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Methodological advances in modelling regional energy systems security and global climate change mitigation

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REACCESS = ***Risk of Energy Availability: Common Corridors for Europe Supply Security***

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1 – Objective of the research

- Evaluating technical, economical and environmental characteristics of present and future energy corridors among Europe and the supplying regions;
- Implementing these energy corridors into a version of the global and EU MARKAL-TIMES models;
- Analysing energy scenarios, in which EU27 import competes with efficiency policies, new technologies, renewable sources, in the framework of the climate change mitigation targets

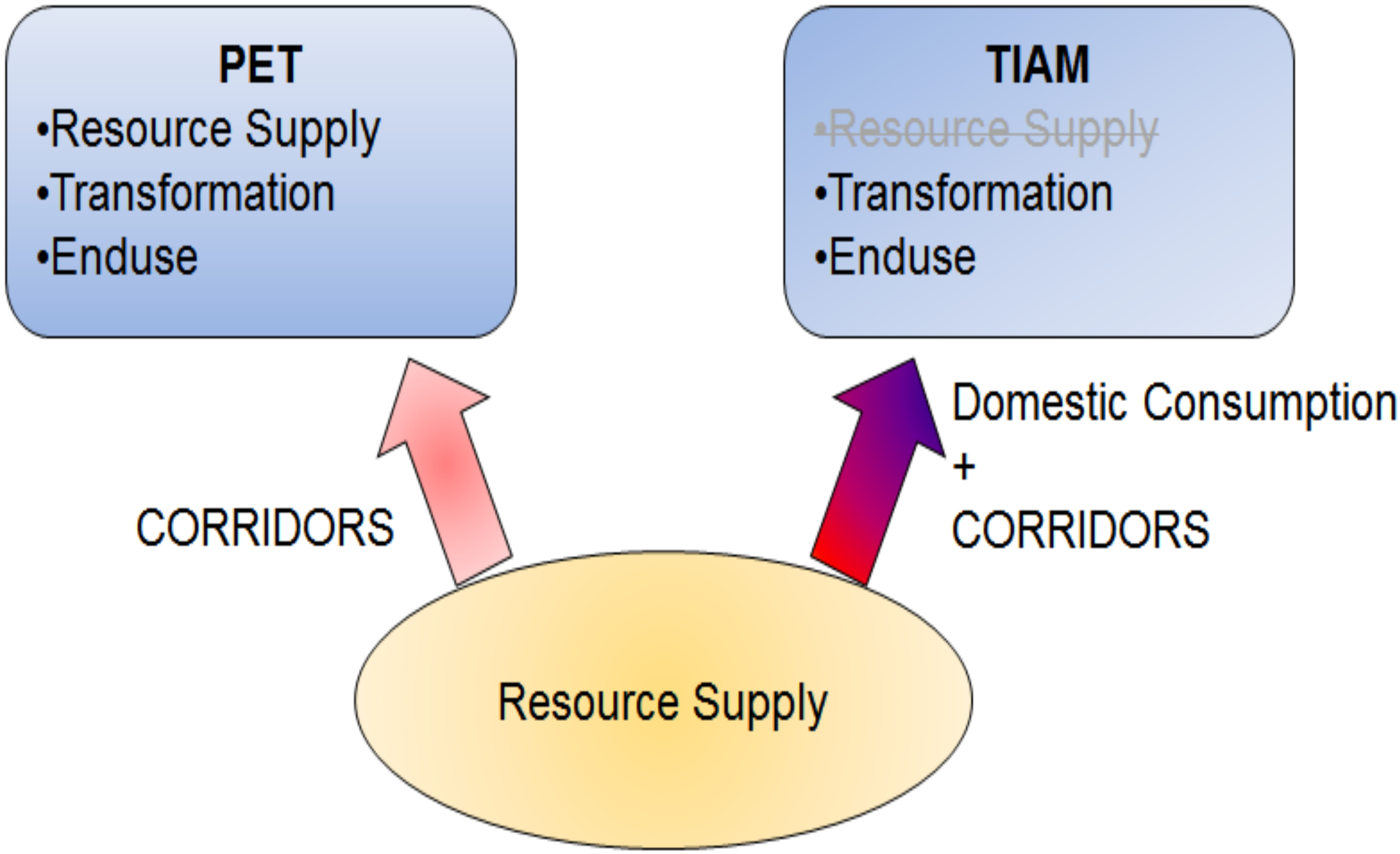
2 – Methodology

1. Representing detailed options in the models
2. Representing the socio-political risk of supply
3. Representing linearly the energy system security risk
4. Implementing the REACCESS Risk Indicator
5. Implementing cost/risk/mitigation trade-offs

