2050 Desert Power

Executive Summary
The Case for Desert Power

Dii
Renewable energy bridging continents

IMPRINT

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2050 Desert Power

» MENA and Europe both need a **secure, affordable and clean supply of electricity**

» Supply and demand for renewable energy are **complementary** in the south and north in all seasons

» Mutual reliance and technical complementarity across EUMENA enhance **security of supply**

» **Both regions are natural partners** and can enable this fundamental transformation together as EUMENA

» **All countries benefit** from access to affordable renewable energy, the creation of new industries, and reduced cost of decarbonization

» It is essential to **act together today as EUMENA** to realize this enormous potential by 2050

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Since its inception in 1972, **Fraunhofer ISI** has been influential in shaping the German and international innovation landscape. The Fraunhofer Institute for Systems and Innovation Research ISI conducts applied research in seven Competence Centers with a total of 22 Business Units and sees itself as an independent institute for society, politics and industry.

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THE CASE FOR DESERT POWER

Creating a secure, affordable and clean electricity supply is one of the key challenges facing North Africa, the Middle East and Europe.

How can the Middle East and North Africa (MENA) supply their growing economies with secure and affordable electricity? How can the EU reach its ambitious climate action goals in a way that is both sustainable and economic?

Desert Power 2050 (DP2050) examines the future energy challenges of Europe as well as the Middle East and North Africa (EUMENA). It shows that these challenges can best be addressed by moving beyond the currently predominant view of the two regions as separate entities. Indeed, Europe and MENA are not just neighbors, tied together by a long history of trade and cultural exchange; in a world of renewable energy, EUMENA should be viewed as a single region.

An integrated EUMENA power system allows Europe to meet its CO_2 reduction targets of 95% in the power sector more effectively and more economically by importing up to 20% of its electricity demand from MENA. Europe thereby saves a total of €33bn. annually, or €30 per MWh of power imported from MENA. Meanwhile, desert power enables MENA countries to supply their own energy needs reliably from the abundant solar and wind resources in the region. MENA can thereby contribute to a 50% CO_2 reduction in its power sector despite a massive increase in demand. At the same time, MENA benefits from an export industry worth up to €63bn. per year. Furthermore, Europe as well as MENA profit from a 40% drop in the marginal cost of CO_2 emission reductions in the power sector.

The idea that renewable electricity should be produced in areas with optimal resources and exported to regions with high demand has become known as the Desertec vision. This intuitive notion suggests that Europe should source some of its electricity production from the deserts on the southern shore of the Mediterranean, with their excellent solar and wind resources and sparsely populated land.

Desert Power 2050 shows how key aspects of the Desertec vision could work in practice while also moving beyond it. It demonstrates how, based on proven technologies, solar and wind resources can be combined with grids to securely supply North Africa, the Middle East and Europe with sustainable and affordable power. It thus expands on previous thinking and considers MENA as a consumer of renewable energy, not just as a producer.

There is great urgency to move towards such a system: the population in the EUMENA region is expected to grow by up to 45% to almost 1.2bn. in 2050, when power demand could exceed 8000TWh. With MENA growing faster than the EU, it is in the interest of the entire region to replace its reliance on volatile fossil fuel prices with a stable, sustainable power system.

Desert Power 2050 shows why an interconnected, renewables-based power system for EUMENA is valuable for reasons of competitiveness, sustainability and security of supply. This requires a paradigm shift from today's weakly interconnected, fossil fuel-based system to an integrated, sustainable one. Enabling this transition will be the topic of the second part of Dii's 2050 strategy, **Desert Power 2050: Getting Started.**

FROM RESOURCES TO ELECTRICITY

The sheer size of largely unused land and favorable climatic conditions in the MENA region make it an ideal location for renewable electricity production.

Figure 1 shows the availability of excellent solar resources in MENA. Prime sites can be found everywhere in the region, from the High Atlas and Tell Atlas in the Maghreb to the Asir Mountains in Saudi Arabia.

Less widely known, but no less important, MENA also has favorable wind conditions, as depicted in ***Figure 2***.

