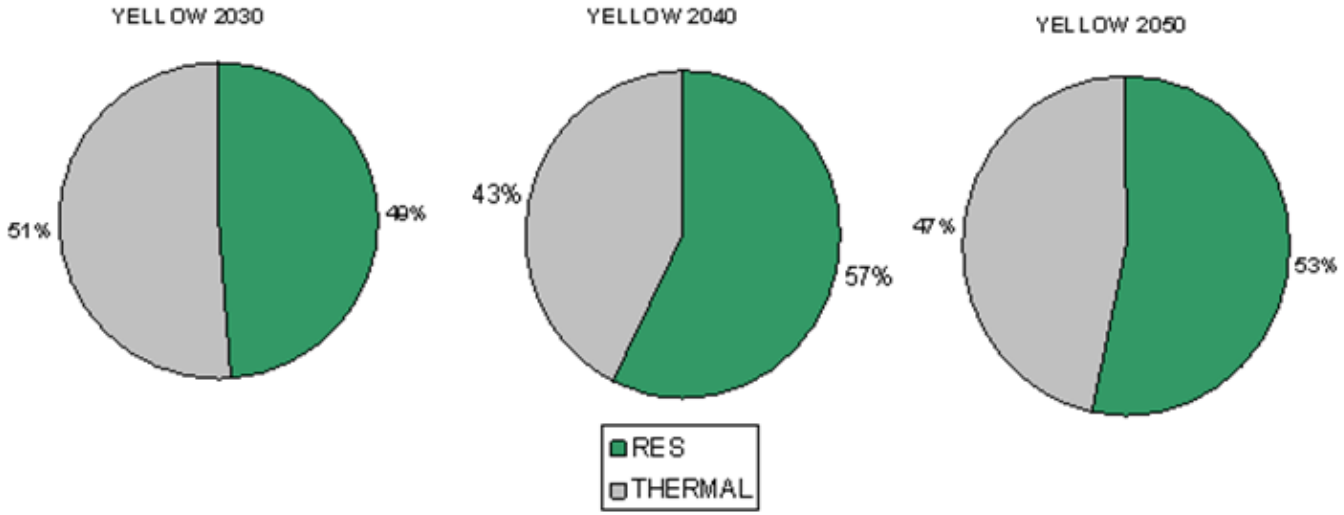
RED	Load shedding	Energy In Excess
2030	BL: 209 GWh CH: 497 GWh DE: 180 GWh	ES: 3 GWh PT: 1 GWh
2040	CH: 0,4 GWh CZ_W: 0,9 GWh DE: 210 GWh	ES: 3120 GWh PT: 1774 GWh
2050	CZ_E: 0,12 GWh CZ_W: 0,4 GWh DE: 0,9 GWh	ES: 8788 GWh PT: 13254 GWh

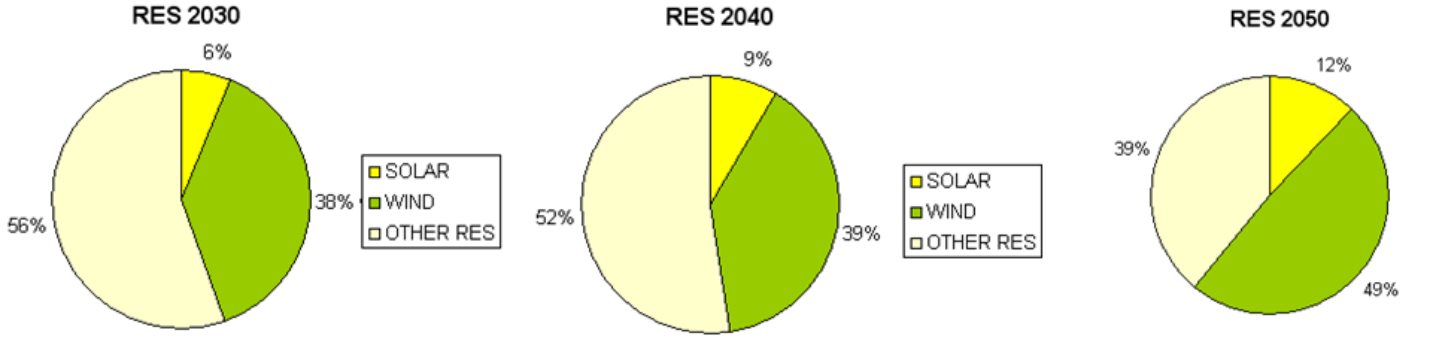
BLUE	Load shedding	Energy In Excess
2030	-	ES: 75 GWh IE: 490 GWh PT: 35 GWh UK: 1395 GWh
2040	DE: 22 GWh	ES: 758 GWh IE: 3323 GWh PT: 113 GWh UK: 17002 GWh
2050	-	ES: 2114 GWh IE: 10782 GWh PT: 158 GWh UK: 53181 GWh