2.1 – Energy system security factors

- Energy dependence
- Domestic market concentration
- Import dependence
- Concentration of foreign suppliers
- Socio-political risk of supply & transit countries

2.1 – Models with detailed options



Models Integration framework

2.2 – Socio-political risk of supply

A socio-political risk indicator $R(r_a)$ was associated to each supply/transit country r_a (0=no risk; 100=max risk).

The socio-political risk of supply / transit countries is converted to energy supply risk by multiplying the flow in each corridor / branch by the socio-political risk parameter of the country of origin / transit.

The “Quantity of Risk weighted Energy” QRE was defined as follows:

$$QRE(s_f,f,y,r_a)\} = R(r_a)*Q(s_f,y,f,r_a)$$

REACCESS

2.3 – Concentration risk indicators

Traditionally the risk of supply is measured by non linear concentration / risk indicators. For instance, the Herfindahl-Hirschmann (H-H) concentration index

$$H\text{-}H = (\Sigma_i\ p_i^2),$$

Where p_i is the share of element i in the total population

The problem was to endogenize such non linear indicators in a linear programming model, without losing the advantage of linearity, which allows the existing large technological and geographical details.

The two sources of non linearity of H-H have been removed as follows:

2.3 – Linearization of risk indicators

1. The HH index normalizes the indexes to make them dimensionless. But normalization is useful (or even essential) only when several independent, separate systems must be compared, but not really needed when applied to a single well defined situation, as is the case with a TIMES model. By eliminating normalization, the first source of nonlinearity is eliminated.
2. The H-H index sums the squares as a mean to penalize dominance of any single source (or fuel), thus encouraging diversification. In this research the sum of the squares is replaced by the Max operator, which is even more effective in penalizing dominant supply (and encouraging diversification), and is essentially linear

2.4 – The REACCESS Risk Indicator

The linear indicator for captive corridors (mainly **p**ipelines):

$$Ri_p = \Sigma_{ra}\ \Sigma_y\ \Sigma_f\ Max_s\ \{QRE(s_f,f,y,r_a)\}$$
$$= \Sigma_{ra}\ \Sigma_y\ \Sigma_f\ Max_s\ \{R(s)*Q(s_f,y,f,r_a)\}$$

The linear indicator for open sea corridors (port to port **s**hips):

$$RI_s = \Sigma_y\ \Sigma_f\ Max_s\ \{\ \Sigma_{ra}\ QRE(s_f,f,y,r_a)\}$$
$$= \Sigma_y\ \Sigma_f\ Max_s\ \{\ \Sigma_{ra}\ R(s)*Q(s_f,y,f,r_a)\}$$

2.5 – Cost-risk-mitigation trade-offs

This approach, which can be put in the class of Multi Criterion Decision Making (MCDM) methods, consists in defining mathematical expressions that capture risky configurations of corridors, and incorporating these mathematical expressions into the model either as constraints or as additional terms in the objective function.

It relies essentially on systemic risk indexes (also called insecurity indexes, in this study the RI), based on the risk characteristics ("coefficients") of individual corridors.

This method compromises between the pure economic dimension and the system risk dimensions.

