"Supergrid preparatory phase: review of existing studies and recommendations to move forwards"

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Table of contents

GLOSSARY **3**

EXECUTIVE SUMMARY **5**

1 FOREWORD **8**

2 SCOPE OF THE STUDY **9**

3 EXISTING STUDIES **9**

4 INDICATORS FOR GAP ANALYSIS **11**

5 SUMMARY OF SELECTED STUDIES **16**

5.1 ENTSO-E studies 16
5.1.1 ENTSO-E: Ten Year Network Development Plan (TYNDP) 2012 16
5.1.2 System Adequacy Forecast 2030 & Vision 4 28
5.2 Booz – Benefits of an integrated European energy market 33
5.3 FOSG – Roadmap to the Supergrid technology 45
5.4 ECF - Roadmap 2050 a practical guide to a prosperous low-carbon Europe 53
5.5 Dii - “Desert Power: Getting Started. The manual for renewable electricity in MENA”, 2013 59
5.6 Greenpeace - “Battle of the Grids – How Europe can go 100% renewable and phase out dirty energy” 65
5.7 SINTEF, 3E, Senergy – Offshore grid 70
5.8 World Business Council for sustainable Development - "Vision 2050 - the new agenda for business" 78
5.9 EURELECTRIC, "Power choices - Pathways to carbon-neutral electricity in Europe by 2050" 81
5.10 The North Seas Countries’ Offshore Grid Initiative (NSCOGI) - WG1 2012 88
5.11 Synthetic summary of the selected studies 97

6 GAP ANALYSIS **101**

6.1 Scoring Criteria 101
6.2 Quantitative evaluation of the selected studies 102
6.3 Considerations on the GAP analysis 105

7 CONCLUSIONS AND STEPS FORWARDS **108**

8 REFERENCES **111**

GLOSSARY

AC	Alternating Current
BAU scenario	Business As Usual scenario
CAPEX	CAPitalEXpenditure
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CCS	Carbone Capture and Storage
CEER	Council of European Energy Regulators
CENELEC	European Committee for Electrotechnical Standardization
CIGRE	International Council on Large Electric Systems
CO_2	Carbon dioxide
CPI	Current Policy Initiative
CSP	Concentrated Solar Plan
DC	Direct Current
Dii	Desertec industrial initiative
DR	Demand Response
DSR	Demand-Side Reduction
EC	European Commission
EENS	Expected Energy Not Supplied
EHV	Extra High Voltage
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
EU	European Union
EUMENA region	European Union Middle East North Africa region
FACTS	Flexible AC Transmission Systems
FOSG	Friend Of the SuperGrid
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTC	Gross Transfer Capacity
HV	High Voltage
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
ICT	Information and Communication Technology
IEA	International Energy Agency
KPI	Key Performance Indexes
LCC	Line Commutated Converters
LCOE	Levelized Cost Of Energy
LOLE	Loss Of Load Expectancy
LOLP	Loss Of Load Probability
MENA region	Middle East North Africa region
NSCOGI	North Seas Countries' Offshore Grid Initiative
NTC	Net Transfer Capacity
OCGT	Open Cycle Gas Turbine

OPEX	OPerationalEXpenditure
PCI	Projects of Common Interest
PV	Photovoltaic
R&D	Research and Development
RES	Renewable Energy Source
SG	Supergrid
SOAF	Scenario Outlook Adequacy Forecast
SoS	Security of Supply
TPA	Third Party Access
TSO	Transmission System Operator
TX	Electrical Transmission Capacity
TYNDP	Ten Year Network Development Plan
UK	United Kingdom
VSC	Voltage Source Converter
WEO	World Economic Outlook
WG	Working Group

EXECUTIVE SUMMARY

In July 2009, the leaders of the European Union and the G8 announced their objective to reduce greenhouse gas emissions by at least 80% below 1990 levels by 2050. In October 2009 the European Council set the appropriate abatement objective to 80-95% below 1990 levels by 2050. The power sector plays a fundamental role, since the achievement of such challenging targets will entail its almost complete decarbonisation by the year 2050.
The new generation mix will be based on RES, most of which are location-dependent, namely wind, which is expected to become the prevailing form of generation in North Europe. Furthermore, a large share of wind farms is expected to be deployed offshore.
To convey a huge amount of power, in the order of several GW / tens of GW, over long distances to the load centres, the concept of Supergrid (SG) has been proposed.

The implementation of the SG sets a number of challenges entailing technical, economic, financial, environmental, regulatory and socio-political aspects. Hence, a multidisciplinary approach shall be adopted. Whilst a number of studies have recently been conducted addressing the greenhouse gas targets modelling, scenarios envisaging a substantial share of RES generation or even a full decarbonisation of the European power system, a thorough investigation addressing all issues to foster implementation of the SG is still missing.

In this context, a Task Force (TF) has been set up within FOSG with a twofold objective:

- review of the results obtained by previous studies addressing the design of the European SG
- identify what is missing for the deployment of the preparatory phase of the SG and formulate a series of recommendations to fill the gaps.

The above objectives can be attained through a so-called “gap analysis”, aimed at highlighting what has already been examined in previous studies and what is missing, and consequently avoiding the risk of launching new activities that overlap available results.
In our analysis we have selected a set of existing studies, taking into account the following criteria:

- geographical boundaries that cover the whole Continent or a substantial part of it
- studies examining different topics relevant to SG
- recently conducted studies.

The studies selected have been examined with respect to EU priorities and the seven indicators defined by ENTSO-E:

- B1. Security of Supply
- B2. Socio-economic welfare
- B3. RES integration
- B4. Variation in losses (energy efficiency)
- B5. Variation in CO_2 emissions
- B6. Technical resilience/system safety margins
- B7. Robustness/flexibility

Finally, further indicators have been taken into account in a qualitative way. These include:

- regulatory schemes and possible specific regulatory provisions to foster the deployment of SG,
- financing schemes to foster the deployment of the SG,
- proposed mechanisms to recover the invested capital.

The analysis of the existing studies in this document confirmed that none of them investigated in a thorough way all the topics related to the realisation of the SG, though all of them are technically very valuable.
More specifically, the main topics examined in the selected studies can be summarized in the following points:

- Firstly the cost-benefit analysis (CBA) of generation and transmission infrastructures is one of the most commonly considered aspects. However CBAs are limited and do not normally cover the technical indicators (B6, B7). Further security of supply (B1) is only examined with reference to the availability of primary energy resources and does not include the relationship of power availability to load behaviour and the intermittency of non-programmable RES generation.
- Secondly, the identification of the priority grid infrastructures that should be realised is generally well investigated in a certain number of studies. The aim of these investigations is to outline the possible structures of the offshore grids in order to catch the benefits arising from an integrated design that takes into account both offshore wind farm and submarine interconnections at the same time.
- Thirdly, although the technology roadmap necessary to realise the development of the technology required to build the electricity highways is covered in detail, this was only in a single study.

On the contrary, the main missing points are:

- The regulatory framework for sharing offshore resources (production) between different countries and the investment burden of the SG, particularly the offshore sections.

- Regulatory issues should be looked at in order to define the right legal framework to be put in place to allow cross-border balancing. In fact, a high share of non-programmable RES generation can cause situations where within one country it is not possible to balance load and generation (phenomenon of “over-generation”). In such situations, one can fruitfully exploit the power transfer capacity of a SG to convey the excess of power to other regions of Europe, provided that mechanisms for cross-border balancing are in place. The introduction of pan-European mechanisms for cross-border balancing coordinated with the day-ahead and infra-day power markets is an urgent action that needs to be addressed now with the highest priority.

- Market analysis concerning the real possibility to manufacture the components necessary to build the SG, with particular reference to special components such as DC circuit breakers and high-depth submarine cables to cross the Mediterranean sea. The commercial availability of these special components calls for substantial investments in R&D to be undertaken by the manufactures.

- Quantification of the technical indicators, with particular reference to the investigation of the security of the system and the security of supply in terms of energy and power availability in presence of a very high share of non-programmable renewable generation. Generation from non-programmable RES is normally uncorrelated from the load pattern and, as such, it becomes of utmost importance to assess the reliable available capacity necessary to cover the load taking into account combined uncertainty in load levels and non-programmable RES generation. Hence, the "upward" and "downward" generation adequacy combined with the contribution of the SG shall be accurately simulated in the mid-long term scenarios to show the feasible operation of a power system with a high share of non-programmable RES generation

- In general, all the examined studies tackled the cost-benefit analysis associated to the new transmission infrastructures, but not in a comprehensive way covering all the market, technical and environmental indicators. The same comment applies to the evaluation of the cross-border cost allocation. This gap is likely to be covered by the study launched by the EC, the results of which shall be available by May 2014.

In conclusion, a lot of work to move towards a decarbonised power sector has been done, but much is still to be done in order to put into reality the concept of SG. To this aim, a further step that FOSG can promote consists of investigating the impact of a significant amount of intermittent renewable generation on the dispatching of conventional generation, and on the necessary storage systems. This is to ensure an adequate level of security of supply and also to identify possible critical situations in the generation mix and in grid infrastructures. In this investigation only the macro-constraints on the SG (i.e.: inter-area transfer capacity) shall be considered since the detailed planning of the transmission grids is within the exclusive competence of the TSOs.

1 FOREWORD

Soon after the approval of the energy and climate package agreed in 2008, more ambitious targets on the energy decarbonisation system were set by the EU consisting in a dramatic cut of greenhouse gas emissions (GHG). In the Energy Roadmap 2050 formulated in 2011 the EU stated his commitment "*to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050 in the context of necessary reductions by developed countries as a group. The European Council has recognised that this commitment will require a revolution in energy systems…*". In the power sector the achievement of the above objective entails not only a substantial change of the generation mix, but also a complete re-design of the European transmission grid. In fact, power generation will be based on renewable energy sources (RES); most of them are location-dependent, namely wind, which is expected to become the prevailing RES generation in North Europe. Furthermore, a large share of wind generation is expected to be deployed offshore.

To convey huge amount of power, in the order of several GW / tens of GW, over long distances to the load centres, the concept of Supergrid has been proposed. According to the Friends of the Supergrid (FOSG) - the Supergrid(SG) is "*a pan-European transmission network facilitating the integration of large-scale renewable energy and the balancing and transportation of electricity, with the aim of improving the European market*". The Supergrid shall be seen as a new layer of the transmission grid, essentially based on (U)HVDC technology, overlapped to the existing HVAC grids with power interchange points; besides, the Supergrid will extend also offshore to gather wind generation and convey the power to the mainland.

The implementation of Supergrid sets a number of challenges entailing technical, economic, financial, environmental, regulatory and socio-political aspects. Hence, a multidisciplinary approach shall be adopted.

In this framework and in the wake of the EU Energy Roadmap 2050, a number of studies have been carried out addressing the challenges to be overcome to achieve a substantial decarbonisation of the European power sector, while ensuring sustainability, security of supply and competitiveness of the European industry: the three pillars of the EU Green Paper. Most of the studies so far carried out either addressed only a possible EU transmission system at the target year 2050 or they examined only part of the SG implications (e.g.: technology, investment costs, etc.). Furthermore, to achieve a dramatic transformation of the European generation and transmission system by 2050, a focused program should start from now. Thus, a roadmap as detailed as possible shall be outlined for the progressive construction of a SG coherently with the expected evolution of the generation mix.

In conclusion, it becomes urgent and necessary to fill the gap between what has been already planned by the EU TSOs up to ten years ahead (and soon up to 2030 according to the four visions of ENTSO-E) and the target structure of the SG in 2050.

To maximise the efficiency of the analyses, the idea is to examine the results already achieved by previous studies, highlight the missing points and then propose a practical study program to fill the gaps and enable the timely deployment of the SG.

2 SCOPE OF THE STUDY

The objective of this study is twofold:

- review of the results obtained by previous studies addressing the design of the European SG (or the "e-highways")
- identification of what is missing for the deployment of the preparatory phase of SG and formulation of a series of recommendations to fill the gaps. These recommendations should constitute the inputs for further in-depth studies to be launched by the interested stakeholders of institutions.

The above objectives can be attained through a so-called "gap analysis", which is a useful tool to highlight what has already been addressed in previous studies and what is missing, and consequently avoiding the risk of launching new activities overlapping with already available results. This analysis turns out to be quite important considering the numerous studies already carried out in the last five years.

3 EXISTING STUDIES

Quite a number of studies have been recently carried out addressing scenarios envisaging a substantial share of RES generation or even a full decarbonisation of the European power system. In our analysis we have selected a set of existing studies, taking into account the following criteria:

- geographical boundaries covering the whole Continent or a substantial part of it
- studies examining different topics
- recently achieved studies

Following a broad screening analysis (see chapter8 "References") the studies shown in the table below were selected. Nevertheless, it is worth mentioning that the main topics examined in the other available studies were in general taken into account when drawing the conclusions on possible deficiencies that should be filled to give a thorough view on SG benefits to potential investors.

Tab. 3-1 – Priority studies selected for the "gap analysis"

Priority Studies
1. ENTSO-E studies: • *Ten Year Network Development Plan (TYNDP)* • *System Adequacy Forecast 2012-2030** • *Vision 4 "Green revolution"* • *(preliminary documents of the e-Highway2050, as far as available)***
2. Booz & Co, "*Benefits of an Integrated European Energy Market*", EC DG-Energy, Brussels, July 2013
3. FOSG, "*Roadmap to the Supergrid technologies*", March 2013

Priority Studies
4. European Climate Foundation, "*Roadmap 2050: a practical guide to a prosperous low-carbon Europe*", McK, KEMA et Al, April 2010, available on www.roadmap2050.eu
5. Dii, "*Desert Power: Getting Started. The manual for renewable electricity in MENA*", 2013
6. Greenpeace, "*Battle of the Grids – How Europe can go 100% renewable and phase out dirty energy*", 2011
7. Sintef, 3E, Senergy, "*Offshore grid*", D8.1 – Draft Final Report, July 2010
8. World Business Council for Sustainable Development "*Vision 2050 - the new agenda for business*", available on www.wbcsd.org, February 2010
9. EURELECTRIC, "P*ower choices - Pathways to carbon-neutral electricity in Europe by 2050*", available onwww.eurelectric.org
10. The North Seas Countries'Offshore Grid Initiative, "*NSCOGI 2012 report*", Brussels, 2012available on http://www.benelux.int/NSCOGI/

** The SOAF 2012 provides scenarios of generation/demand up to 2030. These scenarios are included in the descriptions of the other ENTSO-E studies.*

*** About the ENTSO-E studies, it is highlighted that the "e-Highway 2050" study is on-going and no detailed information is available so far.*

To better frame the studies under examination, a summary of each study is recalled in chapter 5. The summary gives a broad overview of each study featuring:

- *Scope of the study*
- *Target year* (and possible intermediate years whenever a roadmap is outlined)
- *Geographical area covered by the study*
- *Input Scenario*:
  - demand level at the target year(s),
  - study assumptions for investment costs in:
    - generation (both conventional and from RES),
    - transmission (for various candidate technologies),
    - fuels costs,
    - cost associated to CO_2 emission,
    - additional operation costs
- *Output:*
  - Generation mix
  - NTC between countries / regions

- onshore and offshore, transmission infrastructures, and relevant technology
- socio-environmental benefits
- proposals on ownership and financing schemes
- proposals of regulatory measures to foster the deployment of a SG.

Whenever possible, to be more effective and make the comparison between studies easier, the above set of information is also presented in tabular form.

4 INDICATORS FOR GAP ANALYSIS

The European power sector is undergoing major changes driven by a number of factors, among which:

- actions to contrast climate change effects, leading to a substantial change in the generation mix with more generation from intermittent RES located also offshore;
- European market integration;
- evolution of the role of the demand, which will interact in a more active and dynamic way with the rest of the system consequently modifying the load patterns;
- progressive introduction of electric vehicles;
- stricter requirements for security of supply and enhanced resilience to cope with extreme climate conditions.

All the above factors are causing, and will cause in the future, increasing levels of power flows over long distances. Besides, to facilitate the integration of large-scale renewable energy and related balancing requirements, an offshore grid shall be designed, composed by state-of-the art HVDC technologies and components. This newly conceived pan-European grid spanning across Europe, both on the land and under the sea, is defined as SG, which shall not be intended just as an extension of existing or planned point to point HVDC interconnectors between particular EU states, but, on the contrary, as a new transmission layer overlapped to the existing transmission system based almost in its entirety on AC technology with a maximum rate voltage of 400 kV.

Qualitative benefits that can be achieved by the realization of a SG have been clearly identified by FOSG and can be summarized as follows. "*The SG will*:

- *Help to meet EU and national plans to decarbonise Europe's power sector: 20% by 2020 and 90% by 2050.*
- *Integrate all renewable energy into the continent's energy mix. RES are not national resources but continental by their nature.*
- *Bring these renewable resources to load centres across Europe over long distances.*
- *Balance Europe's electricity network and enhance security of supply.*
- *Create a global opportunity for European companies to export sustainable energy technology and create new highly skilled jobs.*
- *Enhance the single European electricity market.*" (quoted from [1])

Thus, the deployment of a pan-European SG evidently turns out to be fully fitting the three key pillars identified by the EU in its Green Paper "*A European Strategy for Sustainable, Competitive and Secure Energy*"[2], i.e.:

- *Improvement of security of supply*
- *Enhanced sustainability*
- *Market integration.*

A number of indicators and related parameters can be associated[1] to the above EU targets:

- *Improvement of security of supply*, in terms of:
  - *Generation adequacy*, including the fulfilment level of the targets of renewable and conventional generation forecasted in the mid-long term. Parameter to quantify the indicator:
    - Adequacy Reference Margin (derived from Net Generating Capacity) (MW or % with respect to the peak load)
  - *Transmission adequacy*, including the matching with technologies that should be adopted to build the SG (DC submarine cables, converter stations, HVDC overhead lines, underground DC cables, AC reinforcements on land,…). Parameters:
    - Reliability indexes: EENS (MWh/yr), LOLE (hr/yr), LOLP (probability)
    - Security criteria: steady state margins and dynamic stability margins.

- *Enhanced sustainability:*
  - Reduction of CO_2 (and in general GHG) emission compared to the 1990 level or with respect to the BAU scenario. Parameter:
    - Reduction of CO_2 emission per year (tonCO_2/yr)
  - Increased amount of RES generation. Parameter:
    - Increased RES generation evaluated as the sum of additional generation from new RES generating units connected to the grid plus the reduction of RES generation curtailment (MWh/yr)

- *Power markets integration:*
  - Reduction of the overall cost/price of energy, taking into account the estimated LCOE of the different generation technologies in the mid-long term. Parameter:
    - Delta cost/price of energy obtained by simulating the same scenario with and without the new project/cluster of projects (€/MWh)
  - Better market integration at the EU level. Parameter:
    - Reduction of price fragmentation within EU and between EU and MENA region (Delta€/MWh)

To give a boost in the huge investments needed for the SG implementation, a quantitative assessment of the various benefit components is required to clearly demonstrate that the overall benefits overweight the total costs (CAPEX + OPEX). This need is in line with what required by the EC Regulation 347/2013 [17]on guidelines for trans-European energy infrastructure, where in Annex IV the rules and

[1]See FOSG TF activity carried out from July to November 2013

indicators to be adopted are illustrated and in Annex V the energy system-wide cost-benefit analysis to be applied is described. Indeed, a quantitative assessment of the benefits deriving from the realization of the various SG clusters of projects[2] has a twofold advantage:

- Help attract investors from the private sector (merchant line scheme with exemption from TPA) and streamline the approval process from Energy Regulators and Energy Ministries (regulated investment with free TPA);
- Enhance the acceptability of the new infrastructures from the concerned population.

The above recalled Regulation aimed at ensuring that strategic energy network will be completed by 2020 and to this target the Regulation proposes a regime of "common interest" for Trans-European transmission grid projects contributing to implementing the three EU priorities. In this context the various SG clusters of projects are qualified as Projects of Common Interest (PCI).

In general, a cost-benefit analysis (CBA) based on agreed indicators is applied throughout Europe to each new transmission project / cluster of projects having a cross-border relevance. ENTSO-E has been entrusted with the responsibility of establishing a cost benefit methodology (see Regulation 347/2013). Hence, also for each SG cluster of projects a similar set of indicators shall be applied. ENTSO-E has defined seven indicators[3]:

- B1. *Security of Supply*: ability of a power system to provide an adequate and secure supply of electricity in ordinary conditions, in a specific area. Parameters to quantify the indicator:
    - LOLE: Loss of Load Expectancy (hours/year)
    - EENS: Expected Energy Not Supplied (MWh/yr or p.u.MWh/yr)

- B2. *Socio-economic welfare*: reduction of the total cost of electricity supply due to the increase of the GTC (Gross Transfer Capacity) between two or more bidding areas. Parameters to quantify the indicator:
    - Reduced generation costs/ additional overall welfare (M€/yr)
    - Variation of internal dispatch costs (M€/yr)

- B3. *RES integration*: reduction of renewable generation curtailment in MWh (avoided spillage) and additional amount of RES generation that is connected by the project. Parameters to quantify the indicator:
    - Additional connected RES (MW)
    - Reduced RES generation curtailment (MWh/yr)

- B4. *Variation in losses (energy efficiency):* variation of thermal losses in the system at constant power transit levels. Parameters to quantify the indicator:
    - Yearly energy losses (MWh/yr)

- B5. *Variation in CO_2 emissions*: by relieving congestion or connecting new RES generation centres, transmission grid reinforcements may enable low-carbon generation to generate more

[2] With the expression "*cluster of projects*" we refer to a specific section of the SG composed by offshore and onshore links, which altogether allow to connect at least two countries and one or more offshore wind farms.

electricity, thus replacing conventional plants with higher carbon emissions. Parameters to quantify the indicator:

- Variation of CO_2 emission (tonsCO_2/yr)

- B6. *Technical resilience/system safety margins*: making provision for resilience while planning transmission systems, contributes to system security during contingencies and extreme scenarios. Parameters to quantify the indicator:
  - A number of KPI (Key Performance Indexes)

- B7. *Robustness/flexibility*: defined as the ability to ensure that the needs of the system are met in a future scenario that differs from present projections. Parameters to quantify the indicator:
  - A number of KPI (Key Performance Indexes).

It is worth mentioning that the first five indicators can be relatively easily monetised, whilst converting the various KPI relevant to indicators B6 and B7 into monetary values proves to be very difficult and in any case a possible conversion into monetary value is bounded to some subjectivity risk. In such a situation, a score is assigned to each project/cluster of projects starting from the various KPI.
In conclusion, a combined approach has been proposed by ENTSO-E consisting of CBA (full monetisation of costs and benefits – indicators B1 to B5) and multi-criteria framework allowing to compare quantities having different metrics (see scheme below[4]). The combination of CBA and a multi criterion framework allows for the most complete project assessment.

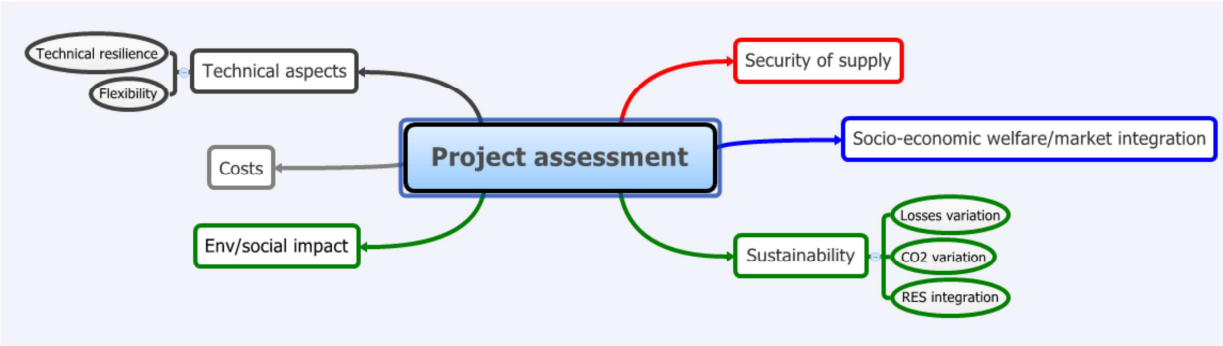


Fig. 4-1 – Project assessment through combination of CBA and a multi criterion framework. Source: ENTSO-E

The quantitative indicators associated to the three EU priorities set in the Green Paper in 2006 and those worked out by ENTSO-E in 2013 show a very good correspondence as summarized in the table here below. Hence, when examining the outcomes of the selected studies (chapter 6), for sake of simplicity we refer to the ENTSO-E indicators that have been widely discussed and agreed with all major European Institutions and stakeholders.

Tab. 4-1 – Correspondence between indicators associated to EU priorities and those worked out by ENTSO-E

EU Priorities & indicators		ENTSO-E indicators						
		B1 Security of Supply	B2 Socio-economic welfare	B3 RES integration	B4 Variation in losses (energy efficiency)	B5 Variation in CO_2emissions	B6 Technical resilience/ system safety margins	B7 Robustness/ flexibility
Improvement of SoS	Generation adequacy							
	Transmission adequacy				(*)			
Enhanced sustainability	reduction of CO_2 emissions							
	increased amount of RES generation							
Power markets integration	Reduction of the cost/price of energy							
	Reduction of price fragmentation							

(*) variation of losses shall be considered as a neutral indicator, since higher power flows over long distances can increase the losses

Beside the assessment of benefits, it is of utmost importance to carefully evaluate the investment effort for each SG cluster of projects so to compare the annualised total costs (CAPEX+OPEX) with the annualised benefits.

Another indicator is relevant to the:

- *Socio-economic impact from the deployment of SG*. Parameters to quantify the indicator:
    - Labour force (number of employees / yr)
    - Manufacturing industry (impact on companies' turnover).

Finally, further indicators that can be evaluated only in a qualitative way, shall be considered to have a thorough view of the SG projects:

- Regulatory schemes and possible specific regulatory provisions to foster the deployment of SG,
- Financing schemes to foster the deployment of SG,
- Proposed mechanisms to recover the invested capital.

Whenever possible and where information is available, we have considered also these latter indicators, being aware that only a complete study addressing the whole set of indicators above recalled will enable decision makers to take a decision on investing in SG projects.

5 SUMMARY OF SELECTED STUDIES

5.1 ENTSO-E studies

5.1.1 ENTSO-E: Ten Year Network Development Plan (TYNDP) 2012

Scope of the study

The scope of the Ten Year Network Development Plan is to provide a support to decision-making processes at regional and European level ensuring the required transparency. On the basis of the network development plans issued by each of the TSOs involved, the report provides a 10 years vision of the European network development plan, in particular:

- build upon national investment plans the guidelines for trans-European energy networks,
- build on the reasonable needs of different system users,
- identify investment gaps, notably with respect to cross-border capacities.

The study is issued every two years.

Target year

The target year of the TYNDP is 2022. Thus, the plan overcomes the 20-20-20 targets of EU.

Geographical area covered by the study

The geographical area covered by the TYNDP is the European Union plus the countries belonging to the European Economic Area and the Western Balkan countries with the exception of Albania. The Member States belonging to the ENTSO-E association are shown in Fig. 5-1, grouped into 6 development regions.

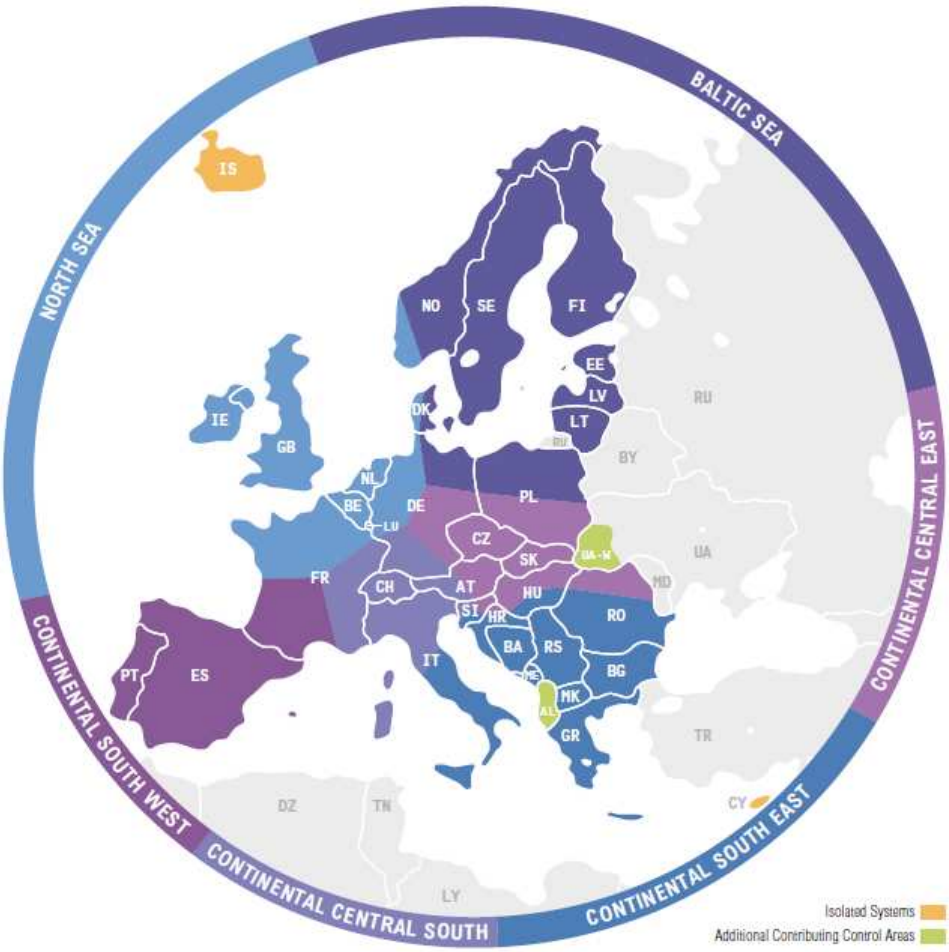


Fig. 5-1 – ENTSO-E System Development Regions

It has to be noted that Cyprus and Iceland are island systems. No interconnectors with other ENTSO-E countries have been considered in the TYNDP 2012.

Input scenario

Two scenarios have been used as a basis for the TYNDP 2012:

- the Scenario EU 2020 (reference scenario) has been built top-down, based on the European 20-20-20 objectives and the National Renewable Energy Action Plans (NREAPs) published by each Member State,
- for the Scenario B ("Best estimate")the present situation is taken as a starting point and the future developments are extrapolated until 2020 based on the best estimate and market players' known intentions (bottom-up).

Scenarios are described in the Scenario Outlook Adequacy Forecast 2012 (SOAF 2012) report of ENTSO-E, which includes also the so-called Scenario A ("Conservative"), derived from Scenario B, taking into account only the generating capacity developments which are considered secure. The peak demand in January and July are shown in Fig. 5-2 and Fig. 5-3.

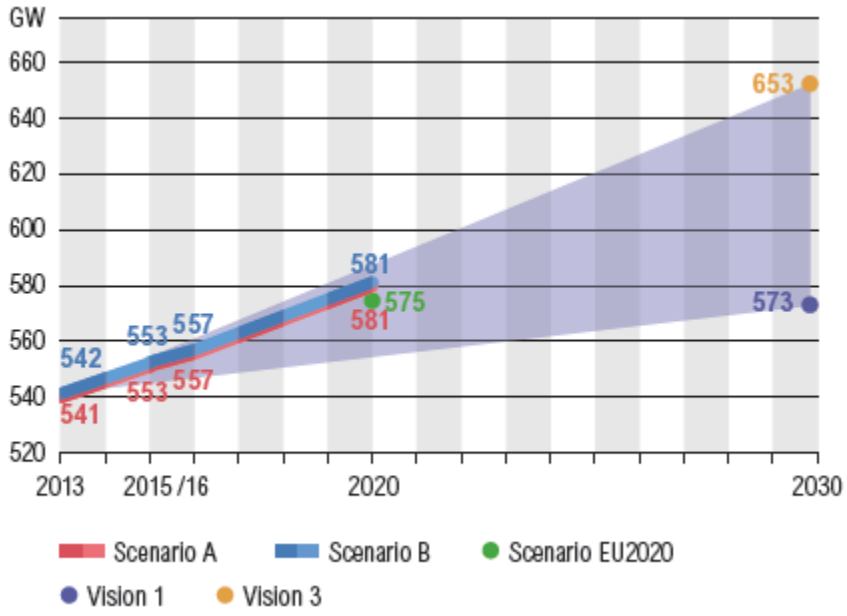


Fig. 5-2 – ENTSO-E forecasted peak load in January

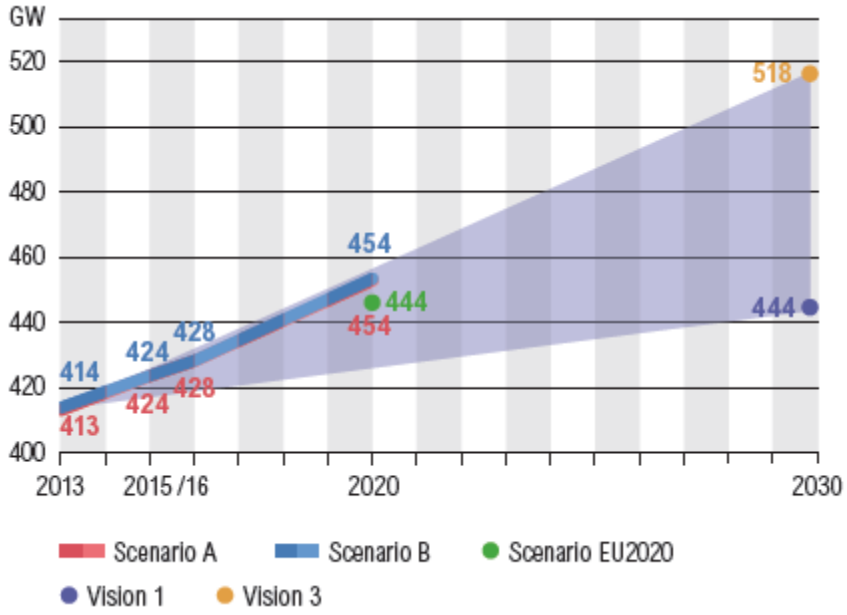


Fig. 5-3 – ENTSO-E forecasted peak load in July

The total installed capacity will reach 1214 GW, with an increasing of 251GW (26%) mainly due to wind and solar generation.. The generation mix for the years 2012 and 2020 are shown in Fig. 5-4.In Scenario B the RES generation capacity is 22 GW lower than in the Scenario EU 2020..

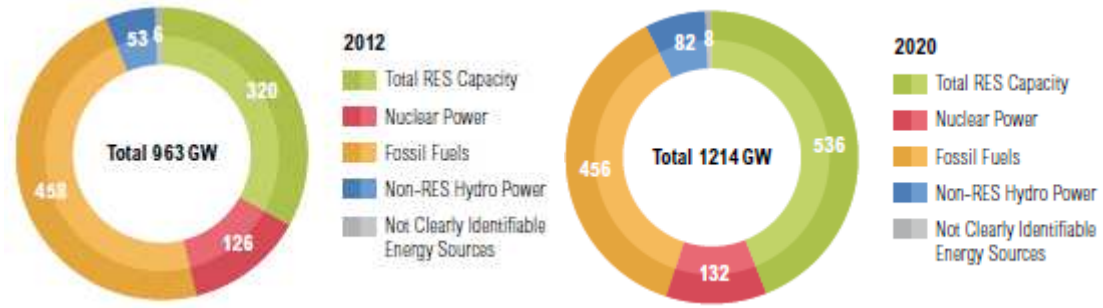


Fig. 5-4 – Generation mix for 2012 and 2020 in Scenario EU 2020

In parallel, the total system peak load increases between 2012 and 2020 by about 35 GW, reaching 575GW in the reference scenario.

New conventional generation develops with the same pace of the load growth. But it is relevant to note that about 25 GW of nuclear capacity is scheduled to be phased out from 2010 to 2020, especially in Germany (16 GW) and the UK (7 GW). Obsolete coal-fired power plants are also scheduled to be phased out in order to meet environmental standards, especially in the UK (9 GW).

Study assumptions: unitary investment costs

The TYNDP doesn't provide specific information regarding the unitary investment costs neither for the generation technologies, nor for transmission technologies.

Study assumptions: operational costs

The TYNDP doesn't provide a synthesis of operational costs of generation and CO_2emissions. These costs are included in the related national development plants.

Study results

The development of the grid in the next decade is dominated by the shift in the generation mix especially due to new large wind and solar capacities, with massive relocation of generation assets and more volatile flows. On the other hand, the decommissioned power plants are mostly located relatively close to the most populated areas.

Market studies basically show larger and more volatile power flows, over longer distance across Europe (see Fig. 5-5 and Fig. 5-6). The dominant flows are north-to-south from Scandinavia to Italy, between central continental Europe and the Iberian Peninsula, Ireland and United Kingdom or east to south and west in the Balkan Peninsula.

Italy, the United Kingdom, Poland and the Baltic states remain major importing countries. France and Scandinavia are the larger exporters, as it is the case today. However, exchanged volumes are higher. Import and exports are almost balanced in Germany, Spain and Portugal, but the exchanged energy volumes are higher.

