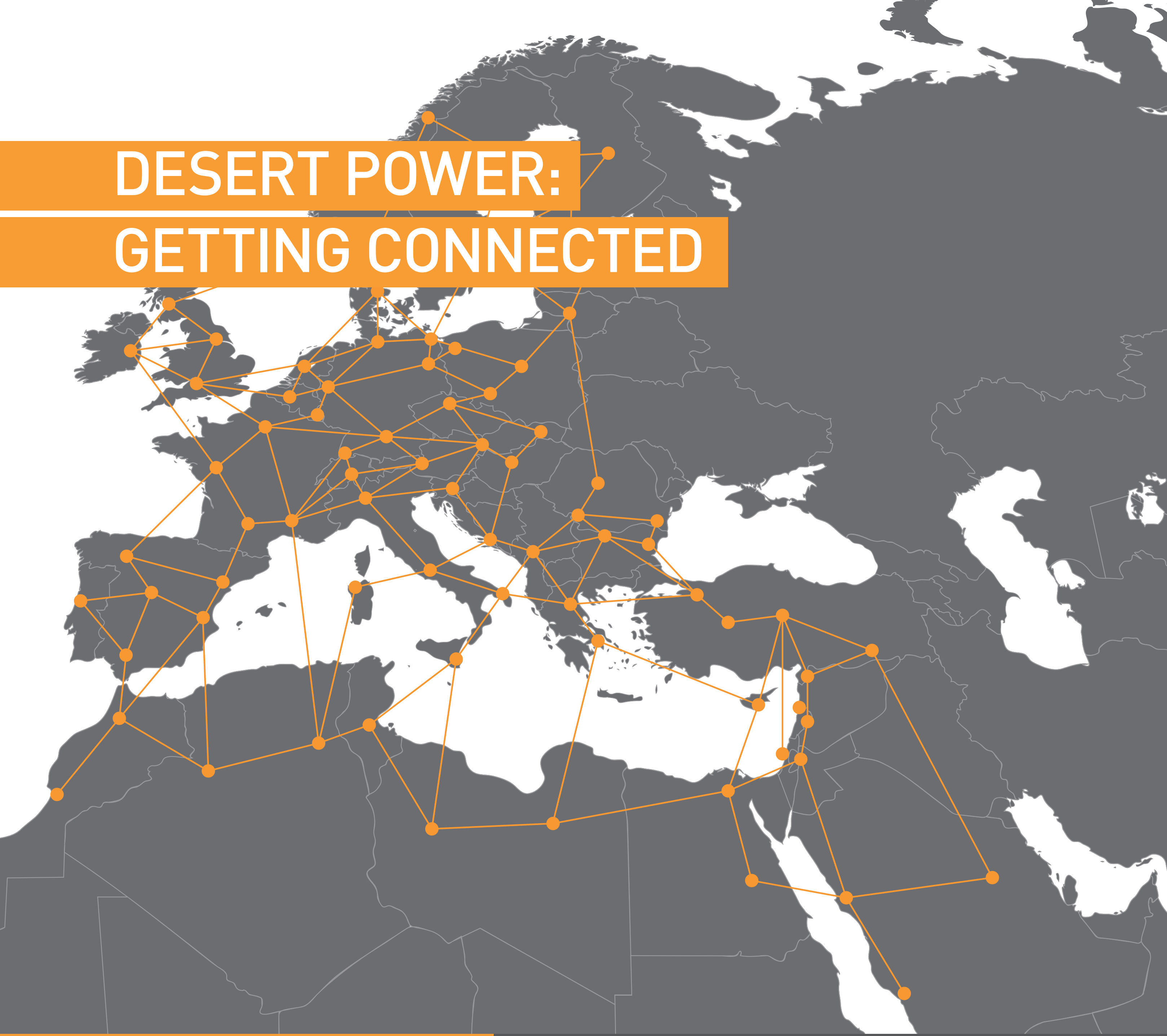
DESERT POWER: GETTING CONNECTED



Starting the debate for the grid infrastructure for a sustainable power supply in EUMENA

Dii

DESERT POWER: GETTING CONNECTED

Starting the debate for the grid infrastructure for a sustainable power supply in EUMENA

Dii has shown - with its 2012 and 2013 reports Desert Power 2050 and Desert Power: Getting Started - that all countries in the EUMENA region would benefit from the synergies of an integrated power system largely based on Renewables.

Desert Power: Getting Connected (DP:GC) complements Dii's previous work on the promotion of an integrated EUMENA power system. It provides a clearer understanding of the requirements of a transmission grid infrastructure that would enable the efficient exchange of large amounts of electricity across the European and MENA power markets.

DP:GC must not be seen as the solution for the transmission infrastructure throughout EUMENA or only between MENA and Europe. While analyses were carried out in close cooperation with Dii's shareholders ABB, Red Eléctrica de España, Terna S.p.A. and RWE, many uncertainties regarding the future power systems and technologies remain and simplifications inherent in modeling exercises were made. Hence, the report does not claim to offer yet the accuracy that would be needed for detailed long term grid planning.

Instead, DP: GC is intended as a contribution to the emerging debates on a pan EUMENA overlay grid in a "high level" schematic way. Such overlay grid will not only increase the level of market integration in the entire EUMENA area. It will also allow for a secure and cost-efficient implementation of long term climate and Renewables targets, e.g. the EU Roadmap for moving to a competitive low carbon economy in 2050 or emerging MENA efforts in this regard.

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EUMENA GRID EXPANSION BY 2030 AND 2050

Building on current grid expansion planning in Europe and MENA, Dii's analyses illustrate the step-wise buildup of an overlay grid for a sustainable EUMENA power system in the coming decades.

2030: First HVDC highways and AC reinforcements

For the year 2030 load-flow based grid models with several hundred nodes and lines per country were applied. For regional and international grid extensions both AC and DC technologies were considered; interaction with the existing high voltage grid was explicitly included in the grid models. The build-up of a EUMENA overlay grid is expected to affect, in the mid-term, mainly the countries at the borders between Europe and MENA; therefore the 2030 grid analysis is focused on three trans-Mediterranean corridors, i.e. the Western corridor from Morocco and Algeria across the Iberian Peninsula up to France, the Central corridor from Algeria, Tunisia and Libya across Italy to its Northern neighbors and the Eastern corridor from Egypt and the Middle East across Turkey to the South-Eastern countries of the EU.

Figure 1 summarizes the results for the year 2030 and shows a first set of possible routes and the respective capacities of new HVDC lines, as well as areas with strong reinforcements of the AC grid.

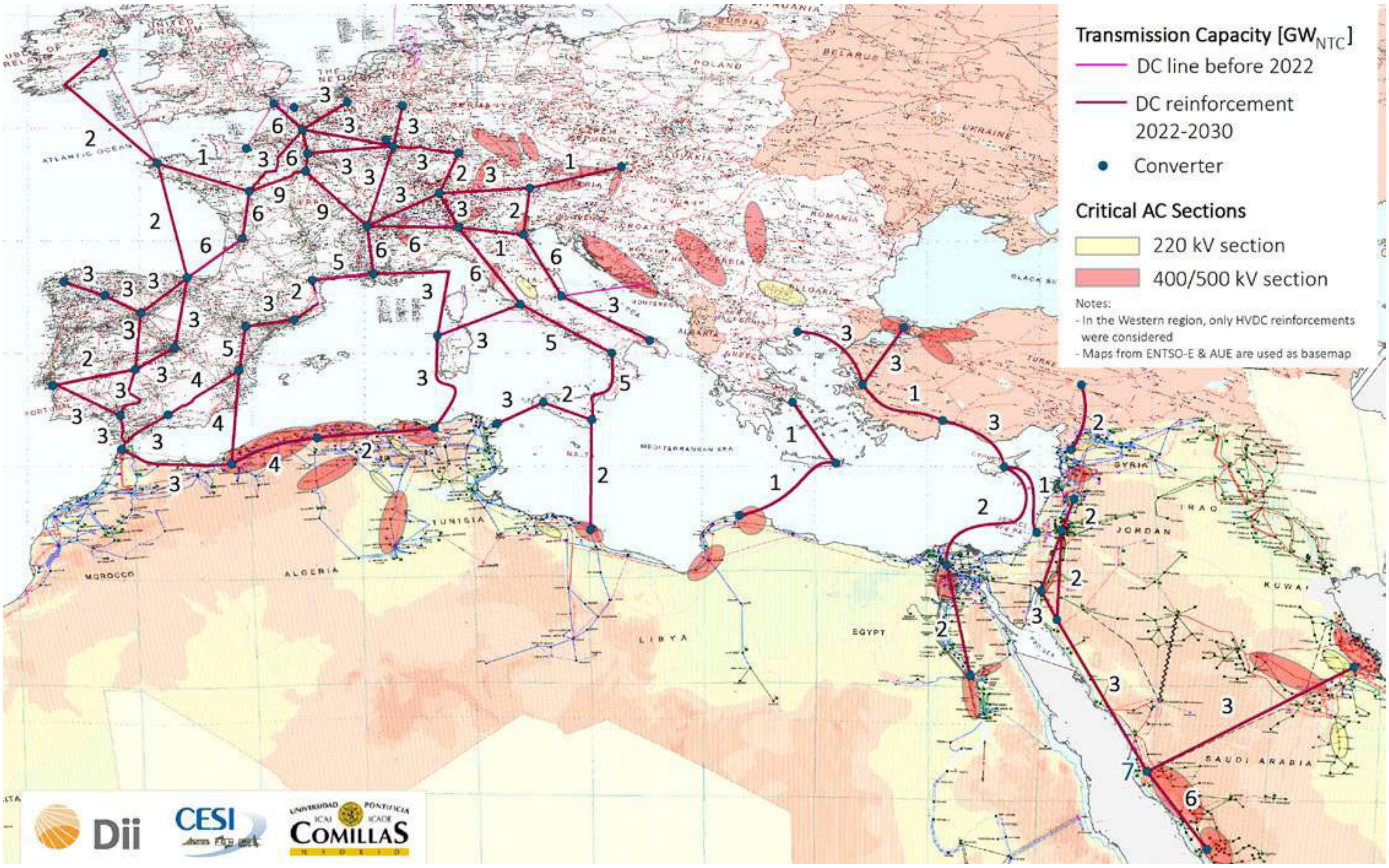

Figure 1 AC and DC reinforcements in EUMENA between 2022 and 2030 [GW_{NTC}]

2050: An EUMENA overlay grid

The analysis for the year 2050 was carried out from a more global perspective, i.e. the applied grid model was less detailed with up to 5 nodes per country. Nevertheless, important technical and economic characteristics of a future "overlay grid" that would connect the most favorable sites for electricity generation from renewables and the demand centers in the EUMENA region were identified. Figure 2 summarizes the results for the year 2050 and shows a first set of possible routes and the respective capacities of an HVDC overlay grid.

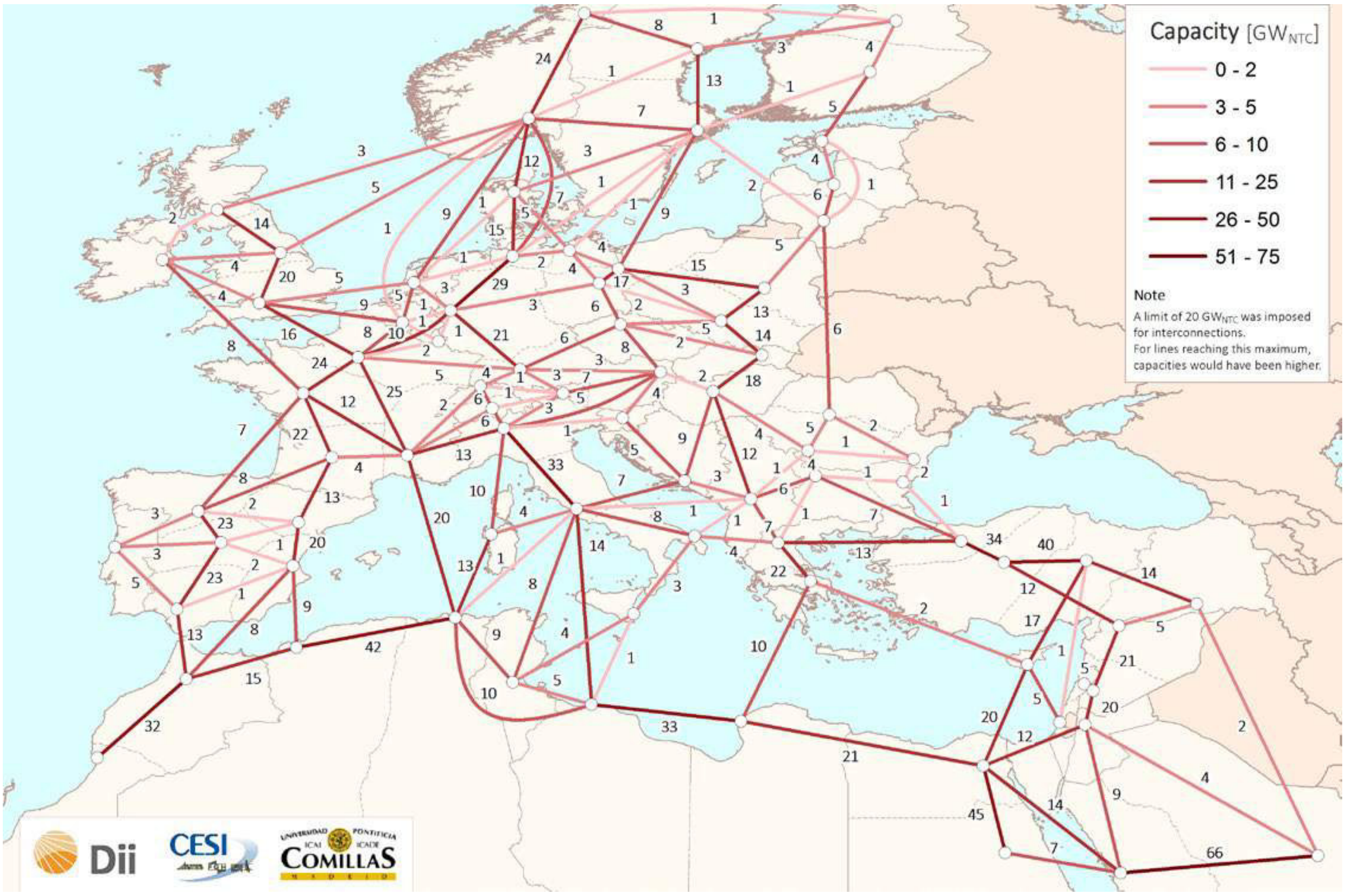

Figure 2 Line capacities of an EUMENA overlay grid by 2050 [GW$_{NTC}$]