2.5 – The main scenarios

Scenario	OBJ	Constraint
REF	$COST_r$	none

REF-RISK: *2 steps*	1=RI_k 2=COST	$COST=(1+\alpha)^* COST_r$ $RI_{min}=(1+\beta) * RI_k$
CLIM	$COST_c$	CO2 emissions

CLIM-RISK	$COST_{ck}$	CO2 emissions $RI_{min}=(1+\beta) * RI_k$

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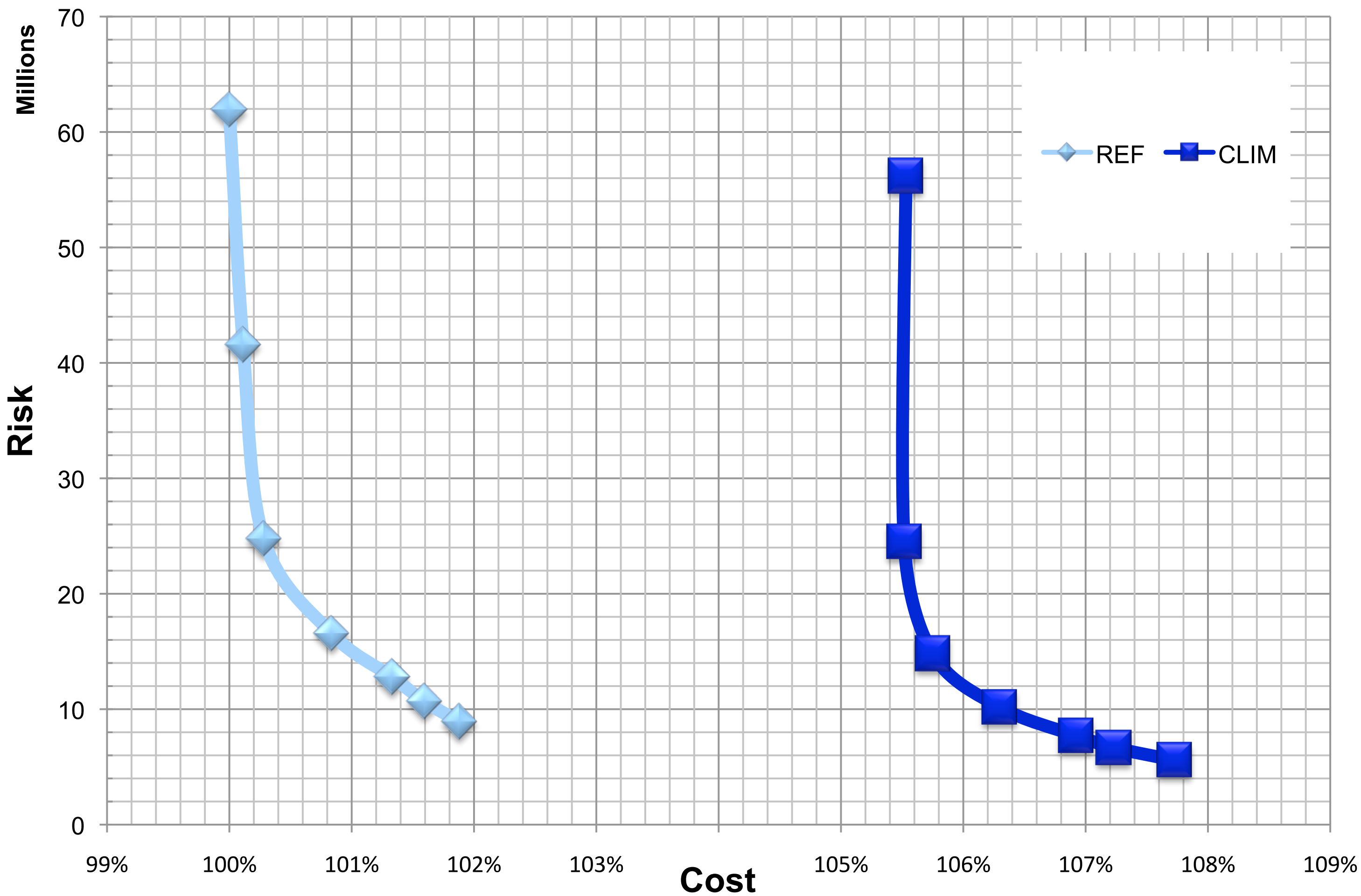
3 – Results

1. Trade-off curves
2. Oil supply vulnerability
3. Sensitivity to socio-political risk developments
4. Sensitivity to the interruption of some important corridors

3.1 – Trade-off curves



Cost-Risk trade off curve for EU27

3.1 – Synergies Mitigation - Security

The task of participating in the global effort of mitigating climate changes turns out to be much more expensive for Europe than risk reduction, as it increases the total system cost of about 5% yearly in the decade 2020-2030.