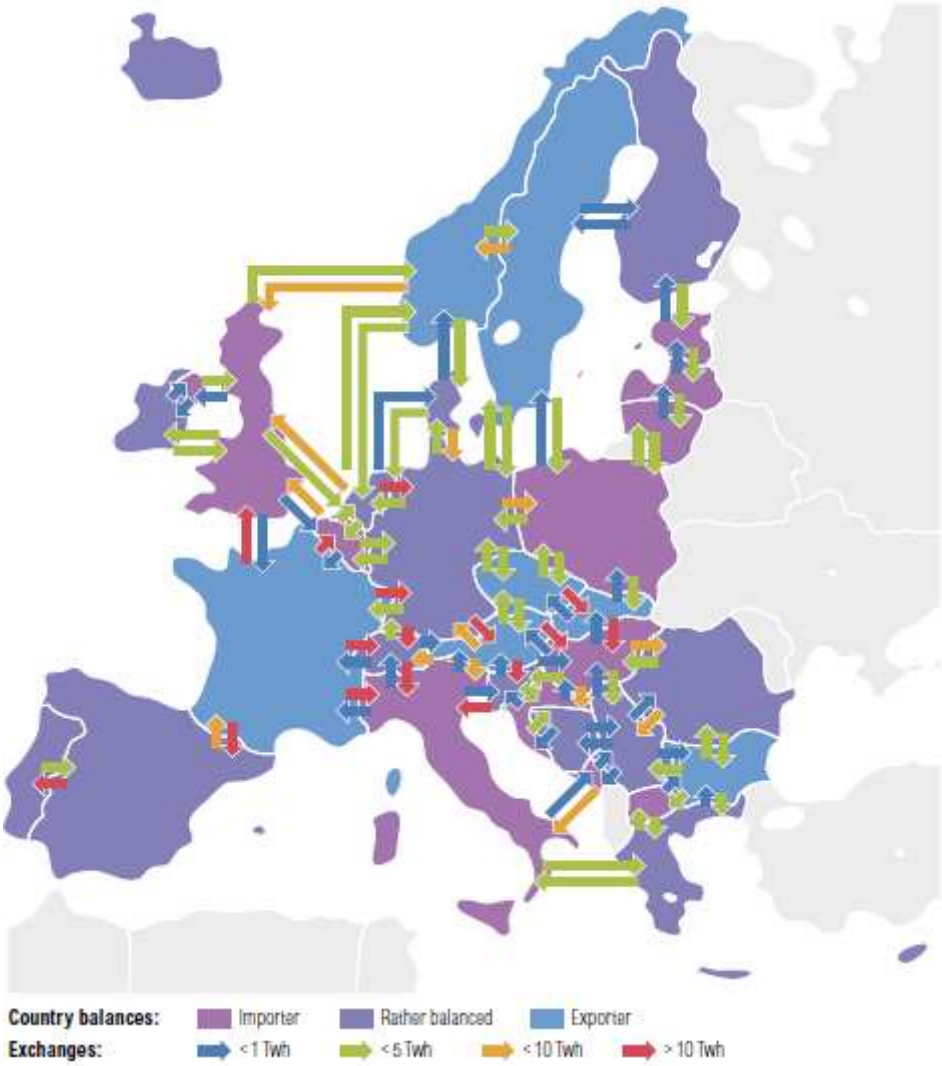


Fig. 5-5 – Expected commercial power exchanges in 2020 between ENTSO-E countries

Fig. 5-6 – 100 main bottlenecks identified in Europe in 2020

Of the 100 bottlenecks highlighted in the system analysis performed by ENTSO-E, about 60% of congestions are related to market integration, 30% to generation connection and 10% to security of supply. But at the same time, it is underlined that about 80% of the bottlenecks are also related to RES integration due to the combination of two factors:

- their non-homogeneous distribution in the interconnected system and
- their uncertain generation availability.

To overcome the aforementioned problem, more than 100 transmission projects of pan-European significance have been identified, 40% of which are interconnections between countries. The overall projects involves 52,300 km of new or refurbished Extra High Voltage lines.

About 10,100 km are related to subsea cables constituting an offshore grid, 1900 km of inland cables and 39,300 km of overhead lines.

The total investments costs for projects of pan-European significance amount to 104 bn€, out of which 23 bn€ are for subsea cables.

Such investments can be translated into about 2 €/MWh of network fee over the 10-year period, which represents less than 1% of the total end-users' electricity bill.

The projects of pan-European significance foreseen in the 2012-2016 and 2017-2022 periods are shown in Fig. 5-7 and Fig. 5-8.

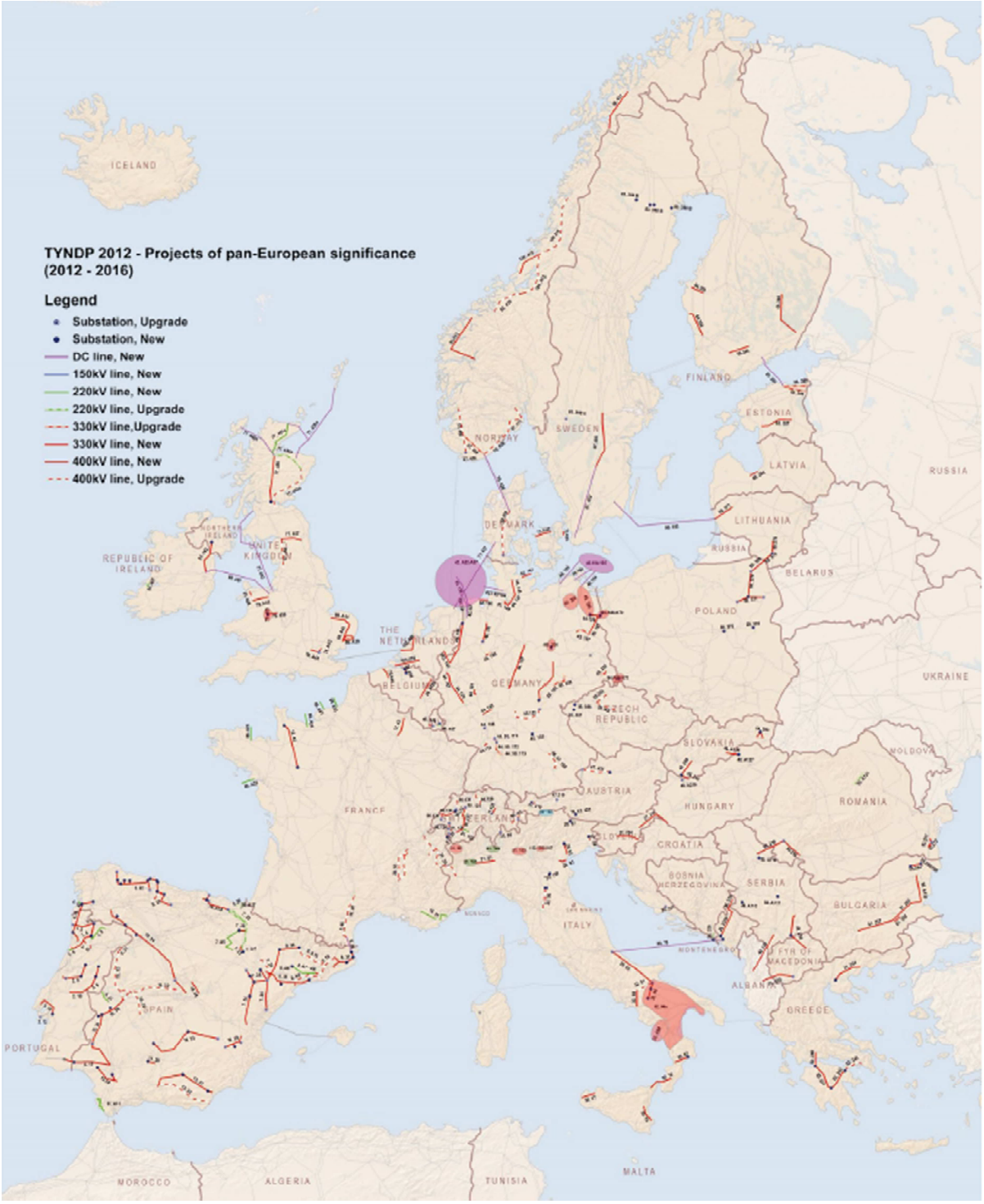


Fig. 5-7 – Locations of pan-European projects in 2012-2016

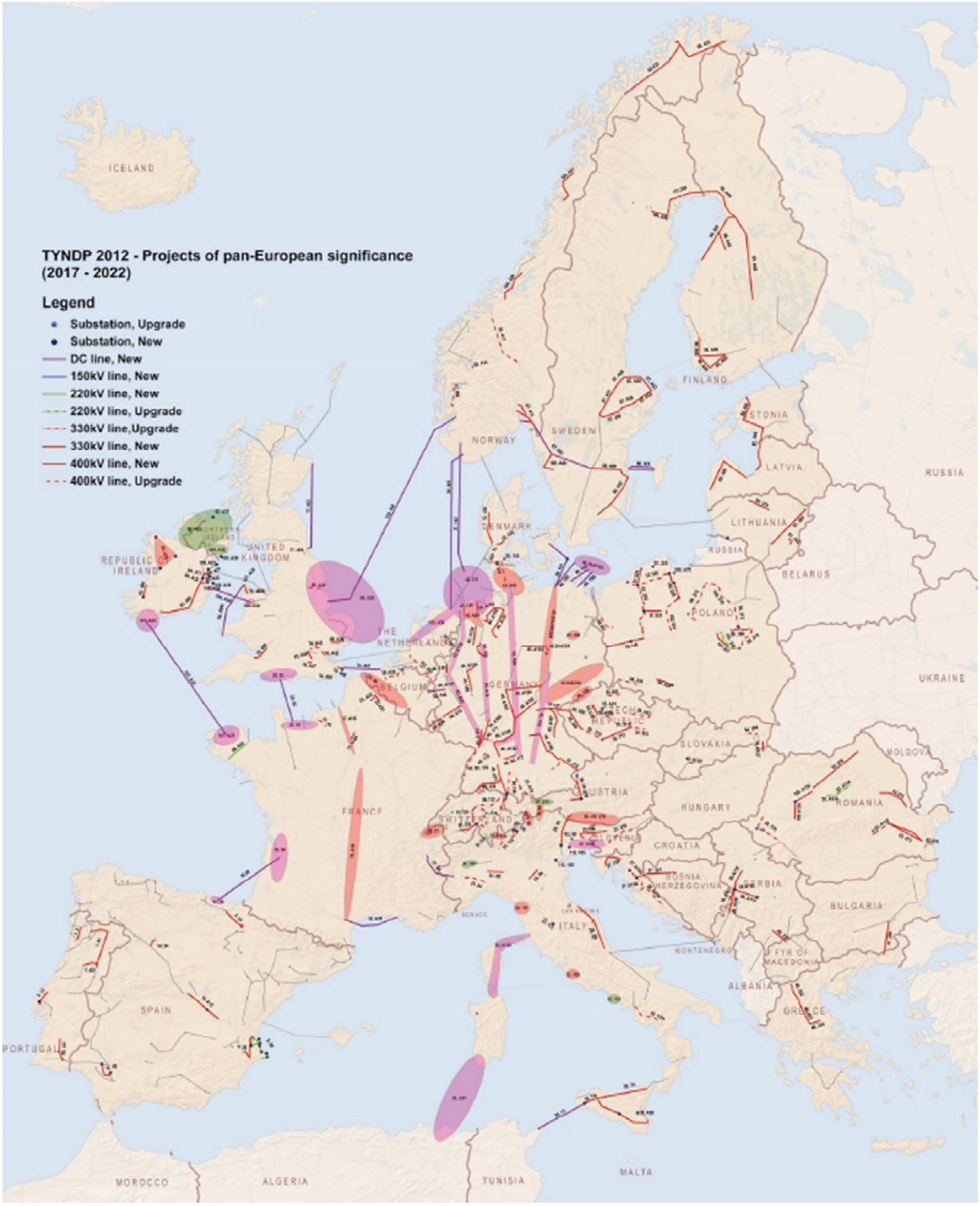


Fig. 5-8 – Locations of pan-European projects in 2017-2022

A set of indicators that include technical, economic, environmental aspects is adopted by ENTSO-E to assess the impact of transmission projects (including interconnections):

1. **Improved security of supply (SoS)**, the ability to provide an adequate and secure supply of electricity in normal conditions;

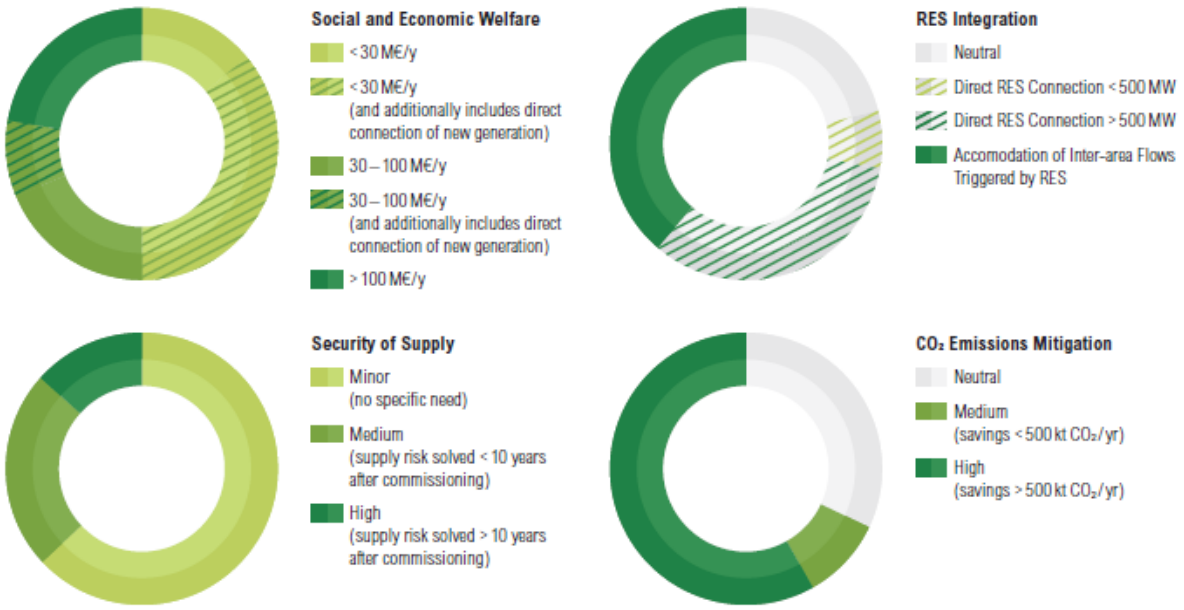
2. **Social and economic welfare** on electricity markets, the ability to reduce congestions and thus providing an adequate grid transfer capability to reduce the total generation costs;
3. **RES integration**, the ability to allow the connection of new RES plants and unlock existing "green" generation, while minimising curtailments;
4. **Variation in losses** (or energy efficiency) in the transmission grid, as the characterisation of the variation of thermal losses in the power system;
5. **Variation in CO_2 emissions**, the characterisation of the variation of CO_2emissions in the power system when unlocking generations with lower carbon content and when losses vary;
6. **Technical resilience/system safety**, the ability of the system to withstand increasing extreme system conditions (rare contingencies);
7. **Flexibility**, the ability to be adequate in a large set of possible future scenarios.

Each indicator is compared to the target adopted by the planning process and classified in:

- Neutral
- Medium compliance
- High compliance

The analyses have been performed articulating market and network studies.

Fig. 5-9illustrates the clustering of the projects included in the TYNDP 2012 of ENTSO-E with respect to those indicators.



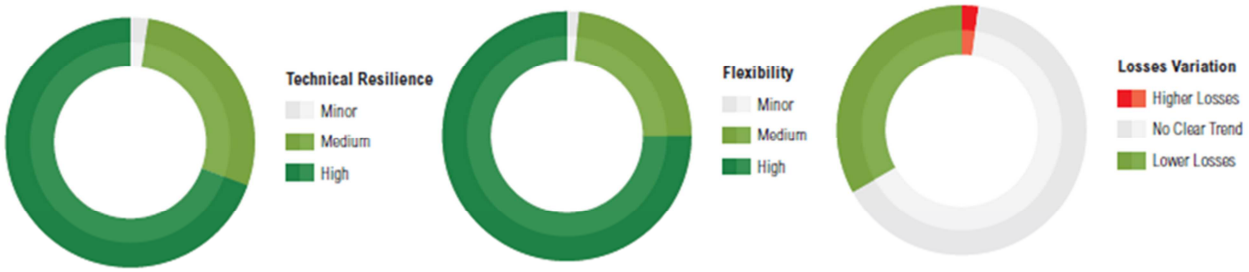


Fig. 5-9 – Clustering of the transmission projects defined in the next 10 years (source: TYNDP 2012 by ENTSO E)

The total benefit in generation savings for the long-term projects regarding the market integration has been evaluated in 5 bn€/year (about 5% of operating costs) compared to about 20 bn€ of investments. Most of the benefits are related to the four regions currently experiencing the weakest integration to the European system namely: Italy, the Iberian Peninsula, Ireland and the UK and Baltic states.

All projects contribute to significantly mitigate CO_2 emissions in Europe (with the exception of the few direct connections of fossil-fuel-fired power plants).CO_2emission savings of 170 Mt$CO_2$are expected, out of which 150 MtCO_2 result from the connection of renewable generation and 20 MtCO_2 stem instead from savings due to further market integration.

All the projects also display high technical performances in terms of technical resilience and flexibility. Losses variation trend is often complex to be determined, since it may be influenced by many factors.

As regards security of supply, the analysis revealed different concerns. Locations and quantification of such problems are shown in Fig. 5-10.
Local problems are related to the supply of large cities or urbanized areas (Lisbon, Catalonia, French Riviera, etc..
But most of the problems are related to:

- countries with a negative generation adequacy forecast (Belgium, Luxembourg) requiring additional cross-border transmission capacity,
- regions within countries with a negative generation adequacy forecast (south of Germany, Brittany, northwest Hungary, northern Norway) requiring additional transmission capacity,
- Baltic States requiring a higher interconnection with EU countries to ensure their supplies.

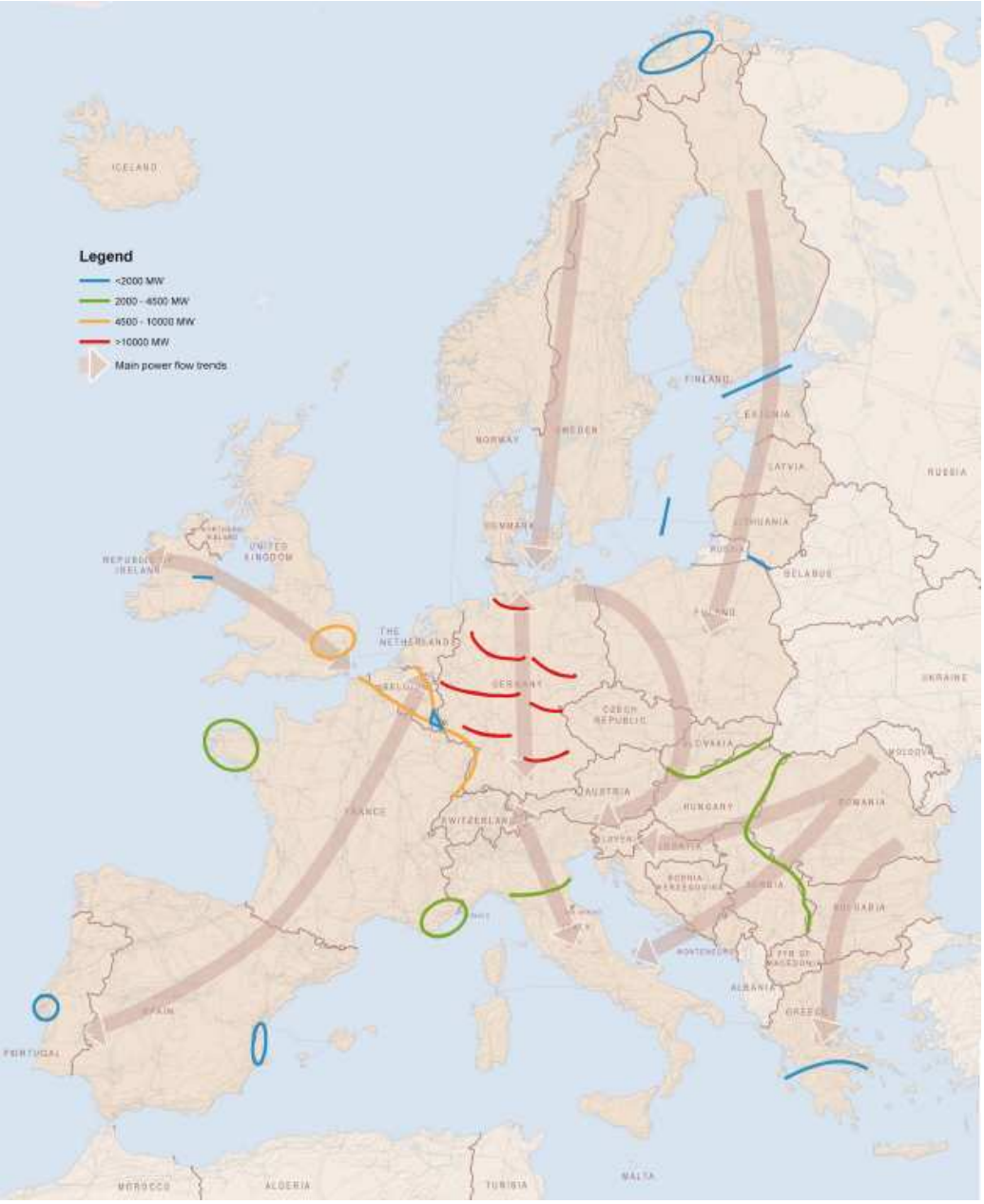


Fig. 5-10 – Locations and quantification of constraints related to security of supply

Recommendations

A major challenge of the foreseen grid development is that the transmission projects may be delayed, hence creating bottlenecks if the RES targets are met as planned by 2020, since permit granting procedures are lengthy, and often cause commissioning delays.

Besides, beyond the coming decade analysed in the study, the focus of the next actions is related to anticipate longer-run needs:

- the North Seas offshore grid concept for 2020 / 2030 following the Memorandum of Understanding for the North Seas Countries' Offshore Grid Initiative (NSCOGI)

- a strategic plan that will provide a vision for a pan-European power system at 2050, and this is the reason why the ENTSO-E leads the consortium "e-Highway 2050".

5.1.2 System Adequacy Forecast 2030 & Vision 4

Scope of the study

The target of the "Visions" is to use the year 2030 as a bridge between the European energy targets for 2020 and 2050. "2030 Visions Approach" aims at ensuring that all future realised pathways fall with a high level of certainty in the range described by the Visions; such studies have been formulated taking into account the results of an extensive consultation.

Target year

The target year is 2030, considered as a bridge between 2020 and 2050.

Geographical area covered by the study

The geographical area objective of the analyses of "Vision 4" is Europe, as shown in Fig. 5-11.

Fig. 5-11 – Geographical area of investigations. Source: Adequacy forecast 2013-2030

Input scenario

As far as the electricity demand is concerned, Europe's estimates are equal to 4,260 TWh/a at the year 2030. The subdivision of the demand among countries is reported in Fig. 5-12.

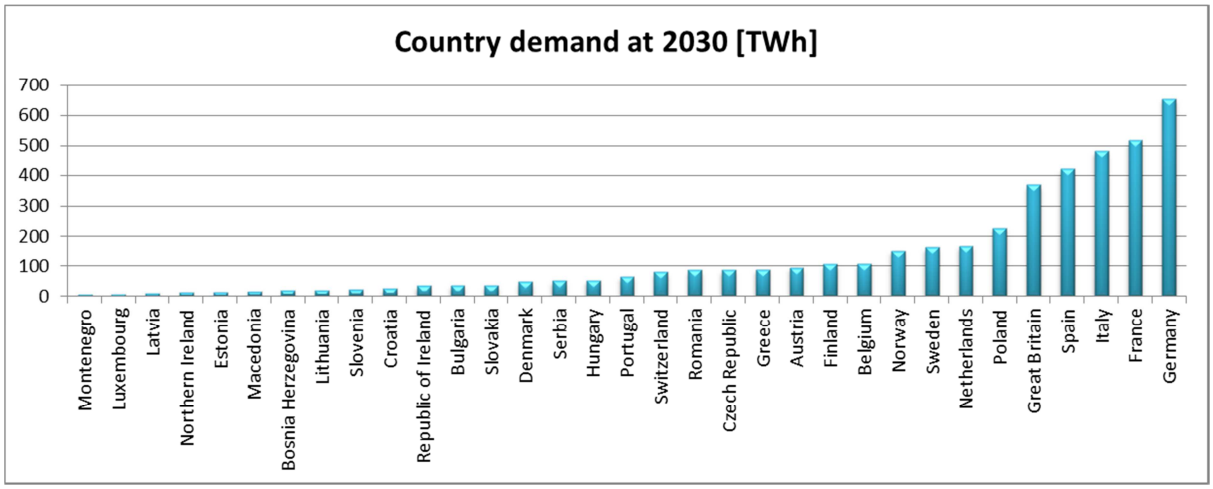


Fig. 5-12 – Demand at the year 2030. Source: Adequacy forecast 2013-2030

Fig. 5-12shows that Germany is the country with the highest value of demand, followed by France, Italy and Spain. These four countries reach about the 49% of the whole European demand.

In "Vision 4" efforts in energy efficiency implementation (e.g. large scale deployment of micro-cogeneration or heat pumps, as well as minimum requirements for new appliances and new buildings) and the development of electricity usage for transport (e.g. large scale introduction of electric plug-in vehicles) and heating/cooling are intensified. Furthermore, the demand response potential is fully used to shift the daily load in response to the available supply, because it allows a saving on back-up capacity and it is cheaper than storage.

To better understand "Vision 4" it is necessary to give a look also at the other three "Visions" in order to integrate "Vision 4" among them and to underline the differences. To this aim, Fig. 5-13 shows the most important characteristics between the four visions, namely:

- Vision 1: slow progress
- Vision 2: money rules
- Vision 3: green transition
- Vision 4: green revolution

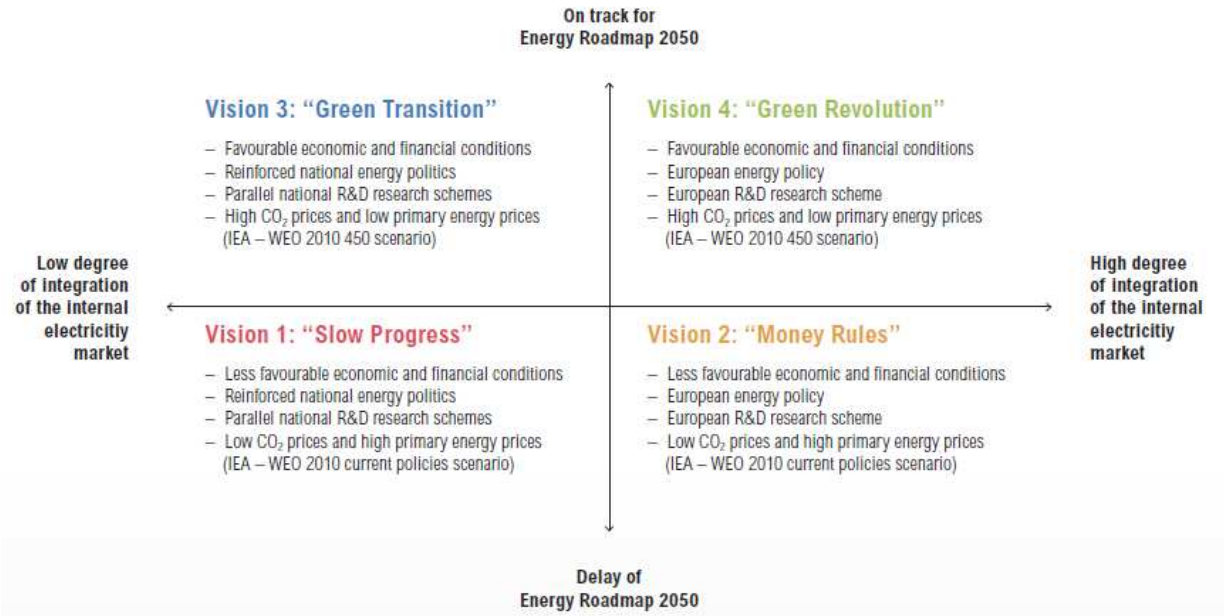


Fig. 5-13 – Overview of the political and economic frameworks of the four visions. Source: Adequacy forecast 2013-2030

Instead, focusing on the electric sector, the differences among them are summarized in Fig. 5-14.

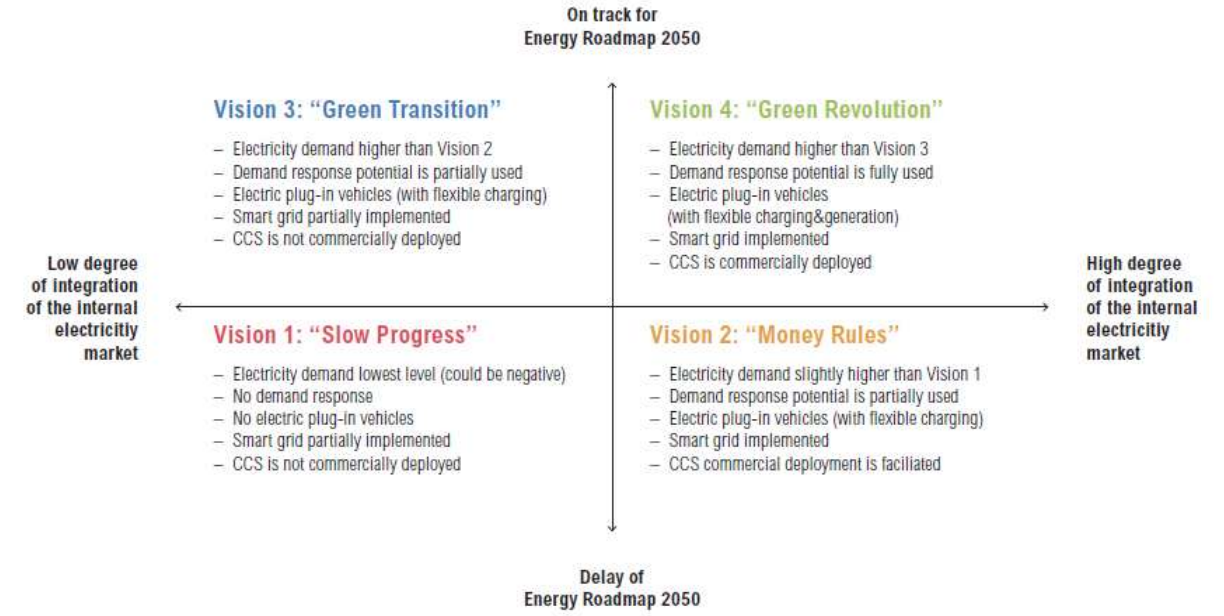


Fig. 5-14 – Overview of the generation and load frameworks of the four visions. Source: Adequacy forecast 2013-2030

The main differences between Vision 4 and the other three visions are:

- the highest demand
- the full use of demand-response technique
- the use of smart grids
- the CCS technology is considered as commercially deployed.

The data adopted in Vision 4 is coherent with Roadmap 2050.

Study assumptions: unitary investment costs

Vision 4 doesn't provide specific information regarding the unitary investment costs neither for the generation technologies, nor for transmission technologies.

Study assumptions: operational costs

As far as the operational costs are concerned, "Vision 4" provides some information on the following aspects:

- cost of conventional fuels
- cost of CO_2 emissions

With respect to the fuel costs, Tab. 5-1 reports the costs of the different fuels. The costs are expressed in [€/GJ].

Tab. 5-1 – Fuel cost for Vision 4. Source: Adequacy forecast 2013-2030

Fuel	Vision 4 2030 Fuel prices (€/Net GJ)
Nuclear	0.377
Lignite	0.44
Hard coal	2.21
Gas	7.91
Light oil	16.73
Heavy oil	9.88
Oil shale	2.3

For CO_2 emissions, "Vision 4" adopts a cost equal to 93 €/ton.

Study results

Fig. 5-15 reports the generation mix adopted for Vision 4.

The future generation mix is determined by a strong European vision that is on track to realize the decarbonisation objectives for 2050 at the least cost. The need for back-up capacity for intermittent renewables in Europe could be 5 times more than the back-up capacity needed for the realization of 3x20 objectives. However, since there is a European common energy framework, the need for back-up capacity will be lower than in Vision 3 "Green transition". This means that besides the demand response potential that is fully used, a central additional hydro storage will be built in Norway, the Alps and the Pyrenees and the remaining additional back-up capacity in 2030 will come from gas units.

This vision takes into account that no technology is preferred among the others but their use competes instead with the other ones on a market basis with no specific support measures. Furthermore, decarbonisation is only driven by carbon pricing (no additional policies on top of carbon pricing are assumed) and public acceptance of nuclear is assumed. The European subsidies for CCS to develop beyond demonstration are intensified in order to speed up to successful commercial deployment.

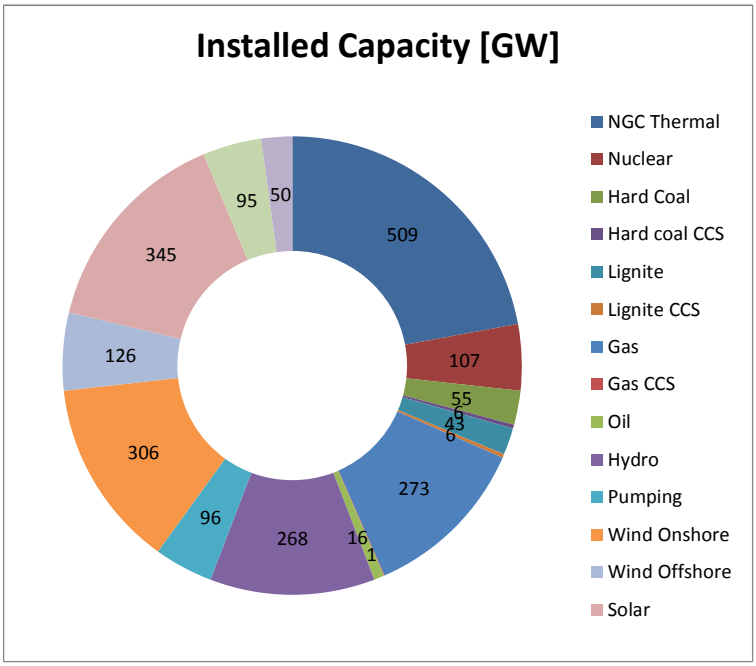


Fig. 5-15 – Generation mix for Vision 4. Source: Adequacy forecast 2013-2030

As for the network, distribution grids and transmission systems should be connected by an advanced monitoring, control and communication link. Distribution grids become active. That configuration allows increased reliability, efficient management of peak demand, reduces required back-up generation capacity, increases environmental sustainability, reduces CO_2 emissions, fully accomplishing with the Roadmap 2050 milestones requirements. Electric vehicles are assumed to be flexible on charging and on the generation side. Load is adapting to generation possibilities.

Socio-environmental benefits, financing schemes and regulatory mechanisms

The general framework of Vision 4 "Green revolution" estimates that the economic and financial conditions are more favourable than in Visions 1 and 2 and, as a consequence, national governments have available money to reinforce existing energy policies. Major investments in sustainable energy generation are undertaken. Furthermore, a strong European framework makes the introduction of fundamental new market designs that fully benefit from R&D developments. This also allows R&D expenses to be optimized so that major technological breakthroughs are more likely.

Since a reinforcement of existing energy policies is foreseen, the carbon pricing (e.g. the EU Emissions Trading System, carbon taxes or carbon price floors) would reach such high levels that base load electricity production will be based on gas rather than hard coal. Carbon and primary energy prices will be based on the 450 scenario of the IEA in their WEO 2011. Gas is likely to push out hard coal for base load electricity generation. This means that countries with a lot of gas in their energy portfolio are likely to be net exporters.

5.2 Booz – Benefits of an integrated European energy market

Scope of the study

The scope of the study is to evaluate the social welfare related to market integration in the gas and electricity sectors in Europe. In particular the study:

- assesses the benefits of the internal energy market and integration of networks up to 2014 and it is expected to be achieved by further integrating the market and interconnecting the networks beyond 2014 up to 2020/30;
- estimates the costs of delayed integration of the internal energy market and insufficient interconnection of networks beyond 2014 up to 2020/30.

A strong link between gas and electricity markets exist, since gas will play a significant role in the power generation to reduce emissions in the short and medium term, as highlighted by European Commission (EC, 2011).

Target year

The target year of the study is 2030.

Geographical area covered by the study

The geographical area covered by the study is the European Union (EU27).

Input scenario

The study distinguishes:

- Policy scenarios, related to the different states of the world, which are compared each other;
- Market scenarios, based upon the defined PRIMES scenarios used by the EC for energy policy.

As regards the gas sector, three Policy scenarios have been compared to the Base Case (current integration of European markets in 2012), as shown in Fig. 5-16.

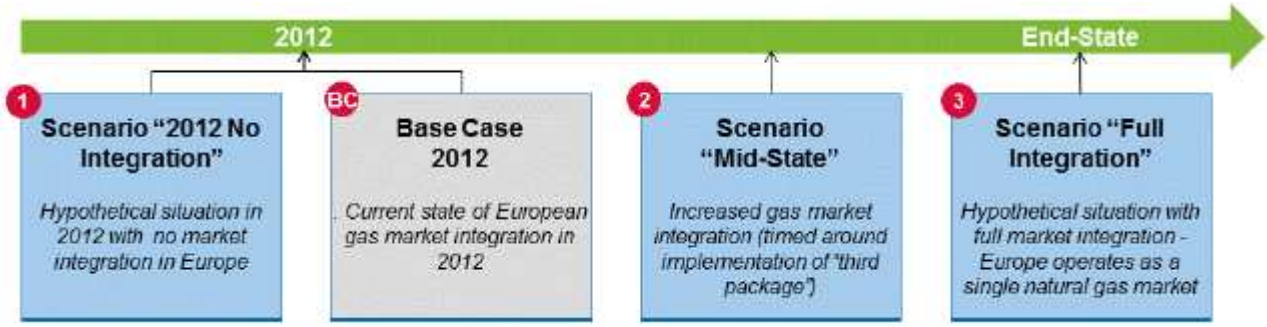


Fig. 5-16 – Gas Policy scenarios

In terms of Market scenarios the references were the PRIMES and ENTSO-G.

As regards the electricity sector, the following Policy scenarios have been considered for the period 2015 to 2030:

- Baseline scenario, considering the persistence of 2014 institutions ("energy neutral baseline"). In this scenario cross-border trade is mainly opportunistic arbitrage in the short run;
- (Fully) Integrated market, in which transmission level, security of supply shared across borders and balance are optimal;
- Integrated with Low TX (Electrical Transmission Capacity), in which only 50% of optimal new transmission capacity is constructed;
- Integrated but Self-Secure, in which security of supply is not shared between member states;
- Integrated with EU Reserve, in which short terms balancing services are shared between countries;
- Integrated with Demand-Side Reduction (DSR), in which DSR is facilitated by demand management techniques, made possible by adoption of smart grid technologies; in this scenario 10% of daily energy is flexible, and 15% peak load reduction can be achieved.