Investment needs

Put briefly, investment for transmission infrastructure of an integrated EUMENA power system would amount to about €60bn by 2030 and €550bn by 2050.
While these are impressive numbers, grid investment is about 10% of overall power system investment in generation, storage and infrastructure.
Within both time periods, about 40% of total grid investments are dedicated for interconnections between countries. About half of these, 20% of the total grid investment, occurs for interconnectors between MENA and European countries. The remaining 50 to 60% of grid investments are dedicated to projects within countries. This means that new transmission grid capacities are not only required for the long-distance exchange of electricity across countries, but also for the connection of local renewables resources to national high voltage grids.
According to ENTSO-E's TYNDP2012, European TSOs plan investments for the transmission grid in Europe as a whole of €104bn between 2012 and 2022. Investment in the regions considered for Dii analysis for the Western, Central and Eastern corridors are in the range of €7-10bn. Comparing these investment plans with the investment of roughly €20bn for each of the three corridors calculated in our analysis for the decade 2020-2030, we can conclude that in most countries TSOs would increase their already ambitious level of investment, doubling (in the Western corridor) or even tripling (in the central corridor) the current level of investment.

HOW TO GET THERE?

Of course, the results of this modeling analysis only show one option for strongly reinforcing and interconnecting the power grids across Europe and the MENA region through a high voltage overlay grid. While reality as implemented by the TSOs will certainly look different, the analysis provides a better understanding of the extent of the challenge and of the main countries and regions affected. It is, on the one hand, intended to serve as a basis to further detail the concrete necessity, technical feasibility and economic viability of the variety of potential projects; on the other hand, it underlines the need for substantial progress and international coordination in planning, constructing, financing, and operating a future power grid. From Dii's perspective, this would entail the following short-, medium- and long-term measures.

Short-term until 2020

By 2020, it is desirable that projects included in the TYNDP and the MENA region master plans are fully implemented without undue delays. In order to demonstrate the techno-economic feasibility of HVDC links between North Africa and Europe, the implementation of the two projects from Italy to Algeria and Tunisia, as included in the TYNDP 2012, would be of great benefit.

Effective collaboration among TSOs in MENA and European countries will make the required exchange of information about the planning and operation of the electricity systems possible. The new European Regulation on guidelines for trans-European energy infrastructure already provides some improvements in this respect for EU member states. The quick development of first cross-Mediterranean interconnectors would greatly benefit from expanding the scope of this regulation towards projects with third countries.

Mid-term 2020 - 2030

In the mid-term, a strong infrastructure ramp-up and international policy convergence between MENA and European countries is assumed.

The exchange of significant amounts of energy on long distances will require the use of common rules not only for the operation of the power system, but also for the whole electricity market.

This includes, firstly, common network codes on security issues as well as on capacity allocation and congestion management practices to ensure the smooth operation of the network.

Secondly, international policies for the development of new transmission infrastructure are required. A starting point in this direction on the European side is the Regulation on guidelines for trans-European energy infrastructure providing favorable regulation and financing to Projects of Common Interest. This regulation should be expanded to all infrastructure projects between MENA and Europe.

In addition, common regional guidelines for transmission planning and investment cost allocation should be adopted. The European Union has made considerable progress in this respect over the last years. It is recommended that the countries in the MENA region also start to establish procedures for regional planning and cost allocation.

Finally, it is important that planning also starts to take place at an EUMENA-wide level. A first step would be for ENTSO-E to take into account grid developments and renewables potentials in the neighboring Mediterranean countries.

Long-term 2030 - 2050

In order to achieve a fully integrated power system, common EUMENA transmission policies are required for infrastructure development and operation.

This should entail the gradual establishment of a regional governance model for an EUMENA-wide transmission grid, including binding region-wide investment plans and network codes. In addition, a regional regulator would oversee the planning process, the enforcement of cost-allocation procedures, and network codes.

1 INTRODUCTION

Dii's mission is to support an accelerated deployment of Renewables in MENA as well as their integration in the growing electricity markets in the region and, ultimately, across EUMENA and beyond. With its 2012 and 2013 reports, *Desert Power 2050*[1] (DP2050) and *Desert Power: Getting Started*[2] (DP:GS), Dii showed that all countries in the EUMENA region would benefit from the synergies of an integrated power system largely based on Renewables. Integrating "desert power" from MENA will be one of the most effective options not only for contributing to security of supply and cost control of electricity, but also for reducing CO_2 emissions.

In order to facilitate the development of a power system that extends from Saudi Arabia to Finland in the East and from Ireland and the UK to Morocco in the West, Dii has already carried out several publicly available studies focusing on renewable potentials, regulatory and financing issues, economic and employment effects as well as required political and institutional frameworks for renewables.

Desert Power: Getting Connected (DP:GC) complements the previous work on the promotion of an integrated EUMENA power system and provides a clearer understanding of the requirements of a transmission grid infrastructure that would enable the efficient exchange of large amounts of electricity across the European and MENA power markets.

For sure, a EUMENA overlay grid will evolve gradually and, as for any grid development, a profound planning process is required. Some projects for the extension of interconnector capacities between Southern Europe and North Africa are already envisaged within ENTSO-E's Ten-Year Network Development Plan[3] (TYNDP) for the coming decade, even if reality shows, that a timely implementation of these trans-continental submarine links cannot be taken for granted. DP:GC provides an outlook beyond these plans, on the potential development of the transmission grid up to the years 2030 and 2050, which would facilitate an integrated EUMENA power system.

It is worth mentioning that the motivation for DP:GC wasn't to compete at the same level with sophisticated grid planning processes, which are the sole responsibility of transmission system operators (TSO) and ENTSO-E.

Nevertheless, DP:GC should rather be understood as a contribution to the emerging debates on an pan EUMENA overlay grid in a "high level" schematic way. Such overlay grid will not only increase the level of market integration in the entire EUMENA area. It will also allow for a secure and cost-efficient implementation of long term climate and Renewables targets, e.g. the EU *Roadmap for moving to a competitive low carbon economy in 2050* or emerging MENA efforts in this regard.

Since DP:GC aims only at initiating the debate among relevant stakeholders on the most appropriate grid infrastructure for the future, any (cost) figures and grid images should be seen within the context of most reasonable assumptions from a present perspective. Hence, the report does not claim to offer yet the accuracy that would be needed for detailed long term grid planning.

In this context the report at hand complements recent analysis carried out on behalf of Medgrid, which evaluated the effects on the European grid infrastructure, if electricity exchange between the two regions was intensified by the year 2025. Hence, in an upcoming report

[1] Dii. (2013). Desert Power 2050: Perspectives on a Sustainable Power System for EUMENA

[2] Dii. (2013). Desert Power: Getting Started. The manual for renewable electricity in MENA

[3] ENTSO-E. (2012). Ten-Year Network Development Plan 2012

Medgrid concludes that a set of several GW of interconnections from MENA can be efficiently and, without major internal reinforcements, easily connected to the European transmission grid.

Additionally, Friends of the Supergrid (FOSG) delivered with the regularly updated *Roadmap of the Supergrid Technologies* a mid- and long-term outlook on high voltage direct current (HVDC) technology developments and proved that technology will likely not be the show stopper for a European and EUMENA overlay grid, respectively.

The present report is based on the results of the extensive study "Pre-feasibility analysis on power highways for the Europe-MENA region integration in the year 2030 and 2050" carried out by a consortium of the Italian consultant CESI S.p.A. and the Spanish Institute for Research in Technology at Universidad Pontificia Comillas. Dii would like to acknowledge the work of the consortium and would also like to highlight the valuable contribution of its Shareholders ABB, Red Eléctrica de España, Terna S.p.A. and RWE as members of the grid study advisory group.

1.1 Report objectives and approach

The analysis of a cost effective EUMENA power system that was carried out for DP:GS is based on an optimization model for the power sector (i.e. no interdependencies between the power and e.g. the gas sector were considered) that represents each country with one node and HVDC interconnections between these country nodes. Even if such an approach has been applied in a number of similar system studies[4] most studies have focused on Europe and not on the MENA or even the EUMENA region. Hence, only some preliminary indications regarding the features of an overlay grid in the whole EUMENA region was provided so far.

Consequently, a specific and more detailed analysis of the power grid can help in identifying the technical and economic feasibility of these new interconnections. DP:GC steps in this vacuum and increases the level of detail for the grid infrastructure that would be needed to allow for the large power exchanges modeled in DP:GS for the mid- (2030) and long-run (2050).

Starting from today's transmission grid and the already planned grid extensions for the year 2022 as announced in the TYNDP 2012 and by MENA countries, DP:GC pursues a twofold approach for the years 2030 and 2050.

For 2030, load-flow based grid models with several hundred nodes and lines per country were applied. For regional and international grid extensions, both AC and DC technologies were considered and the interaction with the existing high voltage grid was explicitly included in the grid models. The analysis delivers a detailed picture of the main transmission corridors and related cost figures between EUMENA as well as the required grid reinforcements within the respective European and MENA countries. Since the build-up of an EUMENA overlay grid will in the mid-term mainly affect the countries at the borders between Europe and MENA, the 2030 grid analysis is focused on three trans-Mediterranean corridors, i.e.

- from Morocco and Algeria to Spain, Portugal and further to France (Western corridor)
- from Algeria, Tunisia and Libya to Italy and further to Central Europe (Central corridor) and
- from Middle East to Turkey and further to South-eastern Europe (Eastern corridor).

Compared to the sophisticated grid modeling for the year 2030, the analysis for

[4] e.g. McKinsey & Company (2010): Transformation of Europe's power system until 2050; European Climate Foundation (2010): Roadmap 2050

2050 was undertaken from a more global perspective i.e. the applied grid model was less detailed with up to 5 nodes per country. Nevertheless, important technical and economic characteristics of a future “overlay grid” that would connect the most favorable sites for electricity generation from renewables and the demand centers in the EUMENA region were identified.

Again, it is important to mention that DP:GC does not only cover the (submarine) interconnections between the two regions but also includes the high voltage grid reinforcements in the considered countries to materialize the transformation of today’s mainly fossil and nuclear based power systems to a system with a share of more than 90 % renewables in electricity production.

1.2 Report outline

A high degree of accordance with the power system configuration calculated for Dii’s *Desert Power: Getting Started* was an important boundary condition both for the above-mentioned grid study carried out by CESI and Comillas, and the present report. For this reason, **Chapter 2: Methodology and assumptions** summarizes the key findings and most important results of DP:GS. Further, Chapter 2 gives a short description of the applied grid models as well as additionally required input parameters for the technical and economic analysis of the identified grid reinforcement needs.

Chapter 3: Results 2030 and **Chapter 4: Results 2050** outline and discuss the results of the underlying grid study for the mid- and long-term horizon, respectively.

DP:GC concludes with **Chapter 5: Conclusions and recommendations,** where the technical and economic key findings of the analysis are placed in context with regulatory issues that can be derived from the study’s results.

2 METHODOLOGY AND ASSUMPTIONS

This chapter provides a glimpse of the DP:GS Connected Scenario, the source of the main boundary conditions of DP:GC as well as the models used, including their technical and economic input parameters.

2.1 DP:GS Connected Scenario in brief

In order to understand how the grid of a sustainable and cost effective EUMENA power system may look like in the mid (2030) and long term (2050), DP:GC has considered as input the results of the main scenario used in Dii's, *Desert Power: Getting Started* (DP:GS), i.e. the *Connected Scenario*.

This scenario identifies the milestones, in terms of generation and transmission infrastructure build-up, leading to a sustainable and cost effective fully integrated EUMENA approach by 2050.

The scenario assumes a strongly interconnected Europe and MENA power system with a generation mix made up of 93% renewables and 7% natural gas by 2050. National Renewable Energy Action Plans (NREAPs) in the EU member states have been considered for solar installations and a 70% rate of self-supply was imposed (for more detail, see 2.1.2).