The climate change mitigation effort [EMF-24, 2010] makes the extra cost of reducing the risk much less than in the absence of a climate objective. Reducing the risk to the same level as in the REF case, implies total system cost increases of about 0.3%, i.e. a cost increase from 5% to 5.3% on an yearly basis in the decade 2020-230.

3.1 – Energy security ‘insurance fee’

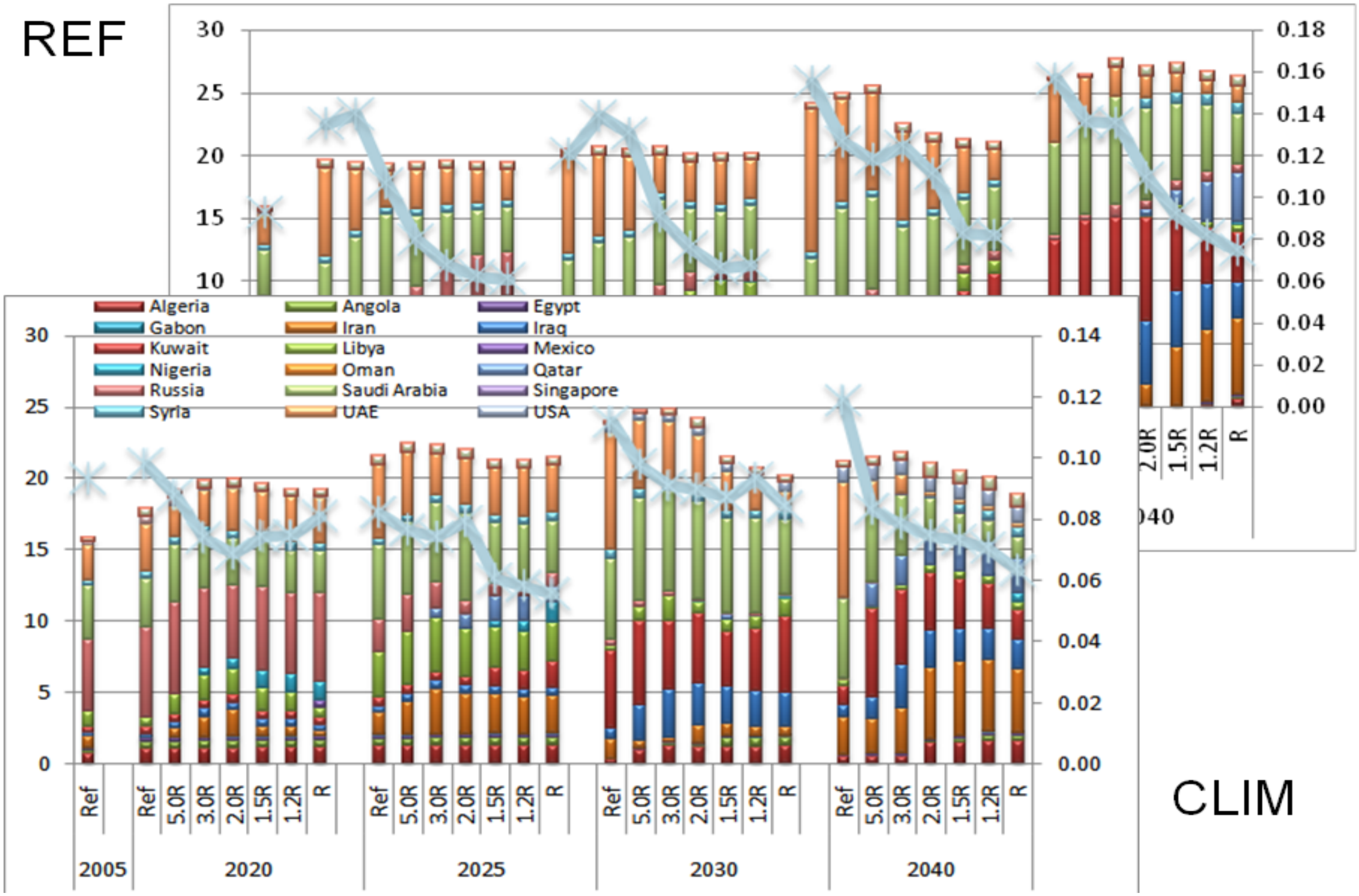
Reducing the risk by a factor of 4 increases total energy system costs by about 0.5%, which in the 2020-2030 decade implies extras cost of less than 1% for EU27.

