Modelling reliability and security of supply: a revised methodological approach and its possible application to the Chinese system

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Introduction

- The REACCESS project
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  - The risk parameter

- The follow-up phase
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  - Risk evaluation
  - Geo-referenced interfaces

- Further Applications
Risk of Energy Availability: Common Corridors for Europe Supply Security, carried out under the 7th Framework Programme (FP7) of the European Commission

The goal of the REACCESS project was

- to analyse the security of energy supply in the European Union

- to build tools suitable for EU energy import scenario analyses, able to take into account at the same time

  - technical
  - economic and
  - environmental

aspects of the main present and future energy corridors (captive or open sea), for all energy commodities and infrastructures.
Commodities

➢ Crude oil
➢ Natural gas and LNG
➢ Refined petroleum products (RPP)
➢ Coal
➢ Nuclear fuel
➢ Biomass
➢ Electricity from CSP
➢ Hydrogen

Infrastructures

➢ Pipelines
➢ Ships
➢ Railways
➢ Cables
REACCESS – GLOBAL MODEL

REACCESS Model

- The REACCESS model **hard-links** three optimization TIMES models:
  1) the Pan European TIMES multi-regional model (**PET36**)
  2) the global multi-regional TIMES Integrated Assessment Model (**TIAM_World**)
  3) the REACCESS CORridor model (**RECOR**)

- The REACCESS model is a large partial equilibrium model of the global energy system. It represents **51 regions:**
  1) the 36 countries of PET36
  2) the 15 regions of TIAM_World remaining after the Europe region is eliminated
The Pan European TIMES (PET) multi-regional model has been developed in the framework of different EU projects such as

- **NEEDS** (FP6 Integrated Project on New Energy Externalities)
- **RES2020** (focused on renewable policy options)
- **REALISEGRID** (FP7, a project for promoting an optimal development of the European trans-national transmission grid infrastructure)
- **REACCESS**

The PET Model version used in REACCESS describes the whole energy system of **36 European Countries**:

- the 28 EU Member States
- Iceland, Norway, Switzerland
- the other Balkan countries
TIAM Model

The multi-regional TIMES Integrated Assessment Model (TIAM) Model has been developed in 2004 and used for several analyses and projects.

The TIAM Model version used in the REACCESS project describes the whole energy system of all the world, divided into 16 regions/macro-areas:

- Africa
- Australia – New Zealand
- Central Asia and Caucasus
- Canada
- China
- Central and South America
- Europe
- India
- Japan
- Middle East
- Mexico
- Other Developing Asia
- Other East Europe
- Russia
- South Korea
- United States of America
REACCESS - RECOR

RECOR Model

- The TIMES REACCESS CORridor model (RECOR) represents in detail
  - the status
  - possible future developments
  of the **energy corridors** bringing energy from suppliers to consumers

It valorises the **spatial characteristics** of the routes, in addition to the technological, economical and environmental ones

- RECOR represents **all the corridors of the database (DBT)** and uses all the technical-economic and geographical information of the DBT
Energy infrastructures (i.e. oil and gas pipelines, oil ships, LNG ships, ...) can be described as a chain of processes linking an exporting region to the energy system of a demand region.
Each corridor can cross different countries of a multiregional model → the chain of processes can include both:

a) **Intraregional** processes: processes belonging to the energy system of a country

b) **Interregional** processes: processes describing the energy trade between two regions

Furthermore, each corridor can describe:

a) Extraction Fields → Resources
b) Primary Production
c) Secondary Production (f.i., LNG liquefaction plants)
d) Ports
e) Other Transformation Plants (LNG regasification plants, refineries)
Both present and future planned/possible corridors are taken into account. They are either

a) Captive:

a series of branches of pipelines, an electric overhead or submarine line, a railway connection → network of connections. Whenever possible, pipelines are grouped by main name: f.i.