As reference, the existing grid plus the planned grid reinforcements according to the ENTSO-E's Ten Year Network Development Plan TYNDP2012 (ENTSO-E, 2012) was used. Adopting a "one-node-per-country" approach, the DP:GS Connected Scenario has examined through a techno-economic optimization the generation mix and interconnection capacities required to ensure the match between demand and supply in EUMENA in every hour of a whole year, in each of the four time steps (2020, 2030, 2040, 2050) and accordingly determines the power flows between countries considered. The geographic scope of this analysis covers 42 countries, and extends from Saudi Arabia to Finland in the East and from Ireland and the UK to Morocco in the West.

Figure 1 shows the resulting evolution of the EUMENA power system.

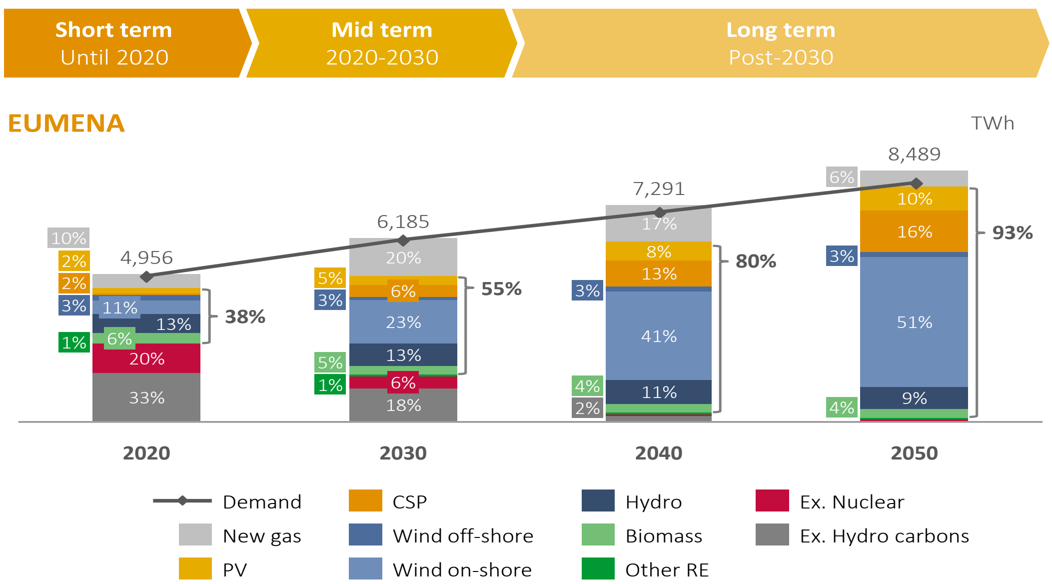

Figure 1 The transition to a sustainable integrated EUMENA power system

In the next paragraphs, the results issued from DP:GS for the two timeframes considered in DP:GC, 2030 and 2050 are highlighted. Further details about this scenario can be found in the full report of *Desert Power: Getting Started* pp. 49-119 (accessed free of charge under http://www.dii-eumena.com/publications/getting-started.html).

2.1.1 EUMENA power system by 2030

The power system calculated for 2030 was optimized for minimum system cost under a EUMENA carbon emission cap of 946Mtonnes p.a. while satisfying a demand of approx. 6,200TWh split to approx. 4,800TWh in Europe and approx. 1,400TWh in MENA.

Regarding the energy mix required to cover this demand, renewables would account for 60% in the electricity mix in Europe and 45% in MENA, leading to a share of renewable energy resources (RES) of 55% in the whole EUMENA region.

From a technology perspective, onshore wind would have the higher part of the renewables share with 23%, followed by concentrating solar power (CSP) with 6% and utility photovoltaic (PV) with 5%. The rest consists mainly of hydro power, biomass and geothermal. With the location and capacity mix considered by the model, this would require 180GW of RES capacities by 2030, distributed as shown in **Figure 2**.

For conventional generation, gas and hydrocarbon installations would account for 38% in the mix and 6% would be covered by nuclear power plants.

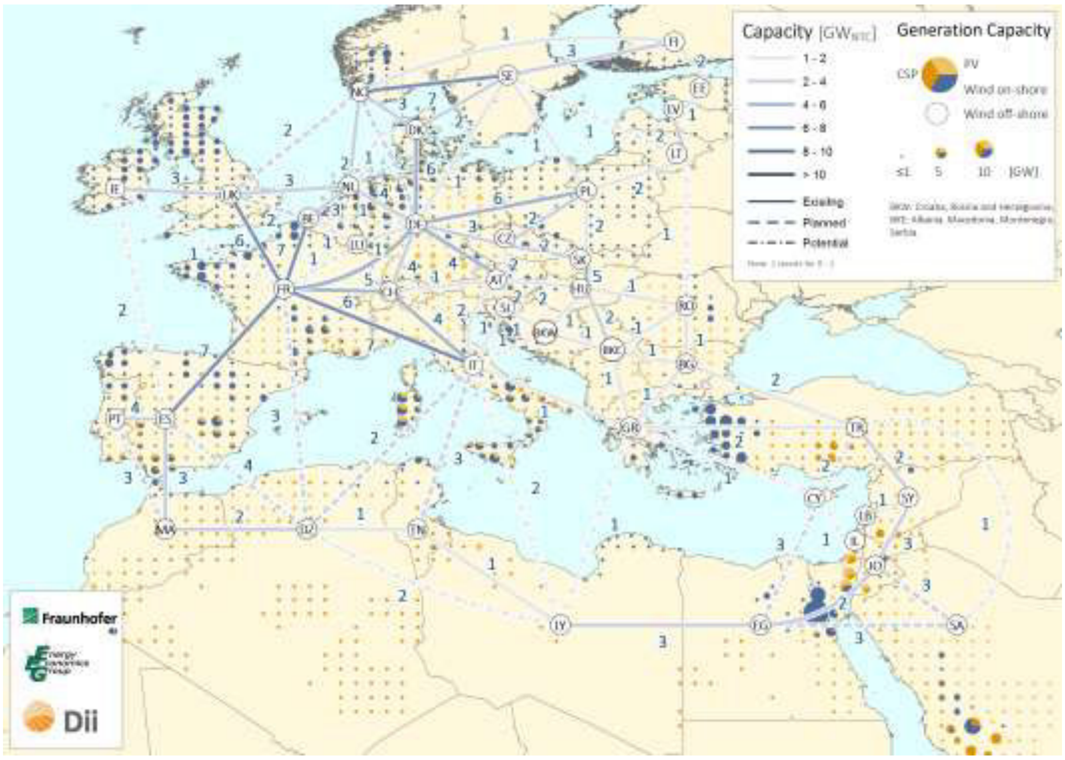

***Figure 2** Generation mix and grid infrastructure in the DP:GS Connected scenario by 2030*

Figure 2 also shows the interconnection capacities required to enable the associated power exchange. Connections of 2-3GW_{NTC} each, would connect seven countries on the Northern shore of the Mediterranean with eight countries in the South. In order to transport electricity from the interconnector's starting points on both sides of the Mediterranean, intra-European and intra-MENA grids are essential.

This infrastructure would ensure gross power flows between countries of approx. 600TWh, which represents approx. 10% of the overall energy produced. Total electricity exchange between MENA and Europe would reach 120TWh with a focus on the South to North direction where power flows represent 70% of the total exchange.

2.1.2 EUMENA power system by 2050

By 2050, the underlying DP:GS Connected Scenario looks at an optimal EUMENA system able to achieve an almost complete decarbonization with a maximum carbon emission cap of 194Mtonnes p.a.

Figure 3 shows countries generation mix and the interconnection capacity required by 2050.

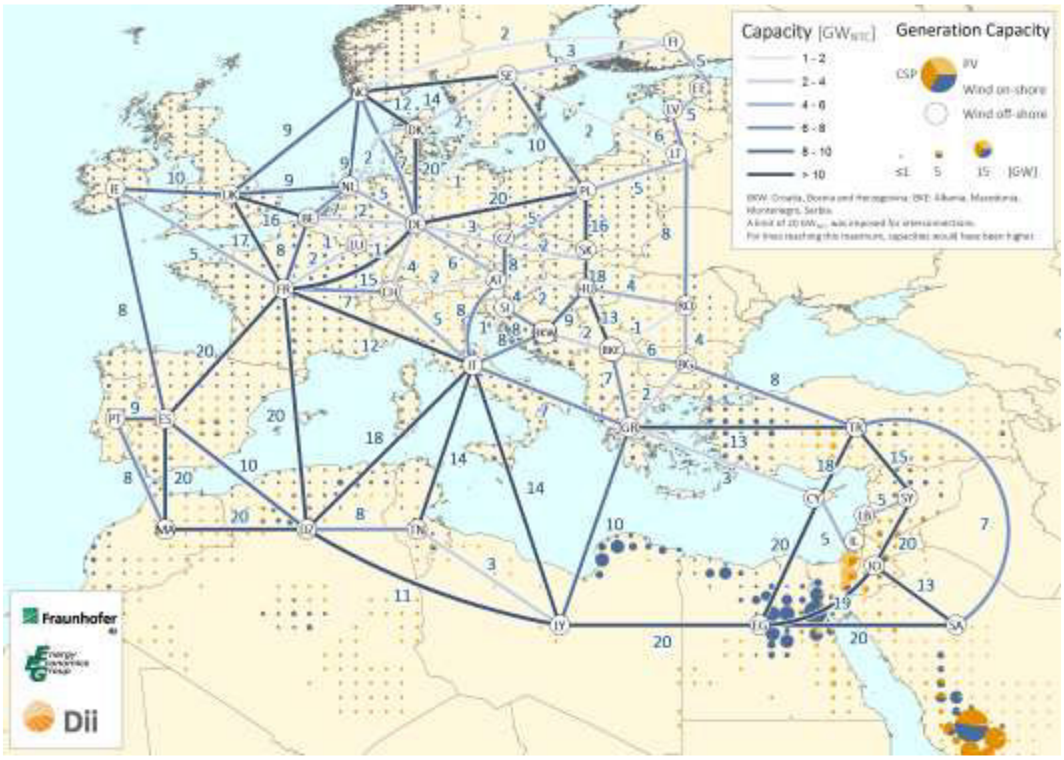

***Figure 3** Generation mix and grid infrastructure in the DP:GS Connected scenario by 2050*

This system would be powered by 93% RES and 7% natural gas. MENA would see an almost complete phase out of conventional generation, while gas power plant capacities would be used only for balancing and reserves. The remaining conventional generation is concentrated in Europe. While more than half of the generation would be produced by onshore wind, solar would contribute with a 26% share, divided between CSP (16%) and PV (10%).

In terms of grids, the expansion suggested would lead to a situation by 2050 in which each corridor in the west, center and east of the Mediterranean would consist of 45 to 60GW_{NTC} of interconnections between MENA and Europe.

Such a geographically balanced increase of interconnection capacities would facilitate an exchange of electricity between Europe and MENA of approx. 900TWh p.a. It should be noted that this value is limited by the upper limit of $20GW_{NTC}$ applied to the interconnections between each two countries.

Overall electricity exchange could increase six-fold from 2030 to 2050, from 600TWh to more than 3,650TWh where net European imports would reach 570TWh, just below 10% of projected European demand.

2.2 Grid Model applied

2.2.1 General description of models used

Figure 4 gives a general overview of the models used in this study.

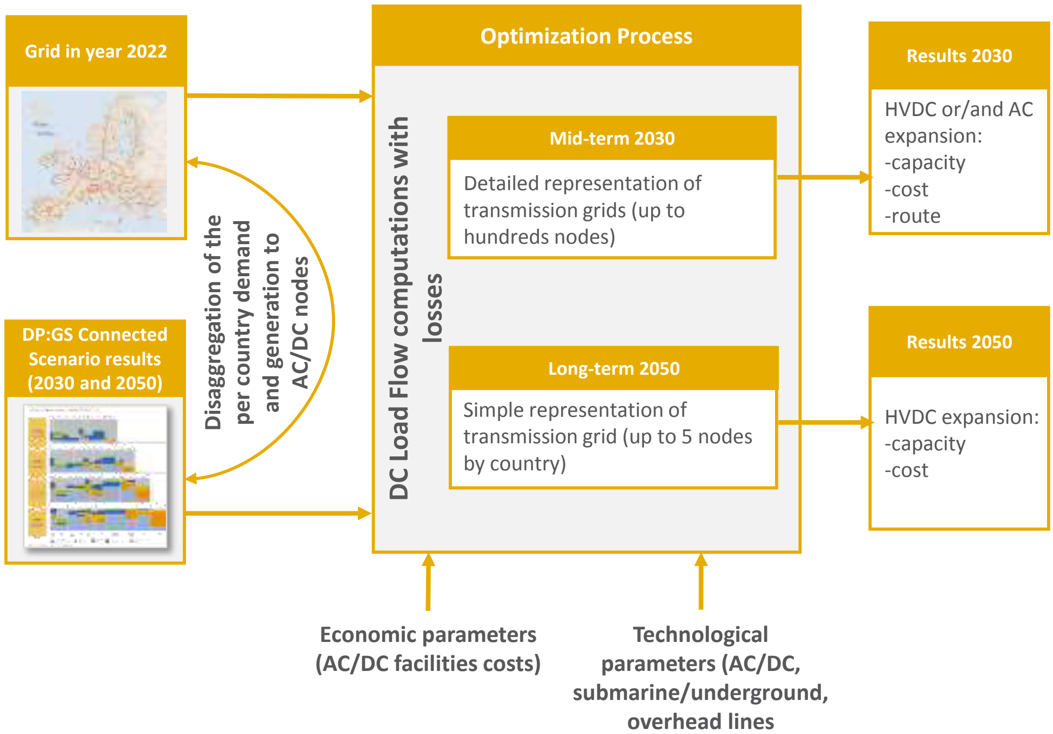

Figure 4 General description of the models used

As a starting point for the models, the planned transmission grids for the year 2022 have been considered. For the European countries, the transmission system was based on ENTSO-E's TYNDP 2012. Regarding the development in MENA countries in the coming decade, country master plans were taken into account, in addition to the consultants' experience in the region.