The best compromise between cost and risk is at a risk reduction level of between 4 and 3, with/out mitigation. In this exercise the suggested annual insurance fee for EU27 would be of the order of 25-30 billions €2000, 0.2% of the expected GDP in the period 2020-30.

This additional cost is used mainly in investments for:

- improving the efficiency of end-use sectors and
- harnessing more domestic resources – renewable and unconventional fossil only in the low mitigation cases.

3.2 – Oil supply vulnerability



EU27 oil import and vulnerability as measured by the H-H-R indicator

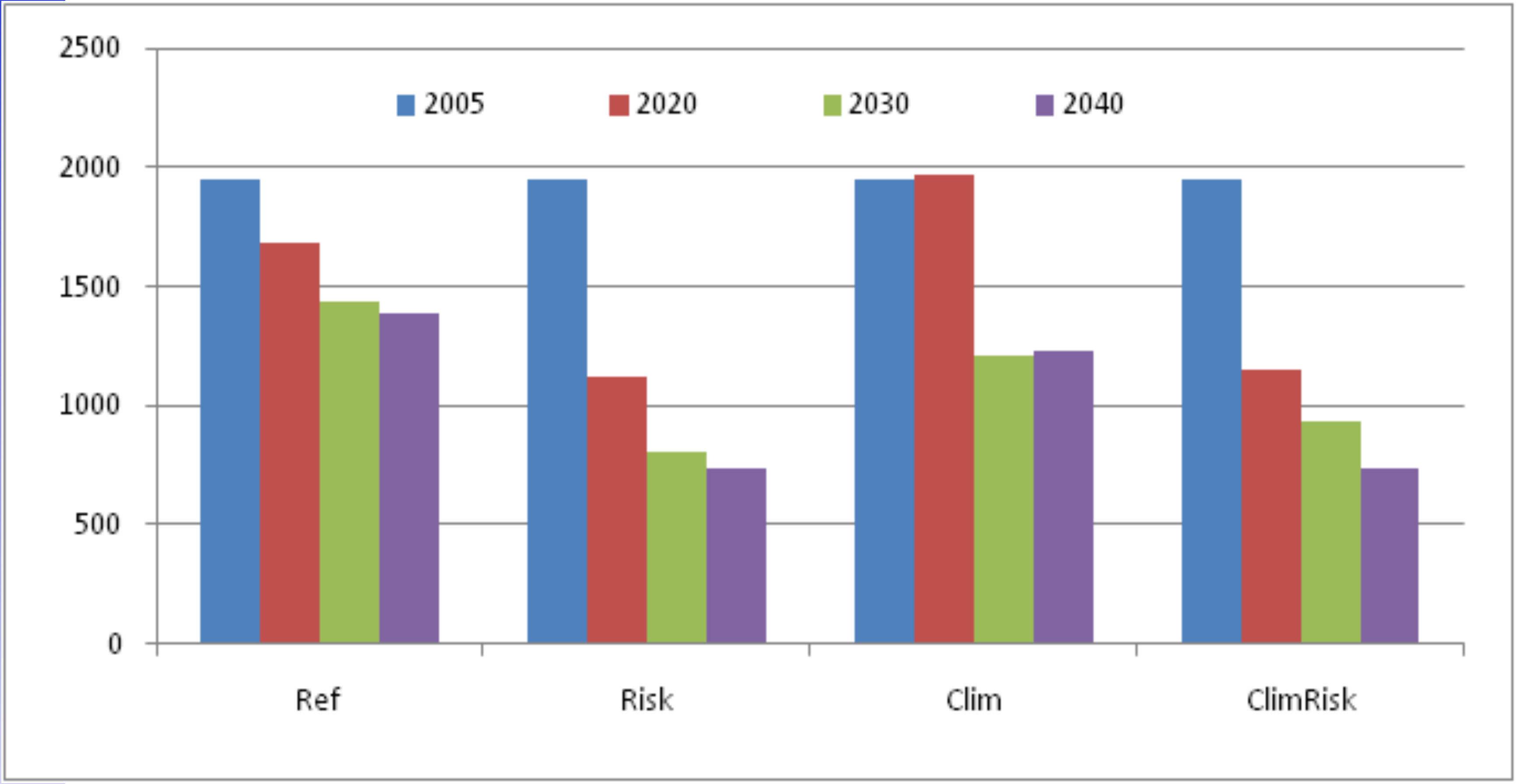
3.2-Behaviour of concentration indexes

Reducing the REACCESS Risk Indicator has the general effect of reducing the value also of the traditional supply concentration indexes.