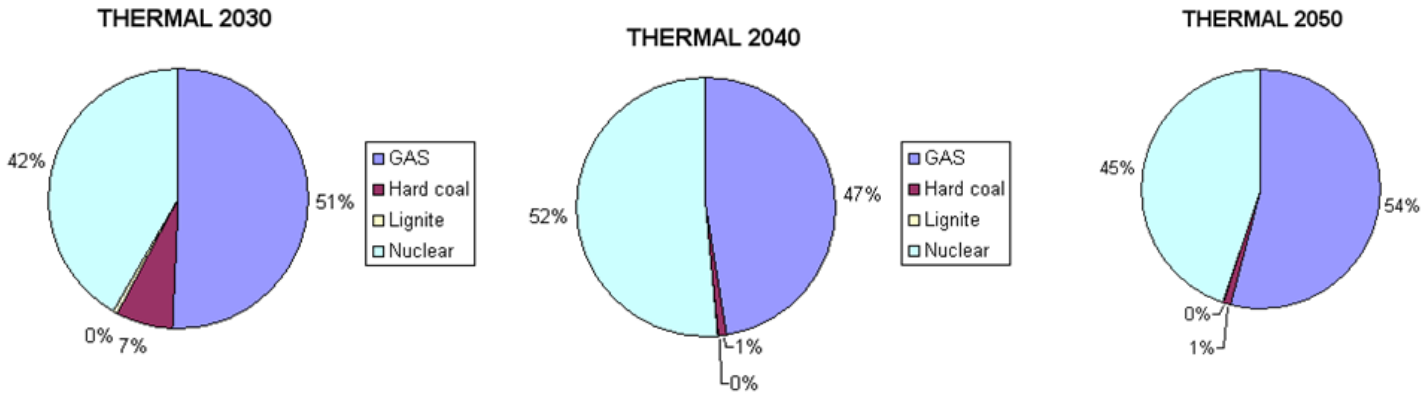
RESULTS: Red Storyline



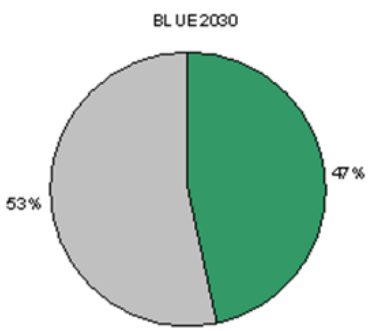
RESULTS: Yellow Storyline

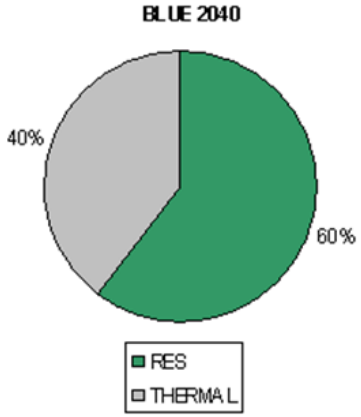


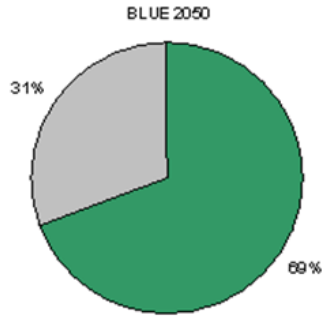


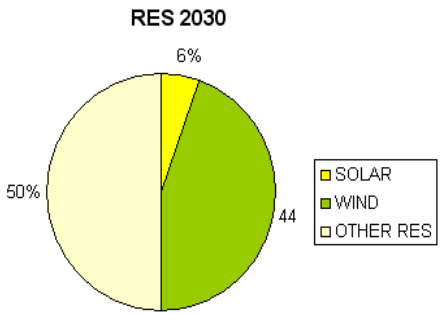


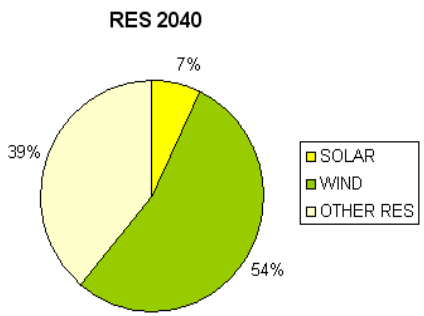
RESULTS: Blue Storyline

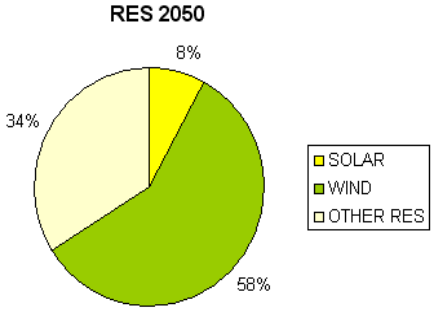


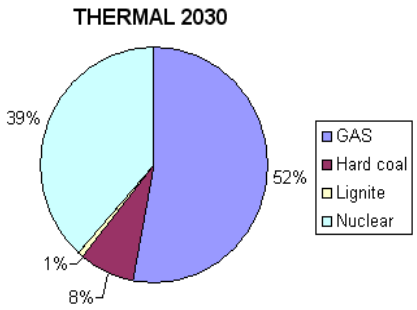