In order to define regional demand and power generation, the results of the DP:GS Connected Scenario were adopted. Therefore, country demand profiles, generation expansion plans at country level and energy cross-border exchanges for the 2030 and 2050 horizons were used as an input. To adapt these input parameters to the DP:GC models, the country level values were disaggregated and distributed between nodes considering:

- For the demand, the current distribution of load centers.
- For the conventional generation, a similar distribution as the current one, with the consideration of the installation and/or retirement of some forecasted units.
- For renewables, the generation by technology, based on 50-by-50km Dii's GIS analyses, the geographical characteristics and the maximum capacity allowed for each technology.

In a second step, an optimization process was carried out based on a set of DC load flows. Taking into consideration the different time scopes of the study, i.e. the years 2030 and 2050, two different modeling approaches were used. The main difference between the two models consists in the level of detail used to represent the transmission grids.

For the year 2030, a sophisticated approach was adopted. Given that the time scope is only 15 years far away, imperative regions were described by their high voltage AC grid, represented by hundreds of nodes.

For the year 2050, countries were disaggregated in up to 5 macro-areas, linked with HVDC interconnectors.

Finally, optimal reinforcements were selected and their related capacities, technologies and routes were given. Generally, HDVC technology was favored for the new connections in order to ease calculations using Net Transfer Capacity (NTC) values. This choice is deemed to be in harmony with the pre-feasibility stage of the study and would not harm the quality of the results. In more detailed planning studies, AC-technology could be the technology of choice in certain cases.

Still, to guarantee consistency of results, the reinforcements identified in the mid-term horizon up to 2030 have been considered in the 2050 analyses.

2.2.2 Modeling approach for the year 2030

For the mid-term (2030), the analyses shed light on the 3 electricity corridors ensuring the electricity exchanges between both sides of the Mediterranean: the Western, the Central and the Eastern corridors.

- For the Western corridor, Portugal, Spain and France are the main focus of the analyses. In addition, in order to take into account power-exchanges, Morocco, Algeria and the neighboring countries in Europe have also been considered.
- For the Central corridor, Italy is the focus of the analysis. However, in order to consider the power flows up to Central Europe, Austria and Switzerland were also considered, as well as interconnections to the South of Germany. Moreover, Algeria, Tunisia and Libya potential reinforcements were qualitatively assessed.
- For the Eastern corridor, Turkey is the focus of the investigations. Again, in order to consider the power flows up to Central Europe, the Balkan region and Eastern Europe up to South Germany have also been inserted in the model. Furthermore, MENA countries in this region have been considered with more details. A quantitative assessment for them is reported.

The grid characteristics in these 3 regions present some relevant differences.

In the Western corridor, several potential interconnectors could link North Africa to Europe (see **Figure 2**). Consequently, potential links including Morocco-Portugal, Algeria-Spain, Algeria-France were examined considering the power system's operation in all hours of the year.

This characteristic is not present to the same extent in the Central and Eastern corridors. In a first stage, Italy is the only European country to be connected to North Africa and, in the latter, the Middle East area represents a narrow corridor for transmitting power from MENA to Eastern Europe.

Therefore and based on Spanish and Italian TSOs feedback (REE and TERNA), two modeling approaches were adopted. While for the Central and Eastern corridors, both AC and DC reinforcements were analyzed, in the Western corridor all grid reinforcements after 2022 were assumed to be implemented with HVDC technology. It is worth mentioning that these different approaches may be considered as case studies aiming at identifying two different options for a cost-effective grid infrastructure by 2030.

In the next paragraphs, the two approaches will be explained further.

Western corridor

The transmission expansion for the Western corridor has been deemed to consist of a set of HVDC links making a meshed network that overlaps with the existing AC grid. This HVDC grid will be built connecting several selected nodes already existing in the AC grid. These up to 11 super-nodes (in the case of Spain) per country are well connected with the existing AC network and are therefore well suited to be crossed by important power flows.

In order to carry out the optimization process, the Spanish Institute for Research in Technology at Universidad Pontificia Comillas (IIT Comillas) adapted and updated its model TEPES[5], which has been used in several EU projects in the past. This model minimizes total network investment and operational costs subject to a set of constraints including mainly node energy balances, energy exchanges among countries and regions and line flow capacity limits.

Computations of DC load flows with losses were applied to a set of 70 snapshots, which cover all major demand, generation and power flow configurations that may occur in the system over the whole target year[6].

In order to compute an optimal HVDC grid, a large set of possible candidates (both AC/DC converters and lines) to be built are provided as an input to the TEPES model. The model selects those that should be built to minimize total costs while complying with boundary constraints and ensure that no overloads would occur. It should be mentioned that neither the N-1 criterion nor dynamic analyses were considered, as these aspects are beyond the scope of this pre-feasibility study.

Central and Eastern corridors

In the Central and Eastern corridors, the transmission system was represented with a so called “bus-bar” model. This model includes thousands of nodes interconnected by high and extra-high voltage AC and DC lines.

Starting from the reference network, a load flow analysis has been carried out using the PSS/E® tool in order to determine the power flows and the possible bottlenecks with respect to the transfer capacity. These grid assessments were performed adopting the “DC load flow” algorithm; dynamic has not been modeled.

The generation dispatch has been based on the merit order of the generating units in relationship with the primary resources and the assumed technologies. Whenever a bottleneck is detected in the reference grid, the transfer capacity is increased choosing the optimal mix of reinforcements between AC and DC technologies in order to relieve the detected overloads and minimize the investment costs. For that aim, three snapshots representing the most binding situations for the network were simulated sequentially:

- Maximum transit from MENA: identification of the network reinforcements necessary to deal with high level of imports from South to North.
- Peak load conditions: in presence of the reinforcements identified in Step 1, the additional infrastructures necessary to deal with the maximum load conditions are identified.
- Maximum transit to Central Europe: in presence of the reinforcements identified in the two previous steps, the additional infrastructures necessary to manage high level of power flows towards Central Europe are identified.

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[5] http://www.iit.upcomillas.es/aramos/TEPES.htm

[6] The choice of the snapshots was carried out via a clustering analysis based on the K-means algorithm

2.2.3 Modeling approach for the year 2050

Given that 2050 is nearly four decades away and many uncertainties exist, a simplified grid modeling approach was used for the long term scenario and the level of detail was decreased. Instead of considering the whole transmission grid, countries were divided in 1 to 5 macro-areas. The number of macro-areas within each country was derived by considering the size of the country, generation and demand distributions and the AC grid characteristics. Generally, the larger the country, the higher the number of nodes that is considered.

As shown in **Figure 5**, each macro-area was represented by one node (bus-bar) chosen among the strongest nodes presented in the area, based on the meshing of the AC grid and the short circuit power.

The nodes, characterized by their load and generation, were interconnected with HVDC lines whose starting transfer capacities were assigned in a conservative way taking into account the power grids configurations as well as their operational aspects.

In order to obtain the reinforcements between macro-areas at the minimal total investment and operational costs, an optimization process was carried out by IIT Comillas with its TEPES model. For simulation 80 representative snapshots were applied to cover possible situations for production, demand, and usage of main interconnection lines among countries.

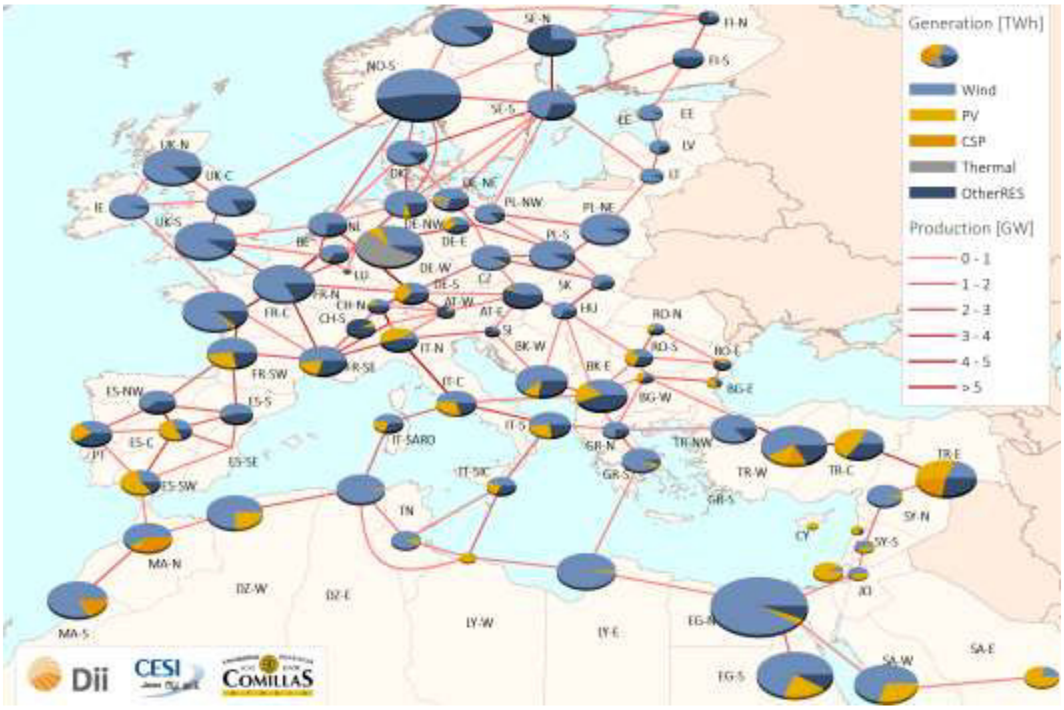

__Figure 5__ The reference power system used for the 2050 grid analysis

2.2.4 Input parameters of DP:GC

Input parameters for the 2030 analyses

For the HVDC reinforcements, the VSC technology with a bipolar configuration of +/-500kV was adopted for the optimization. For all lines' type considered, i.e. overhead, underground and submarine, investments have been assumed of a discrete size, ranging from 1 to 3GW in steps of 1GW. O&M costs were expressed in percentage of the investment costs for each year of the component life.

Table 1 presents the DC investment and operation costs, as well as losses at rated power. We note that these costs were suggested by the consultants based on their experience and could be subject to certain uncertainties due to the large time scope of the study. Furthermore, the costs considered in DP:GC refer to the value of money in 2012. A reserve margin of 20% has been assumed for HVDC lines and considered as an increase of a similar percentage in NTC costs.

Transmission component (HVDC 500 kV (+-)	Investment costs	O&M costs (p.a. in % of investment costs)	Losses (% of rated power)
Overhead line	0.6 M€/km	1%	6.6%/1000km
Submarine cable 3GW	3.4 M€/km	0.1%	3.6%/1000km
On-land cable 3GW	3.7 M€/km	0.1%	3.6%/1000km
AC/DC converter 3GW (one terminal)	225 M€	1%	0.7%

Table 1 *Investment and operation costs for HVDC facilities*

For the AC reinforcements, overhead 220kV and 400kV double circuits were considered with capacities of approx. 1,300MVA and 3,400MVA respectively. **Table 2** shows the associated costs, varying in accordance to the land mix considered based on topological estimates.

	Cost of a double circuit in k€/km	
	220kV	**400kV**
Italy	330	840
Austria	390	990
Switzerland	420	1,060
South Germany	330	810
MENA countries	260	650
Turkey	300	750
Eastern Europe	280	700

Table 2 *AC transmission lines costs*

In addition to the AC lines costs, it is necessary to consider the costs related to the extension of the already existing substations. The values considered in the analyses are those reported in **Table 3**.

Similar to DC overhead lines, 1% of the annual investment was considered for O&M costs. For losses, a distinction was made between Europe and MENA given the different characteristics of their networks in terms of meshing and line length. Subsequently, 1.5% of the total energy was estimated for Europe and 1.8% for MENA. Furthermore, for AC lines crossing long distances, a value of 14% of total flowing energy per 1000km was considered. The cost of losses was calculated for each country referring to the electricity costs in DP:GS Connected Scenario and averages 61€/MWh.

For the reserve margins, a security coefficient of 33% has been adopted for both lines and transformers.

Finally, for both AC and DC components, investment costs were annualized considering an economic technical lifetime of 40 years and a discount rate of 7.5%.