Going from 5*min(RI) to min(RI) the H-H index computed for a single fuel in general decreases, but not always. The H-H-R index behaves better, because it includes the elemental risk in its computation. In general it cannot be expected a smooth reduction behaviour of fuel specific H-H and H-H-R indexes because they differ from the optimization objective.

The traditional index which follows more closely REACCESS Risk Indicator is the H-H-R index that includes all fuels, since it is closer to the spirit of the optimization than the H-H-R index for a single fuel.

3.2 - Supply side vulnerability: all fossil



HH extended to all 31 countries suppliying all fossil fuels to EU27 (max=10000, min=322)

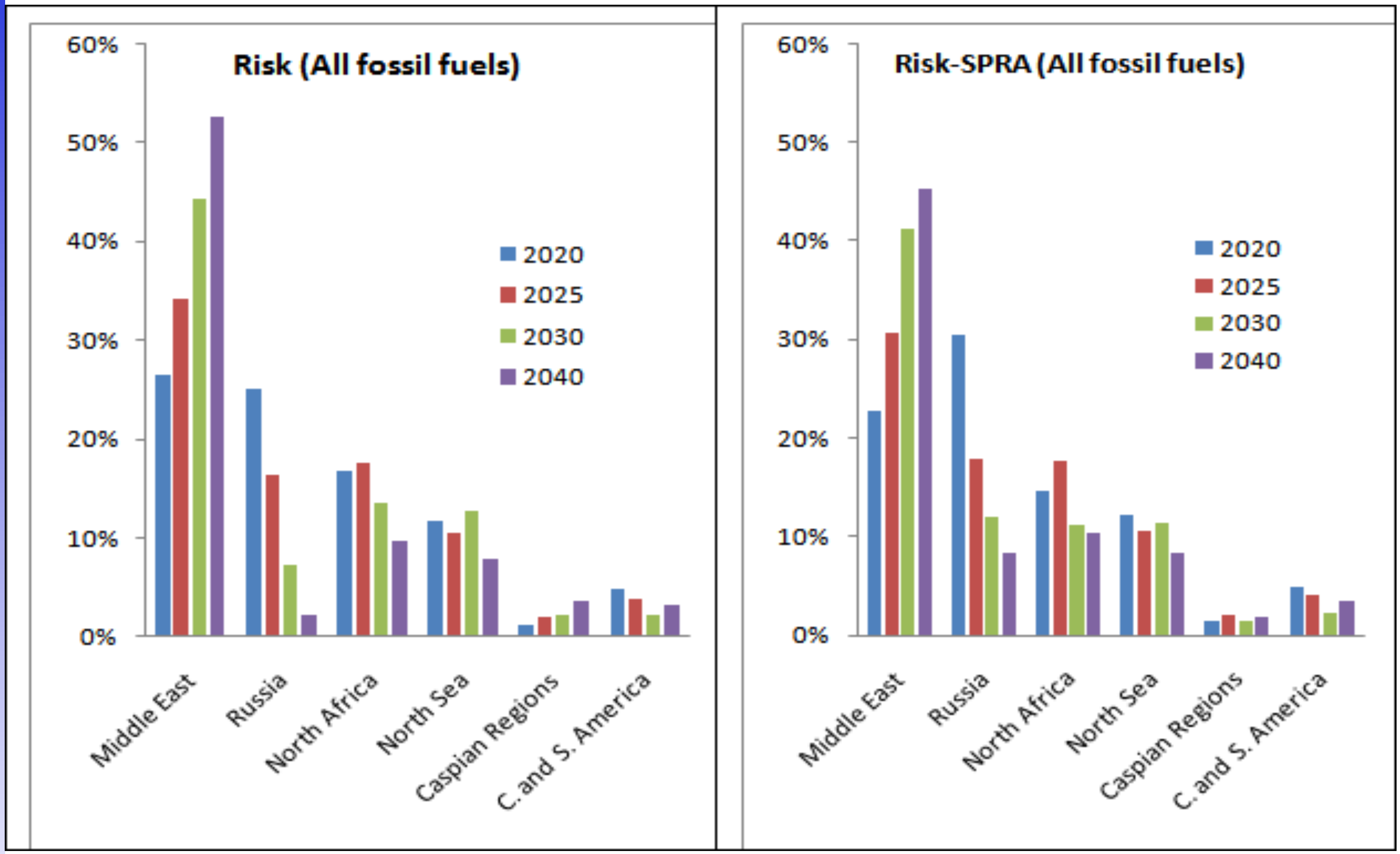
3.3 – Sensitivity to socio-political risk developments