In terms of Market scenarios, the two Current Policy Initiative (CPI) and High Renewables (RES) scenarios of PRIMES have been considered. In addition, a Renewables Investment Coordination (INV) scenario has been considered.

According to CPI scenario, the system peak demand will be 633 GW by 2020 and 664 GW by 2030, with the annual system consumption of 3650 TWh by 2020 and 3833 TWh by 2030, including losses. The electricity generation mix in the same years is shown in Fig. 5-17, under the hypothesis of a cost of CO_2 emission of 15 € per tons in 2020 and 32 € per tons in 2030. The total installed capacity of the different technologies is shown in Fig. 5-18.

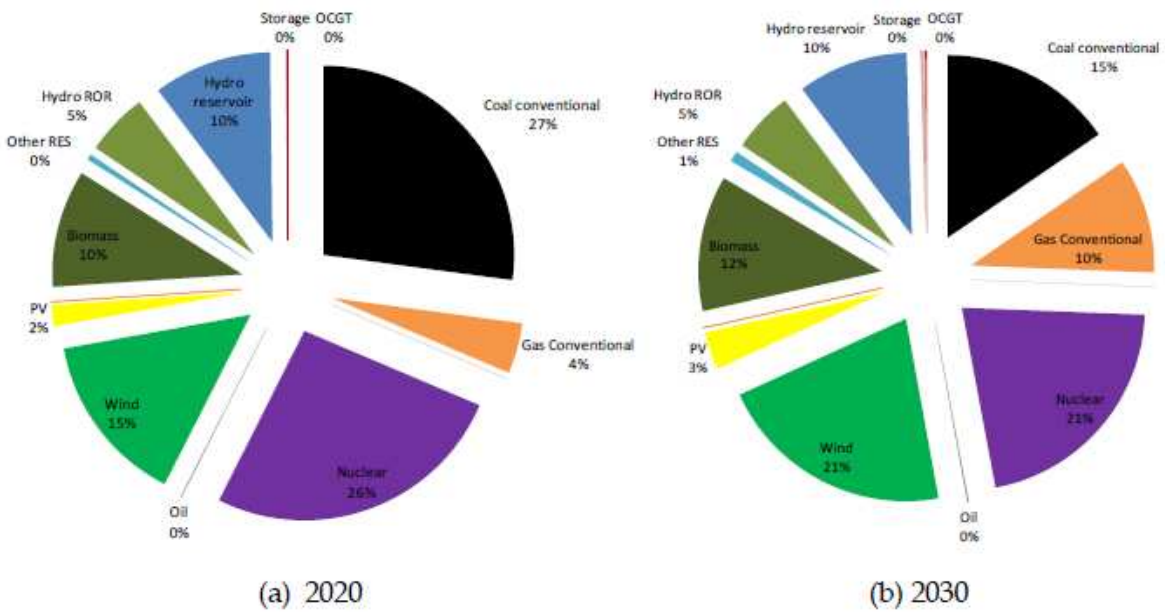


Fig. 5-17 – Electricity mix in 2020 and 2030 according to PRIMES CPI scenario

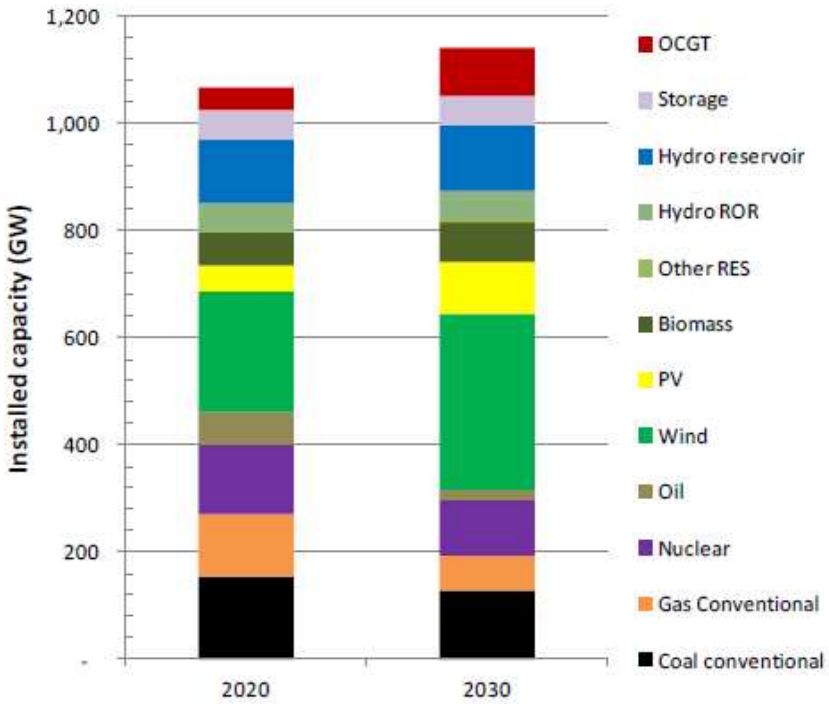


Fig. 5-18 – Installed capacity at years 2020 and 2030according to PRIMES CPI scenario

According to high RES scenario, the system peak demand will be 640 GW by 2020 and 662 GW by 2030, with the annual system consumption of 3681TWh by 2020 and 3834TWhby 2030. The electricity generation mix and the total installed capacity in the same years are shown in Fig. 5-19 and Fig. 5-20. In High RES scenario the costs of CO_2 emission have been evaluated in 25 € per tons in 2020 and 35 € per tons in 2030.

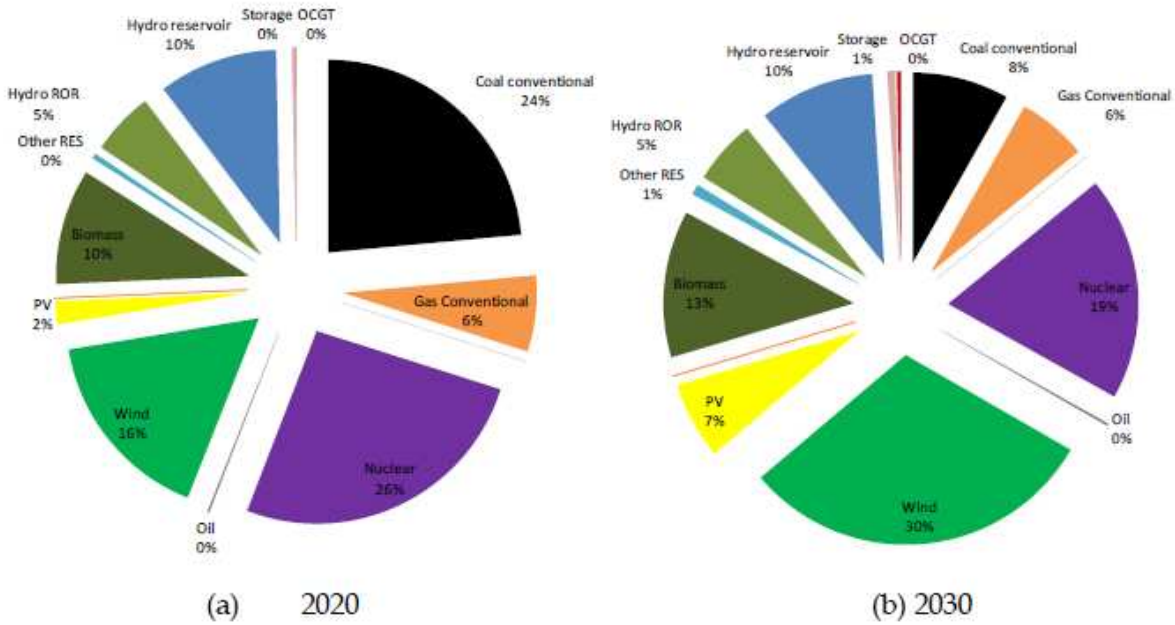


Fig. 5-19 – Electricity mix in 2020 and 2030 according to PRIMES High RES scenario

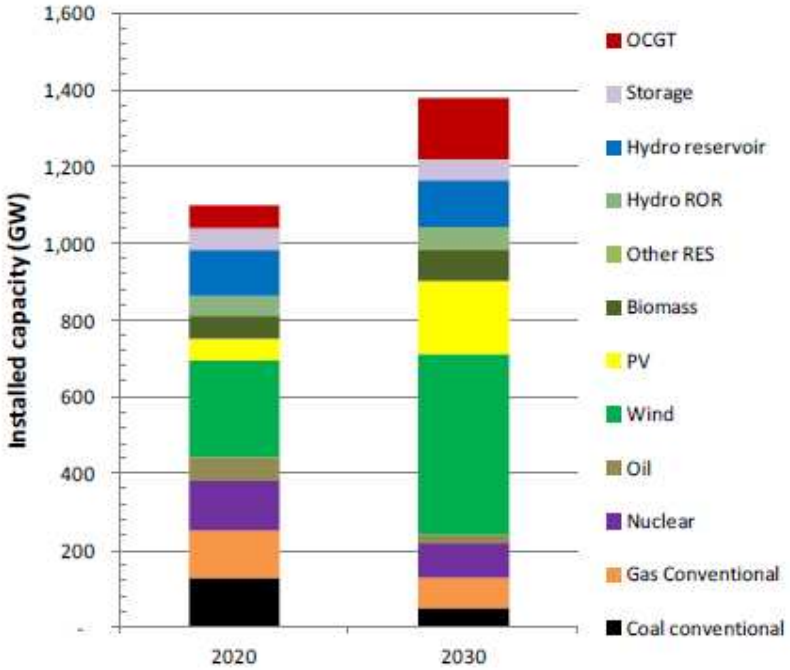


Fig. 5-20 – Installed capacity at years 2020 and 2030according to PRIMES High RES scenario

In the Renewable Investment Coordination scenario a saving of 146GW of RES capacity (53 GW of PV and 93 GW of wind capacity) has been considered by relocating RES plants in the most geographically favourable sites, without affecting the energy produced by all generating sources. The adjustment of RES capacity between the European countries related to this scenario is shown in Fig. 5-21.

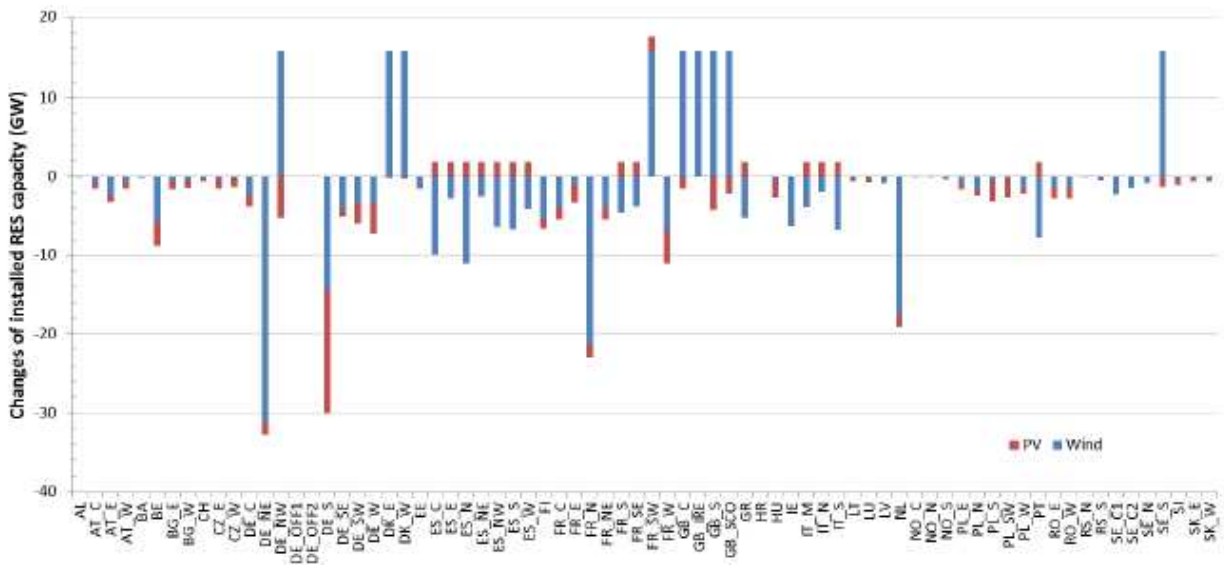


Fig. 5-21 – Locational adjustment of Renewable power plants from RES 2030 to INV 2030

A summary of the policy and market scenarios analysed in the study related to electricity is shown in Fig. 5-22.

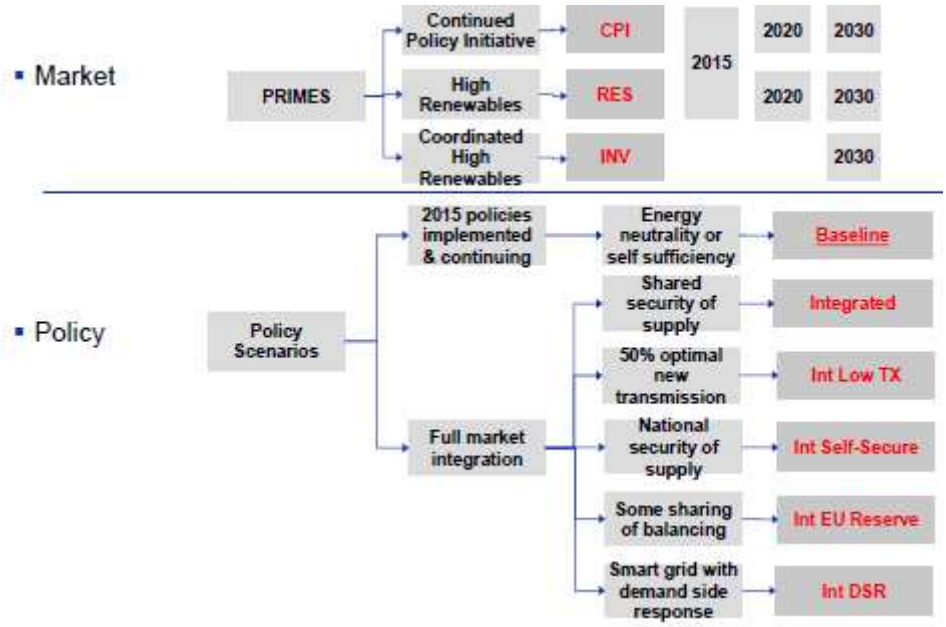


Fig. 5-22 – Summary of scenarios analysed with respect to electricity sector

Study assumptions: unitary investment costs

The study doesn't provide specific information regarding the unitary investment costs neither for the generation technologies, nor for transmission technologies.

Study assumptions: operational costs

The scenarios defined by PRIMES initiative have been used regarding operational costs. As a reference, the fossil fuel prices in Baseline scenario is shown in Fig. 5-23. A cost of CO_2 emission of 15 € per tons in 2020 and 32 € per tons in 2030 has been considered.

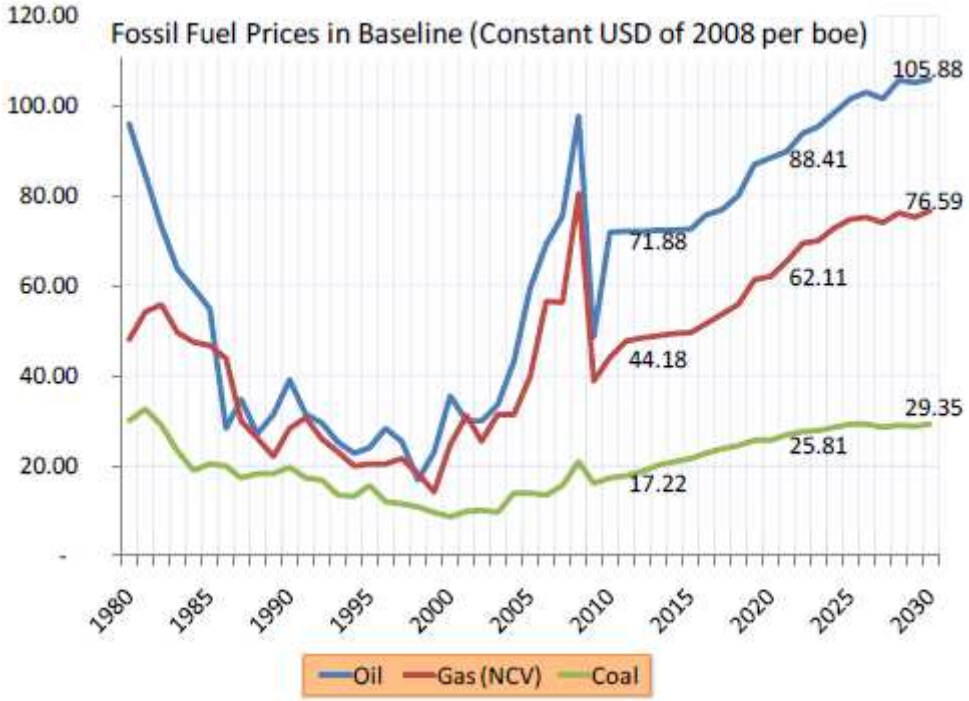


Fig. 5-23 – Fossil fuel prices forecasted in the PRIMES Baseline scenario (source "EU energy trends to2030 - update 2009" of E3M-Lab)

Study results

Gas Market

Maturity of Gas sector in terms of liberalisation and integration is lower compared to Electricity sector. The level of maturity is also different between the countries. An indicative measure of this aspect is shown in Fig. 5-24.

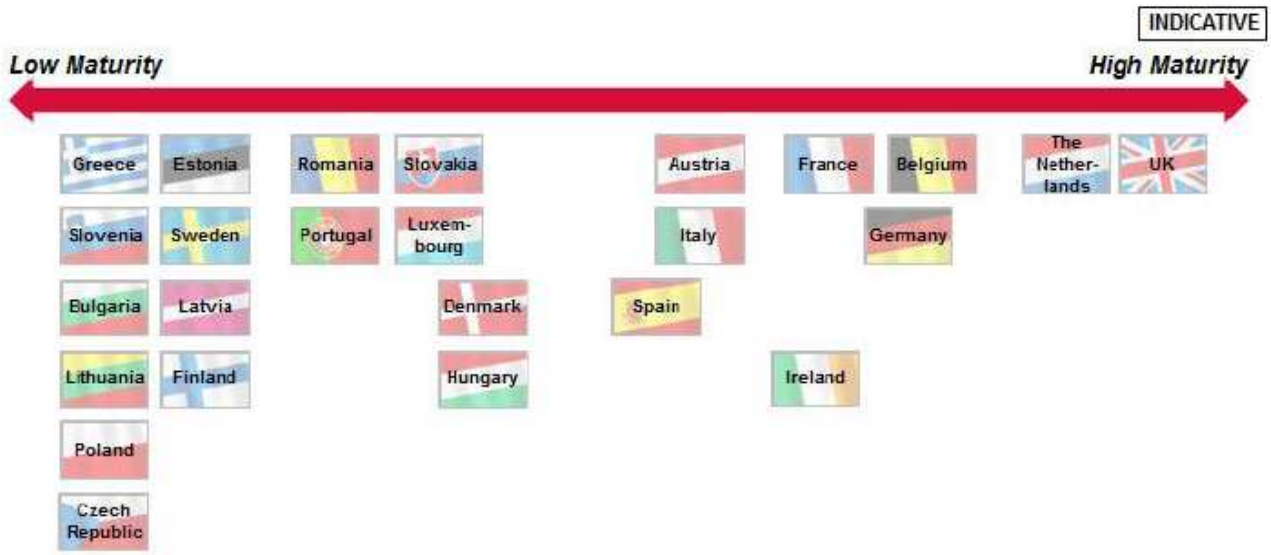


Fig. 5-24 – Maturity level of market liberalisation and integration in European countries in 2012

The study analysed the following points:

- market liquidity
- number of competing natural gas importers in a country
- price formation of border gas[3] (proportion of oil-indexed vs. hub-based prices)
- physical connectivity across markets and price convergence

Among the physical and virtual hubs present in Europe, currently only the British NBP and Dutch TTF are generally considered to be "liquid" hubs.

The analysis of price formation in the different markets revealed that while in some countries prices are fully or partially driven by hub prices, most countries have border prices that are close to oil-linked prices. An indicative measure of this aspect is shown in Fig. 5-25.

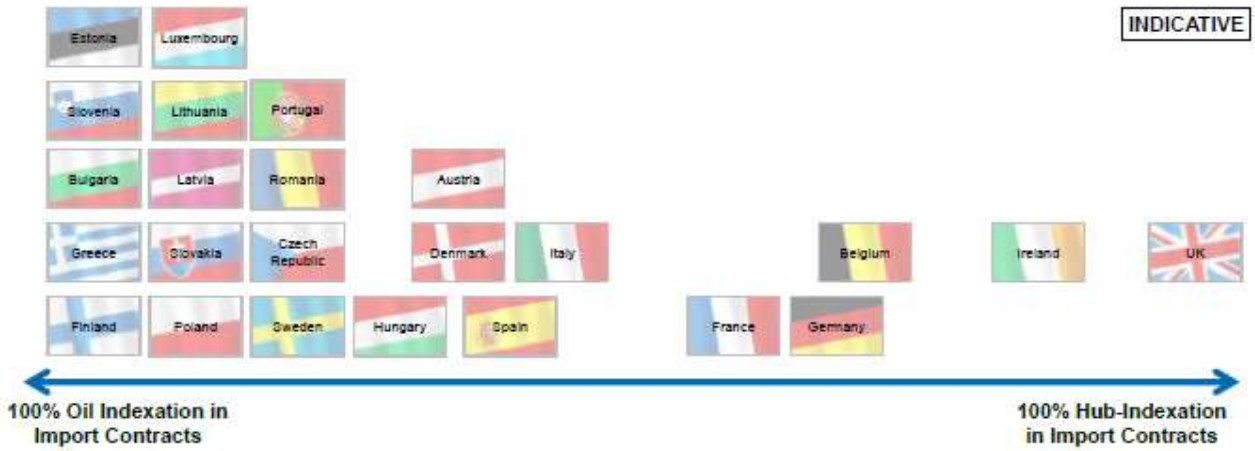


Fig. 5-25 – Price mechanisms for border prices per EU27 Member State in 2012

This is an item directly related to market integration. According to a study performed by Stern and Rogers in 2011[15] price formation will move from the common oil-indexation towards hub-based prices. This has been a relatively quick reality in the majority of markets in NW Europe, but the extension to continental Europe is critical since gas hubs are relatively illiquid. In this respect, the Gas Target Model, the vision of the EU regulators of the future gas market structure (as developed by the CEER, Council of European Energy Regulators) could stimulate the required liquidity and transparency to achieve this transition.

Fig. 5-26 shows the physical connectivity among the European countries in 2022. Only in North-West Europe the connectivity has allowed an effective trading and price convergence among the hubs.

[3] Border prices are the average prices at which gas is imported into a given country from different supply sources.

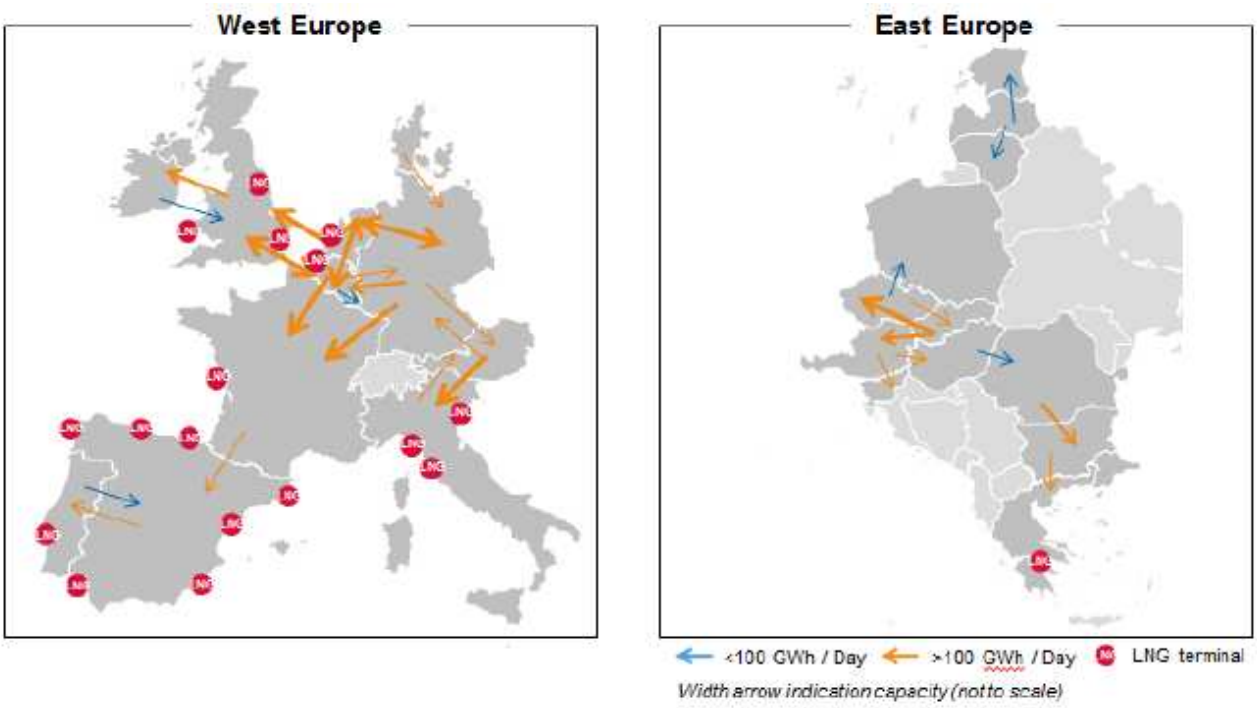


Fig. 5-26 – Physical Cross-Border connectivity in Europe in 2012 for Natural Gas

The study evaluated in 30 bn€ per year the benefit from enhancement of gas market integration for the EU27 for the Full Integration scenario respect to the Base Case.

The opportunities offered by the integration are related to lower prices of gas and flexibility (seasonal variation of price). The results are based on the assumption that the current situation of oversupply will continue in the future.

Several of the EU27 countries are already enjoying the benefits of market integration, and other states could benefit in the future.

To favour market integration three items have to be improved:

- infrastructures, in order to increase the number of suppliers and the market's security of supply;
- supporting regulatory;
- political conditions.

As regards infrastructure, the study assumed, for the Full integration scenario, that each country has a "N-1" security of supply situation in peak demand. The impact of security of supply has been assessed assuming the reduction of GDP following a 1% increasing in the probability that a EU27 member state suffers a total gas supply interruption of one day in duration. This requires 1.5-3 bn€ of investments in infrastructures (import pipe, storage and LNG regasification capacity), in addition to the 10 bn€ of investments (already decided) reported by ENTSO-G by 2022.

The study did not determine whether these extra investments are in fact necessary to achieve market integration, nor analyse the financial attractiveness of it, nor which parties should finance such investments.

Moreover, the study assumed the 2012 situation of supply/demand balance (oversupply) as a reference point to evaluate the benefits, neglecting possible alternative scenarios.

Electricity Market

According to the study, the level of integration is measured by the volumes of trades on the links. In a fully integrated system the total quantity of trades across a given link is a large multiple of the capacity of that link, even though the net flow respects the capacity constraint of the link. This can happen in a world where the directions of movement of electricity across borders will become much more variable, as a result of increasing quantities of intermittent renewable generation. In contrast, the cross-border arrangements in place in Europe currently permit longer-term capacity to be sold only in quantities related to the capacity of the link, without regard for netting out flows by direction. According to the study, reform, for example, along the lines of using financial transmission rights, is required to deliver the necessary flexibility in usage of transmission capacity.

As regards the impact of electricity market integration, the range of cost savings of the integration scenarios compared to Baseline scenario are shown in Fig. 5-27 and Fig. 5-28 for the Current Policy Initiative and RES market scenarios described in the previous paragraph.

The costs measured include fuel costs, annualised generator capital costs, and annualised transmission capacity capital cost. Thus the amounts shown are net benefits, taking account of both savings in fuel and increases or reductions in the annual costs of capital stock. Generally speaking, fuel costs are much the largest component.

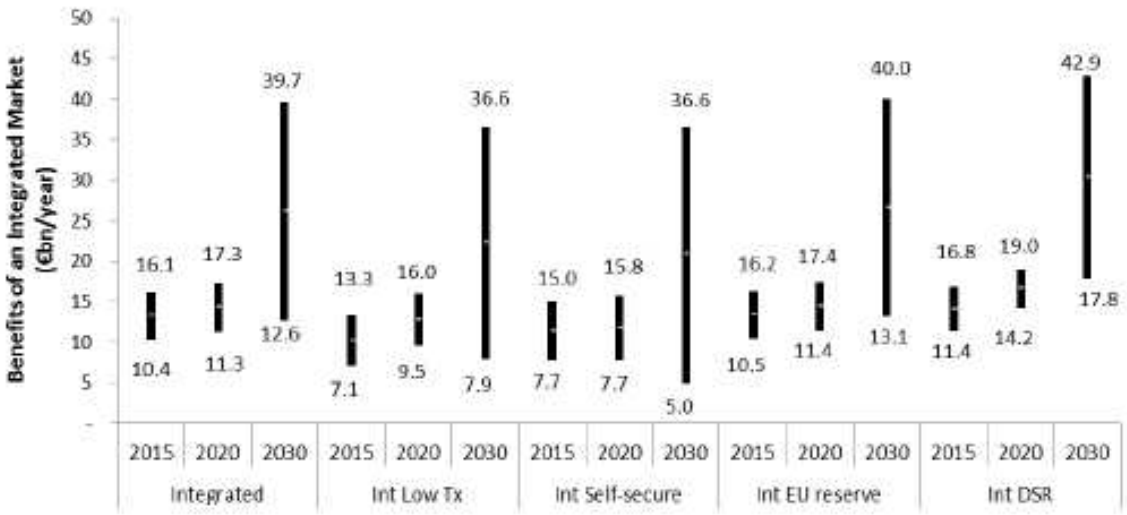


Fig. 5-27 – Range of annual cost savings in integration scenarios relative to baseline, CPI market scenario, 2015-2030

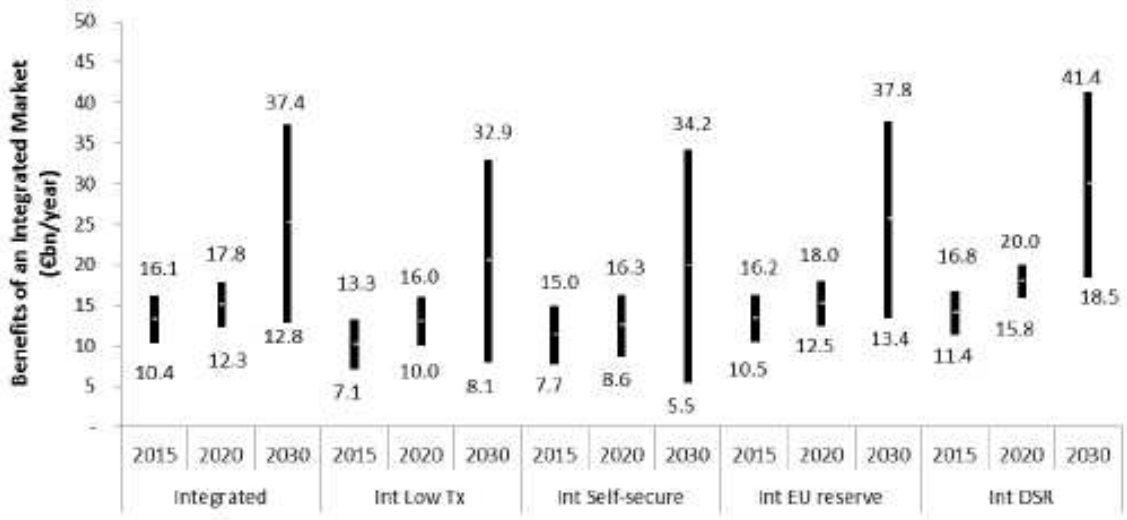


Fig. 5-28 – Range of annual cost savings in integration scenarios relative to baseline, RES market scenario, 2015-2030

Benefits are similar among the integration scenarios analysed and between CPI and RES market scenarios. They are in the order of 10-15 bn€ per year in the short and mid-terms and increase up to 40 bn€ per year at 2030. The major change occurs by 2030 as major changes in the pattern of generation occur at that period.

It is highlighted that in the integrated scenario with limited investments in additional transmission capacity (INT Low Tx) the reduction of benefits are only 10% compared to the fully integrated scenario in the CPI market scenario and 12% in the RES scenario.

Fig. 5-29 summarises the required generation and transmission infrastructures related to the scenarios analysed.

Additional generation capacity is needed in the Baseline (referred to PRIMES scenarios) in order to cope with security of supply standards. In this respect, the fully integrated scenario doesn't allow a significant reduction of the required firm capacity. It is relevant to note the increasing of firm capacity needed in the integrated scenario with limited additional transmission capacity, of about 27% and 47% in the RES and CPI market scenarios respectively. On the contrary, a reduction of the firm capacity of 37% and 63% in the two market scenarios compared to Baseline scenario is possible due to smart grid development and demand side management programs.

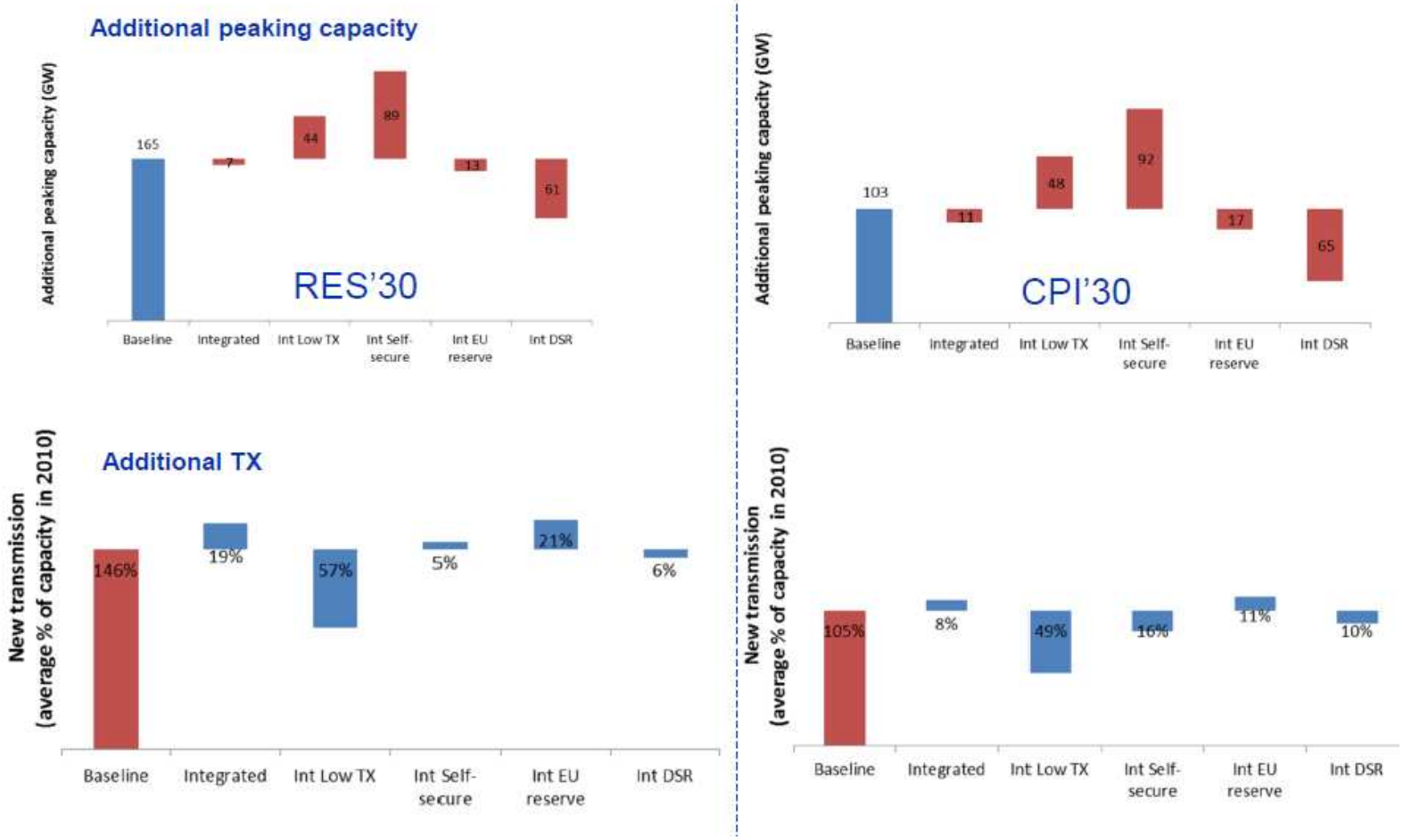


Fig. 5-29 – Investment in additional firm generation capacity needed to maintain security of supply, and additional transmission capacity (compared to 69 TWkm of 2010) required in RES and CPI market scenarios

An additional net saving of about 16 bn€ - 30 bn€ a year (after netting out the effect of additional transmission costs and some generation cost savings) can be achieved considering the coordinated RES investment scenario.

The study also analysed the impact on CO_2 emissions of the scenarios examined. The results are shown in Fig. 5-30 and Fig. 5-31. The two market scenarios show the same attitude to reduce CO_2 emissions increasing the level of integration. Of course the absolute emissions are lower in the RES scenario compared to CPI one.
The integrated scenario reduces CO_2emission by about 5% in the CPI scenario and about 12% in the RES scenario. It is relevant to note that the reduction is due to better efficiency rather than the quantity of energy. Greater efficiency can be achieved through the integration.