Component	Investment cost [k€]
Converter and Line (400 kV) bay	1,750
Line (220 kV) bay	1,300
Transformer Bay	1,420
450 MVA transformer	4,750
Auxiliary	2,050
SCADA - control system	3,100
Connections	300

Table 3 *Substation's extension costs*

Input parameters for the 2050 analyses

By 2050, super-nodes representing macro-areas are assumed to be connected through an HVDC grid based on both on-land and submarine transmission lines. In line with the input parameters, interconnection capacities among countries were limited to 20GW_{NTC}. Except for geographical or socio-political reasons in some areas, this limitation has not been applied to internal transmission lines where large production needed to be transported across some countries to feed load centers.

For on-land lines, a fraction of 50% in Europe and 10% in MENA of underground cable has been considered.

In each macro-area, a single DC/AC converter was considered, sized according to the annual maximum net value of demand and generation output in this macro-area, i.e., the maximum net flow imported or exported.

For the economic assessment, **Table 4** provides the main economic input parameters characterizing the development of the transmission network as well as its operation. The assumed investment costs for each network technology are based on the estimation of Dii partner company experts from TSOs and technology providers. These costs are annualized considering the same assumptions as in 2030, i.e. a lifetime of 40 years and a discount rate of 7.5%.

Technology	Transmission Type	Investment costs	O&M costs (p.a. in % of investment costs)	Losses (% of rated power)
HVDC 3 GW, 800 kV (+-)	Converters (1 terminal)	270 M€	1.00%	0.70%
	Overhead line	0.9 M€/km	1.00%	1.60%
	Underground cable	4.1 M€/km	0.10%	1.60%
	Submarine cable	3 M€/km	0.10%	1.60%

Table 4 *Technical and economic input parameters for the 2050 scenario*

3 RESULTS 2030

This chapter summarizes the technical and economic results of the analysis in the medium term (2030) for each of the 3 corridors analyzed: the Western, the Central and the Eastern Corridors.

3.1 Western corridor

The analysis conducted for the Western corridor is focused on the power systems of Portugal, Spain and France. Furthermore, flow exchanges with neighboring countries have been included, covering Morocco and Algeria in MENA and the UK, Ireland, Belgium, Luxemburg, Switzerland, Italy and Germany in Europe.

Starting from the network as planned for the year 2022, the network expansion planning tool TEPES has determined the HVDC and AC/DC converters reinforcements leading to the lowest possible costs for the 2030 horizon.

3.1.1 Technical results

Figure 6 displays the HVDC grid required in 2030 in the Western corridor including lines that are planned to be in place by 2022, as well as those that would need to be built by 2030.

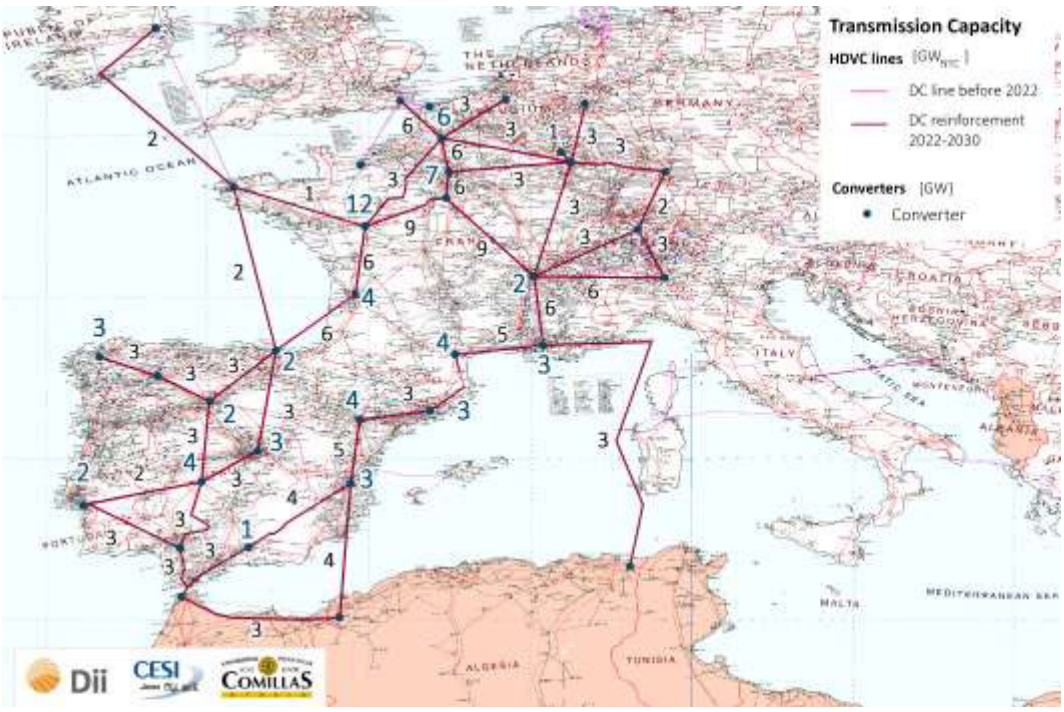

***Figure 6** HVDC lines and converters capacities in the Western corridor by 2030*

By 2030, a total of 152GW$_{NTC}$ of HVDC capacities and approx. 54,000GW$_{NTC}$*km would be built in the Western corridor and neighboring countries. Approximately, 95% of the interconnectors have a size equal or below 6GW$_{NTC}$.

In order to further analyze the main links required and their role in power exchanges, **Figure 7** provides the amount of gross electricity flows and the direction of the net electricity exchange balance between different nodes.

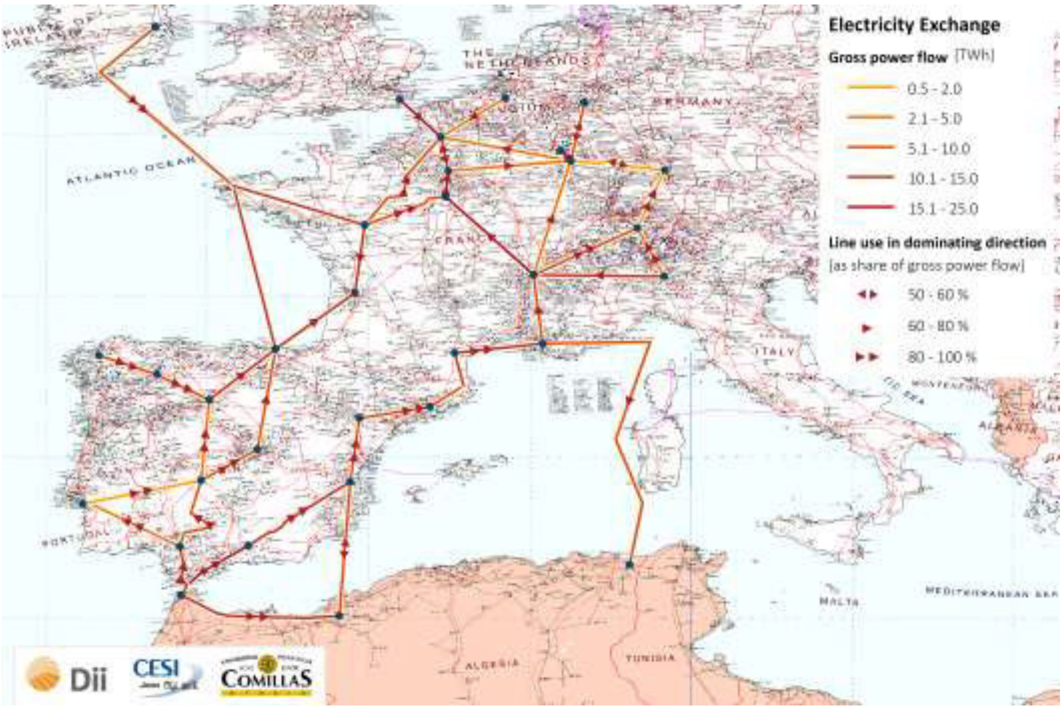

***Figure 7** Electricity exchanges between regional nodes in the Western corridor by 2030*

The backbone of the grid will be constituted by important links, on one hand between countries and on the other hand among internal power systems nodes:

Among North Africa and Europe, four 3-4GW_{NTC} HVDC interconnections would be built in order to exchange electricity between both shores of the Mediterranean. While the 2 lines connecting Morocco with the Iberian Peninsula would serve mainly to export power northwards, the 2 remaining ones would be used to exchange power between Spain and France on one side and Algeria on the other side. The loop is closed with a 3GW_{NTC} interconnection inside North Africa linking Morocco to Algeria.

Between North Western and Central Europe, 2 new submarine connections would be necessary to import power from the North characterized by good wind conditions. A first 2GW_{NTC} link would connect Ireland to Spain through France and serve to feed load in the North of Spain and partially France. A second 6GW_{NTC} interconnection would link the UK to France and supply directly the Paris area.

Between Spain and France, electricity would be exchanged via a new 6GW_{NTC} interconnection that would reinforce the 4GW_{NTC} planned for the year 2022.

With Central European countries, France would be linked directly or indirectly to its eastern neighboring countries in order to exchange electricity through several connectors with capacities up to 6GW_{NTC}.

Inside the Iberian peninsula, 3 highways with capacities between 3 and 5GW_{NTC} transit the excess power coming mainly from the Western and Southern areas and feed the main internal load centers, located especially in the North eastern part of Spain. In total, approx. 8,200GW_{NTC}*km of lines and 27GW of converters would be built by 2030 in both Spain and Portugal.

Within France, 2 large highways with capacities reaching 9GW_{NTC} would be built in western and eastern sides of the country participating in feeding large loads mainly in the North through a meshed network around Paris. Moreover, the eastern interconnector is used to transit electricity eastwards to Germany via Switzerland. As a result, approx.

13,800GW_{NTC}*km of HVDC lines and 41GW of converters would be needed.

For all country-to-country interconnections, capacities in the period 2022-2030 would need to be increased by 50% referring to those that would exist in 2022 passing from approx. 37GW_{NTC} to 60GW_{NTC}.

The lines built in the Western corridor would be used with a rate slightly higher than the current average utilization factor of the Spanish grid, which is about 20-25%. Higher utilization factors occur in the interconnectors among countries, including the interconnector between Spain and France on the eastern side of the border (64%) and the link between France and the UK (46%).

3.1.2 Economic results

The costs of the HVDC grid expansion in the Western corridor were calculated based on the economic input parameters presented in section 2.2.4.

Country/ interconnection	HVDC investments [M€]
Portugal	0 (150)
Spain	1,909 (1,875)
France	3,289 (3,075)
Portugal - Spain	438
Spain-France	1,314
Spain-Morocco	414
Spain-Algeria	1,134
Spain – Ireland	2,458
France – Algeria	4,230
France – Italy	910
France-Switzerland	303
France-Germany	364
France-Luxemburg	32
France-Belgium	127
France-UK	582
France-Ireland	878
Morocco-Algeria	308
Germany-Switzerland	176
Italy-Switzerland	218
TOTAL HVDC	**19,084 (5,100)**

Table 5 *Total costs of the HVDC overlay grid in the Western corridor by 2030 (converters in brackets)*

The results within different countries as well as between interconnections are shown in **Table 5**. It is worth mentioning that for Portugal, only reinforcements in interconnections are needed and hence no internal line capacities are required. Costs presented are in 2012 values.

Regarding the interconnectors among countries, the most expensive are those covering long submarine paths in order to avoid high-depth waters in the Mediterranean Sea. This applies to the interconnectors France-Algeria, Spain-Ireland and Spain-Algeria. Evidently, the challenging submarine link Algeria-France could be substituted by a connection across Spain, but would increase the burden on building lines in Spain even more. The interconnector between France and Spain requires high investments as well, due to its capacity and to the need to be built as a cable (submarine and underground).

The total investment costs of converters in Portugal, Spain and France represent 20% of total investment costs and amount to approx. €5.1bn.

In total, approx. €24.2bn of grid investments would be required in the period 2022-2030, representing approximately the double of what was deemed to be necessary in the decade before 2022 (approx. €11.3bn).

3.2 Central corridor

The analysis of the Central corridor is focused on its geographical backbone, i.e. the Italian peninsula and the submarine interconnections between Italy and North Africa (Algeria, Tunisia and Libya). Furthermore, required grid reinforcements in the neighboring regions of Switzerland, Austria, Southeast France and Southern Germany as well as the above-mentioned North African countries are identified.

Three alternatives of submarine interconnections between Italy and North African countries were analyzed in detail. The starting and ending points of the interconnectors were identified in a way that the HVDC overlay grid can interact with the AC grid in the most efficient way, i.e. they are located at already existing strong AC nodes with high demand and conventional generation capacities. However, different rationales for the three options were applied to test the effects of, e.g., a minimization of submarine or land connections on the results.

Table 6 shows the starting and ending points of the interconnectors for the three options. Since the HVDC nodes in Sardinia (Fiume Santo and Selargius) and Sicily (Partanna and Priolo) allow only limited electricity exchanges between the HVDC and AC system they may be considered as hubs to mainland Italy. Hence, **Table 6** also shows the ending points at the Italian mainland in Montalto and the area of Milan.