“Trans Adriatic Pipeline” (TAP), “Druzhba”
“Brotherhood” “Transalpine Pipeline” (TAL)
“South Stream” “Adria”

...  
For Natural Gas

For Crude Oil ...  

b) Open Sea:

single connections from one port (exporting) to another port (importing)
The code system adopted for each process (branch) and each commodity of a corridor allows the full traceability of an energy flow, from the extraction field to the supply point. For instance:
If a single branch carries a commodity having two or more different origins, two kind of processes are used:

a) **Commodity** Processes: one process for each origin; it represents the topological link necessary for the traceability

b) **Infrastructure** Process: a single process for each branch; it describes the infrastructure and it is characterized by its technical-economical parameters (capacity, investment cost, O&M cost, ...). It has not any input or output commodities

A **constraint** is used in order to link the total activity carried by the commodity processes to the capacity of the infrastructure process:

\[
\sum_{i=1}^{\text{Num. Commodity Processes}} \text{Activity}_i \leq \text{Capacity}_{\text{Infrastructure Process}}
\]
Socioeconomic Risk Factors

- Socioeconomic risk factors take into account all the
  - social,
  - political and
  - economic

variables that influence the reliability of the exporting and transit countries; in the REACCESS project this kind of risk has been analysed at a country level.

- Socioeconomic energy risk is not directly observable in the real world, but we can observe a wide range of related variables that can aid the understanding of how energy risk is formed.

In order to evaluate the overall risk index for each country, in the REACCESS project a statistical technique known as Factor Analysis has been used.
It is assumed that the global country potential risk is the combination of 4 main risk vectors:

a) Social
b) Political
c) Economic
d) Energetic

The overall factor is evaluated as a mean of the 4 factors (previously rescaled by using a 0-100 range).

From 5.4
To 79.4
The original implementation of the risk parameter in the REACCESS project involves a methodological approach called “min-max procedure”, based on three steps:

1) A minimization the total system cost

2) A minimization of the risk value, with a constraint on the total system cost

\[ \text{Total system cost}_{\text{run} 2} \leq (1 + \alpha) \cdot \text{Total system cost}_{\text{run} 1} \]

where \( \alpha \) is a suitable percentage (f.i., 2%)

3) A minimization of the total system cost, with a constraint on the risk value

\[ \text{Risk value}_{\text{run} 3} \leq (1 + \beta) \cdot \text{Risk value}_{\text{run} 2} \]

where \( \beta \) is a suitable percentage (f.i., 1%)
REACCESS – The Follow-up phase

During the follow-up phase of the project, a revision of the model involving both structural and numerical adjustments has been performed

**GOAL:** Update the assembled model and let it be more useful for future developments and also for applications to non-European contexts

In particular, the main changes are related to:

- Structure and **calibration**
- Introduction of **growth/decay** coefficients
- **Risk** evaluation
- Geo-referenced **interfaces**
1. **Structure update and calibration**

- As the international panorama on energy infrastructures is continuously changing
  - a full amendment of the existing corridors and
  - the redefinition of some planned/possible future infrastructures (regarding route, technical-economical features, etc.)

have been performed (especially for natural gas pipelines from Caspian region and Russia to Southern and Western European countries)

- The base year adopted in REACCESS was 2005

  a full **recalibration** of the energy imports by country in the milestone year 2010, for each commodity and each model region, has been implemented
1. Structure update and calibration

By using a fix type constraint, the total amount of the activity delivered by energy corridors – demand country by demand country – is bound to statistical data on interregional commodity trades. The relationship for this constraint is

\[ \sum_{c} \text{Activity}_{2010,f,c,r,s} = \text{Import}_{2010,f,r,s} \]

where:

- \( f \) commodity
- \( C \) corridor
- \( r \) model region
- \( s \) supply country
- \( \text{Activity} \) activity delivered to \( r \) by \( C \) starting from \( s \)
- \( \text{Import} \) statistical value of the import of \( f \) in \( r \) from \( s \) in the m.y. 2010
2. Growth/Decay coefficients