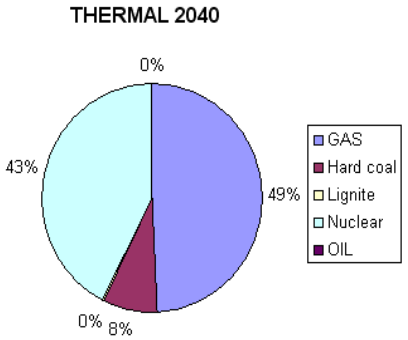


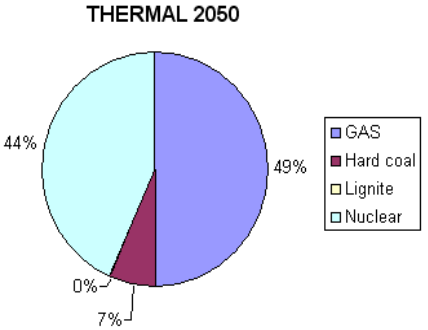




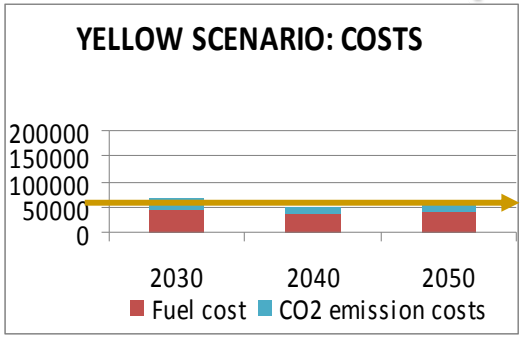


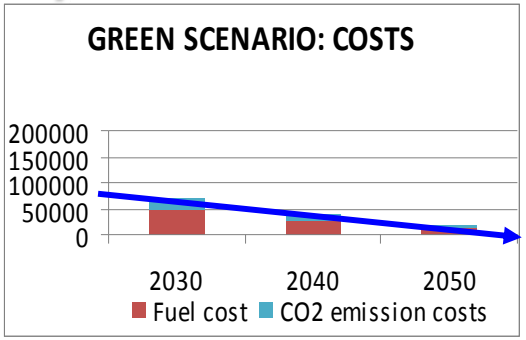


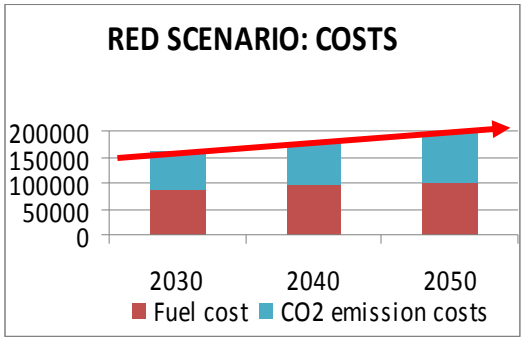


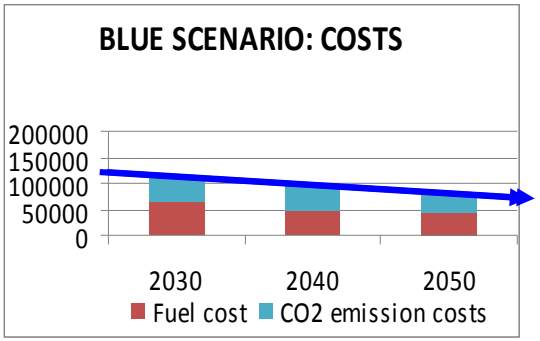


Operational costs (M€)

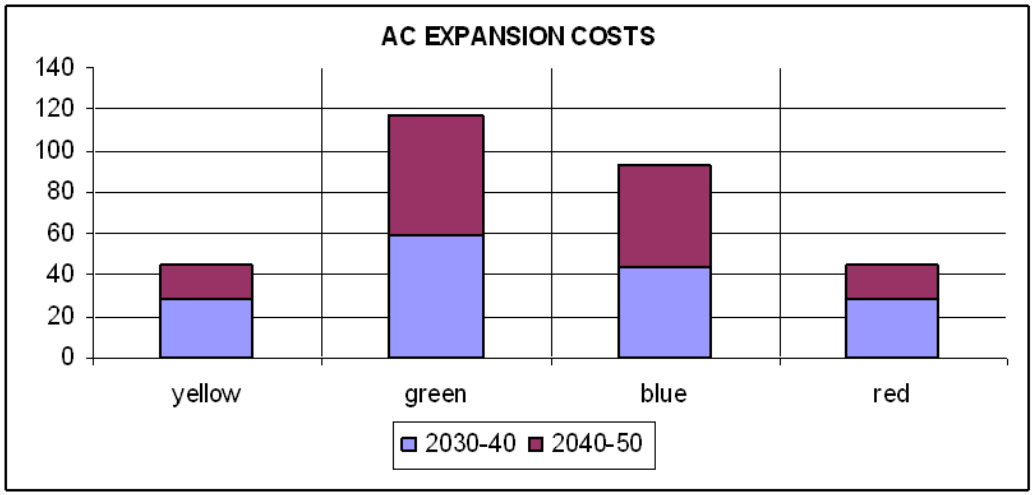








AC expansions costs (M€)



Electricity Results

Assessment of gas and electricity interactions

Interactions

- What is gained by high RES share?
  - Decrease in cost of generating electricity (operational and capital)
  - Decrease in amount of CO_2 emissions (electricity sector)
  - Counter impact on investments in electricity & gas infrastructure

Electricity & gas infrastructure expansion

Contrast between electricity and gas impact

Interactions