	Algeria – Italy	Tunisia – Italy	Libya – Italy
Option I	Koudiet Draouch – Fiume Santo / Montalto / area of Milano	Mornaguia – Montalto	Mellitah – Montalto
Option II	Koudiet Draouch – Fiume Santo / Montalto	El Haouaria – Partanna	Mellitah – Priolo
Option III	Koudiet Draouch – Fiume Santo / Selargius / Montalto	Mornaguia – Cagliari	Mellitah – Priolo

Table 6 *Options investigated for the interconnections North Africa – Italy (Central corridor)*

3.2.1 Technical analysis

Based on the planned grid topology of the AC high voltage grid by the year 2022 and the required interconnector capacities between two countries according to DP:GS, three snapshot analyses were carried out for each option. If a line was congested, the model “decided” whether the buildup of an HVDC overlay grid section or the reinforcement of the existing AC grid would be more reasonable from an economic point of view. As a result, the target grid 2030 was designed in a way that the detected load flows could be managed technically and possible congestions in the AC grid are relieved cost-efficiently.

In the following figures, the basic topology of the 3 HVDC overlay grid options in Italy and Central Europe is shown. The figures also include the length and capacity of the DC lines (red) and the capacity of the converter stations in each node (blue).

Figure 8 Grid reinforcement Central corridor Option I

Figure 9 Grid reinforcement Central corridor Option II

Figure 10 Grid reinforcement Central corridor Option III

In all, the differences in the results between the three options are rather small. In total, the installation of about 20,000GW$_{NTC}$*km of HVDC lines and 35 - 38GW of DC converter stations are required. Depending on the routing of the EUMENA interconnectors, between 10,000 (Option I) and 13,000GW$_{NTC}$*km (Option III) of HVDC lines are built in Italy and between 3,000 (Option III) and 6,000GW$_{NTC}$*km (Option I) are submarine interconnectors from North Africa to Italy. In contrast, only a limited number of HVDC lines between Italy and Central Europe (2,300GW$_{NTC}$*km) and within Central European countries (approx. 1,400GW$_{NTC}$*km) are necessary to comply with DP:GS results for 2030. In North Africa about 2,600GW$_{NTC}$*km of HVDC lines and 12GW of DC converter stations are required to transport electricity to and from the interconnectors to Italy but also to exchange electricity from renewables between the countries.

Besides the build-up of an HVDC overlay grid, the existing AC grid needs to be reinforced to manage the electricity exchange with the HVDC grid but also the integration of the additional generation from local renewable energies. **Table 7** reports the required reinforcements of the 220/400 kV transmission grid to relieve the critical sections in the AC grid.

Option	I	II	III
Italy	440	540	590
Austria	400		
Switzerland	570		
South Germany	580		
North Africa	2,800		

Table 7 *220/400 kV AC reinforcements [km] – Central corridor*

Similar to the build-up of the HVDC grid, the AC reinforcements are rather the same in all of the three options. Due to the strong build-up of renewables generation capacities in North Africa by 2030, the requirements for the reinforcements of the AC grid are significantly higher in North Africa than in Italy and Central Europe. Critical AC sections would be mainly in coastal areas of Algeria and

Libya. **Figure 11** shows the identified critical sections in the North African AC grid as well as the identified HVDC line and DC converter station capacities.

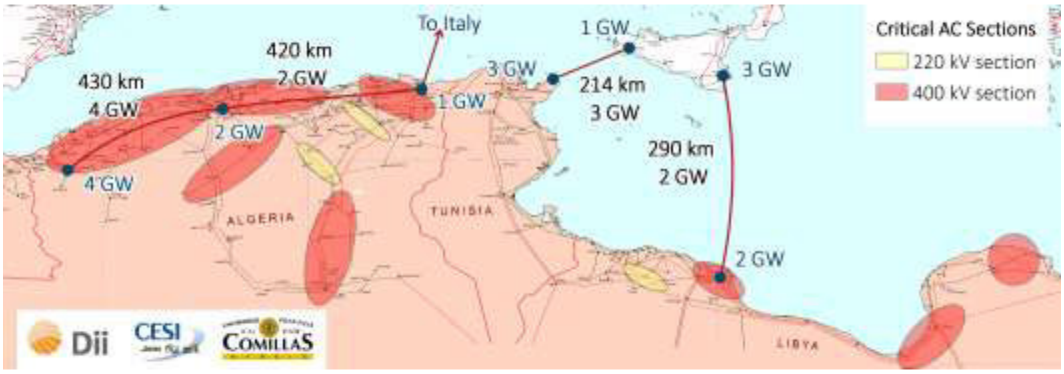

***Figure 11** Critical sections for AC grid in Algeria, Tunisia and Libya*

3.2.2 Economic analysis

Based on the identified network expansions and the investment parameters as defined in section 2.2.4, the total investment costs for the three Central corridor options can be calculated. **Table 8** gives an overview of the investment costs for the new HVDC lines and converter stations. Additionally, the investment costs for the reinforcement of the AC grid are considered for each country and region.

	Option I	Option II	Option III
Italy	5,700 (300)	5,800 (400)	5,400 (500)
Sardinia/Sicily - Mainland Italy	1,600 (-)	2,000 (-)	3,200 (-)
North Africa - Italy	6,800 (-)	3,300 (-)	3,600 (-)
Switzerland	700 (600)	700 (600)	700 (600)
Austria	600 (400)	700 (400)	600 (400)
South Germany	300 (500)	300 (500)	300 (500)
South-East France	400 (-)	400 (-)	500 (-)
North Africa	1,700 (2,300)	1,700 (2,300)	1,700 (2,300)
TOTAL HVDC and AC	**22,000**	**19,200**	**20,400**

***Table 8** Investment costs for HVDC lines and DC converter stations in the Central corridor as well as AC reinforcements (in brackets) [M€]*

Corresponding to the results for the total grid capacity requirements, the results for the total investment costs are also quite similar for the three options modeled and analyzed in detail. However, due to its smaller share of submarine cables, option II (interconnections from Algeria and Tunisia directly to Sicily) would require lowest investment cost, estimated at €19.2bn, for the period between 2022 and 2030.

On the contrary, Option I with submarine interconnections up to the North of Italy requires slightly higher investments (+15%), but might be the option with fewer environmental impacts due to the reduced share of overhead lines in Italy.

For European countries (including the interconnections), approx. €15bn of grid investments would be required in the least cost option. Comparing to what would be required in the decade before

2022 (€5.2bn), level of investments would need to be tripled.

Finally, total operational costs (including cost of losses) for all options equal about €0.6bn p.a., of which 1/3 occur in North African countries.

3.3 Eastern corridor

For the Eastern corridor the analyses focused on Turkey, including the submarine interconnections with North Africa. In order to consider the power flowing up to Central Europe, countries in Eastern Europe and the Middle East have also been analyzed.

3.3.1 Technical analysis

Similarly to the Central corridor, HVDC and AC reinforcements were assessed in the Eastern corridor. The only difference consists in the number of options analyzed regarding submarine links. In the Eastern corridor only one option for the submarine interconnections from Egypt, Libya and Israel to Turkey and Greece has been considered. This is due mainly to the morphology of the Mediterranean Sea in terms of sea depth, which does not allow many alternatives for the submarine interconnections routes.

Figure 12 shows a preliminary proposal of the submarine cables routes as well as the reinforcements required in terms of HVDC lines and converters, while **Figure 13** shows the regions where strong AC reinforcements would be necessary.

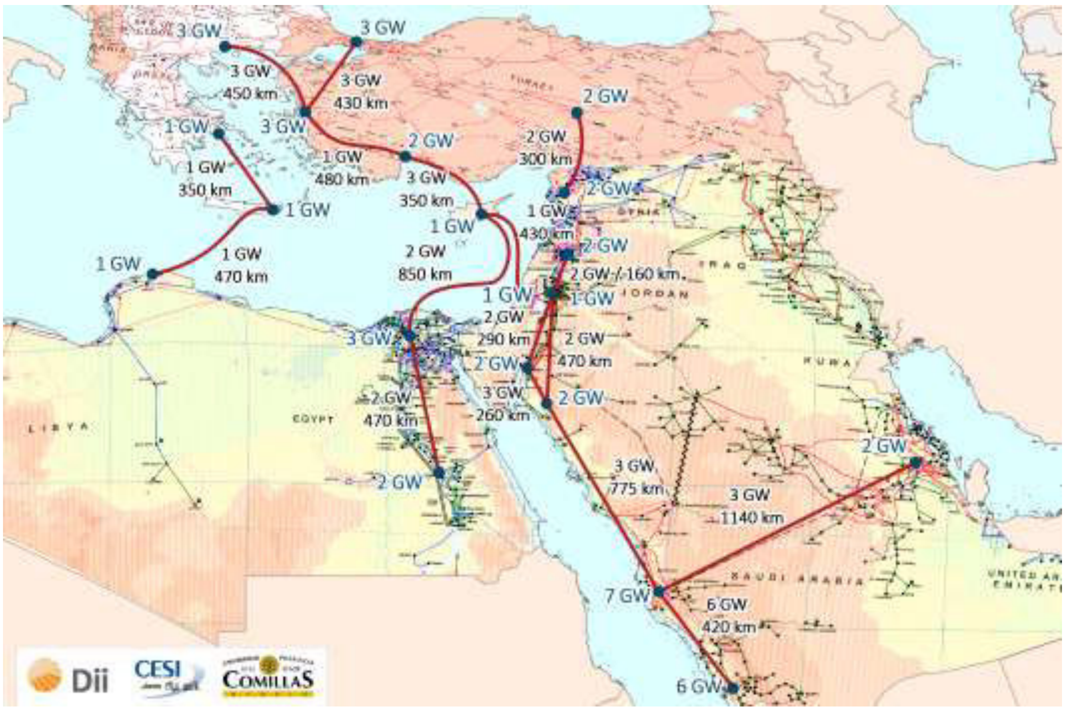

Figure 12 *HVDC overlay grid in the Eastern corridor by 2030*[7]

[7] Cyprus has been considered as an electricity hub used to transport power from Egypt and Israel to Turkey and Greece. This approach does not lead to a significant cost increase since the DC converter station in Cyprus is sized to cover the actual needs in terms of net imports or exports

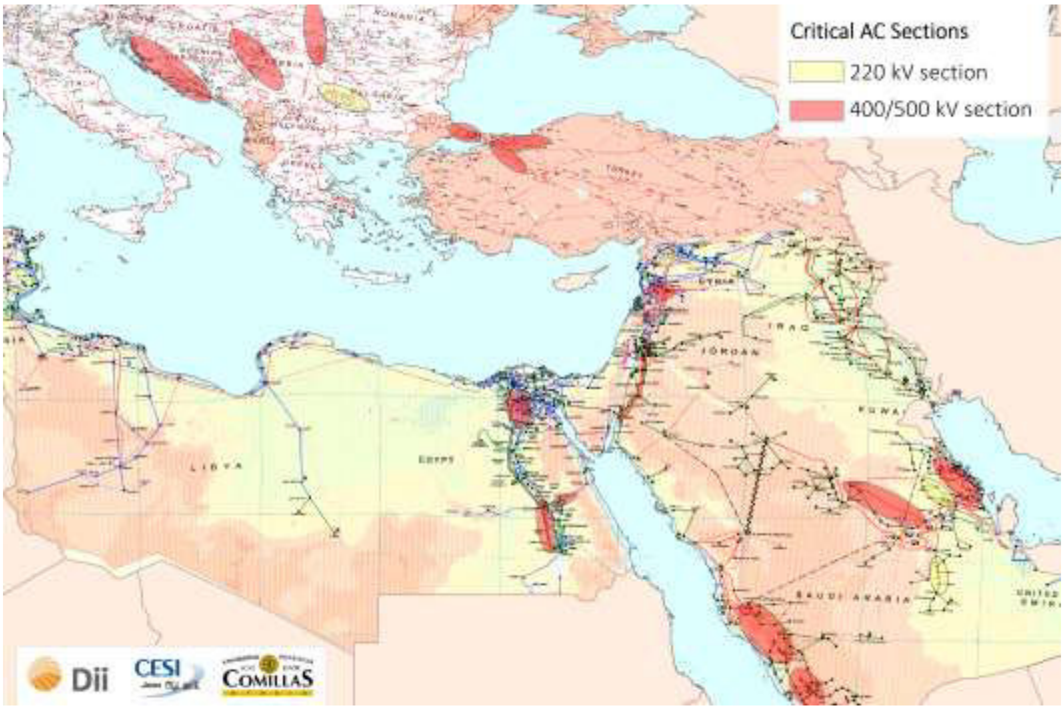

***Figure 13** AC reinforcements in the Eastern corridor by 2030*

In terms of MENA-Europe interconnections, 1 to 3GW_{NTC} HVDC lines would link the North and South shores of the Mediterranean on routes from Libya to Greece, Egypt to Western Turkey and Saudi/Egypt across Jordan and Syria to Central Turkey.

For the submarine links, 4,000GW_{NTC}*km cables would be built with the aim of minimizing sea depths to be crossed. Nevertheless, the assumed submarine link between Libya (Benghazi) and Greece across Crete would reach sea depths of up to 2,600m, while the maximum sea depth of the line from Egypt to Turkey through Cyprus is approximately 2,100m. The capacity of on-land lines amounts to 600GW_{NTC}*km linking Syria with Turkey.