What is the effect of increasing by 20 points the elemental socio-political risk factor of Middle East and North African (MENA) countries after 2017?

- In RISK scenarios, diversification policies increase the market share of Middle East (over 50% in 2040) and North Africa and reduces fossil fuels import from Russia.
- If MENA countries become more risky, their export to EU increases less and imports shift back to Russia, mainly in natural gas import. Europe seems unable to reduce "simultaneously" the market shares of fossil fuels import from MENA countries much below the reference case.

From the methodological point of view, the general energy system risk reduction policies, as suggested by reducing the REACCESS RI, are effective also in preventing the difficulties that can derive from unexpected socio-political changes in the supply countries.

3.3 – If Middle East and North Africa (MENA) countries become more risky

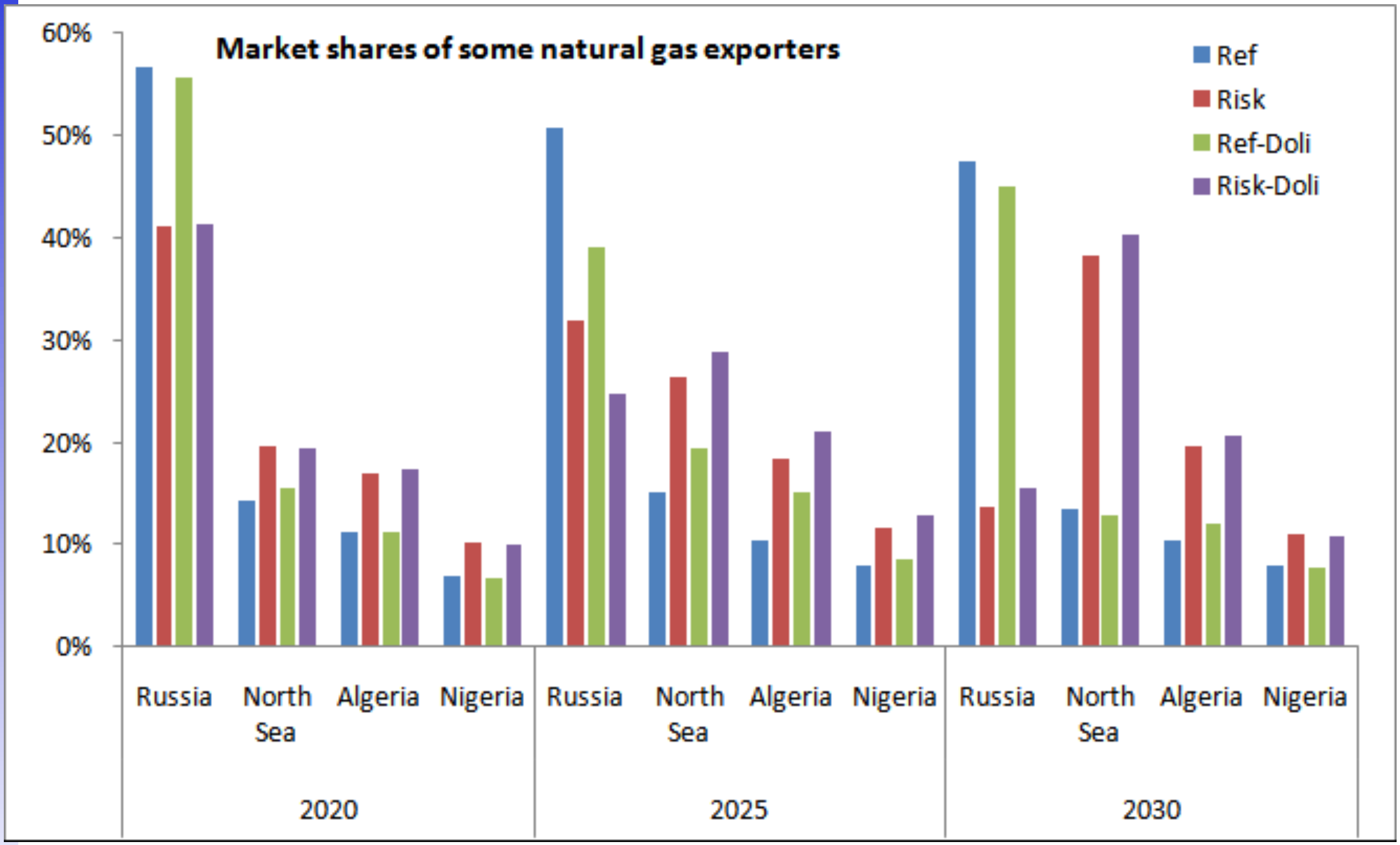


Fossil fuel import shares (SPRA: scenario with risk+20%)

3.4 – Sensitivity to the interruption of some important corridors

What happens if the most important, and apparently most risky, import flow of natural gas from Russia to Europe is cut in 2023-2027 in Dolina (Ukraine)?

3.4 - Cutting a vital natural gas hub



DOLI = scenarios in which the natural gas flow through pipelines crossing the Dolina location in Ukraine is cut in the period 2023-27

3.4 - Cutting a vital natural gas hub

EU27 reduces natural gas consumption from 27EJ to 17EJ in 2030 from REF to RISK, with/out Dolina.

In 2025 Russia looses 19% points of its natural gas market share from REF to RISK scenarios. A disruption in Dolina further reduces the Russian market share by 7%. Russia reduces its market shares of natural gas also in the periods following the interruption period.

Russia exports are very sensitive to the general Risk objective and less sensitive to the specific obstacle due to the disruption of this hub.

This confirms that the objective function chosen to explore energy system security issues is effective and achieves increasing levels of supply diversification.

4 - Conclusion

- A method has been developed to endogenize long term energy supply security concerns in bottom up models
- It is essentially linear, fully compatible with large models, without the need of piecewise linearization
- Scenarios built with this method increase long term supply security, as measured with the traditional concentration / diversity indicators, and energy system security at large
- It is possible to calculate trade-offs with any other model objectives, such as mitigation or cost or local pollution
- The method is coded in the current version of the TIMES model generator, and available to all IEA-ETSAP tools users
- The method can be applied to increase the diversity of any other commodity included in the Reference Energy System