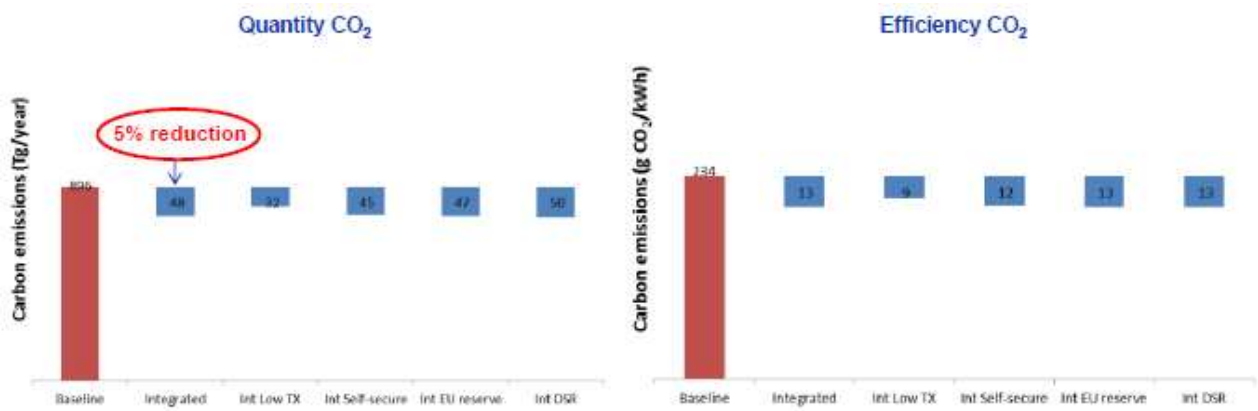


Fig. 5-30 – Total and relative CO_2 emissions in CPI market scenario

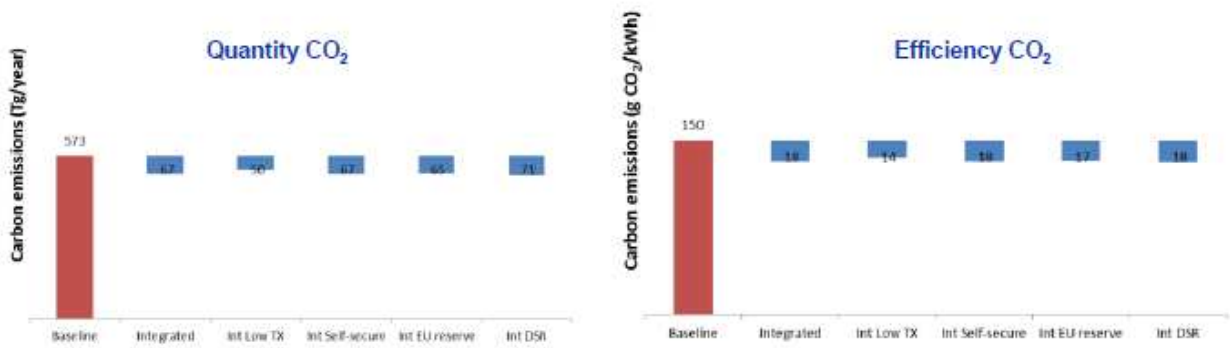


Fig. 5-31 – Total and relative CO_2 emissions in RES market scenario

5.3 FOSG – Roadmap to the Supergrid technology

Scope of the study

This study is focused on technological aspects related to the new Pan-European power transmission system planning, realization and operation to meet the European targets in the energy sector. Indeed, most of the new production will come from offshore wind farms and solar plants. The larger penetration of the two technologies sets new challenges on network development and operation of the so called "Supergrid".

The Report prepared by the WG2 of FOSG is related to technology enhancements in 2012, the role of energy storage systems, AC and DC grid controls (state-of-the-art) and the Roadmap for the development of the SG.

Target year

The target year of the study is 2030.

Geographical area covered by the study

The study is focused on technological aspects related to development of a SG in the European power system.

Input scenario

The main driver for development of a SG is the foreseen reduction of CO_2 emission in the long term vision (2050). Among the long term visions, the study selected those having a target of a 75-80% reduction of emission, as shown in Fig. 5-32.

Stakeholder	Vision	GHG Target*	Fuel Prices	Technologies Development	
				CCTS **	RES ***
Eurelectric	Power Choices	75%	Medium-High	2025	Low
European Gas Advocacy Forum (EGAF)	Low gas price	80%	Medium-Low*****	2030	Medium
	High gas price	80%			
	Low gas price and constrained nuclear****	80%			
International Energy Agency (IEA)	BLUE Map	75%	Low	2015-2025	High
European Climate Forum (ECF)	Roadmap 40% RES	80%	Medium-Low	2020	Medium
	Roadmap 60% RES	80%			
	Roadmap 80% RES	80%			
EREC/ Greenpeace	Energy [R]evolution	80%	High	Not needed	Medium-High

* GHG emission reductions relative to 1990 levels
** Year when it is assumed to be commercially available
*** Learning rates (in qualitative terms)
**** Nuclear capacity constrained at 30GW by 2030
***** The fuel prices considered are the same as in the ECF report, except for gas, for which two different price scenarios (low and high) are considered. The high gas price scenario is the one corresponding to ECF values.

Fig. 5-32 – Targets of CO_2 emission in different long term visions

Concerning the time horizon, the report defined three stages for the development of a SG:

- today – 2015, determined by renewable energy starting to replace older coal fired power plants as well as nuclear power, the latter especially in Germany;
- 2015 – 2020, in which replacement continues while larger and more faraway offshore wind farms are realised,
- after 2020, in which the European-wide overlay grid is developed.

In the first period AC transmission is used as far as possible to connect the wind parks to the onshore grid. Projects that are more than 100 km away from their onshore connection point are connected by radial VSC based HVDC point-to-point links.

In the second period the utilization of wind power is further developed building far offshore (>100 km) bulk power wind park clusters, having power ratings in the range of some Gigawatt. To improve flexibility of the grid, offshore wind parks are connected each other and to DC links interconnecting the northern European countries.

In the third period the bulk DC links are realised to connect Northern areas characterised by wind generation with Southern areas characterised by large scale solar power and storage systems around Europe. Moreover, connections of Europe with North Africa and Middle East are envisaged.

Study assumptions: unitary investment costs

The study doesn't provide specific information regarding the unitary investment costs neither for the generation technologies, nor for transmission technologies.

Study assumptions: operational costs

The study doesn't provide specific information regarding operational costs of generation and CO_2 emissions.

Study results

The common vision about network developments considers HVDC as a key technology for the grid development in combination with strengthening the 380 kV AC transmission system.

The conclusion of the Network Development Plan prepared by the German TSOs states: "*There appears to be a significant and nationwide need for development. In this case, the emphasis is on the high-capacity North-South connections. In the case of lead scenario B, it will be necessary to implement network enhancements and optimisations along a length of 4,400 km in the existing routes by 2022. The construction of new routes spans a length of 1,700 km. The DC transmission corridors are approximately 2,100 km long. They have a transmission capacity of 10 GW along the North-South direction. The expansion of the transmission network will require a total investment of ca. 20 billion € over the next ten years.*" (quoted by the "Grid Development Plan 2012" issued by the four German TSOs, 50Hertz, Amprion, TenneT TSO and TransnetBW).

Also the Swedish TSO (SvenskaKraftnät) has presented an ambitious network development plan by 2025 outlining several new VSC-HVDC lines in construction or planning to Baltics, Norway and Gotland, and possible expansion of the planned three-terminal system down to Germany.

Another example is given by the ENTSO-E vision for 2030 about the North Sea area as shown in Fig. 5-33.

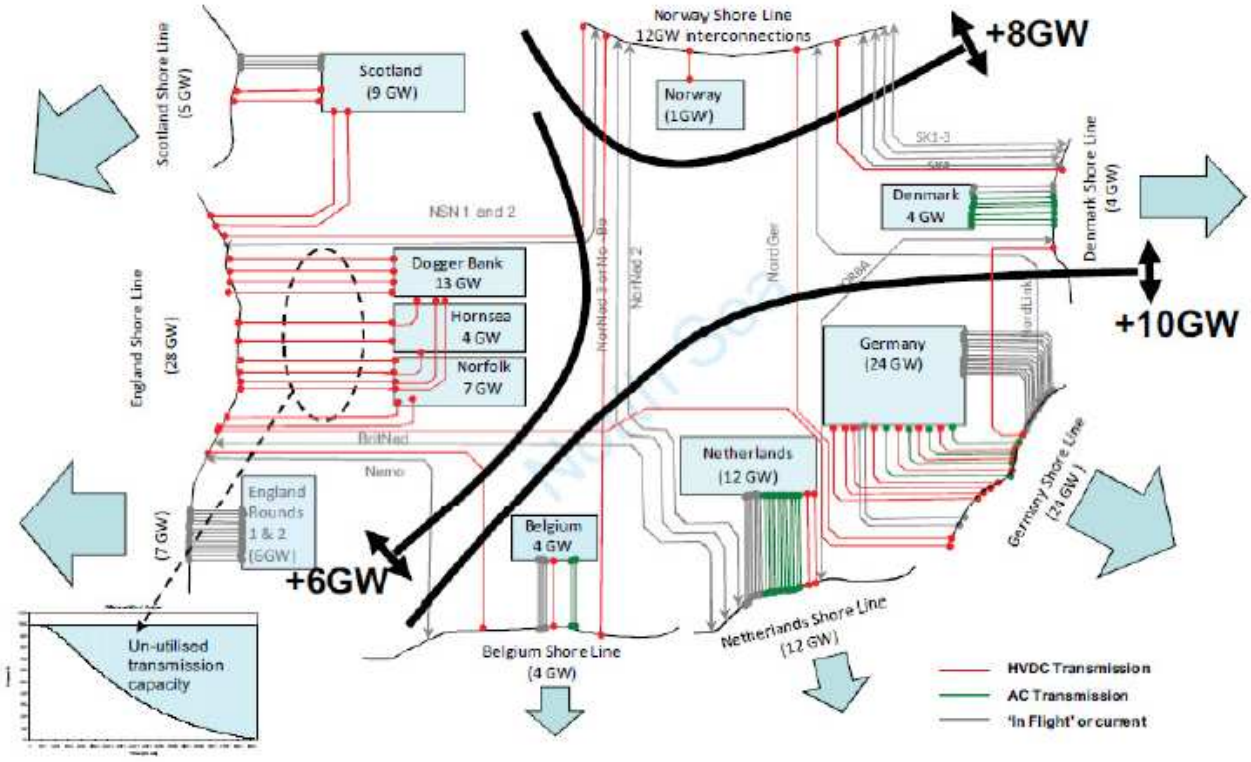


Fig. 5-33 - ENTSO-E vision for 2030 about the North Sea area

The Irish Scottish Links on Energy Study (ISLES) commissioned in 2010 by the governments of Scotland, Northern Ireland and Ireland concluded that:

- *"There are no technological barriers to the development or deployment of an ISLES network. High Voltage Direct Current (HVDC) using Voltage Source Conversion (VSC) technology is a suitable transmission system for the ISLES offshore network …"*
- *"The ISLES concept does not require the development of new equipment, such as HVDC circuit breakers, but rather builds on the capabilities of current devices".*
- *"The ISLES offshore network design allows a phased construction and deployment strategy with potentially wider benefits to the power transfer capacity of onshore grids".*

(Quoted by "Irish Scottish Links on Energy Study (ISLES), Executive Summary" of April 2012)

The importance of DC technology is given by the replacement of old generation with new RES, normally faraway from load centres or offshore (undersea cables are needed for the connection to the onshore grid). Moreover, more transmission and interconnection capacity is needed over long distances to improve the integration of electricity markets. As an example, Fig. 5-34 shows the total NTC required by 2050 according to the Climate Foundation Roadmap for 2050 defined by the Imperial College and Kema.

Interconnection	Capacity additional (existing) [GW]	Annual utilization [%]
UK&Ireland-France	10 (2)	78
UK&Ireland-Nordic	4 (0)	90
UK&Ireland-Benelux&Germany	5 (0)	81
France-Iberia	46 (1)	74
France-Benelux&Germany	14 (6)	77
France-Central-Europe	12 (3)	89
France-Italy&Malta	0 (3)	92
Nordic-Benelux&Germany	0 (3)	85
Nordic-Poland&Baltic	3 (1)	72
Benelux&Germany-Central-EU	7 (4)	68
Benelux&Germany-Poland&Baltic	12 (1)	82
Central-Europe-Poland&Baltic	0 (2)	72
Central-South East EU	7 (2)	76
Central-Europe-Italy&Malta	0 (5)	69
South East EU-Italy&Malta	8 (1)	74
Total	**127 (34)**	

Fig. 5-34 – Climate Foundation Roadmap 2050 for 80% RES with Demand Response

Between the classic technology based on Line Commutated Converters (LCC) using thyristors and the emerging technology based on Voltage Source Converter (VSC) using Insulated Gate Bipolar Transistors (IGBT), the second one seems to be the most adequate. For instance, LCC has the advantage of high power delivery, more than 6,000 MW (at 800 kV) according to the most up-to-date projects. Studies are now in progress to take LCC technology to ±1,100 kV DC voltage and scheme powers of 10,000 MW.

Pros and cons of the two technologies are shown in Tab. 5-2.

Tab. 5-2 – Comparison of LCC and VSC technologies

Item	LCC technology	VSC technology
1	Mature technology with 50 years' experience	Emerging technology, in particular the multi-level converters
2	Good overload capability provided by robust power thyristor devices	Limited overload capability, limited by available IGBT devices
3	Requires strong AC systems at both end of the system (SCR[1]≥2)	Can operate into weak AC systems, SCR is not critical
4	"Black start" capability requires additional equipment to generate voltage source	"Black start" capability is inherent
5	Generates harmonic distortion on the AC and DC systems. Harmonic filters are required	No significant harmonic generation. No AC or DC filters are required in most cases
6	Converters always absorb reactive power, extra shunt reactive power compensation is needed	Converters can control reactive power independently from active power within the station power rating (STATCOM functionality)
7	Large site area required, dominated by AC side harmonic filters	More compact site area, typically 50 - 60% of LCC site area
8	Typically requires converter transformers, built to withstand DC stresses by specialised design and test facilities	Can use conventional grid transformers in some topologies

Item	LCC technology	VSC technology
9	Power reversal is achieved by changing polarity of DC voltage	Power reversal is achieved by changing current direction
10	Polarity reversal requires the use of Mass Impregnated (MI) cable	Lack of polarity reversal means that both XLPE and MI cables can be used
11	Multi-terminal schemes are difficult to engineer due to the polarity reversal issue	Multi-terminal systems are simpler to engineer
12	DC grids are not considered feasible	DC grids become possible
13	Low station losses (typically 0.75%)	Higher station losses (typically 1%)

[1] SCR = Short Circuit ratio = Minimum Short circuit level of the system (MVA)/power transmission (MW)

The major concern related to the technology needed for the SG is the development of:

- optimised, low loss, high power HVDC and hybrid systems,
- extra high voltage undersea and underground cables,
- new concepts in wide area network control and protection for HVAC and HVDC,
- flexible AC Transmission Systems (FACTS),
- high power HVDC switchgear,
- innovative transport and installation methods both on and offshore.

Standardisation is an important aspect to be addressed, since DC technology, with respect to AC, has been always used for point-to-point connections, built by single manufacturers. But standardisation is needed to ensure a competitive and efficient supply chain for network components and provide interoperability of the links. Interoperability of different DC links is a new concept for both the mature LCC and the new VSC technologies.
The foreseen development of the SG is based on building individual HVDC links, interconnected via Supernodes. For this reason interoperability is essential. In a first step, agreement on some fundamental operating principles of HVDC networks is needed, such as:

- Fault behaviour including:
  - short circuit currents of converter stations
  - location of fault clearing devices (at each converter station or at each DC feeder)

- Power System Protection including:
  - separation of normal transients from faults
  - relays and communication to selectively detect faults
  - fault clearing mechanisms including (fault current and overvoltage limitation)
- Converter Control and Protection including:
  - sequences for start-up and shut-down
  - converter station control

- HVDC grid controls

International organisations such as CIGRE and CENELEC are working on these standards. The report summarises the first findings of such activities.

The Report highlights the importance of an open market to speed up the selection/development of the most reliable and cost-effective solution among those available (already and in the future). The

standards shall not define since now the technological solution but shall be focused on functional aspects.

Other important steps toward the development of the SG are highlighted.
The first one is the improvement of cable technologies, for both offshore and onshore links. As a matter of fact, if cables are the only available solution for offshore connections, limited rights of way, preservation of nature, short permitting times and the fact that cable routes virtually do not have any visual impact on the landscape, are important drivers for cable connections also onshore.
Secondly the enhancement of energy storage systems:

- small-scale energy storages to be used for power electronic converters to emulate the inertia of rotating machines;
- middle-scale energy storages to be used as a primary and secondary control reserve to maintain system frequency in case of contingency conditions, like the sudden loss of generation;
- large-scale energy storages can be used to balance renewable energy sources that fluctuate according to the weather conditions or time-of-day.

Besides, also the development of Information and Communication Technology (ICT) is very important for the implementation of the SG.
For instance communication is needed to provide the necessary coordination among the single converter stations of the links constituting the SG. This coordination includes transmitting the necessary signals to run sequences to a converter station, like start-up or shut-down or transmitting the corresponding control characteristics and set-points. On the other side, information on the status of the individual converter station or their associated AC system has to be known. To provide this coordinating function, central controllers, called “HVDC Grid Controllers" are envisaged.
These controllers would provide the control interface to the Transmission System Operators and exchange information with the individual "Converter Station Controllers" allowing to adjust the status of the HVDC Grid System or to optimize its operating point, e.g. to achieve least loss operation as the current regional/country control systems do with the AC transmission network now.
Since there is an interaction between the DC and the AC transmission network, coordination between the control systems of such grids will be needed.

Despite the technological risks related to the envisaged scenario summarised in the report “Offshore Transmission Technology” presented by ENTSO-E in January 2011 (commissioned by NSCOGI):

- there is no VSC Multi-Terminal DC installed onshore yet,
- multi-vendor solutions and work on guidelines and standards is needed,
- at the time of this report, no DC Breaker concepts had been presented,

important technological advances have been achieved in the last years. Fig. 5-35 shows the progresses and the remaining items related to the technological development required to realise the SG.

2012 – 2015
(Supergrid Preparation Phase)

- √ **Increased power ratings for VSC (1,000 MW at 320 kV DC)**
- √ **Demonstrators for DC side fault clearing (e.g. DC Circuit Breakers)**
- √ **MI-PPL 600kV (1.1GW per cable) developed and higher voltages in development**
- √ **Standardization work for HVDC grids in CIGRÈ, CENELEC started**
- √ **AC GIL in operation**
- DC 320 kV cables with extruded insulation in operation at different onshore and offshore projects (500 MW per cable)
- DC cables with extruded insulation >320 kV developed
- MI >500 kV cable developed

2015 – 2020
(Supergrid Phase 1)

- DC cables with extruded insulation >320 kV in operation
- MI-PPL 600kV cable in operation
- MI >500kV in operation
- Development of new extruded insulation compounds for HVDC cables
- System for fast selective fault detection in HVDC networks
- DC side selective fault clearing and system reconfiguration
- Hierarchical control architecture for integrated AC and DC Grid in Europe
- Demonstrators for DC/DC Converter

After 2020
(Supergrid Phase 2)

- Further Development of MI and MI-PPL Cables
- HVDC cables with new extruded insulation compounds in operation
- Superconducting cables
- DC GIL
- DC/DC converter

Fig. 5-35 – Progress towards the future Supergrid done during 2012 (checked and open items)

Finally, the Report includes the roadmap for the development of the SG, specifying the actions needed in each of the three phases.

Tab. 5-3 – Roadmap for the development of Supergrid

Time	Demand	Solutions	New Products and Systems
Today – 2015	• Connecting large scale near shore and far shore offshore wind parks (typical power rating 500 … 1,000 MW) to onshore main grid • Development / strengthening of national and cross country transmission systems • Partial replacement of nuclear power plants in Germany • Replacement of older coal fired power plants • Increase power flow in existing corridors by use of overlay VSC HVDC e.g. German Grid Plan (NEP) • Development of grid code for cross-border HVDC by ENTSOE and approval by ACER	• First HVDC radial (point-to-point) systems connecting offshore wind parks • Increased use of FACTS • Delivery and Construction of embedded point-to-point HVDC transmission e.g. Syd Västlänken (South West Link), Western Link etc. • Planning of Multiterminal Projects, e.g. Kriegers Flak, ISLES, Round Three, Firth of Forth HVDC Hub etc. • Development of demonstrator of Supernode	• Increased power ratings for VSC HB (1,000 MW at 320 kV DC) • Demonstrators for VSC FB applications and HVDC circuit breakers • DC 320 kV cables with extruded insulation in operation[1] at different onshore and offshore projects (500 MW per cable) • DC cables with extruded insulation >320 kV developed[2] • MI-PPL 600kV (1.1GW per cable) developed and higher voltages in development[3] • MI >500 kV cable developed[2] • AC GIL in operation[1] • Standardization work for HVDC grids in CIGRE, CENELEC started
2015 – 2020	• Integration of far offshore bulk power generation (typical 1,000 … 2,000 MW) • European power system integration to balance generation and load in face of increased content of renewable generation • Replacement of nuclear power plants in Germany	• High power long distance multiterminal with few stations (3 to 5) up to 3 GW • Connection of multi-terminal and point-to-point systems by Supernodes • Increased use of FACTS • Small and Middle- scale Energy Storages	• DC cables with extruded insulation >320 kV in operation[1] • MI-PPL 600kV cable in operation[1] • MI >500kV in operation[1] • Development of new extruded insulation compounds for HVDC cables • System for fast selective fault detection in HVDC networks • VSC FB and HVDC circuit breakers (selective fault clearing and system reconfiguration) • Hierarchical control architecture for integrated AC and DC Grid in Europe • Demonstrators for DC/DC Converter
after 2020	• Integration of large scale solar power (e.g. Desertec, Medgrid, etc.)	• European HVDC Grid, no power limit (>> 3 GW) • Interconnecting European Overlay grid	• Further Development of MI and MI-PPL Cables • HVDC cables with new extruded insulation compounds in operation • Superconducting cables • DC GIL • DC/DC converter

[1] in operation=existing project
[2]developed=available to Market
[3] in development=R&D

Recommendations

Apart from the technological aspects, the development of a SG requires the updating of regulatory frameworks in order to overcome the multi-jurisdictional and multi-developer dimensions of the envisaged projects. For instance a Grid Code for the pan European Overlay Grid needs to be defined or at least assess the following items:

- methods to share cross-border renewable subsidiary schemes
- multivendor and multi-stakeholder revenue models

The critical time-line for introduction of new technology lies primarily in solution of non-technical issues that will create a strong market growth and technology push.

5.4 ECF - Roadmap 2050 a practical guide to a prosperous low-carbon Europe

Scope of the study

Roadmap 2050, commissioned by European Climate Foundation, proposes and analyses in detail the power sector in order to achieve, for the target year 2050 a decarbonisation between 90 and 100% with respect to the levels of carbon emissions referred to the year 1990.

An almost complete decarbonisation of the power sector is necessary to reach a much more challenging objective consisting in a reduction of greenhouse gas emissions by at least 80% below 1990 levels by 2050 in Europe.

Target year

The analyses of the study are focused on the long term period, i.e. at the year 2050. However, the same study recognises that the time represents a crucial aspect for reaching the objective of a complete decarbonisation of the power sector: it is for this reason that objectives and considerations are reported also for the intermediate years 2020, 2030 and 2040.

Geographical area covered by the study

The geographical area objective of the analyses of Roadmap 2050 is represented by European countries. In detail, the study groups the different countries in 9 macro-regions, defined as reported below:

- Nordic: Norway, Sweden, Finland and Denmark
- UK & Ireland: UK and Republic of Ireland
- Benelux & Germany: Belgium, Netherlands and Germany
- Iberia: Portugal and Spain
- France: France
- Italy& Malta: Italy and Malta
- Poland and Baltic: Poland, Estonia, Latvia and Lithuania
- Central Europe: Switzerland, Austria, Slovenia, Slovakia and Czech Republic
- South East Europe: Croatia, Hungary, Romania, Bulgaria, Greece and Cyprus

The geographical distribution of the countries is shown in Fig. 5-36.

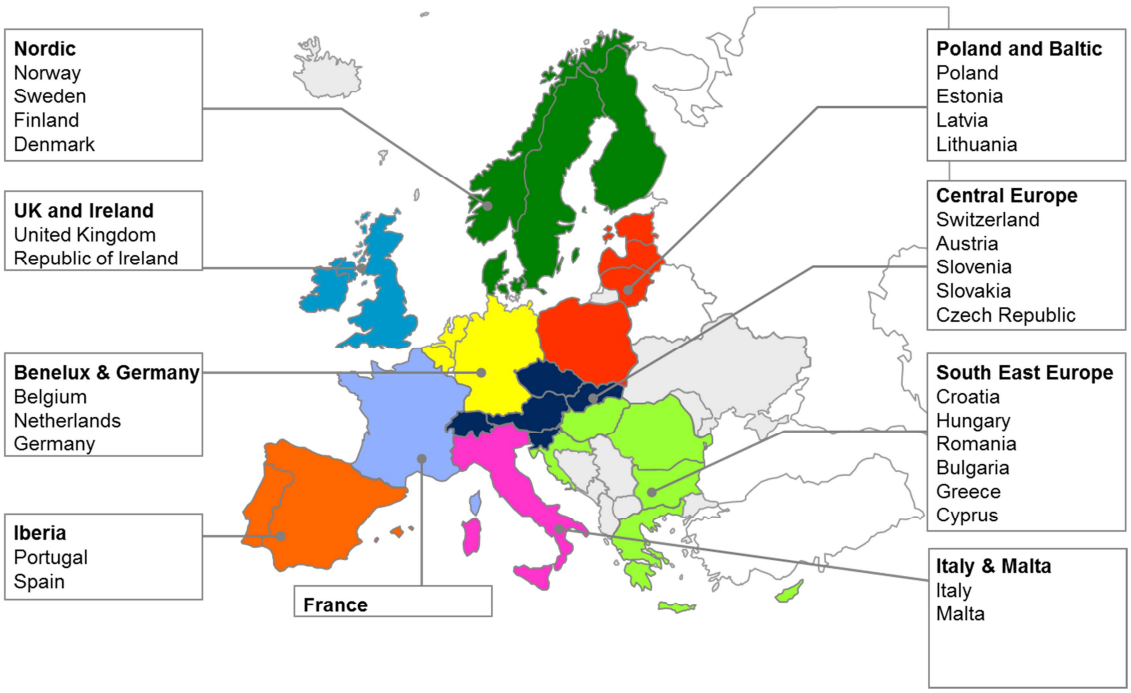


Fig. 5-36 – Geographical area of investigations. Source: Roadmap 2050 and CESI elaboration

Input scenario

As regards the electricity demand in the European countries objective of the analysis at the target year, Roadmap 2050 assumes a value equal to 4,900 TWh; for the intermediate years 2020, 2030 and 2040 instead the demand will respectively be equal to 3,650 TWh, 4,200 TWh and 4,500 TWh.

To reach the objective of a decarbonisation between 90 and 100% in power sector, the study provides the energy mix able to fulfil this requirement.

For this purpose, Roadmap 2050 investigates four different pathways to obtain the above mentioned objective, each of them with a different share of renewable generation:

- 100% pathway, in which the demand is completely satisfied by RES generation
- 80% pathway, in which the 80% of the demand is satisfied by RES, 10% by nuclear and 10% by CCS;
- 60% pathway, in which the 60% of the demand is satisfied by RES, 20% by nuclear and 20% by CCS
- 40% pathway, in which the 40% of the demand is satisfied by RES, 30% by nuclear and 30% by CCS

For each pathway, Roadmap 2050 provides the energy mix in percentage of the total production, as reported in Fig. 5-37.

	Coal	Coal CCS	Coal CCS retrofit	Gas	Gas CCS	Gas CCS retrofit	Nu-clear	Wind On-shore	Wind Off-shore	Solar PV	Solar CSP	Bio-mass	Geo-thermal	Large Hydro
100% RES 0% CCS 0% nuclear	0	0	0	0	0	0	0	15	15	19	20	12	7	12
80% RES 10% CCS 10% nuclear	0	3	2	0	5	0	10	15	15	19	5	12	2	12
60% RES 20% CCS 20% nuclear	0	7	3	0	10	0	20	11	10	12	5	8	2	12
40% RES 30% CCS 30% nuclear	0	7	3	0	10	0	20	11	10	12	5	8	2	12

Fig. 5-37 – Mix of production for all pathways (% of production). Source: Roadmap 2050 and CESI elaboration

Study assumptions: unitary investment costs

The study reports in detail the investment costs adopted for the analyses, with respect to both the renewable and the conventional generating units. The values referred to the year 2050 are reported in Fig. 5-38.

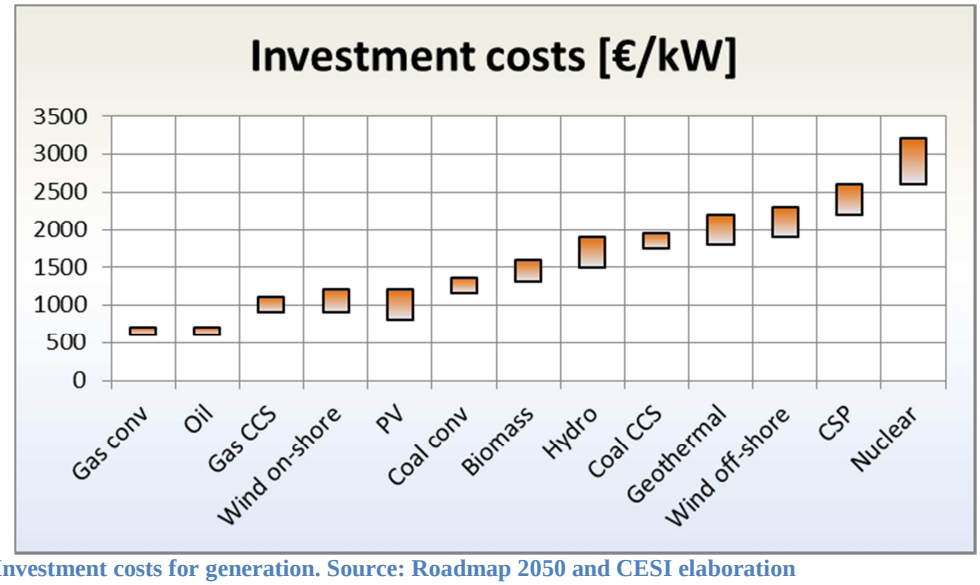


Fig. 5-38 – Investment costs for generation. Source: Roadmap 2050 and CESI elaboration

As far as the transmission lines are concerned, a mix of 73% of AC and 27% of HVDCs has been adopted. A fraction of 67% and 33% of overhead lines and cables has been adopted for each technology. The associated costs for transmission is considered equal to 1,000 €/MW/km. This means considering a cost equal to 1 M€/km for 1 GW of NTC.

Study assumptions: operational costs

The operational costs considered in Roadmap 2050 are mainly related to:

- fuel costs

- cost associated to CO_2 emissions

As regards the fuel costs, Fig. 5-39 reports the values adopted in Roadmap 2050 ranked in a crescent order.

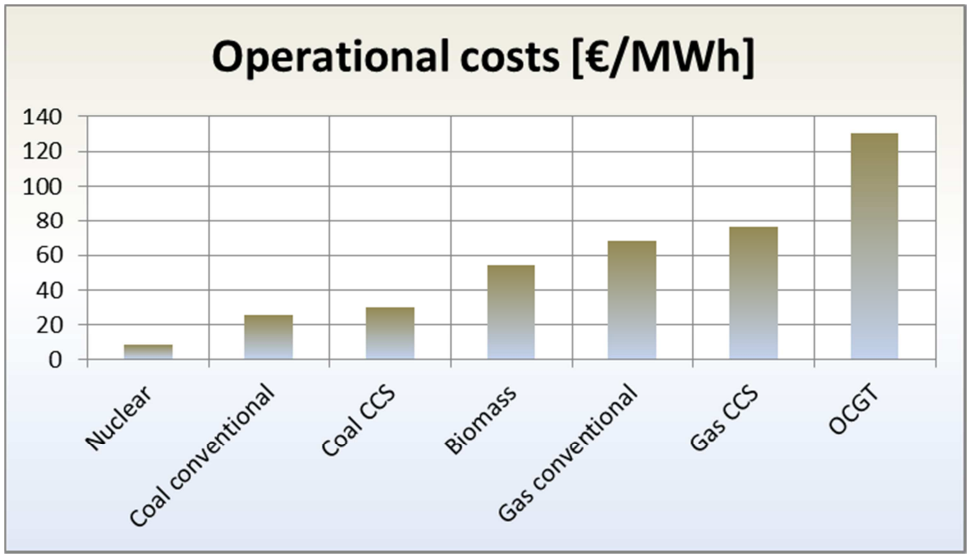


Fig. 5-39 – Operational costs for generation. Source: Roadmap 2050 and CESI elaboration

Instead, as for the cost associated to CO_2 emission, the study reports different considerations regarding the carbon price, nevertheless the main analyses are based on a carbon price in the range of 20-30 €/t. Furthermore, Roadmap 2050 considers also the costs referred to operation and maintenance (as a percentage of the investment costs) and the operation cost related to transport and storage system for CO_2: about 10-15 €/tCO_2.

Study results

For each pathway considered in the analysis, Roadmap 2050 provides detailed results for the generation mix. In this regard, Fig. 5-40 reports the aggregated results for the whole European countries.

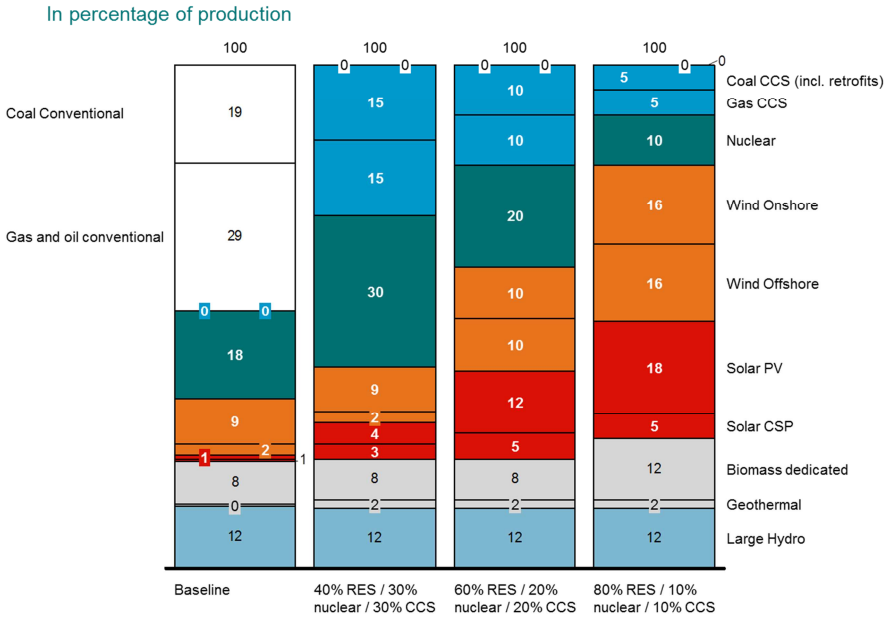


Fig. 5-40 –Generation for the different pathways. Source: Roadmap 2050

The results of necessary NTCs among the macro-regions are very detailed and they are shown in Tab. 5-4. The values are provided for three pathways considering the presence and the absence of the Demand Response (DR). The complete results are reported in Tab. 5-4.

Tab. 5-4 – Net Transfer Capacities between macro-regions. Source: Roadmap 2050 and CESI elaboration

Interconnection	Capacity additional (existing) [GW]					
	80% RES		60% RES		40% RES	
	No DR	DR	No DR	DR	No DR	DR
UK&Ireland - France	19 (2)	10 (2)	12 (2)	8 (2)	12 (2)	12 (2)
UK&Ireland - Nordic	9 (0)	4 (0)	0 (0)	0 (0)	0 (0)	0 (0)
UK&Ireland - Benelux&Germany	5 (0)	5 (0)	4 (0)	3 (0)	0 (0)	0 (0)
France - Iberia	52 (1)	46 (1)	40 (1)	32 (1)	16 (1)	16 (1)
France - Benelux&Germany	23 (6)	14 (6)	15 (6)	14 (6)	11 (6)	10 (6)
France - Central-Europe	11 (3)	12 (3)	7 (3)	7 (3)	2 (3)	2 (3)
France - Italy&Malta	6 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
Nordic - Benelux&Germany	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
Nordic - Poland&Baltic	5 (1)	3 (1)	4 (1)	4 (1)	4 (1)	4 (1)
Benelux&Germany - Central-EU	7 (4)	7 (4)	0 (4)	0 (4)	0 (4)	0 (4)
Benelux&Germany - Poland&Baltic	13 (1)	12 (1)	9 (1)	9 (1)	4 (1)	4 (1)
Central-Europe - Poland&Baltic	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)
Central-Europe - South East EU	5 (2)	7 (2)	2 (2)	1 (2)	0 (2)	0 (2)
Central-Europe - Italy&Malta	0 (5)	0 (5)	0 (5)	0 (5)	0 (5)	0 (5)
South East EU -Italy&Malta	11 (1)	8 (1)	9 (1)	9 (1)	6 (1)	6 (1)
TOTAL	**166 (34)**	**127 (34)**	**103 (34)**	**87 (34)**	**56 (34)**	**55 (34)**

Socio-environmental benefits

Roadmap 2050 study includes a specific session where some socio-economic effects of the implementation of a decarbonised electric system are reported. In particular, in this dedicated session the following items are discussed:

- technology policies
- low carbon power system need of a new market design: discussion on the role of capital intensive generation and infrastructures
- the role of Climate and Resource Directives

For these points, considerations about public welfare, the effects on employment and on the GDP are reported.

Financing schemes and regulatory mechanisms

The financing schemes and investment frameworks are also considered on the second volume of the study. In particular, the document reports several recommendations for financing the transition towards a decarbonised electric sector, assuring adequate funds and regulatory mechanisms. The most important suggestions are the following:

- explore new sources of funding to leverage sufficient private capital investments in energy efficiency, renewables, CCS and network infrastructure, including carbon auction revenues, network system charges and new retail savings products;
- develop incentive measures and a stable and sufficient source of funding to underpin delivery of energy efficiency targets
- ensure mandates to regulators support a business case for private sector financing of the required networks investments
- consider whether new institutions need to be created to focus on financing low carbon investments

5.5 Dii - "Desert Power: Getting Started. The manual for renewable electricity in MENA", 2013

Scope of the study

Dii's mission is to enable the markets for Solar and Wind power in the MENA region for local use and export to Europe. With its 2012 report, Desert Power 2050, Dii showed that all countries in the EUMENA region would benefit from a sustainable and integrated power system.