Inside MENA countries, where electricity needs to be transported over long distances to load centers, high transmission capacities would be required, especially in Egypt and Saudi Arabia. Reinforcements would be necessary in both AC and DC technologies. For the HVDC interconnectors, a total amount of 11,500GW_{NTC}*km line capacities and 31GW of converters would be needed. Concerning AC reinforcements, 7000km of 400/500kV lines and 1700km of 220kV lines would be necessary. Most critical AC sections would be in Egypt (Cairo urban area and area of Nag Hammadi) and Saudi Arabia. Here, main load centers are in the East of the countries, while most attractive solar and wind resources are in the South West along the Red Sea. Consequently, HVDC lines are built to connect the two parts of the country, as well as to transmit power northbound along the Red Sea coast, while extensive AC reinforcements are needed in the areas of main generation as well as load centers (areas of Shuqayq and Shedgum).

Inside Europe, capacities needed are less important compared to the MENA region. In fact, for the HVDC grid, approx. 3,100GW_{NTC}*km of HVDC lines associated with 16GW converter capacities would be built. AC bottlenecks would occur in Turkey (Area of Alibeykoy) and across Eastern European Countries. The critical AC sections would be covered mostly by approx. 1,500 Km of 400kV lines.

Table 9 summarizes the technical findings for the Eastern corridor.

	HVDC lines	Converters	AC 400/500KV	AC 220KV
	GW_{NTC}*km	GW	km	km
Turkey	3,120	16	640	-
Eastern Europe	-	-	900	100
MENA	11,565	31	7,000	1,700
Interconnections	4,600	-	-	-
Total	**19,285**	**47**	**8,540**	**1,800**

***Table 9** HVDC and AC capacities in the Eastern corridor*

3.3.2 Economic analysis

Considering the optimum grid reinforcements resulting from the technical analysis, the cost of the required investments and operating costs were calculated. **Table 10** reports the investment costs for both DC and AC grid infrastructure.

Country/interconnection	HVDC links	Converters	AC
Turkey	548	784	513
Eastern Europe	-	469	720
MENA (including interconnections) - Egypt - Saudi Arabia	2,643 282 1,620	2,431 392 1,334	5,263 1,210 3,300
Libya-Greece	933	-	-
Egypt-Turkey	2,320	-	-
Israel-Turkey	790	-	-
Syria-Turkey	180	-	-
Greece-Turkey	410	-	-
TOTAL	**7,824**	**3,684**	**6,496**

***Table 10** Investment costs for HVDC and AC infrastructure in the Eastern corridor [M€]*

In MENA, investment costs are divided almost equally between AC and HVDC infrastructure reaching in total approx. €10.3bn. Since only a few HVDC links would be needed in Turkey and Eastern Europe, the grid investments in this part of the Eastern corridor are approx. 3 times lower than those of MENA with a value estimated to €3bn.

Regarding interconnections, the most expensive ones are those crossing the Mediterranean Sea, namely Libya-Greece, Israel-Turkey, and in particular the long submarine link from Egypt to Turkey across Cyprus. Their costs alone represent more than 85% of total interconnection investments in the Eastern corridor.

In total, €18bn of grid investments would be required in the Eastern corridor between 2022 and 2030. For the European countries members in ENTSO-E, costs amount to approx. €1.2bn, approx. 1/3 the costs evaluated in TYNDP 2012 for the decade 2012-2022.

Total operational costs including the costs of losses are about €1.3bn p.a.

4 RESULTS 2050

This chapter provides the results of the EUMENA HVDC grid development in the 2050 time horizon in terms of network reinforcements and required expenditures.

4.1 Technical results

Figure 14 and **Figure 15** show the capacities and the power flows of the EUMENA overlay grid by 2050.

Large cross-border power interfaces connect countries on the South shore of the Mediterranean to their counterparties on the North side in order to route power to demand areas in Central Europe. Besides that, South to South highways connect Morocco to Algeria, Libya to Egypt, and Jordan to Syria. Regarding the transfers of power from Northern Europe to Central and Eastern Europe, main links are those connecting Norway and Denmark with Germany, and Poland with Germany.

Within countries, large corridors would be built, either to import, export and transit electricity, or to transport energy from generation sites to load centers in the countries. The latter is for example the case of the line linking the West and East of Saudi Arabia (approx. 66GW), in order to transport renewable energies (RE) produced in the West to consumption areas in the East. The corridor between South Egypt and North Egypt (approx. 45GW) is used to transport RE produced in the South to the North, from where power flows into Italy, South-Eastern Europe, and the Middle East. Similarly, large lines would link East and West Libya, central and North Italy, South and North France, and North and West Germany.

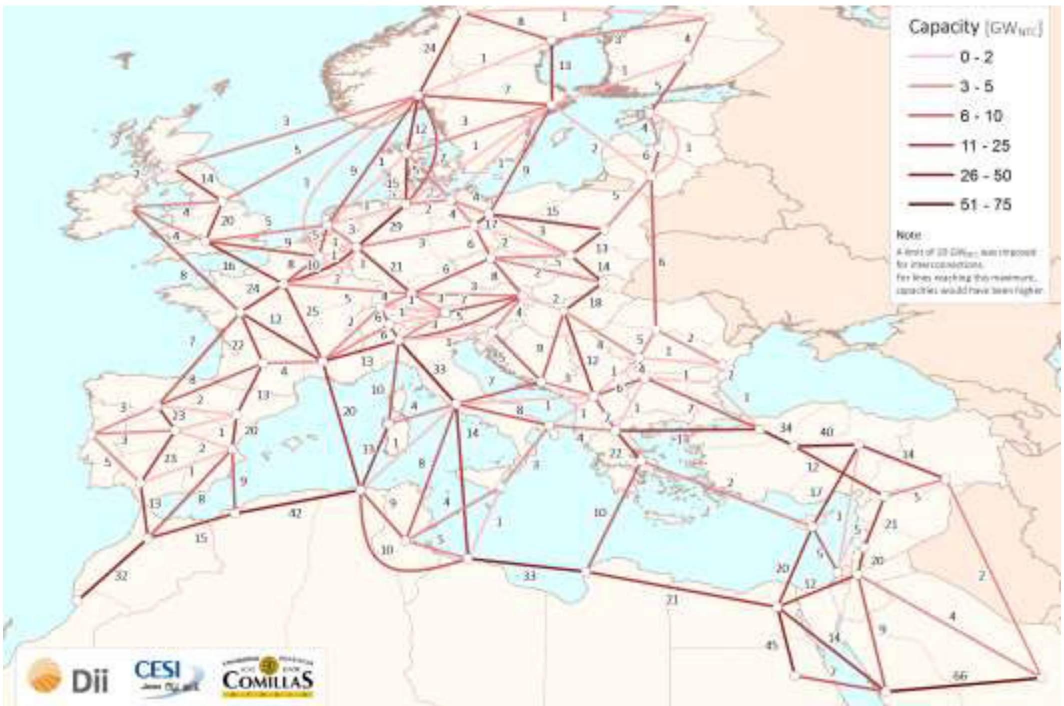

Figure 14 *Line capacities of the EUMENA overlay grid by 2050*

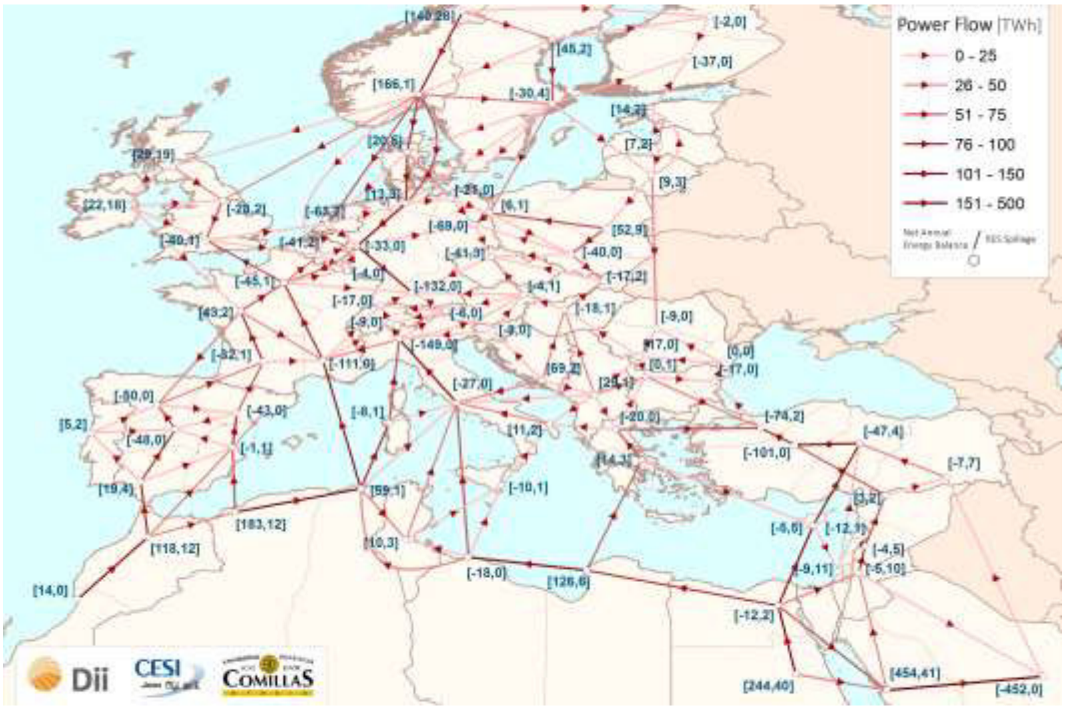

Figure 15 Net power flows in the EUMENA overlay grid by 2050

Figure 16 shows the capacities of internal lines and interconnections for several EUMENA countries. Taking the system as a whole, reinforcement capacities are divided almost equally between interconnections and internal transmission lines with 628GW for the latter and 625GW for the former.

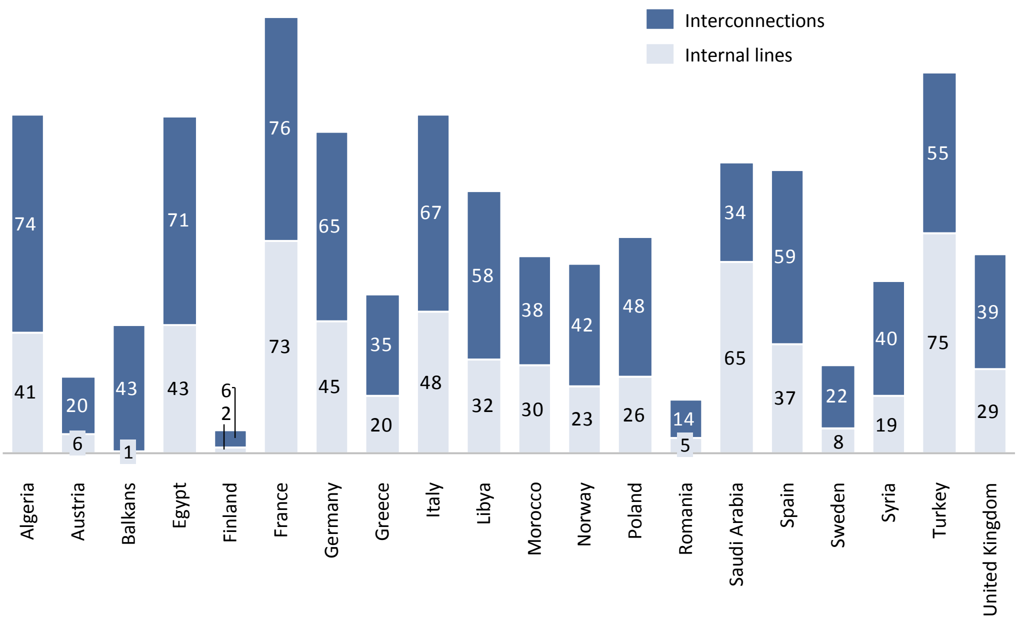

Figure 16 Capacities of internal lines and interconnection in countries by 2050 [GW]

As shown in **Figure 17**, a build-up of approx. 659,000GW*km of new capacity is needed by 2050. Around 47% of the new grid will be allocated in Europe and 38% in MENA. The part of interconnections doesn't exceed 15%.

To ensure the link between the HVDC overlay grid and the AC network, approx.

1,300GW of converter capacities are required.

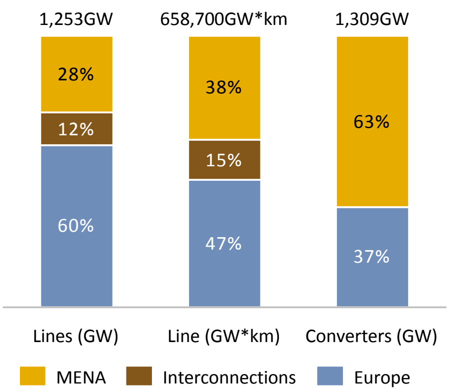

Figure 17 *Capacities of the HVDC overlay grid by 2050*

Transmission line losses (without conversion to AC) in the high HVDC grid would represent 1.27% of overall demand, which is in line with the current level of losses for the high voltage and extra high voltage grid. Therefore, even in the presence of large flows crossing the large EUMENA system, losses could be kept well within reasonable limits, thanks to the widespread use of efficient HVDC technology largely available already today.

4.2 Economic results

Table 11 presents the total and annual investment costs related to the EUMENA overlay grid by 2050.