- Annual G/D coefficients for the main commodities delivered by energy corridors, for each supply branch and for each extraction field have been introduced, thus allowing a maximum range of variation in order to
  - avoid unreasonable oscillation in the supply trends
  - better simulate the supply composition of each demand region
  - describe the evolution of energy imports for all the countries, taking into account potential stiffness deriving from supply contracts or specific import policies
2. Growth/Decay coefficients

The relationships that describe the growth and decay constraint are

\[
\text{GrowthCoeff}^{TPL_{t-1}} \cdot Activity_{t-1} + \text{Starting Value} \geq Activity_t
\]

\[
\text{DecayCoeff}^{TPL_{t-1}} \cdot Activity_{t-1} \leq Activity_t
\]

where:

- \text{GrowthCoeff} \quad \text{growth coefficient}
- \text{DecayCoeff} \quad \text{decay coefficient}
- \text{Starting Value} \quad \text{initial activity value; e.g. if } Activity_{t-1} \text{ is equal to zero, in the m.y. } t \text{ the } Activity_t \text{ can be less than or equal to the Starting Value}
- \text{TPL}_t \quad \text{time period length of the milestone year } t
3. The risk evaluation

During the follow-up of the project, 2 risk indicators and 6 commodities were introduced in order to allow an alternative approach to risk evaluation.

1) Risk Probability of Failure

For each supply process, a risk parameter (Risk – Probability of Failure) is evaluated as a composition of the risk indicators that can be interpreted as the likelihood that a corridor crossing a country will fail. F.i., in the case of 3 crossed countries, the risk value is

\[ R_{C,\text{PoF}} = 100 \cdot [1 - \left(1 - \frac{R_1}{100}\right) \cdot \left(1 - \frac{R_2}{100}\right) \cdot \left(1 - \frac{R_3}{100}\right)] \]

where: \( R_i \) (i=1,2,3) is the Overall Risk Index of the traversed country.

→ the probability of success of the corridor is the product of the probabilities of success of the 3 crossed countries, assumed independent.
3. The risk evaluation

- 3 additional commodities are introduced:
  
  a) \textit{RiskPoF}: for each supply branch of the corridor C, it is obtained by multiplying $R_{C,PoF}$ by the delivered activity

  \[ RiskPoF_C = R_{C,PoF} \cdot Activity_C \]

  b) \textit{TotPoFRisk}: it is defined, for each demand region, as the sum of all the RiskPoF values for a region

  c) \textit{TotPoFRiskEU}: it is defined for the 28 EU Member States and, as \textit{TotPoFRisk}, it is the sum of all RiskPoF values for each of the 28 EU countries

- Constraints on these commodities can be imposed in order to perform scenario analyses
3. The risk evaluation

2) Risk Average

- This approach is based on the introduction of a risk indicator, specific for each energy corridor, that is defined as the average value of the Overall Risk Indexes of all the countries crossed by a corridor. F.i., for a corridor crossing 4 countries this indicator is

\[ R_{C,Average} = 100 \cdot \frac{\left(\frac{R_1}{100} + \frac{R_2}{100} + \frac{R_3}{100} + \frac{R_4}{100}\right)}{4} \]

- As for the Risk PoF, 3 additional commodities are introduced:
  
  a) RiskAverage: RiskAverage\(_C = R_{C,Average} \cdot Activity\_C\)
  
  b) TotAverageRisk
  
  c) TotAverageRiskEU
3. The risk evaluation

3) Risk Source

• In addition to the two above described methodologies, another indicator \( R_{C,Source} \) and 2 commodities were introduced to quantify the risk related to the activity exported through energy corridors for each supply country. \( R_{C,Source} \) is set equal to the Overall Risk Index of the region where the feeder branch of the corridor \( C \) starts. The 2 additional commodities are:

\[
RiskSource_C = R_{C,Source} \cdot Activity_{Feeder,C}
\]

\( TotSourceRisk \): it is defined for each supply region as the sum of all \( RiskSource \) values that region
3. The risk evaluation

- All the risk commodities are implemented as a CO$_2$ emission commodity

  - risk reduction policy scenarios can be defined and introduced in the model by using the same method as for pollutant emissions reduction