The assessment of renewables promotion and grid integration in EUMENA builds on a set of quantitative as well as qualitative analyses covering all aspects relevant to a renewables project:

- the regulatory, financing and offtake aspects of the investment framework
- national and international transmission regulation
- wind and solar potentials and the cost of electricity generation from these sources
- system integration of RES generation and its role for demand/supply match
- economic and employment effects

Target year

The analyses of the study are focused on the long term period, i.e. at the year 2050. However, many considerations are reported also for the intermediate years 2020, 2030 and 2040.

Geographical area covered by the study

The geographical area objective of the analyses of "Desert Power: Getting Started" (DP:GS in the following) is represented by European countries (including Turkey), North African countries (from Morocco to Egypt) and Middle East, including Lebanon, Israel and Saudi Arabia.

The geographical area is shown in Fig. 5-41.

Fig. 5-41 – Geographical area of investigations. Source: Dii and CESI elaboration

Input scenario

With respect to the electricity demand in all the objective area of the analysis at the target year, DP:GS assumes a value equal to 5,870 TWh for Europe and 2,180 TWh for the MENA region. At the same time, the study provides also the target for carbon emissions that in the year 2050 shall reach a value equal to 88 Mt and 106 Mt respectively for European and MENA countries.

All values are reported in Fig. 5-42.

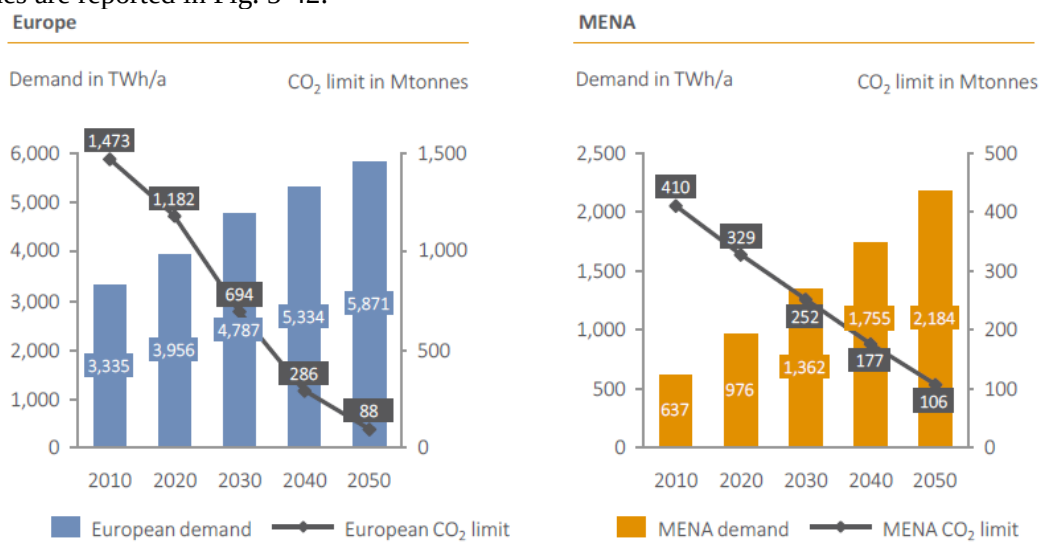


Fig. 5-42 – Target of demand and CO_2 emissions for Europe and MENA region. Source: Dii

As for the energy mix, the study provides the target of renewable and conventional generation for the year 2050 and for all intermediate years distinguishing between Europe and MENA. The objective, for the whole area under investigation, is to reach an amount of RES generation equal to 93% at the year 2050.

Tab. 5-5 – Mix of conventional and renewable generation. Source: Dii and CESI elaboration

Year	Europe		MENA region		EUMENA	
	RES	Conv.	RES	Conv.	RES	Conv.
2020	42	58	18	82	38	62
2030	58	42	44	56	55	45
2040	79	21	81	19	80	20
2050	91	9	98	2	93	7

Study assumptions: unitary investment costs

The study reports in detail the investment costs adopted for the analyses, with reference to both the renewable and the conventional generating units.

The study analyses the possible behaviour of the costs for renewable technologies (focusing mainly on photovoltaic, CSP, wind onshore and offshore) taking into account the development and the diffusion of such technologies. This behaviour is reported in Fig. 5-43.

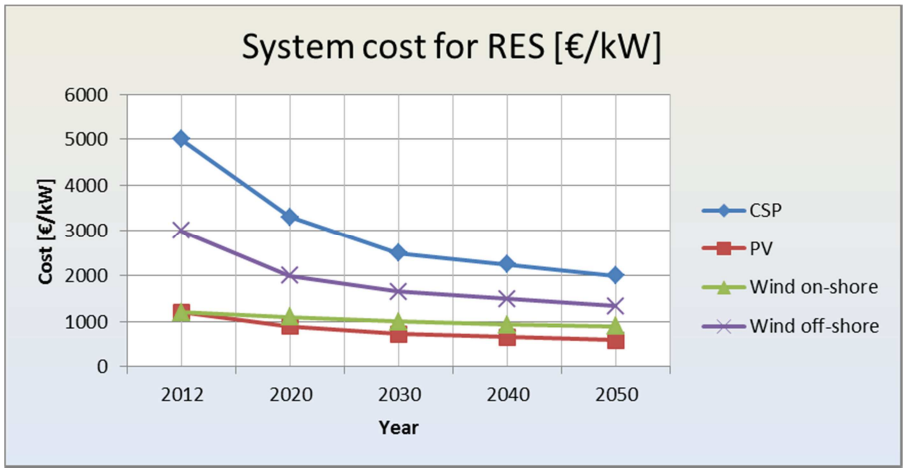


Fig. 5-43 – Costs of RES technologies. Source: Dii and CESI elaboration

Instead, as far as the investment costs of conventional technologies are concerned, the following values are assumed in the study:

- 750 €/kW for the Combined Cycle Gas Turbine
- 380 €/kW for the Open Cycle Gas Turbine
- 1450 €/kW for coal
- 1500 €/kW for Lignite
- 1600 €/kW for Hydro (dam and run of river)

Nuclear technology is not considered at the target year; also CCS technology is not included in the analyses.

As for the technology for the transmission, the study considers an underground cable share of 50% within Europe and 10% within the MENA region.
The associated costs for transmission considering the above mentioned mix and a size of 1 GW are equal to 828 k€/km for Europe, 396 k€/km for the MENA region, 992 k€/km for submarine interconnections and 180 M€ for AC/DC converter stations.

Study assumptions: operational costs
The operational costs considered in "Desert Power: Getting Started" are mainly related to:

- fuel costs
- cost associated to CO_2 emissions

This scenario assumes an approximately flat gas price of 7.1€/mmBTU, corresponding to approximately 24€/$MWh_{thermal}$ and a coal price of 51€/ton, corresponding to approximately 6.3€/$MWh_{thermal}$.
The cost associated to CO_2 emission, are assumed instead in a value approximately equal to 113 €/t.
Furthermore, DP:GS considers also the costs referred to operation and maintenance (as a percentage of the investment costs) and the cost of losses.
Fig. 5-44 reports the cost of energy assumed in the study.

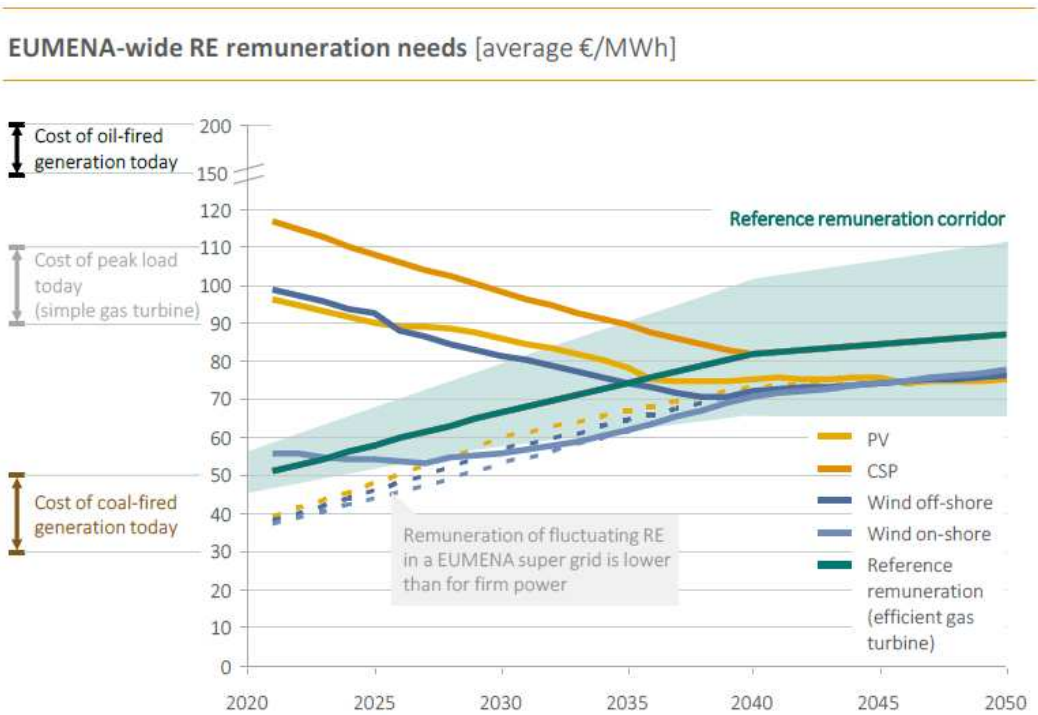


Fig. 5-44 – Costs of energy. Source: Dii

Study results

For the target year and for each intermediate year, Desert Power: Getting Started reports in detail the generation mix distinguishing between Europe and the MENA region.

Furthermore, the energy exchanges between Europe and MENA represent an important result of the study: at the year 2050 it is estimated that about 10% of the European demand will be fulfilled by import from MENA (see Fig. 5-45).

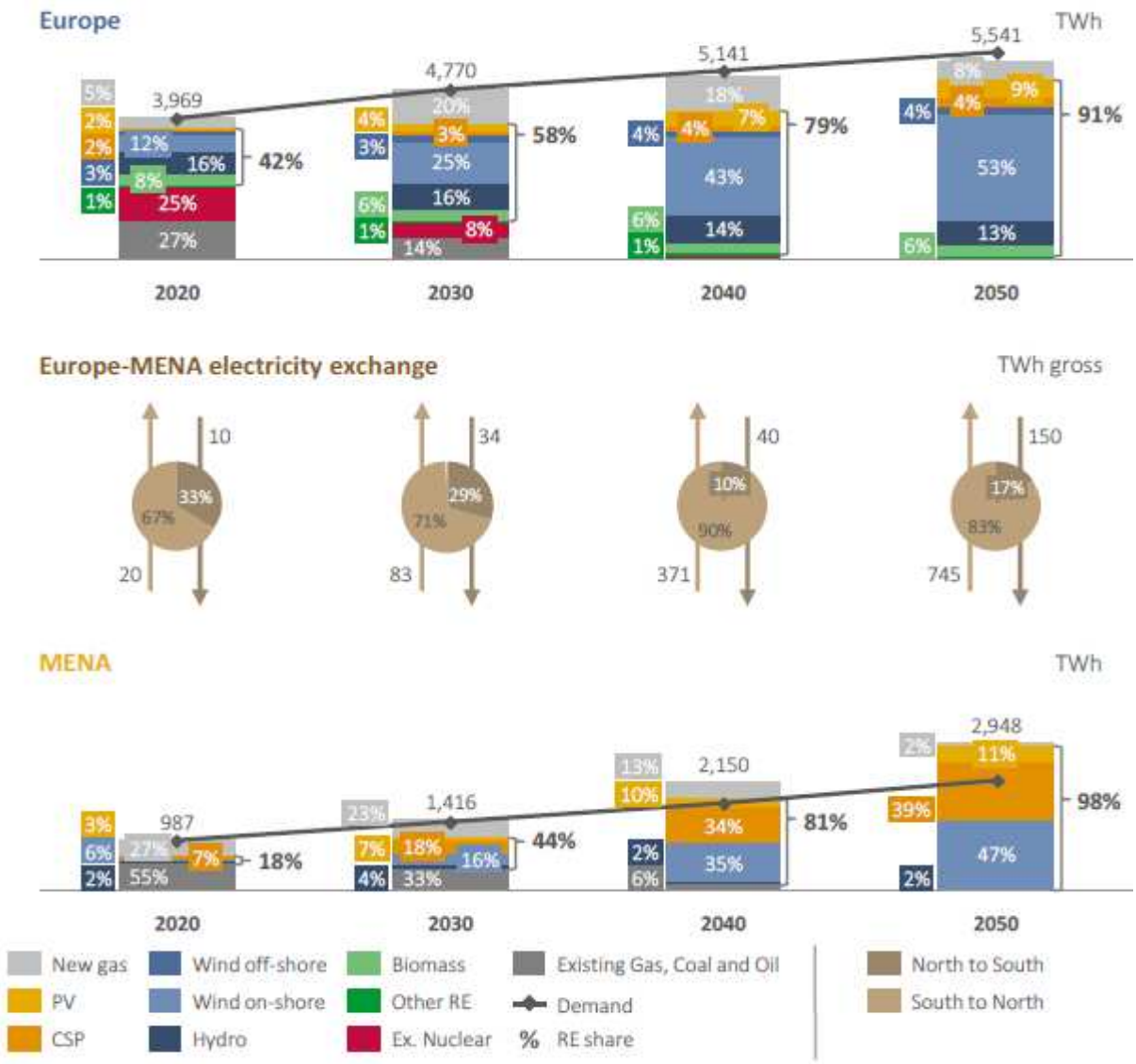


Fig. 5-45 – Generation mix and power exchanges between Europe and MENA. Source: Dii

The results of NTCs in Europe, MENA and in between are very detailed as well. Fig. 5-46 reports the aggregated values of grid development and the associated utilization, while Fig. 5-47 shows in detail the NTCs expected between Europe and MENA.

An important assumption of the study to calculate the capacities is the definition of a limit equal to 20 GW for each corridor, considered in order to reduce the local opposition and increase the public acceptance.

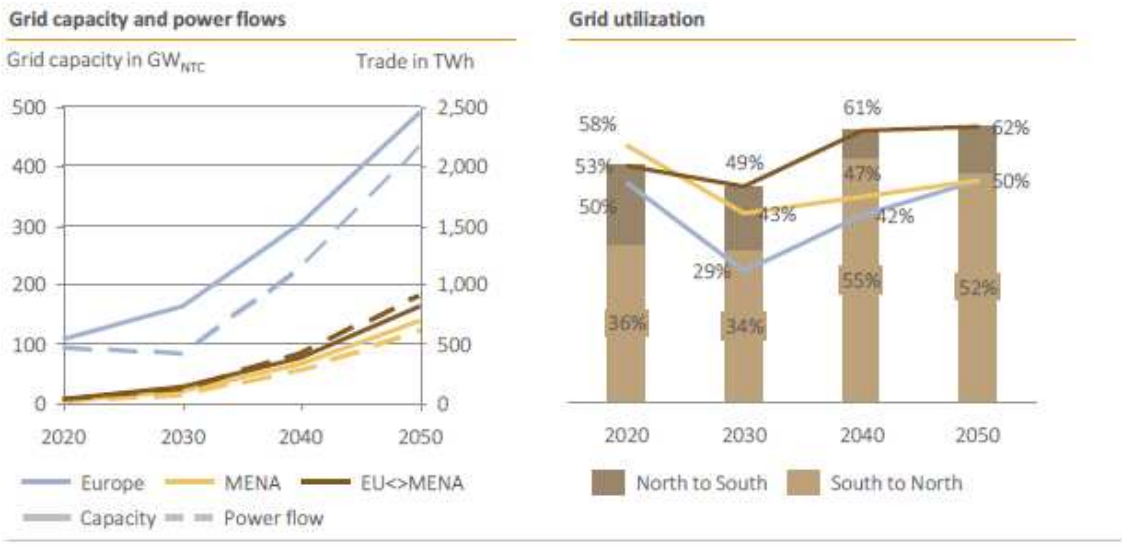


Fig. 5-46 – Grid and electricity exchange development in Europe, MENA and in between. Source: Dii

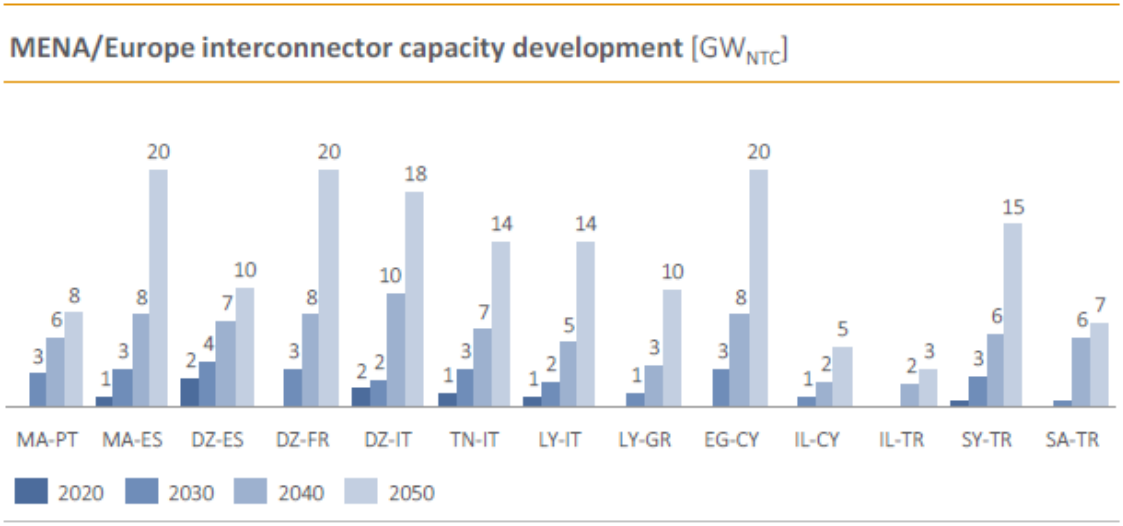


Fig. 5-47 – NTCs between Europe and the MENA region. Source: Dii

Socio-environmental benefits

The study analyses the effect on the economy of the counties involved in the projects assessing different aspects on the welfare of the territory. These aspects mainly include:

- the analysis of the type of industry considered for the realisation of the components and the projects,
- the economic benefits and the GDP developments,
- the employment effects in terms of how many jobs will be created.

At the end of the analyses, policy recommendations are provided in order to coordinate the efforts to reach the objectives.

Financing schemes

The financing schemes and investment frameworks are also widely considered, especially for the MENA region. The analysis carried out in these terms includes the assessment of the country risk, an analysis of the regulation and the structure of the power sector.

Regulatory mechanisms

To this aim, the study defines the points that could be crucial for investors. These include:

- the analysis of the permits necessary to build a power plant,
- how to gain the access to the transmission grid,
- what are the transmission tariffs and the congestion management,
- analysis about the quality of regulation.

For this purpose the study underlines the need to have a stable, reliable and transparent regulation and thus, the attention has been drawn on the importance of national and international regulations.

5.6 Greenpeace - "Battle of the Grids – How Europe can go 100% renewable and phase out dirty energy"

Scope of the study

The scope of this study is to demonstrate the feasibility of a 97% renewable electricity vision.

Target year

The analyses of the study are focused on the long term period, i.e. at the year 2050 and on the mid-term 2030.

Geographical area covered by the study

The geographical area objective of the analyses of Battle of the Grid is Europe, as shown in Fig. 5-48.

Fig. 5-48 – Geographical area of investigations. Source: Battle of the grid and CESI elaboration

Input scenario

As regards the electricity demand in the European countries objective of the analysis, Battle of the grid assumes a value equal to about 4,300 TWh at 2050 and 3,200 TWh at 2030.

Battle of the grids investigates two different scenarios to obtain the above mentioned objective:

- import scenario (in which Europe is connected to North Africa). In this scenario, the maximum demand in Europe is forecasted to be equal to 931 GW at 2050
- regional scenario (in which Europe is considered isolated from North Africa): In this scenario, the maximum demand in Europe is forecasted to be equal to 885 GW at 2050

CO_2 emissions in the electricity sector can fall by 65% in 2030 compared to 2007 levels. Between 2030 and 2050 gas can be phased out and we reach an almost 100 % renewable and CO_2-free electricity supply.

With respect to the energy mix, the study provides the target of renewable and conventional generation for the years 2030 and 2050 and for some intermediate years to show the evolution from now to the long term period. All values, both in tem of power and energy, are reported in Fig. 5-49 and in Fig. 5-50.

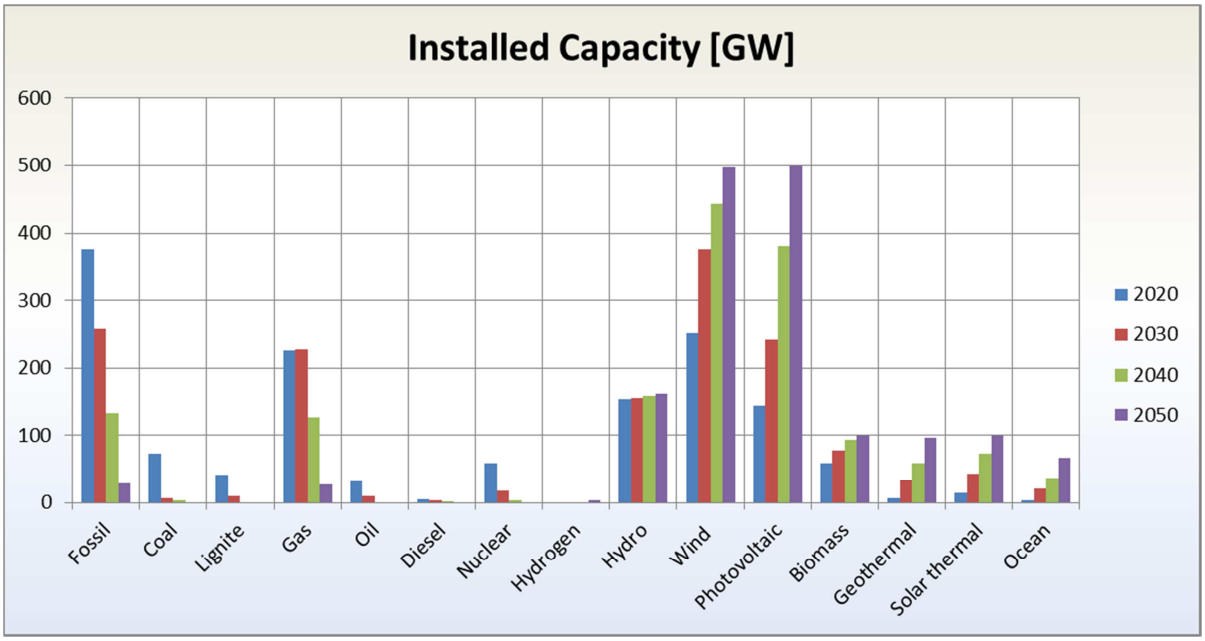


Fig. 5-49 – Installed Capacity in [GW] for EU27. Source: Battle of the grids and CESI elaboration

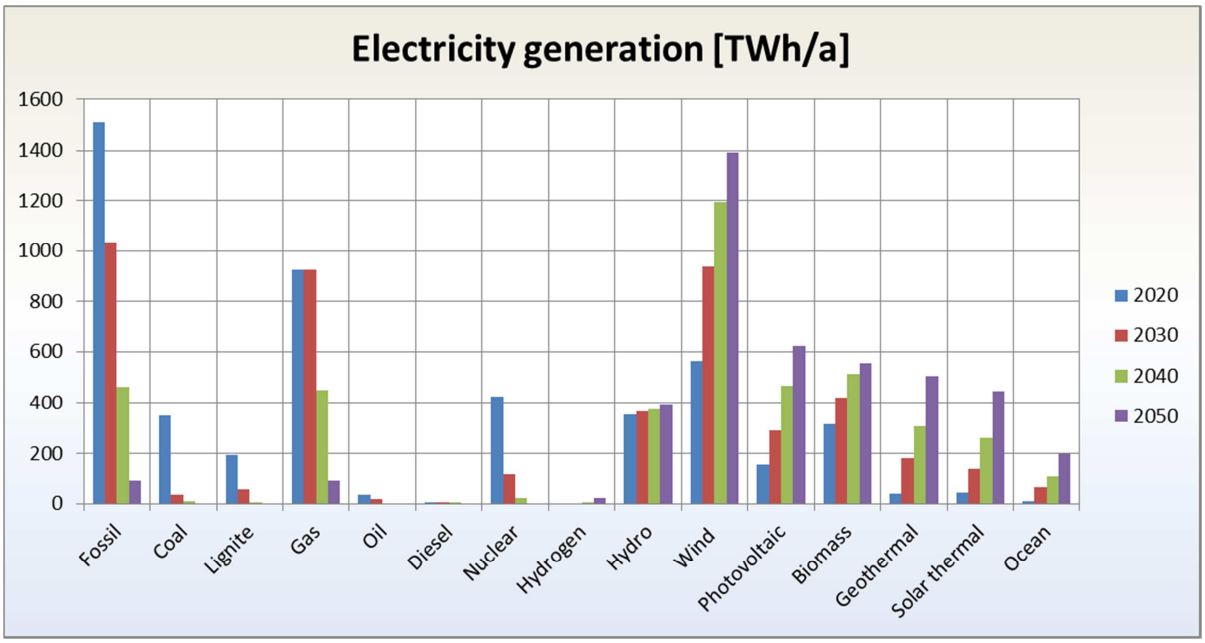


Fig. 5-50 – Electricity generation in [TWh/a] for EU27. Source: Battle of the grids and CESI elaboration

Study assumptions: unitary investment costs

The study reports investment costs in term of Net Present Value of an investment to a new 1,000 MW power plant, based on different technologies, assuming different load factors. The values are reported in Fig. 5-51.

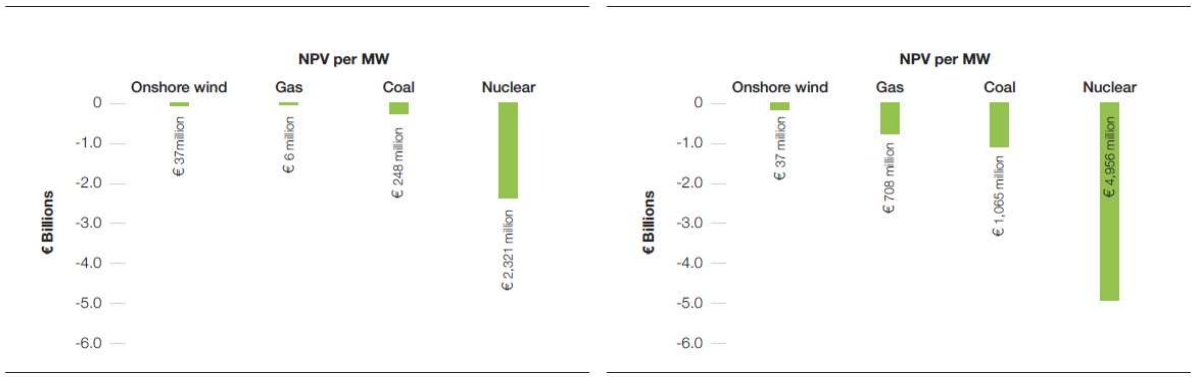


Fig. 5-51 – Net Present Value of an investment to a new 1,000 MW power plant assuming 85 % load factors (on the left) and 33% load factor (on the right). Load factor always equal to 25 % for wind. Source: Battle of the Grids

Regarding the technology for the transmission, priority is given to HVAC system upgrades, making use of existing routes. However, the existing routes will often not be sufficient to take the necessary upgrades. The study limits the upgrade per route to three times today's installed capacity. Any additional power would have to be transported via HVDC connections, provided that it is larger than 1 GW; in this case either overhead lines or cables can be used. Such onshore HVDC connections will most likely form an HVDC SG overlaying the HVAC grid to transport high power over long distances

The associated costs for transmission considered in the analysis are equal to 150 k€/MW for HVDC cables, instead the operational costs are fixed to 400 €/MW/km for HVAC and 1500 €/MW/km for HVDC cables. The costs for cables are, however, almost four times higher than for overhead lines.

Study assumptions: operational costs

The operational costs considered in Battle of the Grids are mainly related to:

- fuel costs
- cost of energy losses

The study assumes the cost of one kWh in 2050 equal to 6.7 €cent in the Advanced scenario, compared to 9.5 €cent in the IEA Reference scenario.

Compared to the IEA Reference scenario, fuel cost savings of average 62bn€/year in the electricity sector make up for the added investment cost of average 43bn€/year (2007-2050).

In addition, Battle of the Grids assumes an operational cost for energy losses equal to 100 €/MWh.

Study results

For the target year 2050 and for the intermediate year 2030, the study reports detailed results for the characteristics of the European grid and the amount of renewable energy curtailed.

Even if priority is given to the dispatching of renewable generation the RES curtailment, due to the unpredictability of the natural resources, reaches the value of 98 TWh/a at the year 2030 (i.e. the 4% of the RES generation) and 219 TWh/a at the year 2050 (i.e. the 5% of the total RES generation).

In detail, the curtailed renewable energy will be divided as follows (the values are expressed in TWh/a):

	Year 2030	Year 2050
Hydro	0	4
Wind	91	62
Photovoltaic	4	131
Biomass	0	0
Geothermal	2	17
Solar thermal	2	0
Ocean	1	5

With respect to the expansion of the grid, the study reports detailed results for the year 2030 and for the year 2050. In particular, at the year 2050 two scenarios are considered:

- the "import scenario", in which Europe is connected with North Africa
- the "regional scenario", in which Europe is isolated from North Africa

Tab. 5-6 reports in detail the grid upgrades forecasted for the years 2030 and 2050.

Tab. 5-6 – Summary of grid upgrades. Source: energynautics and CESI elaboration

		Year 2030	Year 2050	
			Import scenario	Regional scenario
Capacity [GW]	HVAC	879	1311	995
	HVDC Onshore	71	1221	266
	HVDC Offshore	97	419	161
	Total	**1046**	**2951**	**1421**
Length [1000*km]	HVAC	170	242	190
	HVDC Onshore	19	125	26
	HVDC Offshore	43	135	62
	Total	**233**	**501**	**278**
Costs referred to 2010 grid [bn€]	HVAC	20	59	31
	HVDC Onshore	21-49	300-452	65-89
	HVDC Offshore	29	168	53
	Total	**70-98**	**528-679**	**149-173**
Costs referred to 2030 grid [bn€]	HVAC	-	39	10
	HVDC Onshore	-	279-403	40-44
	HVDC Offshore	-	139	24
	Total	**-**	**458-581**	**74-79**

The 2050 grid compared to the current grid in 2010 requires between 1421 and 2951 GW of network upgrades. The costs fall between 149 and 679 billion euros, corresponding to the regional scenario and import. It should be kept in mind that the regional scenario relies on a heavy increase in installed capacity of new generators such as solar PV, wind and biomass within Europe. Of course, the costs of installing extra generation capacity may be far beyond the discrepancy between the two grid costs evaluated here.

For the year 2030 there is an intermediate situation for which 1046 GW of network upgrades are required, with costs falling between 70 and 98 billion euros.

Furthermore, Battle of the Grids reports six steps to be followed to upgrade the grid:

- more lines to deliver renewable electricity where it is needed
- priority for renewable energy on the European grid to reduce losses
- additional lines to allow renewable energy through the bottlenecks
- demand management and smart grids to reduce transmission losses (2030 only)
- adding storage in the system (2030 and 2050)
- security of supply

Socio-environmental benefits

The study analyses that the renewable scenario will create about 1.2 million jobs in the power sector in 2050.

Financing schemes

The financing schemes and investment frameworks are only discussed with some advices. In particular, the study recommends that, to overcome bottlenecks to international transmission, the European Commission should propose financing mechanisms for international transmission projects where the individual business case does not sufficiently reflect the wider economic benefit.

Regulatory mechanisms

As for regulatory mechanisms, Battle of the Grids reports some considerations. In particular, a European-wide legal framework is required to build and operate a cross-border transmission system. It should include a regulatory approach for international transmission and continue to harmonise network codes.

5.7 SINTEF, 3E, Senergy – Offshore grid

Scope of the study

OffshoreGrid is a techno-economic study funded by the EU's Intelligent Energy Europe (IEE) programme. The aim of the study is to provide a view of potential developments of an offshore grid in northern Europe taking into account technical, economic, policy and regulatory aspects.

Due to high connection costs, most of the offshore wind farms are located not further than 100 km from the coasts. But in the North Sea, with a potential of several hundreds of Gigawatt of wind power, an offshore grid could favour at the same time the integration of wind farms and the enhancing of interconnections between different Member States, facilitating competition and electricity trade between countries.

Apart from the evident advantages of wind integration in terms of reduction of dependency from fossil fuels, the offshore grid envisaged in the study can enhance integration between different countries and enable the spatial smoothing effects of wind power, thus reducing the need for flexibility (it is relevant to note that flexibility should be provided by large hydropower capacity in Scandinavia).

Target year

The study is related to the medium term (2020) and long term (2030) development of offshore wind farms in the North Sea. The economic analysis takes into account an operating period of 25 years.

Geographical area covered by the study

The study is focused on the development of offshore wind farms in the North and Baltic Seas, the English Channel and the Irish Sea. Thus, the study covers the whole area between the northern coasts of Continental Europe and Ireland, Great Britain and Scandinavian countries.

Input scenario

The OffshoreGrid scenario is based on national government targets, on the EWEA offshore wind development scenario(EWEA, Pure Power – Wind energy targets for 2020 and 2030, updated in November 2009) and on the onshore wind power scenarios from IEE project TradeWind (Work Package 2: Wind Power Scenarios, WP2.1: Wind Power Capacity Data Collection, 27 April 2007).

According to the foreseen development, 42 GW of offshore wind capacity is expected in Europe by 2020 and 150 GW in 2030, of which about 126 GW will be located in Northern Europe. The expected installed capacity in the area covered by the study is shown in Fig. 5-52 and Fig. 5-53.

The study takes into account also the development of interconnections between northern countries included in the Ten Year Network Development Plan (TYNDP) planned by ENTSO-E.

For generation and demand, the scenarios included in the EU Energy Trends to 2030 study by the European Commission have been considered(Report by E3M-Lab, August 2010 - PRIMES scenarios).