	Transmission lines investments		Converter investments	
	Total (bn€)	Annual (bn€/a)	Total (bn€)	Annual (bn€/a)
Europe (internal)	226.4	16.73	74.4	5.50
MENA (internal)	117.7	8.70	43.4	3.21
Interconnections	91.6	6.77	-	-
TOTAL	**435.7**	**32.20**	**117.8**	**8.71**

Table 11 *Total investment costs in grid infrastructures*

The whole amount of investments attains a total of approx. 550bn€, out of which 79% is for high voltage transmission lines and the remaining 21% for converter stations.

Annual investments amount to approx. €20bn; half of it would be attributed to Europe.

Figure 18 shows the investments costs as reference to the country where it would occur.

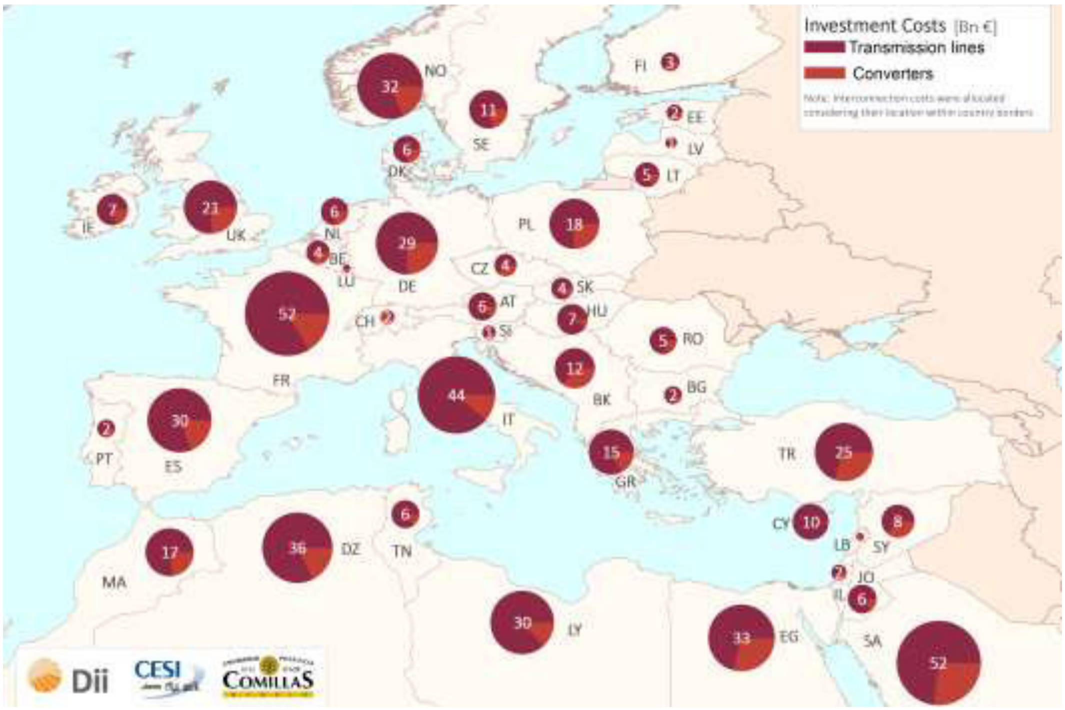

Figure 18 *Grid investment costs by country up to the year 2050*

For transmission lines, large investment costs would occur in those systems where corridors need to be built to host a significant increase with respect to current levels. This could occur in countries where it is necessary to transfer power internally over long distances either to feed main load centers (e.g. Saudi Arabia), or to export/transit electricity (e.g. Italy Algeria and Norway).

Regarding converters, larger investment costs take place mainly in countries featuring large consumption or generation centers. If both large consumption and generation centers exist within a country, investments are larger when power production and consumption do not take place in the same area. This is the case of countries like Germany, France, the UK, Egypt, Saudi Arabia, and Turkey. The results clearly show that investment needs are far from being evenly distributed among countries. In particular for the case of transit countries, investments will only take place, when a fair distribution of costs among countries according to the benefits associated with new lines will take place. This will be one element of regulatory reform, which we address in the concluding chapter.

5 CONCLUSION AND RECOMMENDATIONS

With *Desert Power: Getting Connected,* Dii provides a detailed view of the transmission infrastructure that could facilitate the development of an integrated EU-MENA power market. Based on sophisticated grid models, not only technical and economical parameters were calculated but also a first set of possible routes were identified. Thus, the results of this report can be considered as a pre-feasibility stage in the process of the required analysis of electricity highways between the MENA region and Europe. Generally, this "need for action" does not only address technical and financing aspects but also social issues since the acceptance by the local population and governments is crucial for the success of any transmission infrastructure project.

Put briefly, investment needs for transmission infrastructure of an integrated EUMENA power system – about €60bn by 2030 and €550bn by 2050– might be considered to be notably high. However, these costs are put into perspective if one takes into account that they represent only about 10 % of the total required investment needs in the power sector.

Within both time periods, about 40% of total grid investments are dedicated for interconnections between countries. About half of these, 20 % of the total grid investment, occurs for interconnectors between MENA and European countries.

The remaining 50 to 60% of grid investments are dedicated to projects within countries. This means that new transmission grid capacities are not only required for the long-distance exchange of electricity across countries, but also for the connection of local renewables resources to national high voltage grids. Especially in large MENA countries, where the most promising sites for wind and solar are remote from load centers (e.g. Saudi Arabia, Algeria and Egypt), significant investments in the local transmission grid would be required to tap this renewable sites.

According to ENTSO-E's TYNDP2012, European TSOs plan investments for the transmission grid in Europe as a whole of €104bn between 2012 and 2022. Investment in the regions considered for Dii analysis for the Western, Central and Eastern corridors are in the range of €7-10bn. Comparing these investment plans with the investment of roughly €20bn for each of the three corridors calculated in our analysis for the decade 2020-2030, we can conclude that in most countries TSOs would increase their already ambitious level of investment, doubling (in the Western corridor) or even tripling (in the central corridor) the current level of investment.

Of course, the results of this modeling analysis only show one option for strongly reinforcing and interconnecting the power grids across Europe and the MENA region through a high voltage overlay grid. While reality as implemented by the TSOs will certainly look different, the analysis provides a better understanding of the extent of the challenge and of the main countries and regions affected. It is, on the one hand, intended to serve as a basis to further detail the concrete necessity, technical feasibility and economic viability of the variety of potential projects; on the other hand, it underlines the need for substantial progress and international coordination in planning, constructing, financing, and operating a future power grid. From Dii's perspective, this would entail the following short-, medium- and long-term measures.

Short-term until 2020

Transmission grid developments by 2020 are dominated by an efficient integration of renewable energies into the national AC grids and by the reinforcements of AC interconnections. Hence, it is desirable that the projects included in the TYNDP and the MENA region master plans are fully implemented without undue delays.

To demonstrate the techno-economic feasibility of HVDC links between North Africa and Europe, the implementation of the two projects from Italy to Algeria and Tunisia, as included in the TYNDP 2012, would be of great benefit.

HVDC interconnections are mainly used for submarine links, while AC cables aren't feasible. Yet, DC power highways over long mainland distances are in general not required.

Effective collaboration among TSOs in MENA and European countries will make the required exchange of information about the planning and operation of the electricity systems possible.

The new European Regulation on guidelines for trans-European energy infrastructure (No 347/2013) already provides some improvements in this respect for EU member states. Infrastructure projects covered by this regulation benefit from easier and faster permit granting procedures, improved regulatory treatment (incl. international cost allocation), and access to financial support from the Connecting Europe Facility (CEF).

However, until this date, interconnections between Member States and third countries are excluded from this beneficial regulatory treatment. The quick development of first cross-Mediterranean interconnectors would greatly benefit from expanding the scope of Regulation 347/2013 towards projects with third countries.

Mid-term 2020 - 2030

In the mid-term, a strong infrastructure ramp-up and international policy convergence between MENA and European countries is assumed.

This period will see the evolution of "two types" of electricity highways - one in Northern Europe, able to exchange power between countries in Central Europe, and one in the Mediterranean area, able to exchange power between the countries in Southern Europe.

However, these regional electricity highways will still be independent to a certain extent, since only some exchanges among Southern and Northern countries are already expected to take place.

With regard to the evolution of an integrated EUMENA power system, a significant acceleration of the development of interconnections in the Mediterranean area would be of high value.

The exchange of significant amounts of energy on long distances will require the use of common rules not only for the operation of the power system, but also for the whole electricity market. Hence, it will be very important to adopt common policies in Europe and in MENA for both technical and regulatory aspects.

This includes, firstly, common network codes on security issues as well as on capacity allocation and congestion management practices to ensure the smooth operation of the network. ENTSO-E and ACER are in the process of developing new European wide network codes. These should be taken into account – or might even serve as the blueprint – in the development of EUMENA wide network codes. The Association of Mediterranean TSOs (MedTSO) as well as the Association of Mediterranean Regulators (MedReg) are already active today in establishing guidelines for the interaction between the different Mediterranean power systems.

Secondly, international policies should drive the development of new transmission infrastructure. A first starting point in this direction on the European side is the Regulation on guidelines for trans-European energy infrastructure providing favorable regulation and financing to Projects of Common Interest. This regulation should be expanded to all infrastructure projects between MENA and Europe.

In addition, common regional guidelines for transmission planning and investment cost allocation should be adopted. The European Union has made considerable progress in this respect over the last years. Since 2009, ENTSO-E is in charge of conducting the bi-annual 10 year network development plan for all EU Member States. Regulation 347/2013, in addition, foresees cost-benefit assessment for all Projects of Common Interest, which could serve as the basis for EU-wide cost- allocation schemes.

It is recommended that the countries in the MENA region also start to establish procedures for regional planning and cost allocation. This could be pursued by providing a corresponding mandate to MedTSO or another competent authority. In a first step, national regulators and ministries should ensure that their national transmission plans are in line with this regional transmission plan. In a second step, this regional plan, e.g., for the Southern Mediterranean, could be made binding. A regional institution with strong powers and region-wide authority would support this. In addition, the interaction between ENTSO-E's TYNDP and a potential Mediterranean investment plan would need to be clarified.

Finally, it is important that planning also takes place at an EUMENA-wide level in order to promote the development of cross-Mediterranean interconnections. A first step would be for ENTSO-E to take into account grid developments and RE potentials in the neighboring Mediterranean countries when setting up its TYNDP. To this end, a separate regional group within ENTSO-E could be established and tasked with network planning and capacity building in the Southern Mediterranean. This would also force European TSOs to account for RE potentials and grid developments in the Southern Mediterranean and can lead the way to a more institutionalized and rules-based approach towards international transmission projects. This does not imply that a European institution should conduct network planning in the MENA region, but rather that European TSOs should account for developments in MENA in their own transmission plans. In order to make regional planning an effective tool, not only a regional body in charge of planning, but also a regional body with competencies for regulatory oversight is needed.

Long-term 2030 - 2050

By 2050 electricity systems in Europe and MENA would – to a large extent – be fully integrated. Strong HVDC electricity highways will serve as an overlay grid to the AC grids to exchange significant quantities of electricity between the countries and regions.

The build-up of a strong backbone for the EUMENA markets will be the objective of the evolution of the transmission grid in the long-run.

In order to achieve a fully integrated power system, common EUMENA transmission policies are required with respect to the development of operation of the infrastructure.

This should entail the gradual establishment of regional institutions governing the development and operation of an EUMENA-wide transmission grid. These institutions would need to set up binding region-wide investment plans and network codes. In addition, regional regulators would oversee the planning process, the enforcement of cost-allocation procedures, and network codes.

It is time to act now

When we look decades ahead in the future of the energy sector of a region as large, diverse, dynamic and contradicting as Europe, the Middle East and North Africa, many uncertainties regarding economic, political, technical and societal development prevail. How will population growth, economic activities and power demand develop? Will political commitments for international climate policies happen? Will power markets be coherently regulated to allow for fair competition among market participants and a level playing field among generation technologies? What will be the role of decentralized generation facilities? Will societies be ready to cooperate and accept the construction of transmission infrastructure as a means to do so? What interactions will take place across the energy sector, e.g. between the power and gas sector?

What remains unquestioned, however, are the evidently great benefits of connecting power systems across large geographical regions with different solar and wind regimes, time zones and demand patterns. Engaging in a serious debate on how an interconnected transmission grid for Europe and the MENA region could look like and develop is therefore more than worthwhile in any case. Dii looks forward to continue contributing to this discussion with policy makers, regulators, transmission system operators and all interested stakeholders.

6 ABBREVIATIONS

€	Euro
€bn	Billion Euro
€M	Million Euro
AC	Alternating Current
CSP	Concentrating Solar Power
Dii	Dii GmbH
DP:GC	Desert Power : Getting Connected
DP:GS	Desert Power : Getting Started
DP2050	Desert Power 2050
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
EUMENA	European Union, Middle East – North Africa region
FOSG	Friends of the Supergrid
GW	Gigawatt
HVDC	High Voltage Direct Current
IIT Comillas	Institute for Research in Technology at Universidad Pontificia Comillas
MENA	Middle East – North Africa
NTC	Net Transfer Capacity
PCI	Projects of Common Interest
PV	Photovoltaic
RES	Renewable Energy Source
TSO	Transmission System Operator
TWh	Terawatt hour
TYNDP	Ten-Year Network Development Plan
VSC	Voltage Source Converter

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