  - scenario runs for the reduction of total CO$_2$ emissions or of the risk value in a single country or in a group of countries (f.i., the EU) can be performed. F.i., the reduction of the total risk average value by a percentage $\alpha$ in a region $r$ and in a milestone year $t$ can be implemented through a fix type constraint:

$$ UC_{LHS_{r,t}} \cdot TotAverageRisk_{r,t} = UC_{RHS_{r,t,\alpha}} $$

$$ UC_{LHS_{r,t}} = 1 $$

$$ UC_{RHS_{r,t,\alpha}} = \alpha \cdot TotAverageRisk_{r,t,Baseline} $$
GIS INTERFACES

REACCESS – Geo-referenced Interfaces

Spatial dimension of energy corridors

Geo-referenced representation. GIS tools

**DWGA**

*Digital Web GIS Application:*

- Web tool for an on-line geo-referenced graphical visualisation of the results

**PAIVI**

*Program for Analysis and Interface for Visualization:*

- Application software to visualise the results and to graphically interact with the model
DWGA:

- It represents, in a geo-referenced way, all the European energy supply **corridors** that are described in the model database
- It directly imports output files (.txt) of the model
- It can visualise:
  - For each commodity, the **activity** carried by each branch of a selected infrastructure
  - **Import** and **export** for each country
  - Activity in relevant **nodes** (f.i., extraction fields, ports, energy hubs)
  - Data on country energy **balances**
- It can create **charts** and **tables** which are exportable to Excel
Dolina – Natural Gas Hub
PAIVI:

- It imports the gdx output file of the model and it shows the results in both graphical and tabular form.
- For each branch of a selected infrastructure, it can visualise:
  - A geo-referenced map
  - The main characteristics (origin, destination, ...)
- It allows to disrupt a branch, to create a scenario file and to perform a new run.
- For each region and for each commodity, it can show:
  - The active supply corridors for a selected run
  - The delivered activity
  - The related risk value
- It allows to export charts, tables and GIS maps.
Interaction with the model
FURTHER APPLICATIONS of the REACCESS methodology

- The detailed description of the energy corridors,
- The methodologies for risk evaluation and
- The geo-referenced representation method developed in REACCESS

could be successfully applied to extra-EU energy systems, like the Asian ones, in order to assess the reliability of energy infrastructures
EXAMPLE – The role played by China

➢ According to the major forecast analyses, China will become the world’s largest energy importer

Import dependence: from 15% to 20% by 2035 (BP Energy Outlook 2035)

Existing and planned gas pipelines and LNG terminals.
(Source: IEA - Oil & Gas Security 2012)

Evolution towards an increase and a diversification of the supply
EXAMPLE – The role played by China

- The investigation of all the aspects related to the supply of the main energy commodities, focusing in particular on the security, could be performed making use of the REACCESS methodological approach which would prove beneficial for the possibility of:

  • evaluating the risk related to each supply corridor and of implementing reduction scenarios

  • taking into account ad hoc policies on imports, by using appropriate constraints as the Growth/Decay ones (particularly important in a rigid planning economy)

  • estimating the air pollutant emissions related to the energy imports and of linking them to the security of supply
Conclusions

- The REACCESS project has introduced a new methodology for investigating the **security of energy supply** in the EU over a mid/long-term time horizon by using forecasting optimization models.

- Some **refinements** implemented during the follow-up phase of the project and the development of a new graphical interface have made the model more useful for assessing also both single countries and extra-EU regions.

- In particular, a new procedure for **risk evaluation**, based on single-corridor composite risk indicators and on new commodities similar to CO₂ emissions, allows for new combined risk and pollutant emissions reduction scenarios.

- Furthermore, the introduction of **Growth/Decay** constraints on each supply branch allows to take into account specific policies on imports.

- As a consequence, this procedure could be usefully applied to analyse the energy supply of **extra-EU areas**, such as Asia.
Thank you for your attention

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