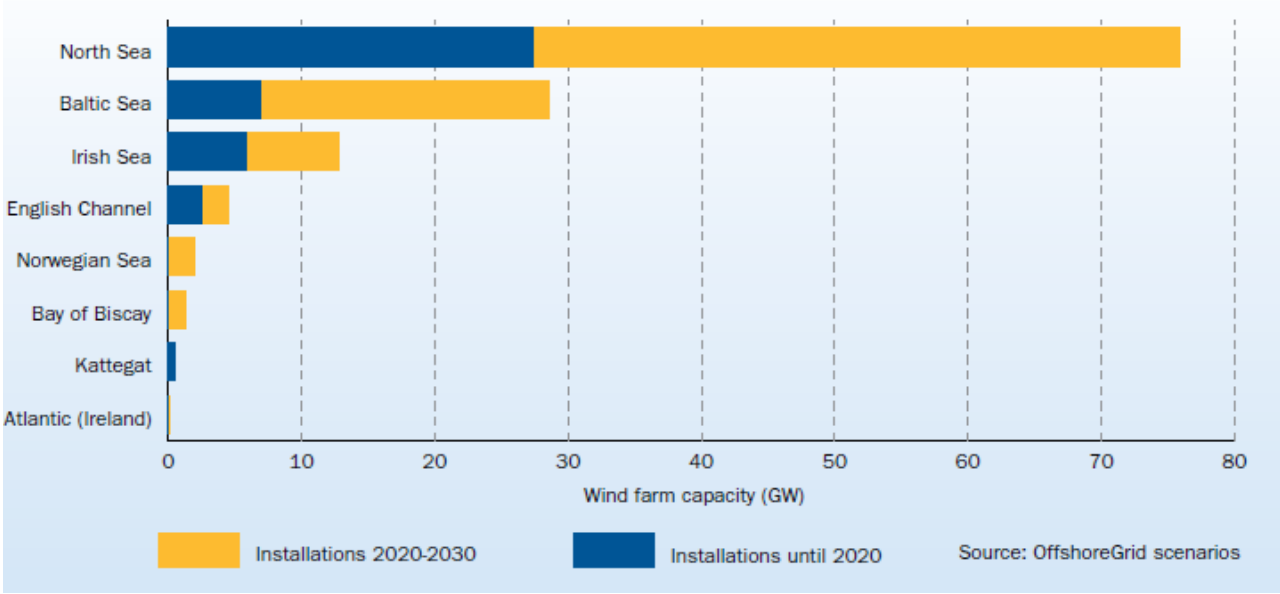


Fig. 5-52 – Expected offshore wind farm capacity installed in 2020 and 2030 in the Northern Europe

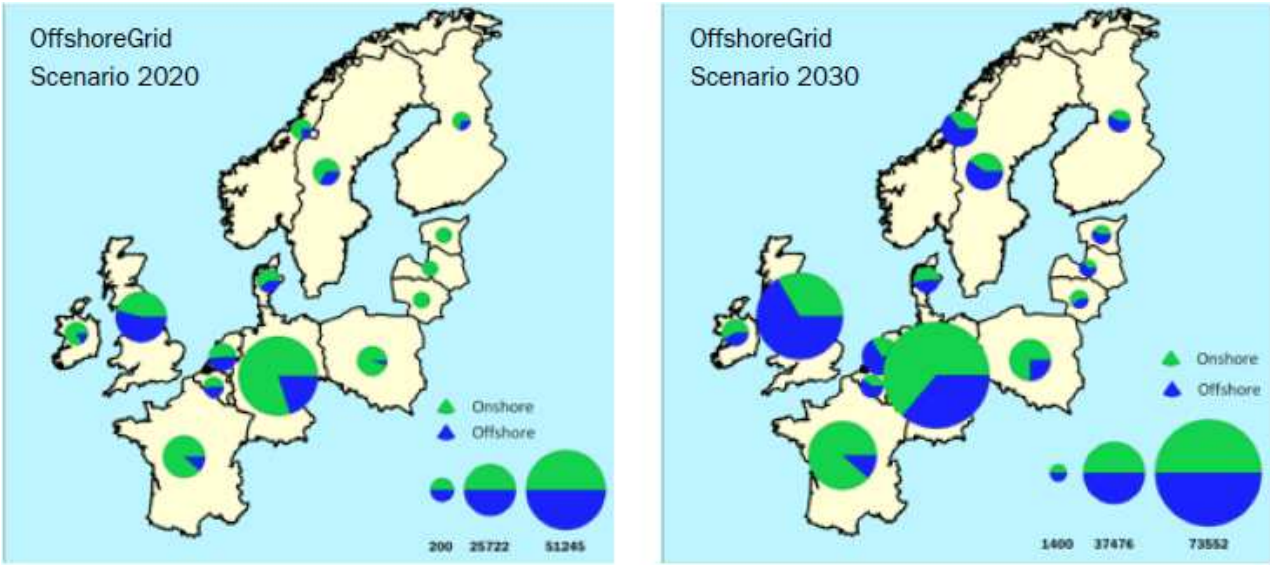


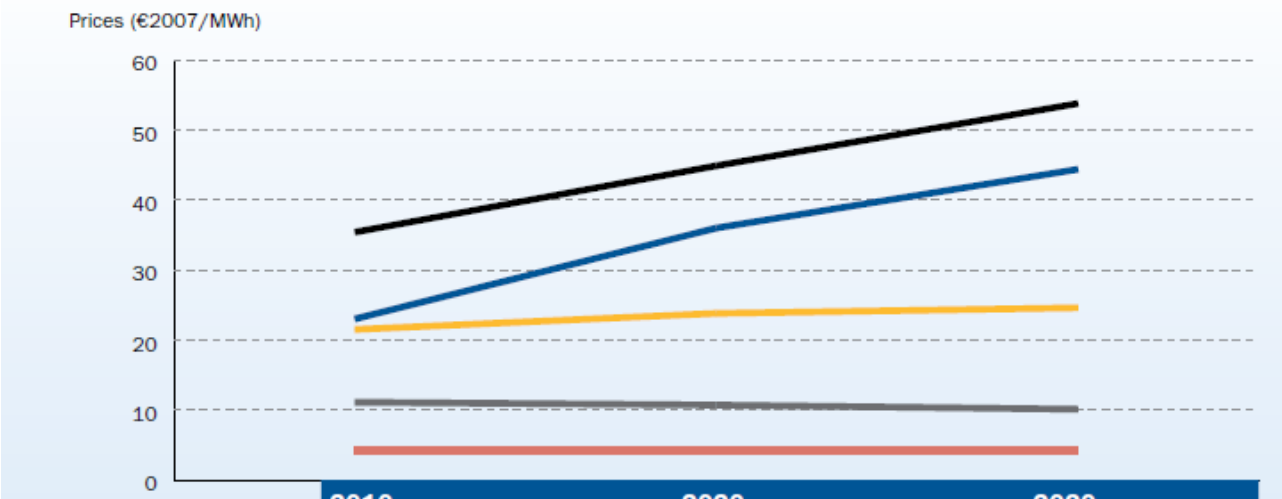
Fig. 5-53 – Offshore and onshore wind farms installations in Northern Europe in 2020 and 2030 (values in MW)

Study assumptions: unitary investment costs

The study doesn't provide specific information regarding the unitary investment costs neither for the generation technologies, nor for transmission technologies.

Study assumptions: operational costs

The costs of primary fuels and CO_2 emission taken into account in the study are shown in Fig. 5-54. The prices are almost constant during the study period with the exception of crude oil and CO_2 emission.



	2010	2020	2030
Crude oil	35,4	44,9	53,8
Hard coal	11,1	10,7	10,1
Lignite EU	4,2	4,2	4,2
Gas EU	21,5	23,8	24,6
CO_2 (€ 2007/t)	23,0	36,0	44,4

Fig. 5-54 – Costs of primary fuels and CO_2 emission in 2010, 2020 and 2030

Study results

The study compares three ways for designing an offshore grid taking into account 321offshore wind farm projects in the Northern Europe. The overall investment to provide individual connection for each of these projects amounts to 83 bn€.

Hub base case scenario

On the basis of the installed capacity and spatial locations of the projects, 114 of the 321 wind farms have been clustered in hubs, with the purpose of reducing the infrastructures needed to connect the wind farms to the onshore grid. This option allows to save 14 bn€ up to 2030 compared to the option of connecting each of the 321 wind farms individually to the shore (total investment would be 69 bn€). The saving is particularly high in Germany (9.4 bn€), the United Kingdom (1.9 bn€) and the Netherlands (1.8 bn€), where wind farms are often far from shore and concentrated in a few specific areas.

With respect to the base case scenario, two highly cost-efficient interconnected grid designs were drawn up.

Direct Design

The main drivers of the offshore grid development are the interconnectors that would be built to promote unconstrained trade between countries and integration of the electricity markets. Tee-in, hub-to-hub and meshed-grid concepts are included to outline an overall grid design.

Split Design

In this case the design of an offshore grid is focused around the planned offshore wind farms. With respect to the *Hub base case scenario*, not only direct interconnectors are investigated but interconnections are also built by splitting the connection of some of the larger offshore wind farms between countries.

These offshore wind farm nodes are then, as in the *Direct Design*, further interconnected to establish an overall meshed grid where beneficial.

Both Direct and Split designs were developed following an iterative approach based on the modelling of infrastructure costs and system benefits.

Fig. 5-55 – Examples of hub connection, tee-in connection and connection between hubs creating an interconnection between countries

The overall investment costs are 86 bn€ for the Direct Design and 84 bn€ for the Split Design. The investments includes 69 bn€ of investment costs for the most efficient connection defined in the *Hub base case scenario* and 9 bn€ for interconnectors planned within the TYNDP of ENTSO-E. The

remaining part is related to the development of the meshed offshore grid foreseen in the Direct Design (8 bn€) and the Split Design (€ 6bn).
These relatively small additional investments generate system benefits of 21 bn€ (Direct Design) and 16 bn€ (Split Design) over a lifetime of 25 years. Thus, the designs are both profitable. They are comparable, however Split Design is slightly more cost-effective in terms of benefit-to-CAPEX ratio.

The investments costs of the designs analysed are shown in Fig. 5-56.

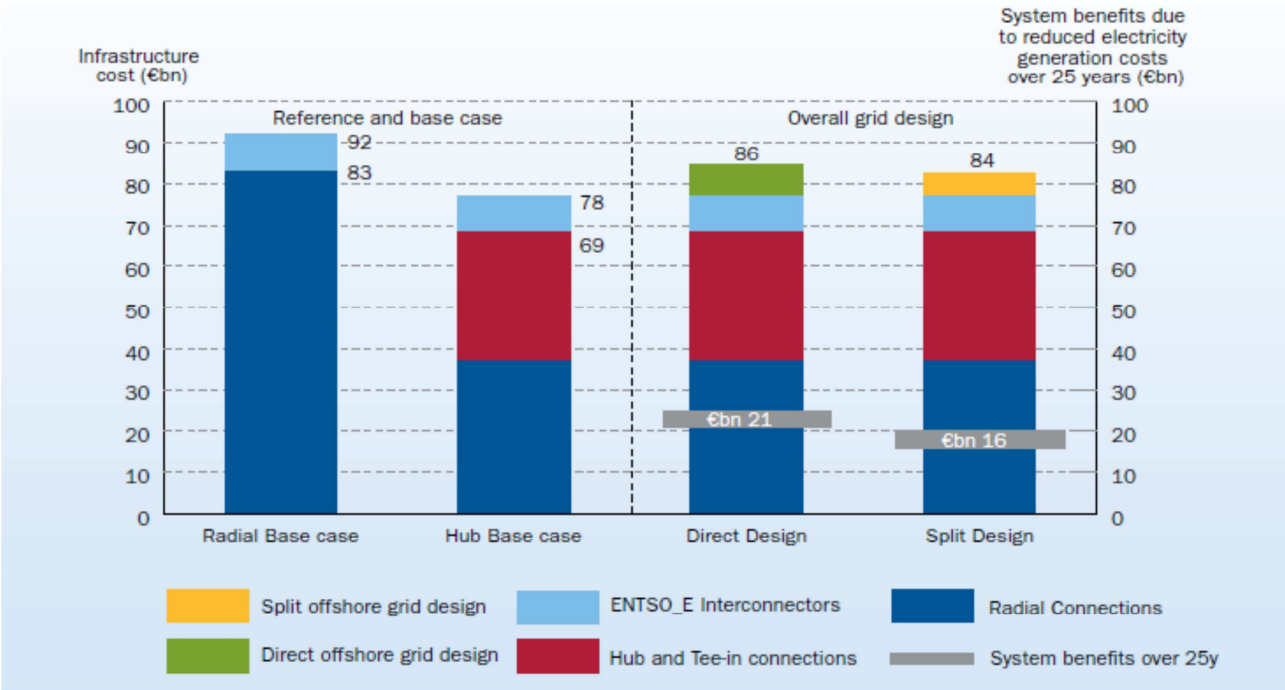


Fig. 5-56 – Comparison of investments for the designs of the offshore grid

The *Hub base case scenario* calculates 27,000 km of cable length, while the additional length needed for both offshore grid designs is about 3,000 km. Thus the overall length of cables is 30,000 km, 10,000 km of AC cables and 20,000 km of DC cables.

The additional investment in offshore grid, allows to:

- enhance the integration between countries and electricity markets, since the interconnection capacity boosted from 8 GW today to more than 30 GW,
- favour the integration of wind farms connecting them to the large hydro power "storage" capacities in northern Europe, which can lower the need for balancing energy within the different European regions,
- reduce the impact of cable laying and favouring security of supply due to meshed offshore grid.

The study provides recommendations and general guidelines regarding the choice of the best connection concept.
Hub connections generally become economically viable for distances above 50 km from shore, when the sum of installed capacity in a small area (~20 km around the hub) is relatively large, and standard available HVDC Voltage Source Converter (VSC) systems can be used. Wind farms located closer than

50 km to an onshore connection point are virtually always connected individually to shore. In countries where hubs can be easily planned, grid connections costs can be reduced of up to 34%.
Offshore farms are not always built at the same time or at the same speed, requiring the hub connection to be sized considering the capacity of all the farms once completed. Therefore it might be necessary to oversize the hub temporarily until all the planned wind farms are built, leading to risk of stranded investments. Anyhow, the study conclusions state that the risks are limited and hubs are beneficial also in case of large delays in the development of some wind farms of even they are not built at all.
Tee-in connections are beneficial when:

- electricity price differences between the connected countries are not too large,
- the wind farm is far from shore and close to the interconnector
- the wind farm capacity is low compared to the interconnector capacity (low constraints),

By connecting the wind farm hub to two countries instead of one, the wind farms are connected to the shore and at the same time an interconnector is created with a modest additional investment (split connection).
Hub-to-hub connections are generally beneficial when the potentially connected countries are relatively far from each other, and the wind farm hubs are far from shore but close to each other. In this way the costs saved thanks to reduced infrastructure generally outweigh the negative impact that can occur due to trade constraints imposed by transmission capacity reduction. One of the keys to the successful implementation of a hub-to-hub connection is long-term planning.

Recommendations
In order to favour such designs, regulatory framework and support scheme incompatibilities between European countries shall be solved at bi-lateral, European and international levels as soon as possible.
Support of decision makers and regulatory frameworks. Incentives should be targeted towards creating favourable conditions for the necessary investments and in a timely manner to avoid stranded investments.
For instance, in countries where there is currently no strategic siting or granting of concessions, policy makers should aim at fewer areas with a larger number of concentrated wind farms, with projects within one area to be developed all at the same time, rather than at more and smaller concession areas. In line with the expected development of technology, the optimal installed capacity in areas where a hub connection is possible should be around 1,000 MW for areas developed in the coming ten years, and 2,000 MW for areas developed after 2020.
The policy for merchant interconnectors which receive exemption from EU regulation should be reviewed in order to avoid risks of conflicts of interest, since the owner of a merchant could have an incentive to obstruct any new interconnector, as this would reduce their return on investment.

Technological risk
Furthermore the safe multi-terminal operation of such an offshore grid based on HVDC VSC technology requires fast DC breakers, which are still in the development phase at the time of writing.

Coordination between interconnectors and wind development (integrated solutions) produces benefits. Offshore grid development should be a joint or, at least, coordinated activity of the developers of the wind farm's hubs connections and the TSOs.

The North Baltic Seas' countries should adapt their regulatory frameworks to foster such a coordinated approach.

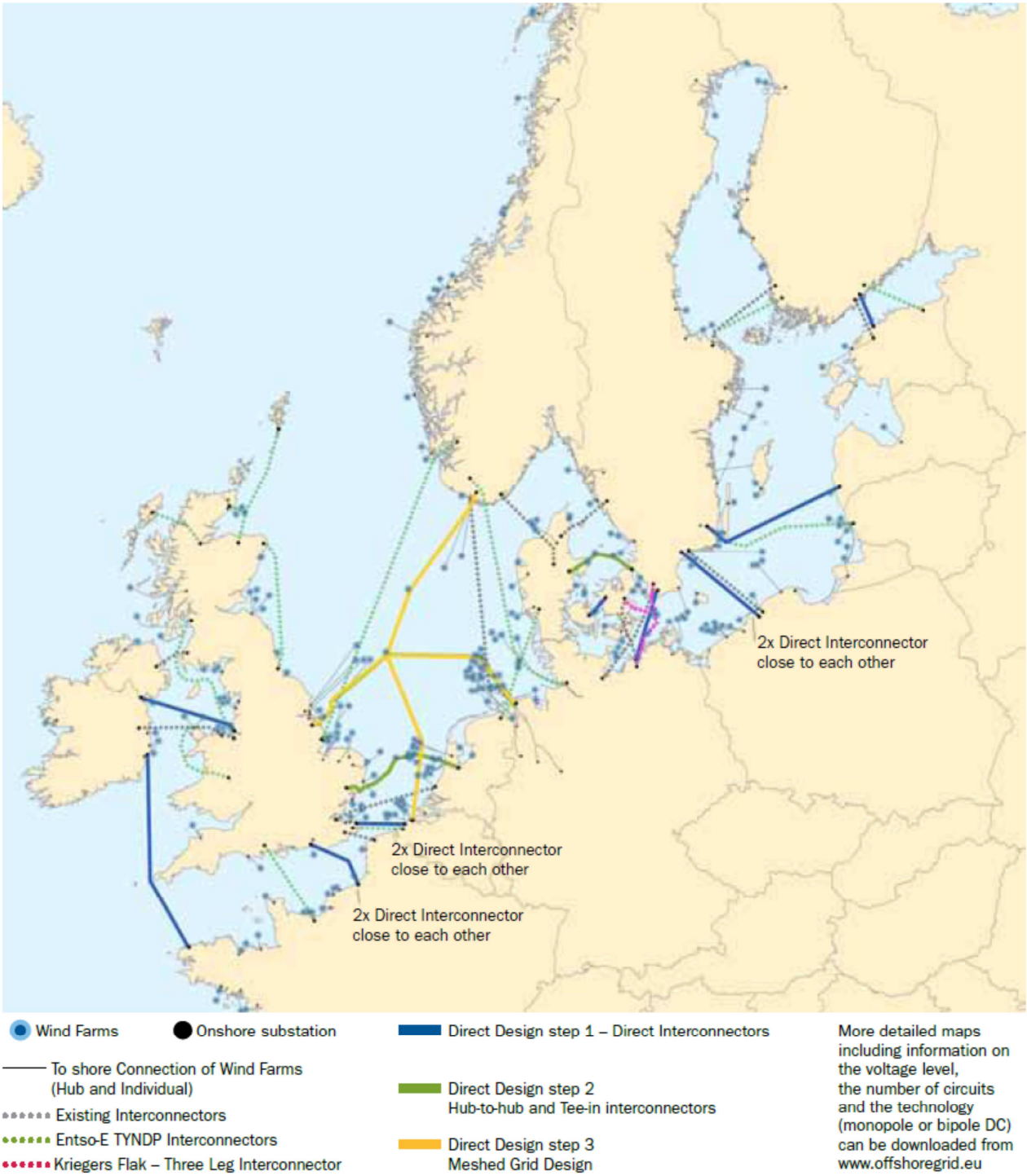


Fig. 5-57 – Direct offshore grid design

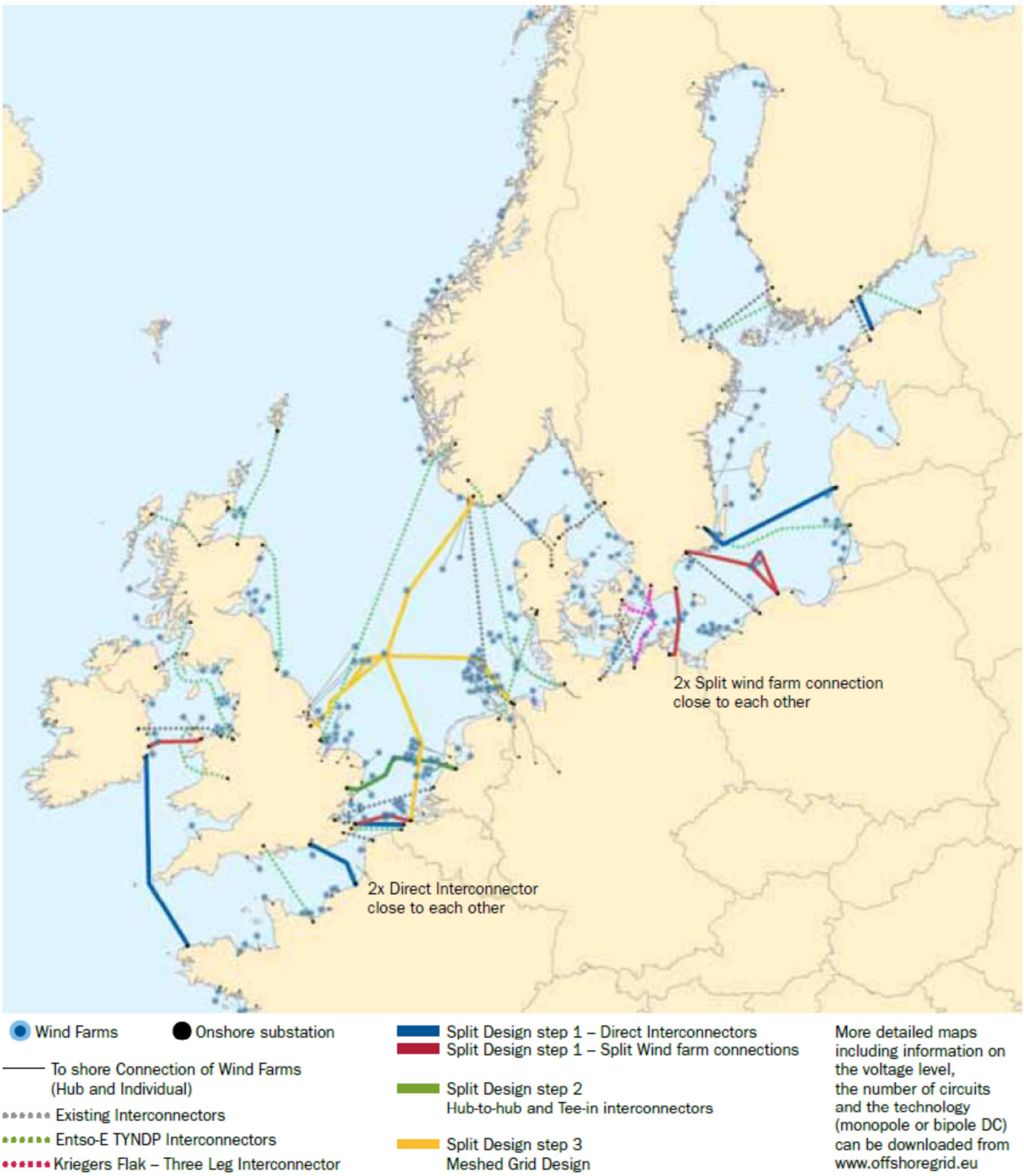


Fig. 5-58 – Split offshore grid design

5.8 World Business Council for sustainable Development - "Vision 2050 - the new agenda for business"

Scope of the study

The Vision 2050 work provides a basis for interaction with other enterprises, civil society and governments about how a sustainable future can be realized. This report does not offer a prescriptive plan or blueprint but provides a platform for dialogue, for asking questions. Its highest value may be in our narrative of the gap between Vision 2050 and a business as- usual world, and the queries and dilemmas it raises.

The study is not focused on the electric sector, but it gives recommendations for all polluting sectors. CO_2 emissions have to be reduced by 50% worldwide respect to 2005 levels.

Target year

The target year is 2050, but intermediate analyses are reported also for 2020, 2030 and 2040.

Geographical area covered by the study

The study considers a global vision.

Input scenario

CO_2 emissions have to be reduced by 50% worldwide respect to 2005 levels.

Global emissions from the energy and power sector have been reduced to 14 Gt of CO_2 per year, roughly an 80% reduction from business-as usual projections (see Fig. 5-59).

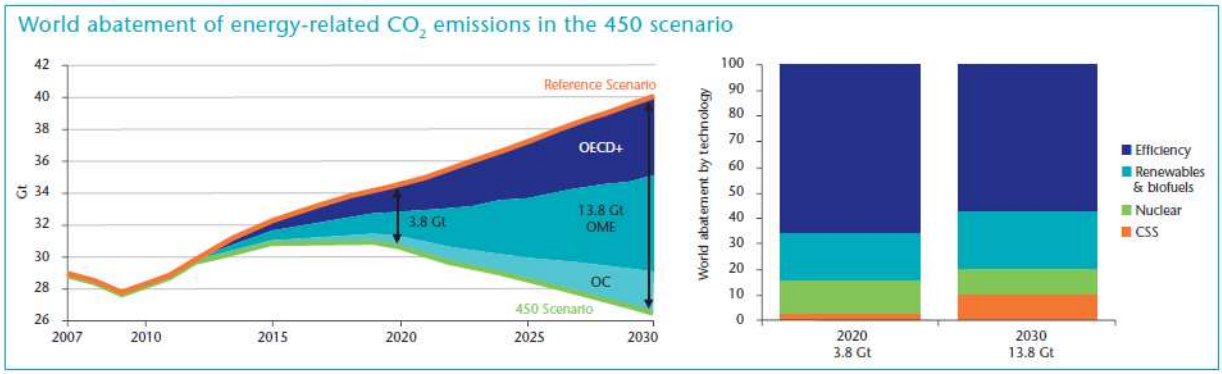


Fig. 5-59 – A new energy mix to reduce CO_2 emissions

As far as the energy mix is concerned, the study reports that it should be comprise around 50% renewables and about 25% each for nuclear and fossil fuels equipped with carbon capture and storage (CCS) from 2030 onwards. Fig. 5-60 reports the additional capacity that shall be added for reaching the energy mix objective of this study.

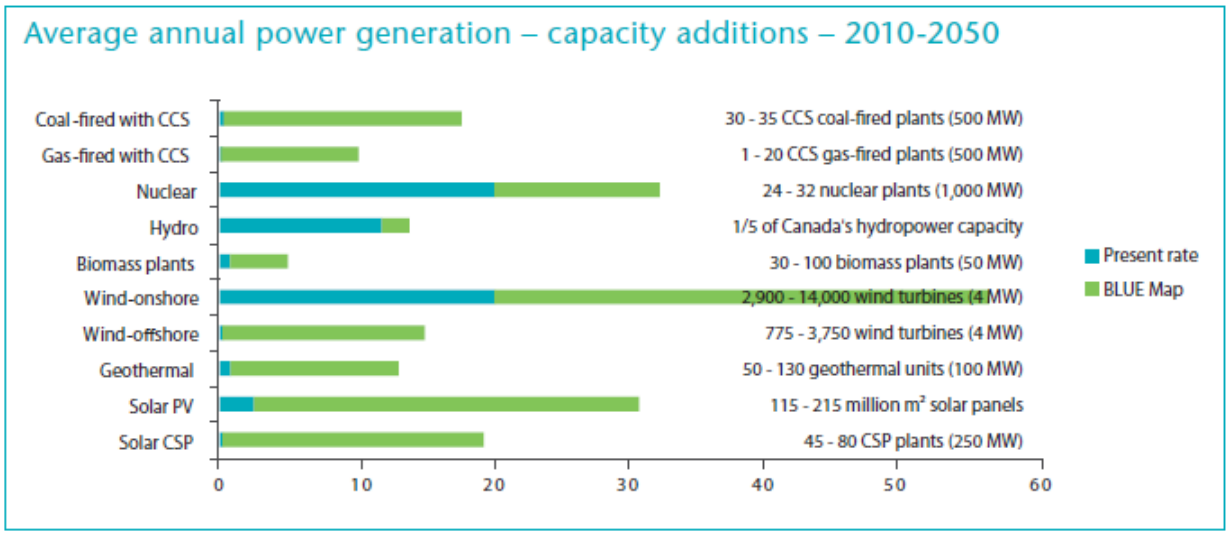


Fig. 5-60 – Capacity additions needed to deliver the new energy mix

For "Vision 2050", nuclear power generation has been a key technology in climate change mitigation efforts. Furthermore, CCS-adapted power stations become commercially viable and grow to account for nearly 12% of power production by the end of the 2030s.

Study assumptions: unitary investment costs

The study reports the costs and the competitiveness of the different technologies in a qualitative way. In detail, "Vision 2050" considers that:

- wind power becomes competitive
- government support ensures that onshore wind electricity becomes cost competitive
- international agreements lead to cross-border grid connections
- carbon offset schemes increase hydroelectricity projects in developing countries.
- solar becomes competitive
- R&D efforts make offshore wind and solar photovoltaic cost-competitive. Investment costs for these two technologies dive below those of coal, oil and gas.

With respect to the transmission grid, "Vision 2050" details that there is a need for an estimated US$ 13 trillion investment in upgrading transmission and distribution networks worldwide by 2030. The use of geographically dispersed sources of electricity generation will require high voltage DC transmission lines and ultra-high voltage AC lines to move energy to centers of end-use.

Substations with energy storage devices will manage the integration of intermittent and base load supplies. When combined, this infrastructure amounts to the essentials of smart grids

Study assumptions: operational costs

As regards the operational costs, "Vision 2050" doesn't provide particular information. A specific data is referred only to the costs of CO_2 emissions, considered equal to 20 €/t.

Study results

As reported in the objective of the study, the Vision 2050 work provides a basis for interaction with other enterprises, civil society and governments about how a sustainable future can be realized. It is for this reason that the study doesn't provide detailed results, but it lists the opportunities that can be obtained in different sectors, such as energy, forestry, agriculture and food, water, metals, health and education.

Socio-environmental benefits

Illustrative estimates (see Tab. 5-7) suggest that the sustainability related global business opportunities in natural resources (including energy, forestry, agriculture and food, water
and metals) and health and education (in terms of social sustainability) could build up steadily to around US$ 3-10 trillion annually in 2050 at constant 2008 prices, or around 1.5-4.5% of world GDP at that time. By 2020 the figure could be around US$ 0.5–1.5 trillion per annum at constant 2008 prices (assuming a broadly linear build-up of these opportunities over time as a share of GDP).

Tab. 5-7 – Illustrative estimates of the global order of magnitude of potential additional sustainability related business opportunities in key sectors in 2050. Source: Vision 2050

Sectors	Annual value in 2050 (US$ trillion at constant 2008 prices: mid-points with ranges shown in brackets)	% of projected world GDP in 2050
Energy	2.0 (1.0-3.0)	1.0 (0.5-1.5)
Forestry	0.2 (0.1-0.3)	0.1 (0.05-0.15)
Agriculture and food	1.2 (0.6-1.8)	0.6 (0.3-0.9)
Water	0.2 (0.1-0.3)	0.1 (0.05-0.15)
Metals	0.5 (0.2-0.7)	0.2 (0.1-0.3)
Total: Natural resources	**4.1 (2.1-6.3)**	**2.0 (1.0-3.0)**
Health and education	2.1 (0.8-3.5)	1.0 (0.5-1.5)
Total	**6.2 (2.9-9.8)**	**3.0 (1.5-4.5)**

Financing schemes

Vision 2050 reports some recommendations regarding the financing schemes. In general, the urgent and radical transformations need substantial financing. However, traditional financing models will not suffice and more innovation is needed to create instruments that are robust enough to quickly adapt to the conditions of need, i.e., scalable, practical, affordable, easy to implement and suitable for mass replication.

5.9 EURELECTRIC, "Power choices - Pathways to carbon-neutral electricity in Europe by 2050"

Scope of the study

The Power Choices scenario aims at an optimal portfolio of power generation based on an integrated energy market. This optimal portfolio has to be obtained by defining an emission reduction target for the EU which is consistent with global action aiming at stabilising the concentration at 450ppm.

Target year

The target year is 2050, but intermediate analyses are reported also for 2020, 2030 and 2040.

Geographical area covered by the study

The geographical area objective of the analyses of "Power choices" is Europe (EU27), as shown in Fig. 5-61.

Fig. 5-61 – Geographical area of investigations. Source: Power choices and CESI elaboration

Non-EU countries (Switzerland and Norway, as well as all Balkan countries and Turkey) are considered regarding exchanges of electricity and the operation of the interconnected system. However, for the purpose of this study, those countries are only assessed in terms of EU import-export projection.

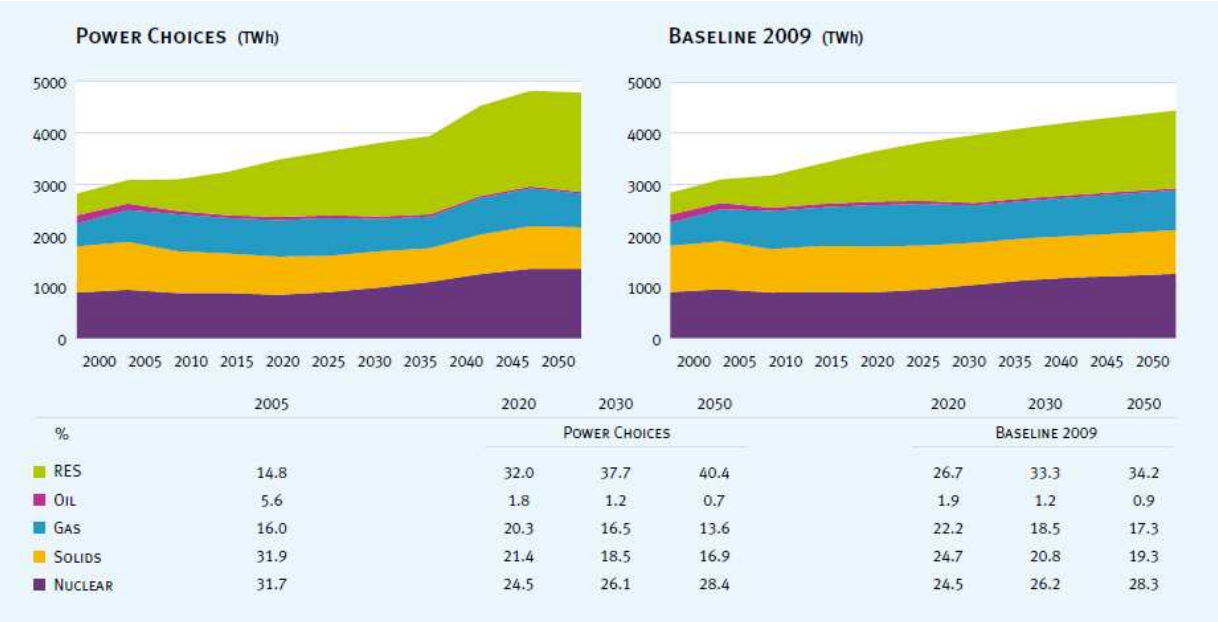
Input scenario

As regards the electricity demand, Europe estimates are equal to about 4,800 TWh at the year 2050.

Power choices investigate two alternative scenarios to obtain the above mentioned objective for EU-27 countries:

- baseline scenario assuming all existing policies are pursued
- Power choices scenario which sets a 75% reduction target for greenhouse gases across the entire EU economy

As far as the energy mix is concerned, in the Power Choices scenario, power generation (see Fig. 5-62) from solid fuels declines by 1.2% per year in the period 2005-2035; it increases after 2035 driven by the application of CCS technology but despite this re-emergence, the projection shows that solid-fuel based generation is likely to be 12% lower in 2050 than its level in 2005.



%	2005	2020	2030	2050	2020	2030	2050
		Power Choices			Baseline 2009		
RES	14.8	32.0	37.7	40.4	26.7	33.3	34.2
Oil	5.6	1.8	1.2	0.7	1.9	1.2	0.9
Gas	16.0	20.3	16.5	13.6	22.2	18.5	17.3
Solids	31.9	21.4	18.5	16.9	24.7	20.8	19.3
Nuclear	31.7	24.5	26.1	28.4	24.5	26.2	28.3

Fig. 5-62 – Summary of Power Generation Structure. Source: Power choices

Such a massive development of RES generation aims at putting climate action as a priority and allows EU to set and reach the target of cutting via domestic action 75% of its CO_2 emissions from the whole economy versus 1990 levels.

The 75% reduction objective refers only to the EU; additional emissions reductions could be achieved through international carbon offsets.

In this respect, this objective is in line with the more recent EU objective of reaching 80 to 95% emission reductions by 2050.

The energy mix above reported will be generated by the capacity reported in Fig. 5-63.

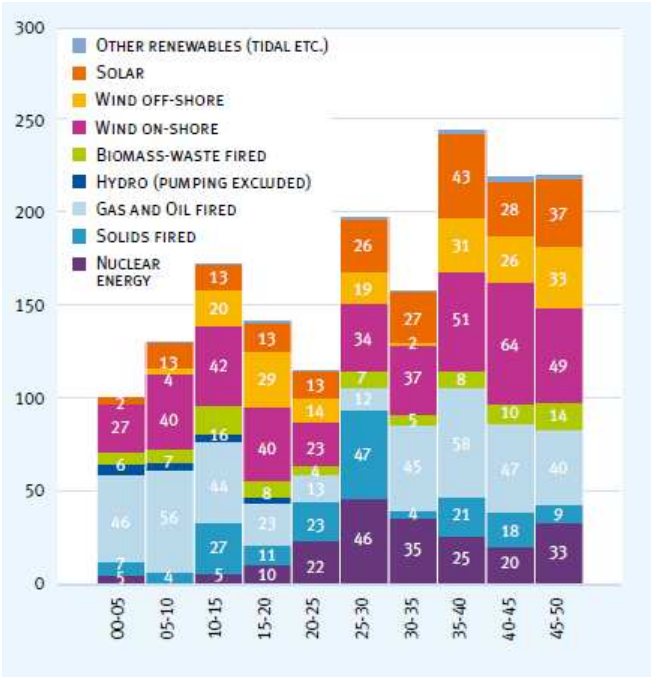


Fig. 5-63 – Power Generation Investment in Power Choices [GW]. Source: Power choices

Detailed values of the new installed capacity in the two scenarios considered in the study are reported in Tab. 5-8.

Tab. 5-8 – Power generation expansion [GW]. Source: Power choices

GW net	2011-2030	2030-2050	Total	2011-2030	2030-2050	Total
	Power Choices : Capacity Expansion			Baseline 2009 : Capacity Expansion		
Nuclear	83.3	113.6	196.9	85.7	98.4	184.1
Solids w/o CCS	46.0	4.0	50.0	64.4	37.7	102.1
Solids with CCS	61.9	48.4	110.3	35.0	23.6	58.6
Gas/Oil w/o CCS	90.1	110.4	200.4	136.0	270.9	406.9
Gas/Oil with CCS	1.0	79.6	80.6	0.1	2.3	2.4
Hydro	12.2	5.1	17.3	12.0	5.3	17.4
Wind onshore	139.8	200.2	340.0	108.6	129.8	238.3
Wind offshore	82.0	91.8	173.8	79.0	60.4	139.5
Solar	65.0	134.3	199.3	61.1	90.7	151.7
Biomass	35.3	37.2	72.5	30.0	39.1	69.1
Tidal. Geothermal	6.6	10.9	17.6	6.0	6.0	12.0

Study assumptions: unitary investment costs

The study doesn't provide specific information regarding the unitary investment costs neither for the generation technologies, nor for transmission technologies.

Study assumptions: operational costs

As for the operational costs, "Power choices" provides several information on different aspects of economic evaluations:

- cost of energy produced by RES technologies

- cost of conventional fuels
- cost of CO_2 emission and the cost associated to its transportation

Fig. 5-64 shows the levelled unit costs of RES technologies assuming a discount rate of 9% in real terms.

Fig. 5-64 – Key Assumptions about Costs of RES Technologies. Source: Power choices

Fig. 5-65 compares the unit costs of power generation from fossil fuels and nuclear with varying carbon prices. The technical and economic data assumed show that at a carbon price above 30 $€_{(2008)}/tCO_2$ CCS is competitive vis-à-vis non-CCS fossil fuel plants in the period beyond 2030.

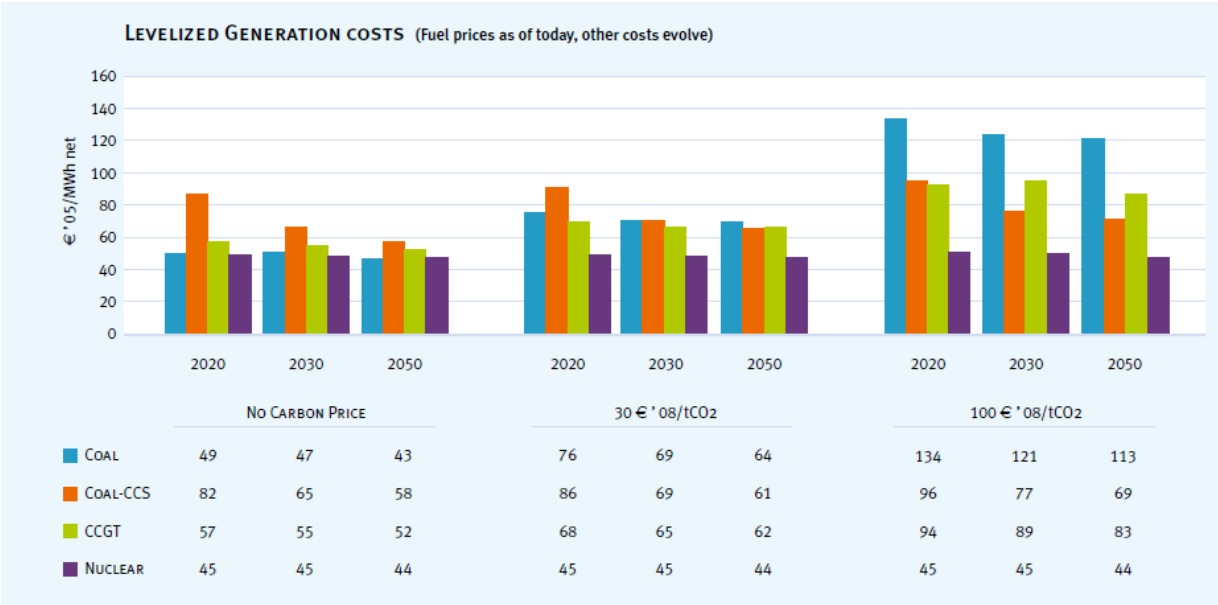


Fig. 5-65 – Comparison of Fossil Fuel Technologies in Terms of Unit Costs of Generation. Source: Power choices

With respect to the costs of CO_2, carbon prices alone drive changes in the power sector after 2020, as no binding RES targets are considered beyond 2020. The carbon prices are determined at the energy system level in order to deliver emission reductions of 40% in 2030 and 75% in 2050 in the EU relative to 1990 levels. The model-based estimations suggest that carbon prices should rise to 52.1 €/tCO_2 (in 2008 money terms) in 2030 and 103.2 €/tCO_2 in 2050, significantly increased from 25 €/tCO_2 in 2020.

Furthermore, the cost of CO_2 transportation and storage ranges from 6 €/tCO_2 to in excess of 25 €/tCO_2 depending on the storage potential and its rate of utilisation.
Average storage and transportation cost start from 10 €/tCO_2 in 2030 and rise to 20 €/tCO_2 on average between 2030 and 2050.

Study results
The results of Power choices range in the mix of generation up to the estimation of GHGs abatement.
Fig. 5-66 shows the evolution of total installed capacity in the Power Choices scenario divided by energy type. It shows also a decomposition of total installed capacity into dispatchable and intermittent generation and compares this evolution with total peak demand for power.
Throughout the projection period, all scenarios ensure that the dispatchable part of total installed power capacity (thermal plants, nuclear, lakes and pumped storage) exceeds significantly the level of total peak load in each country as well as at the level of the EU regional electricity markets. Wind and solar share in total power generation attains a level of 25% in 2050.
In the extreme case of assuming zero capacity credit for intermittent resources, the nominal reserve margin decreases over time and reaches a level of 10% in 2050, which is below the 30% level observed at present. If, on the other hand, capacity credit for the intermittent resources is considered to be greater than zero, then the nominal reserve margin comes close to 20% by 2050.
The simulation of power dispatch shows that nuclear and CCS operate in base load and thus achieve high utilization rates, compared to gas plants and non-CCS equipped thermal plants. These achieve low utilisation rates (close to 40%) and are used for load following. Pumped storage facilities and hydropower lakes serve peak loads.

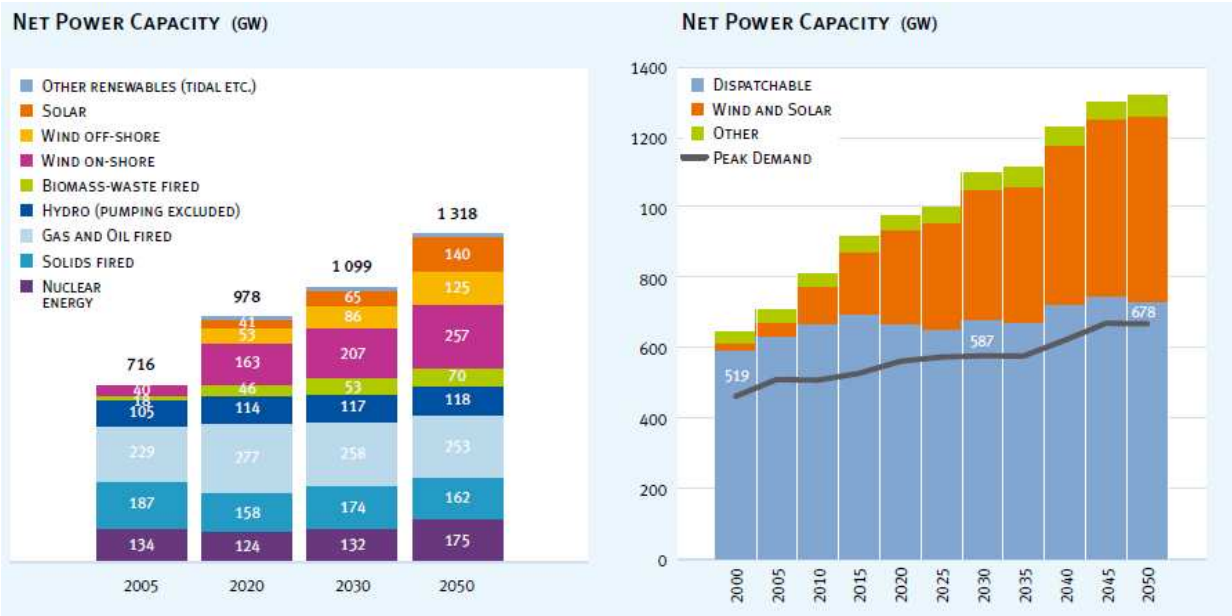


Fig. 5-66 – Operating Power Capacity. Source: Power choices

Fig. 5-67 reports the decomposition of emission reductions divided by each technology adopted in the power sector. The figure shows how important is the role of the energy efficiency and the CCS technology that become very important in the long-term period.

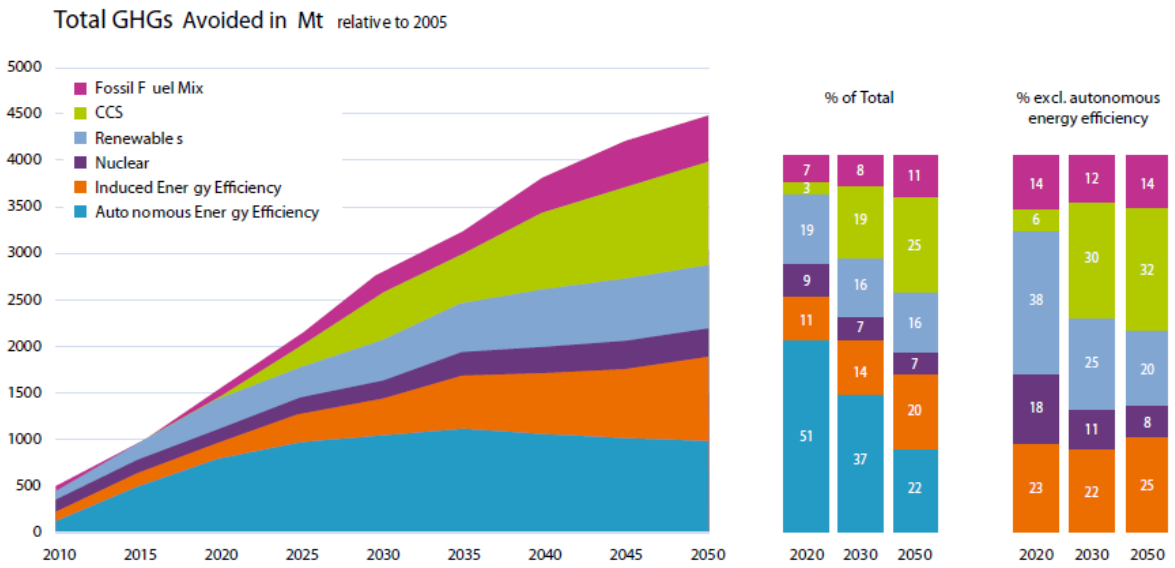


Fig. 5-67 – Decomposition of Emission Avoidance. Source: Power choices

As far as the transmission grid is concerned, "Power choices" reports some general considerations here summed up.

The total capacity of the transmission lines between countries was 179 GW in 2005; this is projected to increase to 245 GW by 2020 and to 253 GW by 2030; after 2030 the transmission capacity remains stable.

The model simulations show no major congestion problems in the projected transmission network within the broader European grid.

Socio-environmental benefits

From the environmental point of view, the objective of Power choice is to limit the carbon concentration to 450 ppm, thus holding the risk of global temperature rise to an average of 2°C over the pre-industrial level.

Another social benefit, as shown in Fig. 5-68, is represented by the cost of energy as a percentage of the GDP. After an increase in the mid-tern, this percentage is forecasted to decrease in the long-term at levels lower than the current ones. The same figure shows that in the Power choices scenario the cost of energy is only slightly higher that the value obtained in baseline scenario.

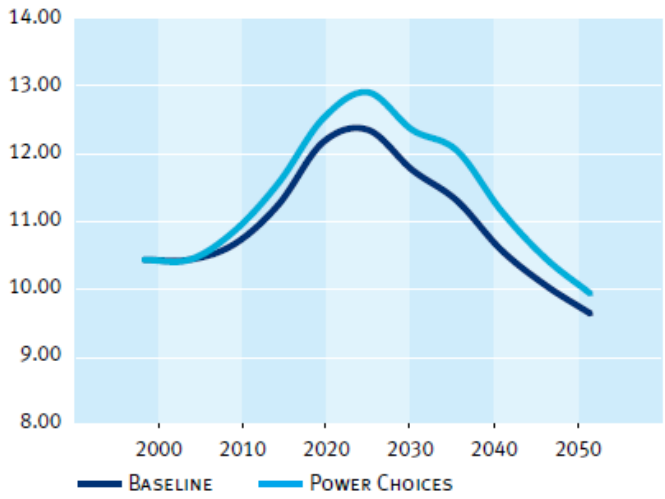


Fig. 5-68 – Total cost of energy as a percentage of GDP. Source: Power choices

Financing schemes

The report provides only some considerations concerning the financing mechanisms.

Investments in the electricity sector will be substantial and need to be undertaken in the most cost-efficient way. Moreover, in view of the on-going financial crisis, the scale of finances needed requires an adequate framework to promote large scale capital investment.

The Power Choices scenario demonstrates that reducing carbon emissions provides savings on auctioning payments that are almost sufficient to finance the additional investment costs which enable achievement of the carbon-neutral goal.

Regulatory mechanisms

Also, with respect to the regulatory mechanism, the study reports only some general considerations: electricity market design and regulatory policies need to address this complex decision making context, which will involve volatile carbon prices and cost margins with a simultaneous requirement for high capital intensive investment.

5.10 The North Seas Countries' Offshore Grid Initiative (NSCOGI) - WG1 2012

Scope of the study

The aim of the study is to evaluate the possible advantages and disadvantages of the long term development of an optimised, integrated (or meshed) offshore grid in the North Seas by providing a view of how that possible grid might develop in the future against changes to the electricity energy requirements.

The whole initiative involving energy ministries, TSOs and regulators of the Northern European countries and the European Commission, covers three items:

- grid design (WG1),
- market and regulation (WG2),
- permission and planning (WG3).

The study analysed is related to the first item.

In particular the study compares the "go it alone", or "doing it together" approaches in the development of the offshore grid due to the development of offshore wind farms and undersea interconnections between the countries in the North Seas region.

Compared to what described in Chapter7, this study is more focused on the approach of TSOs to the network planning.

Target year

The target year of the study is 2030 while the starting point is the year 2020.

Geographical area covered by the study

The study area includes the ten Northern European countries around the North Seas, as shown in Fig. 5-69. The NSCOGI (North Seas Countries' Offshore Grid Initiative)area includes Belgium, Denmark, France, Germany, Great Britain, Ireland, Luxembourg, Northern Ireland, The Netherlands, Norway and Sweden.

Fig. 5-69 – NSCOGI area (in violet)

Input scenario

The scenario defined in the study is based on the governments' best view of energy generation and demand in 2030 while, for 2020, the Scenario EU2020 has been considered as expressed in summer 2011.

The demand in the ten countries of the study area is shown in Fig. 5-70. The overall demand is about 1900 TWh in 2020 and 2100 TWh in 2030.

The installed generation and fuel consumption of the whole study area are shown in Fig. 5-71 and Fig. 5-72. It can be highlighted the increasing of the installed capacity of gas fired power plants (70% more in 2030 compared to 2020) compared to the reduction of those of other fossil fuels. But its contribution to the fuel mix decreases from 13% to 8%. On the contrary, the production increases for coal-fired capacity of around 200% between 2020 and 2030 due to the lower production cost assumed in the study compared to gas-fired capacity. The contribution of RES (excluding hydropower) to the fuel mix increases from 28% in 2020 to 32% in 2030 due to development of onshore and offshore wind farms.

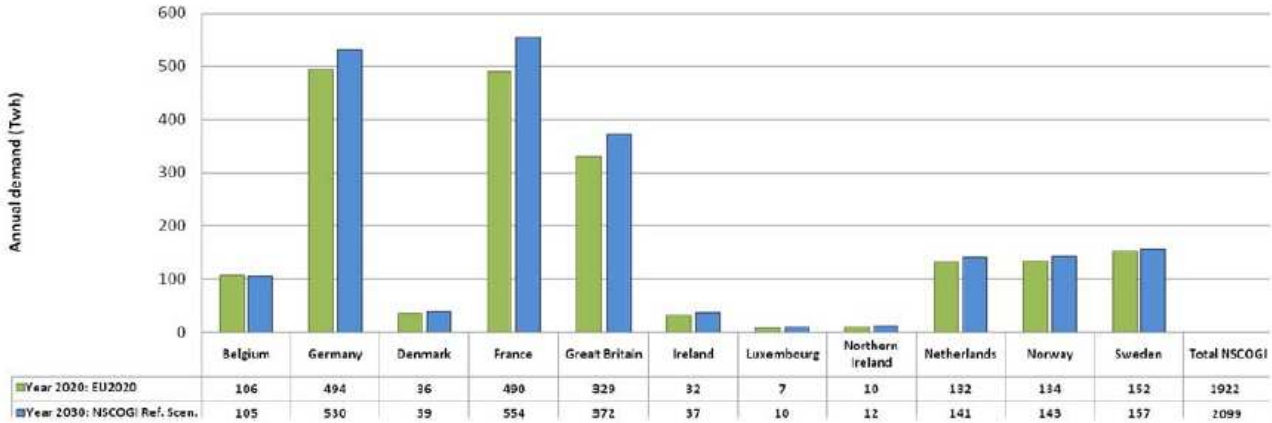


Fig. 5-70 – Annual demand in the NSCOGI area in 2020 and 2030

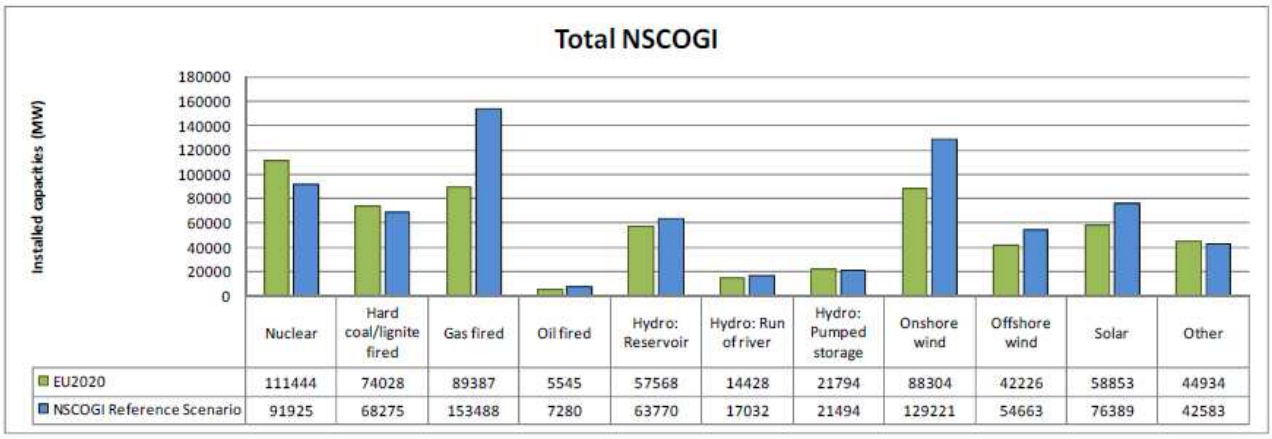


Fig. 5-71 – Installed capacity in the NSCOGI area in 2020 and 2030 by primary fuel

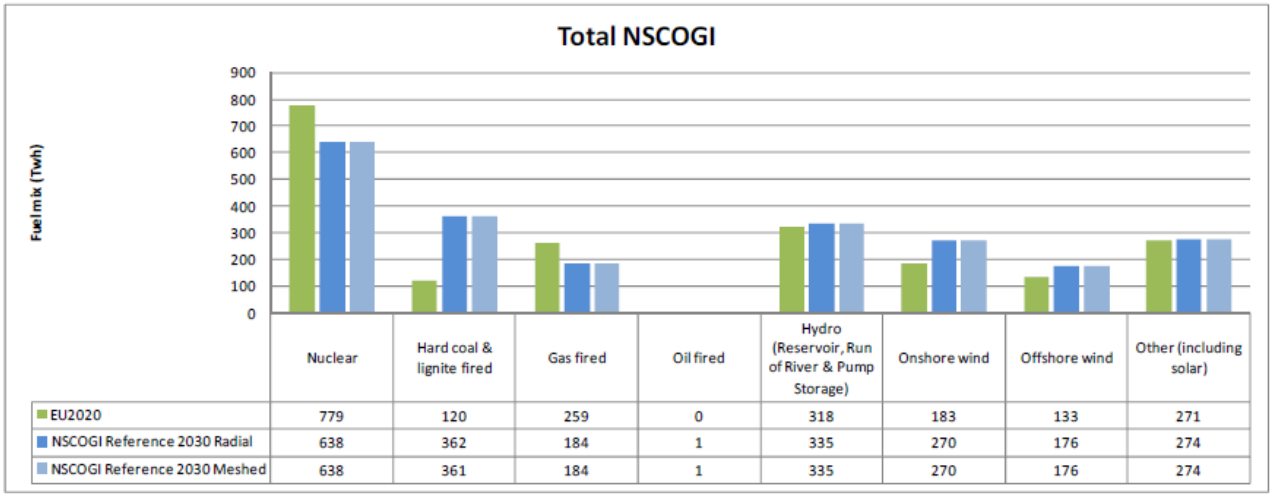


Fig. 5-72 – Fuel mix in the NSCOGI area in 2020 and 2030

In particular,Tab. 5-9 resumes the offshore wind capacity at year 2030 assumed in the reference scenario and in the sensitivity scenario.

Tab. 5-9 – Offshore Capacityinstalled in 2030 in the NSCOGI area

Offshore Wind Capacity(GW)	NSCOGI Reference Scenario	RES+ sensitivity
Belgium	3.1	4.0
Germany	16.7	25.0
Denmark W	0.9	3.4
Denmark E	0.3	1.0
France	6.5	13.0
Great Britain	17.7	49.0
Ireland and N.Ireland	2.3	7.0
Netherlands	6.0	12.0
Norway	0.7	1.0
Sweden	0.7	2.0
TOTAL	55.5	117.4

Besides, the study takes into account the reinforcements included in the TYNDP 2012 of ENTSO-E as a starting point for grid development.

Study assumptions: investment costs

The study doesn't provide specific information regarding the unitary investment costs neither for the generation technologies, nor for transmission technologies.

Study assumptions: operational costs

Fuel prices were taken from the IEA World Energy Outlook 2010 scenario (New policies scenario). An exchange rate from $ to € of 0.74 has been used. The CO_2 price of 36 €/tons was taken from PRIMES scenarios.

The production costs of thermal capacity assumed in the study are resumed in Tab. 5-10. The list includes short-run marginal costs of fuel, CO_2 emission and variable operating and maintenance costs. A 0 €/MWh price for RES production has been considered.

Tab. 5-10 – Production costs of thermal capacity assumed in the study

Unit Type	Unit Efficiency at full capacity (%)	Fuel Type	Production Cost €/MWh
Nuclear	33	UOX - MOX	12.9
Coal CCS	35	Coal	40.0
Lignite New	43	Lignite	46.5
Coal New	46	Coal	53.3
Lignite Old	36	Lignite	54.9
Coal Old	35	Coal	69.1
CCGT New	58	Gas	77.0
CCGT Old	48	Gas	92.7
OCGT New	40	Gas	110.9
Conventional Gas Old	35	Gas	126.0
Oil	35	LSFO	144.5
OCGT Old	30	Gas	147.3

Note: CCS = Carbon Capture Storage; CCGT = Combined Cycle/Gas Turbine; OCGT = Open Cycle/Gas Turbine

Study results

The study compares four patterns for developing an offshore grid on the basis of the development of offshore wind farms and undersea interconnections in the North Seas region.

Radial design: the offshore wind farms are individually connected to the onshore grid and separated from the undersea interconnections.

Meshed design: integrated approach in which offshore wind farms are connected at local or international basis together with undersea interconnections

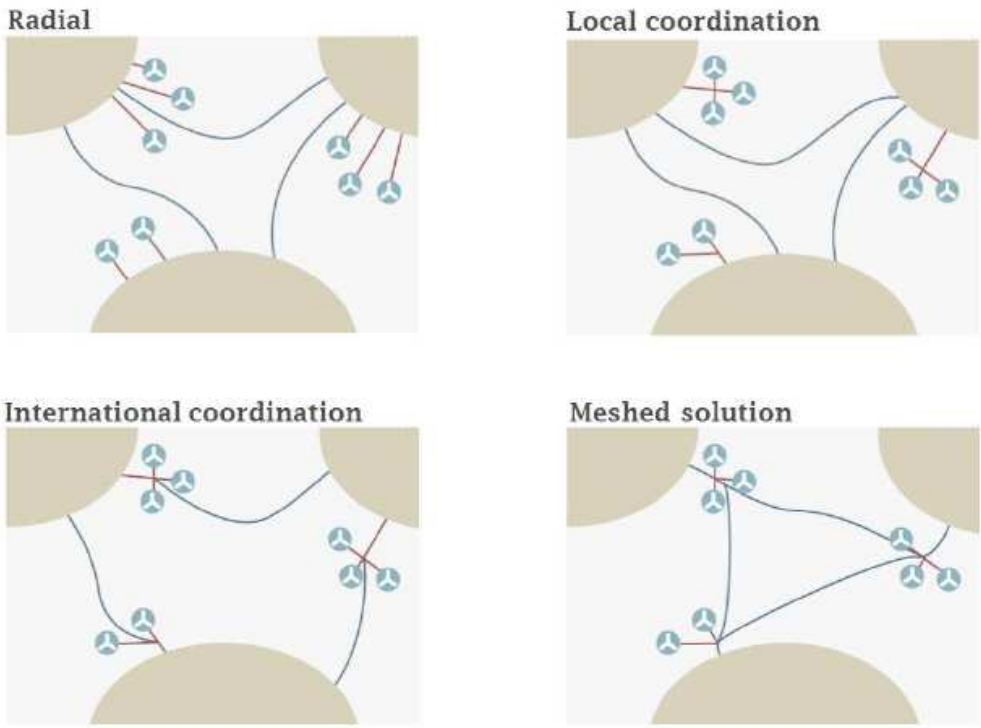


Fig. 5-73 – Assumed general pattern of the Offshore Grid Development

Both the Radial and Meshed approaches produce similar levels of interconnection, with similar associated production cost savings, although there are significant differences in how they were achieved (e.g. Norway-Great Britain link in the radial design is replaced by Norway-Germany and flows through Continental Europe in the meshed design).

The two approaches require also similar reinforcements in the onshore grids.

The proposed offshore grid designs are shown in Fig. 5-74 and Fig. 5-75. Compared to those described in Chapter 7, in this study the grid designs have been created without an iterative approach, since they are only a reference for comparing the design approaches. The actual design of the offshore grid will depend first of all on the actual offshore wind farm projects.

The grid designs include around 8890 km of new links, of which 4500-4600 km of HVDC offshore, about 650 km of HVDC onshore, 1100-1300 km of AC offshore and 2400 km of AC onshore, as resumed in Fig. 5-76.

The most relevant difference is the replacement of the long interconnection between Great Britain and Norway foreseen in the Radial design with a power corridor from Scandinavia to Germany, through the continental systems and a meshed grid in the south west corner of the North Sea and Channel to Great Britain.

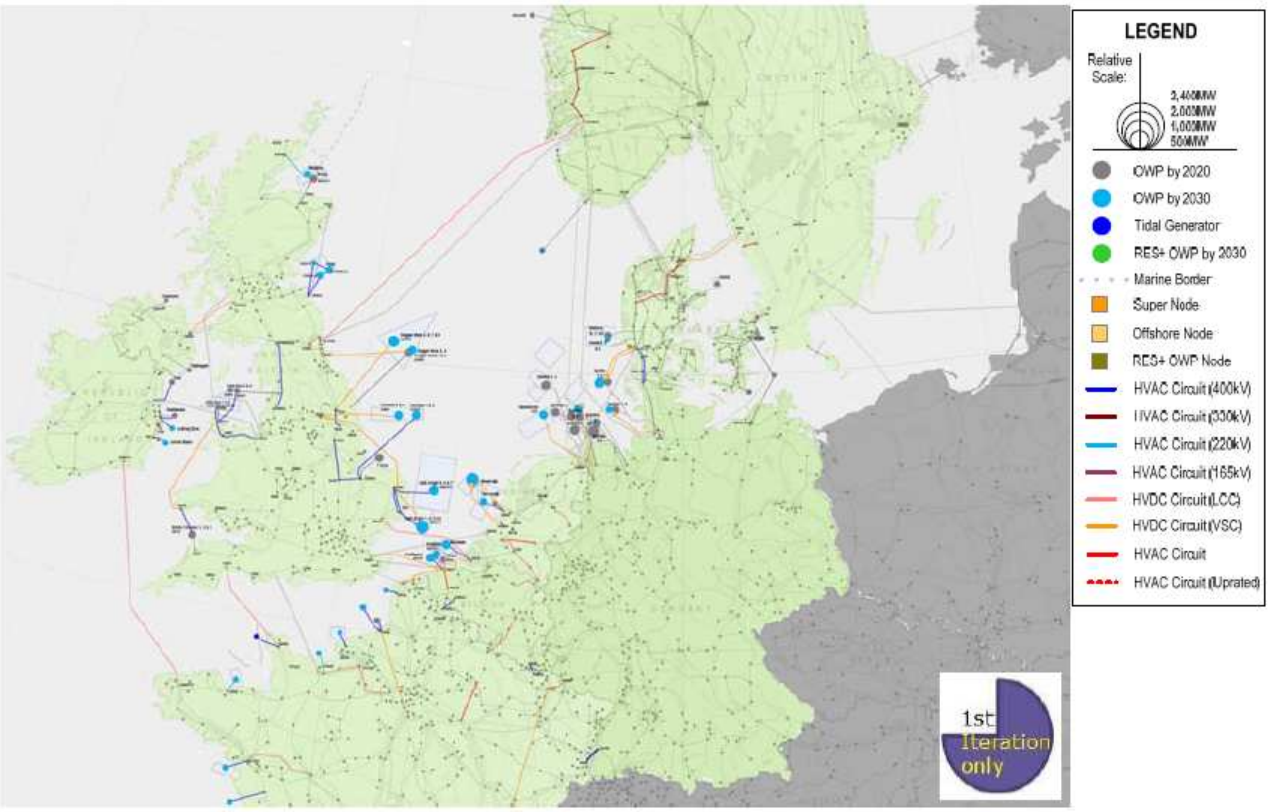


Fig. 5-74 – Radial Design of the offshore grid for 2030

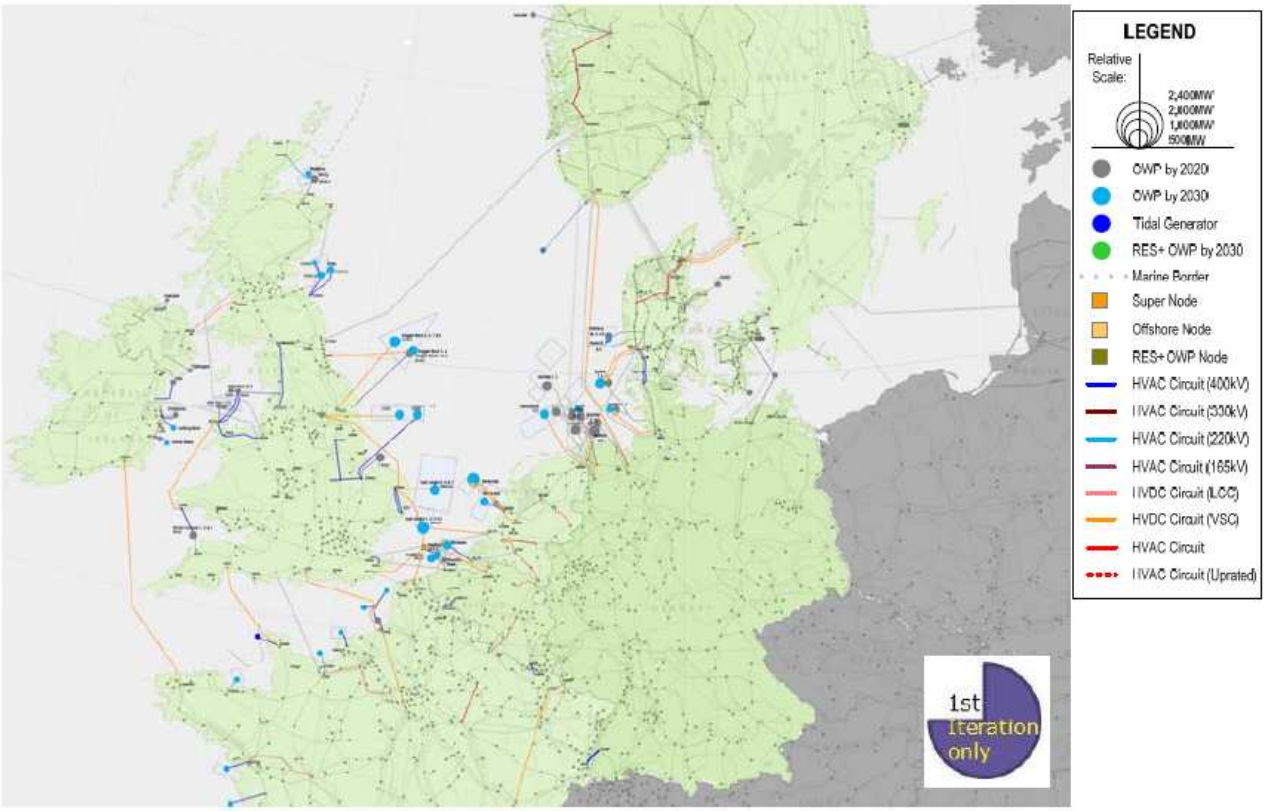


Fig. 5-75 – Meshed Design of the offshore grid for 2030

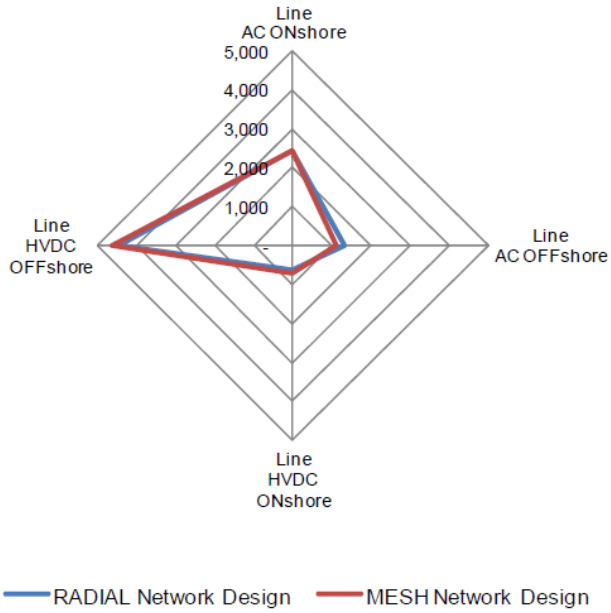


Fig. 5-76 – Total length of new links in the Radial and Meshed designs

The total investment cost of the optimised 2030 radial grid design is 30.9 bn€ (in addition to those included in the TYNDP 2012). Almost 40% of the cost of the radial design is related to new buildings in and around Great Britain. The French share is also high, especially due to the need of onshore internal grid development between the Normandy Coast and Paris area and from the north-eastern border to the south-eastern one.

The total of the investment costs of the optimised 2030 meshed grid design is 30 bn€ (additional to those included in the TYNDP 2012).In this case the Great Britain share of the costs is reduced to about 33%, while the German and French investment costs have increased.

The investment costs related to the Radial and Meshed designs are resumed in Fig. 5-77. The investment costs by country are shown in Fig. 5-78.

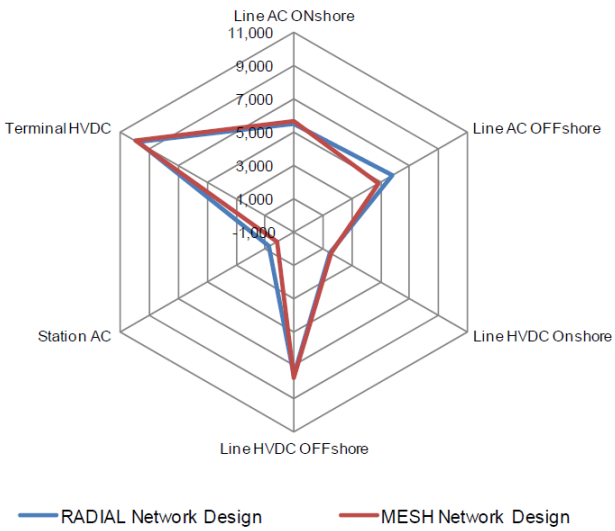


Fig. 5-77 – Investment costs for Radial and Meshed designs by asset class for 2030 reference scenario (in M€)

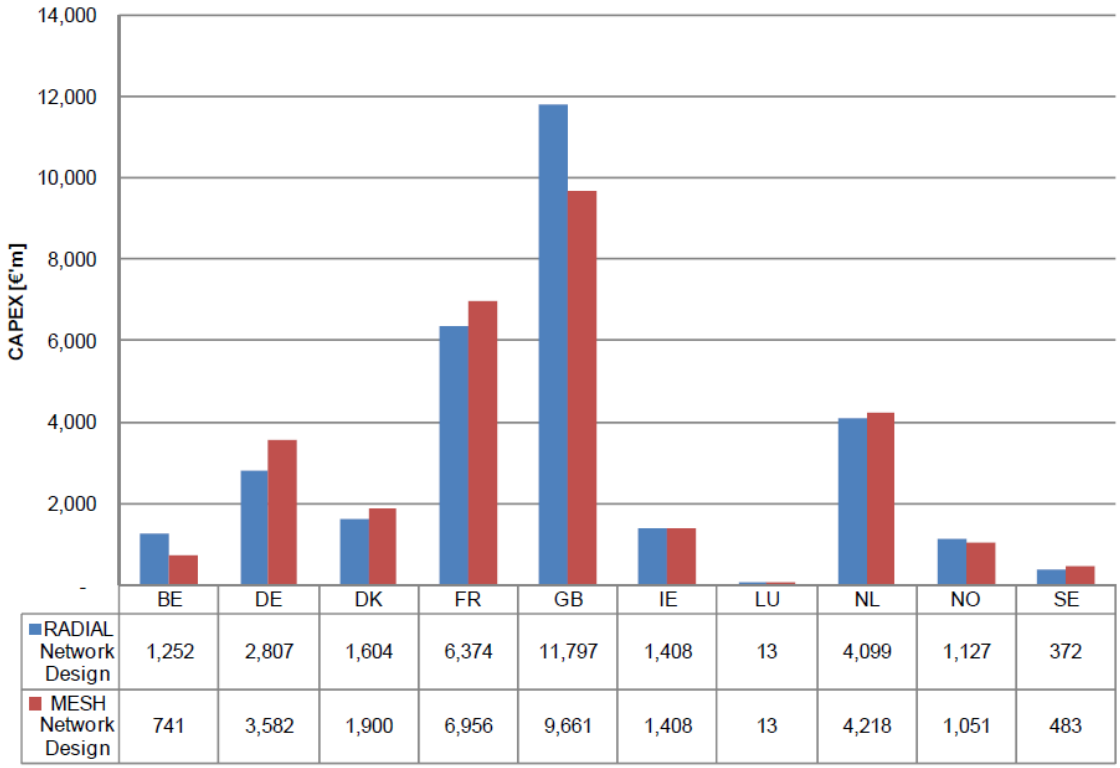


Fig. 5-78 – Investment costs by country for year 2030 for Radial and Meshed designs (in M€)

The radial and meshed designs generate an annual saving in overall production costs across the NSCOGI region of 1,449 M€ and 1,456 M€ respectively, starting from an overall production cost of 43.6 bn€.Tab. 5-11 resumes all the annual costs and benefits for the two designs. The meshed design results profitable compared to the Radial design. A sensitivity analysis confirmed the advantages of an integrated approach in case of higher amount of offshore wind power.

Tab. 5-11 – Summary of Costs (excluding OWPP connection costs) and Benefits for Radial and Meshed designs

	A	B	C = A+B	D	E = D-C	F = E/C
	Annualised Investment Cost excluding the radial OWPP connection costs	Annual VOM costs	Total Costs	Production CostSavings	Net benefits	Net benefit related to total costs
	M€ p.a.	M€ p.a.	M€ p.a.	M€ p.a.	M€ p.a.	[%]
Radial design	1,152	336	1,488	1,449	-39	-2,6
Meshed design	1,096	322	1,418	1,456	38	+2,7
Radial vs. Meshed	-56	-14	-70	7	77	

As abovementioned, the hypothesis on fuel and CO_2 emission prices lead to a decreasing of 30% of the production of gas-fired power plants despite their increased installed capacity, replaced by coal-fired capacity. Thus, some doubt on the profitability of gas-fired capacity exists. Thus the study concludes

that the resulting infrastructure for the reference scenario should be re-evaluated, if the production mix assumptions are changed in the light of the results presented in the study.
The same hypothesis explains the fact that Belgium and Great Britain are the largest importers in this scenario (high proportion of gas-fired generators in their systems) while Germany, France, the Netherlands, Norway and Sweden are large exporters, as shown in Fig. 5-79. It is interesting to note that the region as a whole is exporting approximately 110 TWh towards its neighbouring countries outside the region, which is about 5% of the region's annual demand.
In terms of percentage of their own demand, Luxembourg, Denmark East and Belgium are the largest importers, while the Netherlands are a large exporter country.

Fig. 5-80 shows the CO_2 emissions of each country at year 2030 on the basis of their production.

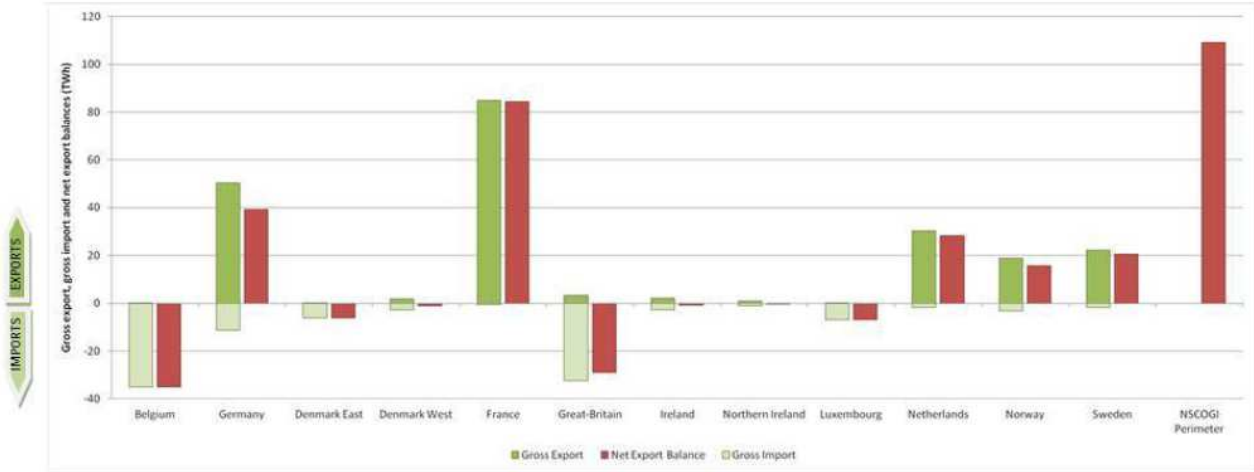


Fig. 5-79 – Energy balance in the NSCOGI area at year 2030

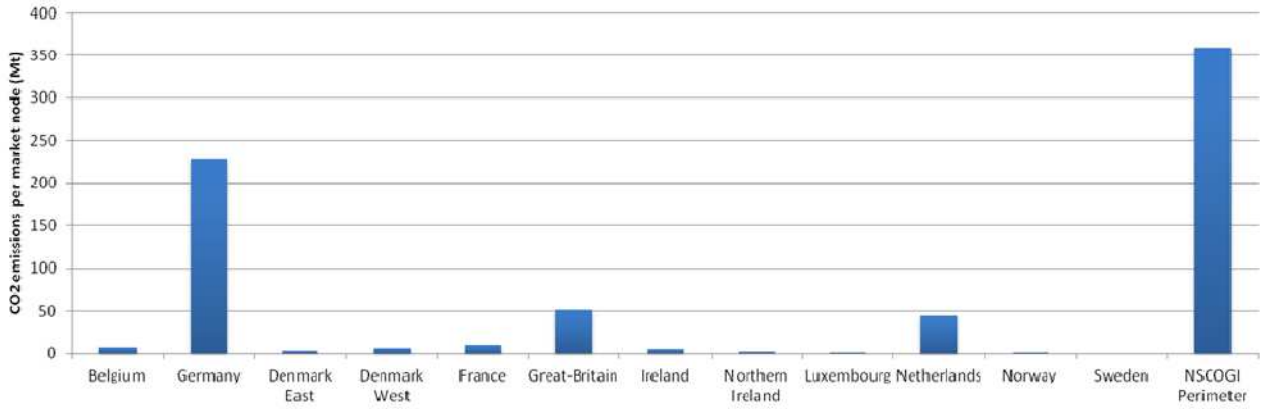


Fig. 5-80 – CO2 emissions in the NSCOGI area

5.11 Synthetic summary of the selected studies

The synthesis of the main information included in the selected studies is shown in the following table.

Project	Scope of the study	Target year	Input Scenario			Output
			Geographical area	Demand level	Study assumptions	
ENTSO-E TYNDP 2012	To provide a support to decision-making processes at regional and European level of coordination among national development plans with respect to European targets of network development	2022	European Countries	575 GW max demand in January, 444 GW max demand in July for the scenario EU2020	Network structures and foreseen reinforcements are provided by Member States. The studies are based on scenarios of demand and generation mix already defined by ENTSO-E in the SOAF.	Evaluation of Pan-European transmission reinforcements with respect to European targets of system development.
ENTSO-E Vision 4	To provide a scenario for the year 2030 in compliance with the target included in Roadmap 2050	2030	European Countries	4,260 TWh at 2030	Operational costs considered for all technologies CO_2 cost: 93€/t	European generation mix Assessment of the social benefits
Booz - Benefits of an Integrated European Energy Market	To evaluate the social welfare related to market integration in the gas and electricity sectors in Europe	2030 Intermediate year 2020	European Union (EU27)	633 GW by 2020 and 664 GW by 2030 according to Current Policy Initiative scenario	Forecasted demand according to ENTSO-G and PRIMES scenarios. CO_2 emission of 15 €/tons in 2020 and 32 €/tons in 2030according to current Policy Initiative scenario. Large number of policy scenario with increased degrees of integration	Benefits and costs related to enhancement of gas and electricity market integration in Europe.
Roadmap to the Supergrid technologies	Roadmap for development of Pan-European Supergrid from a technological perspective	2030	European Countries	No specific demand levels are included in the study	75-80% reduction of CO_2 emissions in the long term vision (2050)	Roadmap for the development of the Supergrid in the three phases: today-2015, 2016-2020, beyond 2020
Roadmap 2050	To provide different scenarios of renewable generation in order to reach a 90-100% CO_2 reduction in power sector respect to 1990's levels	2050 Intermediate years: 2020, 2030 and 2040	Europe – excluding Balkan region Countries – grouped in macro-regions	4,900 TWh at 2050 4,500 TWh at 2040 4,200 TWh at 2030 3,650 TWh at 2020	Three pathways: 40% - 60% - 80% RES share + sensitivity pathway 100% RES CCS and nuclear considered Investment and operational costs considered for all technologies Transmission: 73% of AC and 27% of HVDCs; 67% of OHL and 33% of cables	Generation mix for each pathway for each macro-region NTC values between each macro-region Evaluation of the social benefits

Project	Scope of the study	Target year	Input Scenario			Output
			Geographical area	Demand level	Study assumptions	
					Grid costs equal to 1,000 €/MW/km CO_2 cost: 20-30 €/t + cost of storage: 10-15 €/t	Recommendations for financing and regulatory mechanisms
Desert Power	To demonstrate the feasibility of a scenario based on a high renewable shareable to reach an almost complete decarbonisation of the power sector and a fully integration of EU and MENA countries	2050 Intermediate years: 2020, 2030 and 2040	Europe, North Africa and Middle East.	5,870 TWh at 2050 for Europe+Turkey 2,180 TWh at 2050 for the MENA region	One scenario: EU and MENA fully interconnected, RES share about 93% CCS and nuclear NOT considered Investment and operational costs considered for all technologies Transmission: 100% HVDCs; 50% underground cable in Europe; 10% in MENA – Maximum NTC between countries: 20 GW Grid costs: 828 k€/km/GW for Europe; 396 k€/km/GW for MENA, 992 k€/km/GW for submarine interconnections; 180 M€/GW for AC/DC converter stations CO_2 cost: 113€/t	Generation mix for each country Power exchanges EU-MENA NTC values between each country Evaluation of the social benefits Recommendations for financing and regulatory mechanisms
Battle of the Grids	To demonstrate the feasibility of a complete decarbonisation of the power sector	2050 and 2030	Europe	4,300 TWh at 2050 3,200 TWh at 2030	Two scenarios: import scenario (Europe imports from North Africa); regional scenario: Europe isolated CCS and nuclear NOT considered Investment costs considered for main technologies Transmission: AC up to three times today's installed capacity, HVDCs for additional capacity Grid costs: 400 €/MW/km for HVAC; 1500 €/MW/km for HVDC cables	Generation mix for each country Detailed analysis of the grid Advices for financing and regulatory mechanisms
SINTEF, 3E, Senergy – Offshore grid	To provide a view of potentials of developing an offshore grid in northern Europe taking into account technical, economic, policy and regulatory aspects	2030 Intermediate year 2020	North and Baltic Seas, the English Channel and the Irish Sea	Gross electricity generation of 2,657 TWh (2,340 TWh consumption) at 2030 in the selected region. The scenario refers to a consumption of 3,582 TWh in the EU27 area	126 GW of offshore wind capacity located in Northern Europe in 2030. PRIMES scenarios of demand and generation	Investments and benefits related to the development of the offshore grid in the Northern European Seas. Proposals for offshore grid structures

Project	Scope of the study	Target year	Input Scenario			Output
			Geographical area	Demand level	Study assumptions	
Vision 2050	To provide an energy scenario able to reach the 50% CO_2 reduction worldwide respect to 2005 levels	2050 Intermediate years: 2020, 2030 and 2040	Global vision	Primary energy demand forecasts. Electrical demand data not provided	50% CO_2 reduction worldwide – 80% CO_2 reduction in power sector Energy mix: 50% RES, 25% nuclear, 25% fossil fuels with CCS – CCS developed from 2030s Investment costs considered for main technologies in a qualitative way Transmission: both AC and DC connections are considered necessary CO_2 cost: 20€/t	lists of opportunities obtainable in many sectors (energy, forestry, agriculture and food, water, metals, health and education) assessment of business opportunities in 2050 Advices for financing schemes
Power choices	To provide a scenario able to reach the emission reduction target for the EU consistent with global CO_2 concentration at 450ppm	2050 Intermediate years: 2020, 2030 and 2040	EU-27 Countries considered individually	4,800 TWh at 2050	Two scenarios: baseline scenario (with existing CO_2 reduction policies); power choices scenario: 75% GHG reduction in the whole EU economy versus 1990 levels CCS and nuclear considered Investment and operational costs considered for all technologies CO_2 cost: 103.2€/t at 2050, 52.1€/t at 2030	European generation mix General results for network reinforcements Assessment of the social benefits General considerations for financing and regulatory mechanisms
North Seas Countries' Offshore Grid Initiative (NSCOGI) - WG1 2012 report	To evaluate the possible advantages and disadvantages of the long term development of an optimised, integrated (or meshed) offshore grid in the North Seas	2030	Northern European countries around the North Seas	1,900 TWh in 2020 and 2,100 TWh in 2030 in the region (ten countries)	Offshore grid capacity of 55.5 GW at 2030 n the Reference Scenario, 117.4 GW in the RES+ Sensitivity Scenario. CO2 price of 36 €/tons at 2030	Investment costs and benefits related to the offshore grid developed in the analysed region. Indicative offshore grid structures

6 GAP ANALYSIS

This chapter details the investigations performed to identify the differences among all the studies described in chapter 5. In particular, the analysis is carried out with a twofold objective:

- to compare the scenario assumptions in the various mid-long term studies (2025-2050)
- to identify gaps (see indicators in chapter 4) that shall be filled through new dedicated studies.

The aim is to measure in a "quantitatively" way how the indicators selected in chapter 4 are included in the examined studies and thus defining the items that could be investigated further.

6.1 Scoring Criteria

The scores of each study against the indicators explained in Chapter 4 are summarised below in Tab. 6-1. The criteria adopted to evaluate the studies against the relevant indicators are explained in more detail as follows:

- For all indices, the score equal to zero means that the items included in the correspondent indicators are not covered in the study
- For all indices, the maximum score (3) has been given where there is evidence of thorough processing of the arguments, including also numerical and quantitative evaluations.
  More specifically, for the indices "Variation in CO_2 emissions" and "RES integration" the maximum score has been given when they represent the target of the study and are consequently quantitatively assessed, i.e. the development of renewable generation has to reach a specific goal or has to allow a specific reduction in the GHG emissions.
- As far as the other scores are concerned, they have been used to quantify analyses with an intermediate level of detail. More specifically:
  - "Security of supply": score "1" has been adopted when the analysis is referred to generation and e-highways only, i.e. without considering the detail of the network; score "2" has been used instead when this criterion is considered as an input of the analysis and the numerical results take into account the grid with a more accurate level of detail (i.e. not only the e-highways in terms of main corridors are considered, but also the transmission grid at HV and EHV levels is analysed)
  - "Socio-economic welfare": score "1" has been adopted in presence of a rough estimation in which only generation costs (but not transmission costs) are considered, score "2" has been used instead in the presence of a good analysis of the effects of generation costs but always in absence of the transmission costs
  - "RES integration": score "1" has been adopted for a rough and qualitative estimation of the maximum amount of renewable generation that is possible to connect to the network, score "2" has been used instead for a quantitative evaluation carried out without taking into account the constraints of the grid
  - "Energy efficiency": score "1" has been adopted when this aspect is not considered as an input for the analyses, but it is estimated ex-post, score "2" means instead that the energy efficiency has been included in the computation process in order to define the

grid topology but without optimising the network infrastructures for minimisation of losses.

- "Variation in CO_2 emissions": score "2" has been adopted when this quantity is calculated but it doesn't represent the target of the study
- "Technical resilience/system safety margin": score "1" has been adopted when this item is considered in a qualitative way and it is not the focus of the study, score "2" means instead that the technical aspects have been considered in a quantitative way even if they are not the target on which the scenarios have been built.
- "Robustness/flexibility": score "1" has been adopted when this item is considered in a qualitative way, score "2" instead when some additional sensitivity analysis has been reported to demonstrate the robustness of the scenarios proposed in the study.

6.2 Quantitative evaluation of the selected studies

Tab. 6-1 reports the quantifications of the different indicators for all studies considered in the analysis.

Tab. 6-1 – Results of the GAP analysis

	Security of supply	Socio-economic welfare	RES integration	Variation in losses (Energy efficiency)	Variation in CO_2 emissions	Technical resilience/ system safety margin	Robustness/ flexibility
Vision 4	2	1	2	1	3	0	1
ENTSO-E: Ten Year Network Development Plan (TYNDP) 2012	3	3	3	3	2	3	3
Benefits of an Integrated European Energy Market	3	3	1	1	2	0	3
Roadmap to the Supergrid technologies	0	0	1	0	0	1	1
Roadmap 2050	1	3	3	1	3	0	3
Desert Power	1	3	3	2	3	2	1
Battle of the Grids	2	1	3	3	3	0	0
Offshore grid	2	3	3	1	2	1	2
Vision 2050	0	1	2	0	3	0	0
Power choices	1	2	2	1	3	0	1
NSCOGI 2012 report	1	3	3	1	2	1	1

Furthermore, all indicators are shown in "radar" format, as reported in the figures here below.

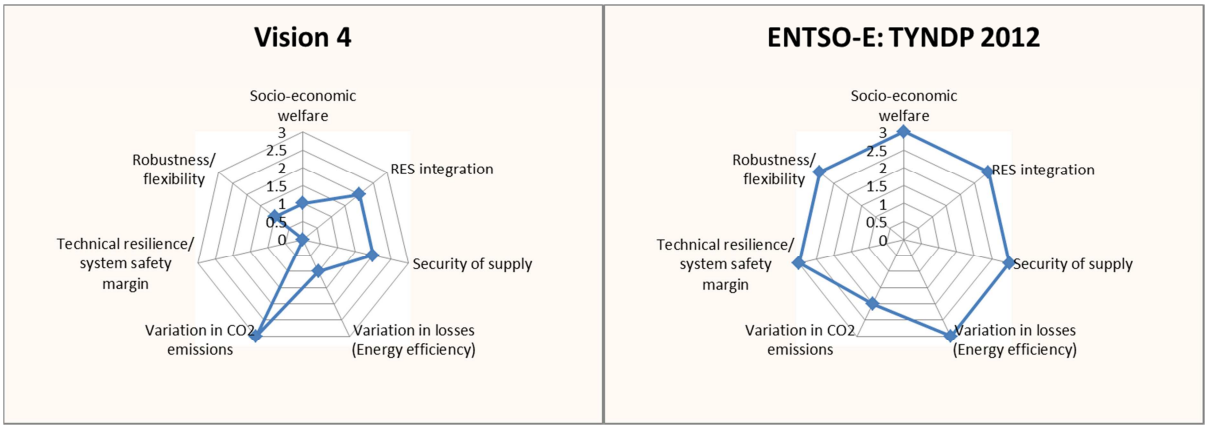


Fig. 6-1 – Illustration of indicators'assessment: Vision 4 and ENTSO-E TYNDP 2012

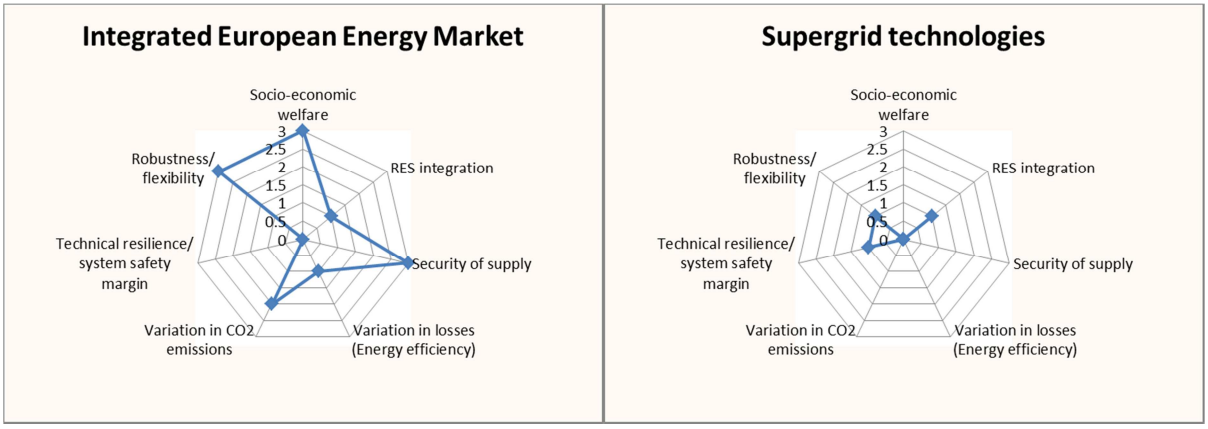


Fig. 6-2 – Illustration of indicators'assessment: Benefits of an Integrated European Energy Market and Roadmap to the Supergrid technologies

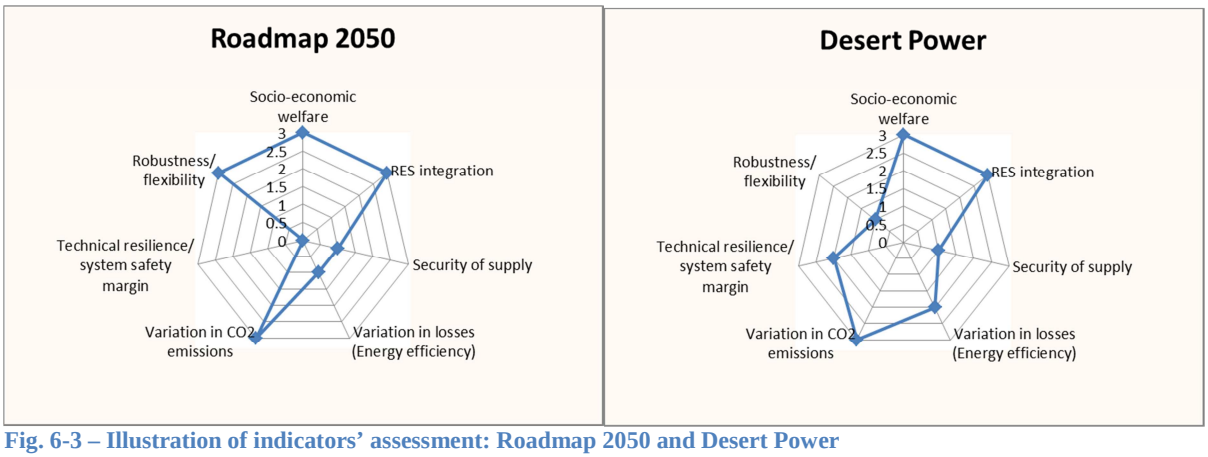


Fig. 6-3 – Illustration of indicators' assessment: Roadmap 2050 and Desert Power

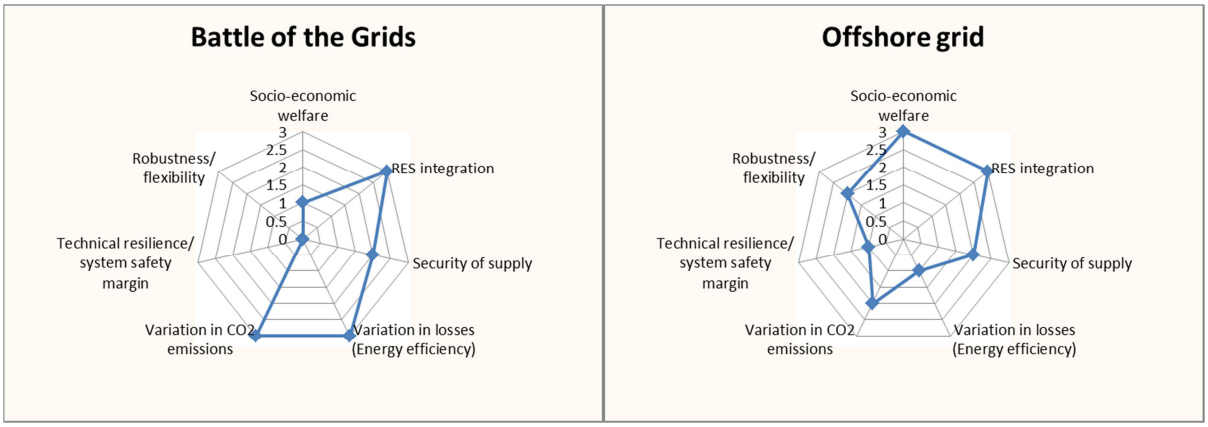


Fig. 6-4 – Illustration of indicators'assessment: Battle of the Grids and Offshore grid

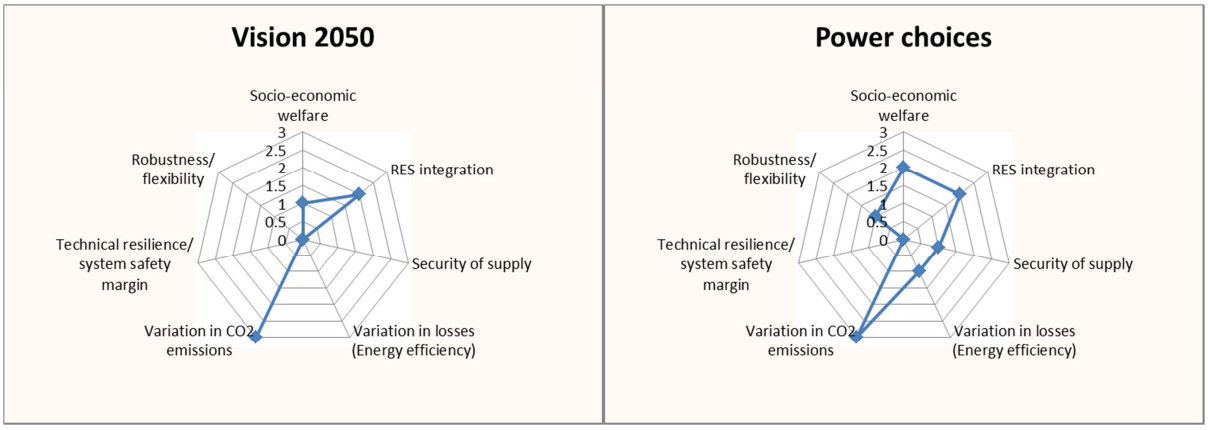


Fig. 6-5 – Illustration of indicators'assessment: Vision 2050 and Power choices

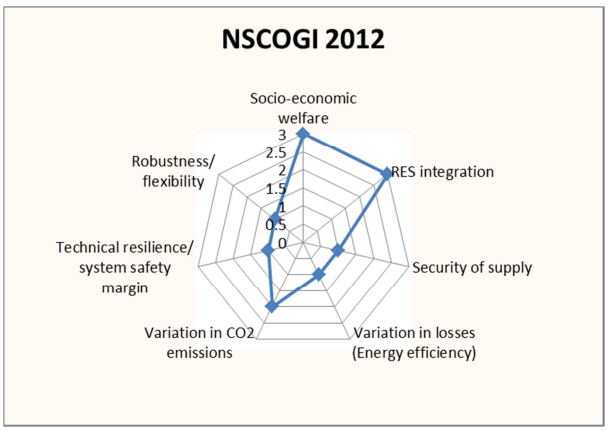


Fig. 6-6 – Illustration of indicators' assessment: NSCOGI 2012

6.3 Considerations on the GAP analysis

Taking into account the above mentioned criteria, the most important conclusions of the GAP analysis can be summarized in the following points.

- ENTSO-E TYNDP 2012 and Vision 4 cover well all selected indicators, in particular the TYNDP. However, the time horizon of this study (2022) doesn't yet include any electricity highway. A more detailed analysis covering the period up to 2030 is expected in the next TYNDP 2014, which shall also include the application of the CBA proposed by ENTSO-E.

- Accordingly with the aim of the Booz study, the aspects related to security of supply (SoS) and social welfare are well covered. In particular these items have been assessed taking into account many scenarios of electricity and gas market integration. It is worth mentioning that the SoS has been investigated in terms of availability of primary energy resources. On the other hand, in presence of a remarkable share of non-programmable RES generation, the behaviour of which is usually uncorrelated with demand patterns, it becomes of utmost importance to assess the "reliable available capacity" in the various time periods to be compared with the estimated load, so to check if the minimum threshold of adequacy reserve margin is fulfilled in accordance with the ENTSO-E criterion. Another aspect that shall be addressed consists of the role of the SG to ensure an adequate reserve margin, a very important aspect to be further explored for warranting the reliability of the system and the security of supply in presence of high levels of renewable generation.

- With respect to the others, the Roadmap to the Supergrid technologies study of FOSG is the only study that is focused on the technological aspects related to SG development. The aspects related to planning (e.g. social welfare, security of supply, quantity of RES capacity integrated) however are not covered, being out of the study scope. From this point of view, this work represents a meaningful step forward with respect to the other studies, since it provides a picture of the status and a foreseen development of the technology needed to build the SG.

- Roadmap 2050 provides many results and detailed analysis for the year 2050 both considering technical and economic aspects of the generation mix and the e-highways structures. This study includes the analysis of different pathways able to attain the target of CO_2 abatement providing, for each of them, the generation mix necessary to cover the demand, the capacity of the electricity highways and the associated costs. On the other hand, the study doesn't examine in detail the SoS levels associated to the deployment of the e-highways envisioned by the year 2050. In particular, the assessment of system safety margins and technical resilience according to the criteria adopted by ENSTO-E are not investigated.

- Desert Power is one of the most complete studies concerning analyses in the long-term period (year 2050). In fact, this study includes the analysis of several indicators providing forecasts not only on the amount of renewable generation, but also on the effects that such important changes in generation mix will have on the economy of the countries and in the structure of the electricity grid, with the identification of the e-highways necessary to transmit the power over long distances. The study identifies the main electricity corridors that will be part of the

European and Euro-Mediterranean SG. Starting from the identified backbones composing the SG, one should go further examining the technical performances of the system. Furthermore, the generation mix has been optimised starting from the potential of primary resources (e.g.: wind, solar radiation, wood or other resources for biomasses, etc.) on the territory considering some "high level" constraints in the generation mix (e.g.: a minimum level of local controllable generation in each country). What is not covered in detail in this study addresses the assessment of generation adequacy, taking into account the effective availability of primary resources and the role of the SG.

- Battle of the Grids provides some interesting results on the impact of renewable generation on the structure of the grid and on the amount of investment necessary to increase renewable generation. However these results are more detailed for the year 2030 than for 2050. Comments already formulated above concerning the assessment of SoS and the technical performances of the future system apply also to this study.

- The Offshore Grid study provides an in-depth analysis of the integrated design of the offshore grid in the Northern Europe, taking into account almost all the items related to the selected indicators. A gap emerging from the Offshore Grid study concerns the assessment of the system technical resilience and the safety margins.
  Similar considerations apply also to the NSCOGI study (see below).

- World Business Council for sustainable Development - "Vision 2050 - the new agenda for business" provides important analyses of possible scenarios to reach the objective of a worldwide 50% CO_2 reduction compared to 2005 levels,examining all the sectors that contribute to GHG emissions. In this approach, the power sector represents a field where significant reductions of carbon emission are required in the following decades. The study is very general addressing all energy sectors, not only electricity.

- EURELECTRIC - "Power choices" reports an in-depth analysis of the generation mix for the European power sector in order to reach the objective not to exceed the concentration of 450 ppm of CO_2 in the period up to 2050. To this purpose, the study illustrates in detail the evolution of geneation mix from now up to 2050, together with the assessment of the associated investment costs.

- Similar to the Offshore grid study, the NSCOGI - WG1 2012 report covers all items related to the development of the offshore grid in the Northern Europe from a planning perspective. Thus, this study also covers almost all the selected indicators. There is particular emphasis on the social welfare assessment, RES integration and variation of CO_2 emissions. Some indicators, like SoS, technical resilience/safety margins and robustness/flexibility could be examined more in-depth in further stages of the study.

Tab. 6-1 shows that the indicators related to the integration of RES and to CO_2 reduction are considered in depth in most studies, since they generally are the target on which the different scenarios are built. On the contrary, the more technical indicators related to the technical resilience and robustness of the system are generally not widely covered, especially in the studies with a long-term vision. A similar

consideration is valid also for the indicator related to energy efficiency (see variation of losses) and security of supply, which are mainly considered in the studies focused on the mid-term period. The indicator related to the analysis of socio-economic welfare is treated in studies covering both mid and long-term tome horizons.

The other indicators not included in the GAP analysis (regulatory schemes, financing schemes, impact on the manufacturing industry, etc.) are considered only in some studies, but without reporting a detailed analysis and practical proposals.

7 CONCLUSIONS AND STEPS FORWARDS

The main outcome from the literature review and the gap analysis consists of providing practical suggestions on the next step forwards. This is not oriented on the discussion of long-term scenario assumptions, but rather to outline a methodology to identify the first cluster of projects and how to design the "optimal" offshore transmission grid through a robust "cost-benefit analysis" (CBA).
A robust CBA is indeed essential to get the approval of the investments by the Regulatory Bodies and Energy Ministries (case of regulated assets) or to attract investments from the private sector (merchant offshore cables). Furthermore, a clear, simple and transparent assessment of the benefits deriving for a SG will help enhance the social acceptance of the new infrastructures by the affected population and the local authorities.

Focusing on the topics widely addressed in the examined studies so far, it is possible to draw the following considerations.

- Many aspects related to CBA have been already investigated in several studies that report estimations on investments in generation and transmission infrastructures necessary to meet the objective of an almost complete decarbonised power sector with the ability to transmit renewable generation over long distances. This is, for example, the case of the Power Choices study with respect to generation and Desert Power and Roadmap 2050 studies for the SG high level structure and the generation mix.

- In order to identify the priority grid infrastructures to be realised, the studies addressing the possible structures of the offshore grid (Offshore grid and NSCOGI 2012) evaluate the benefits arising from an integrated design of offshore wind farms jointly with submarine interconnections. In the TYNDP 2012, proposed by ENTSO-E, these two items are instead separately examined, first of all because the current approach to offshore wind integration is structured on country basis and secondly as there is no body accountable for the identification of optimal boundary transfer capability between member states. Hopefully ENTSO-E has changed this approach for the preparation of the new TYNDP to be issued in 2014.

- Another aspect of utmost importance for the development of a Supergrid is represented by the technology roadmap necessary to identify the development of the technology required to build the electric highways. To this purpose, detailed information is included in the FOSG document "Roadmap to the Supergrid technologies". This is the only study which focus on this crucial aspect although it did not cover in detail the real capability of manufacturers to provide the components in terms of quantity and technology.

On the contrary, the main points that should be better investigated and for which there is a lack of information are:

- <u>the regulatory framework for sharing offshore resources (production) between different countries</u> and the investment burden of the SG, particularly the offshore sections.

- <u>Market analysis concerning the real possibility to manufacture the components necessary to build the SG</u>, with particular reference to special components such as DC circuit breakers and

high-depth submarine cables to cross the Mediterranean sea. The commercial availability of these special components call for substantial investments in R&D to be undertaken by the manufactures.

- Quantification of the technical indicators, with particular reference to the investigation of security of the system and security of supply in presence of a very high share of non-dispatchable renewable generations. As a matter of fact, SoS is often examined referring to the availability of primary energy sources to supply the load and not as power availability in relation to the load patterns and the non-programmable RES generation (wind and solar). In fact, generation from non-programmable RES is normally uncorrelated from load behaviour and, as such, it becomes of utmost importance to assess the reliable available capacity necessary to cover the load taking into account the combined uncertainty in load levels and non-programmable RES generation. Hence, the "upward" and "downward" generation adequacy combined with the contribution of the SG shall be accurately simulated in the mid-long term scenarios to show the feasible operation of a power system with a high share of non-programmable RES generation

- Regulatory issues should be looked at in order to define the right legal framework to be put in place to allow cross-border balancing. In fact, a high share of non-programmable RES generation can cause situations similar to that shown in the diagram here below (Fig. 7-1) where within one country it is not possible to balance load and generation; see green areas denoting periods with an excess of generation with respect to the load: phenomenon of "over-generation". In such situations, one can fruitfully exploit the power transfer capacity of a SG to convey the excess of power to other regions of Europe, provided that mechanisms for cross-border balancing are in place.

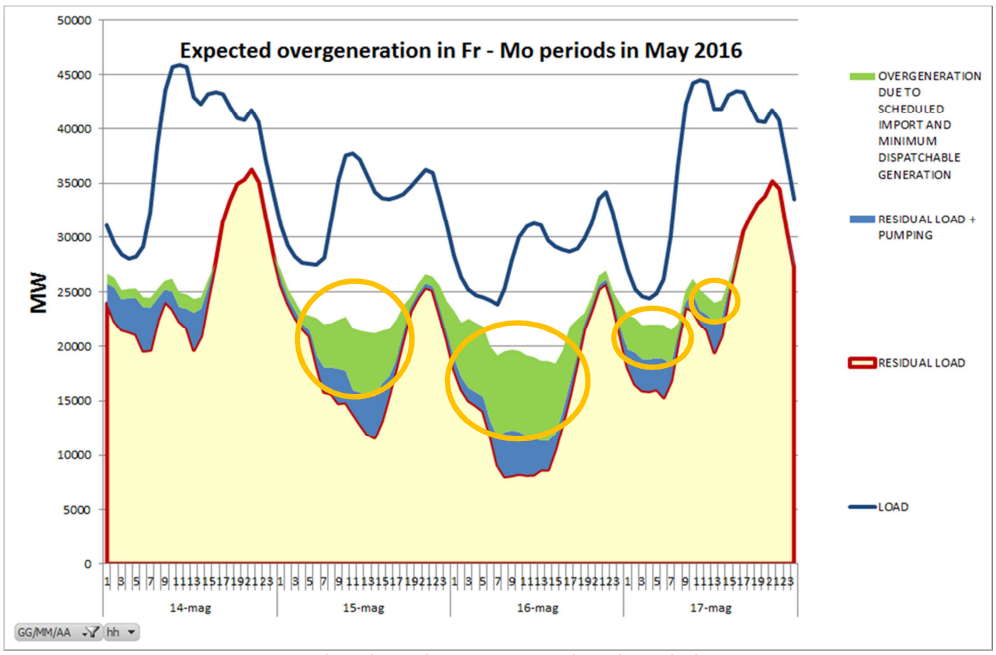


Fig. 7-1 - Estimation of "overgeneration" in Italy in 2016

The introduction of pan-European mechanisms for cross-border balancing coordinated with the day-ahead and intra-day power markets is an urgent action that shall be addressed now with the highest priority.

- In general, all the examined studies tackled the cost-benefit analysis associated with new transmission infrastructures, but not in a comprehensive way covering all the market, technical and environmental indicators (see, f.i., the seven indicators proposed by ENTSO-E). The same comment applies to the evaluation of the cross-border cost allocation. This gap is likely to be covered by the study launched by the EC, the results of which shall be available by May 2014.

In conclusion, a lot of work has been done to move towards a decarbonised power sector, but much is still to be done in order to put into reality the concept of SG. To this purpose, it would be important in future to pay more attention to the quantification of the technical indicators, particularly those already identified by ENTSO-E: "technical resilience/ system safety margin" and "robustness/ flexibility", adopting appropriate KPI.

To this aim, a further step that FOSG can promote consists of investigating the sustainability of the generation mix to reach the CO_2 reduction target, in terms of security of supply and considering the transfer capacities of the SG between countries. As mentioned above, SoS shall be examined not only in terms of energy, but also of availability of power in the various periods of the year.
This study shall examine the impact of a significant amount of intermittent renewable generation on the dispatch of conventional generation, as well as on the necessary storage systems required, in order to ensure an adequate level of security of supply. This will also identify possible critical situations in the generation mix and in the grid infrastructures. In this investigation only the macro-constraints on the SG (i.e.: inter-area transfer capacity) shall be considered since the detailed planning of the transmission grids is within the exclusive competence of the TSOs.

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