Exceptional wind potentials can be found, for example, on Morocco's Atlantic coast and the Red Sea. Furthermore, the entire continent, stretching between these two coasts, hosts attractive sites for wind power generation.

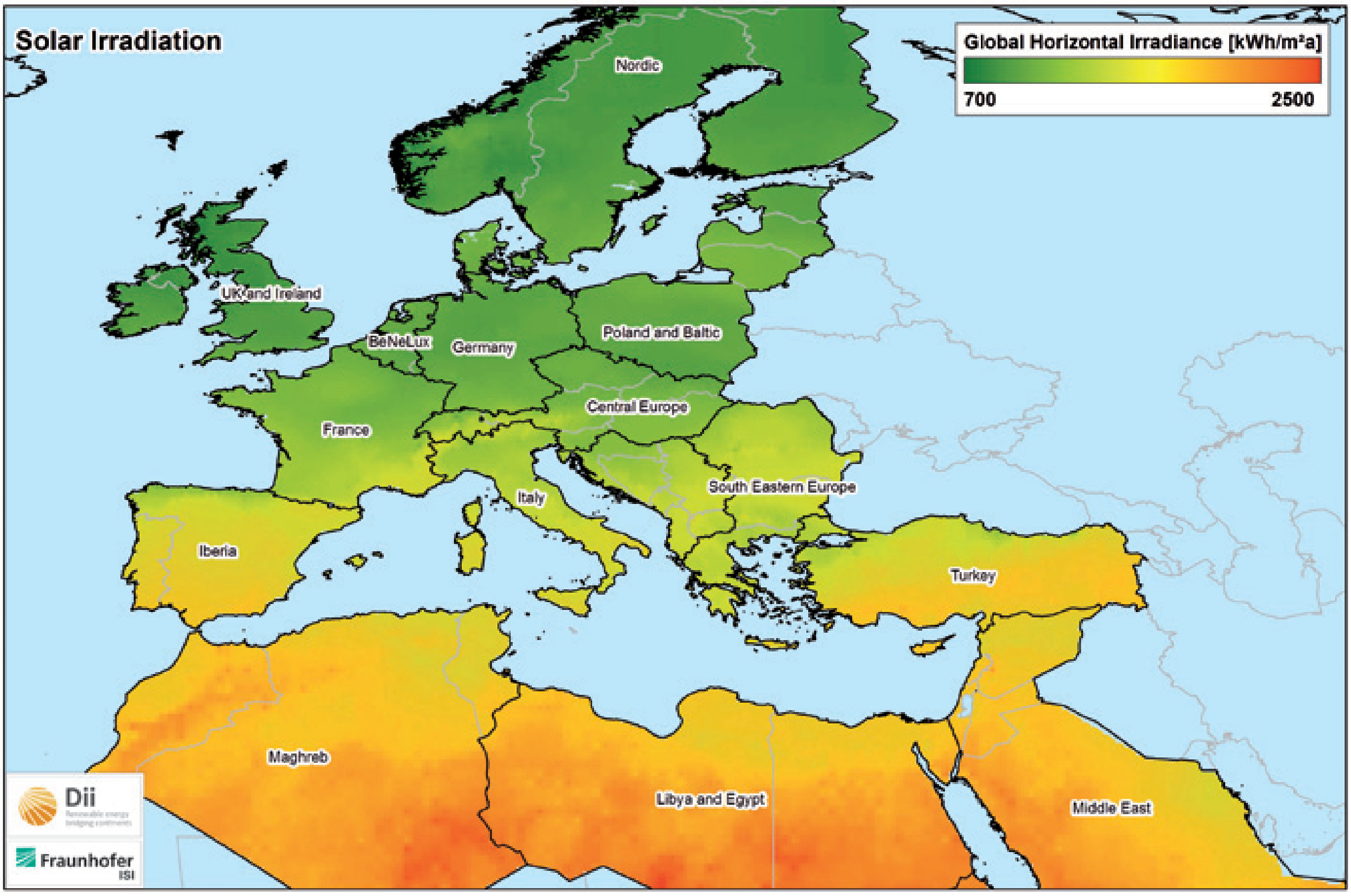


Figure 1: Solar resources in the EUMENA region

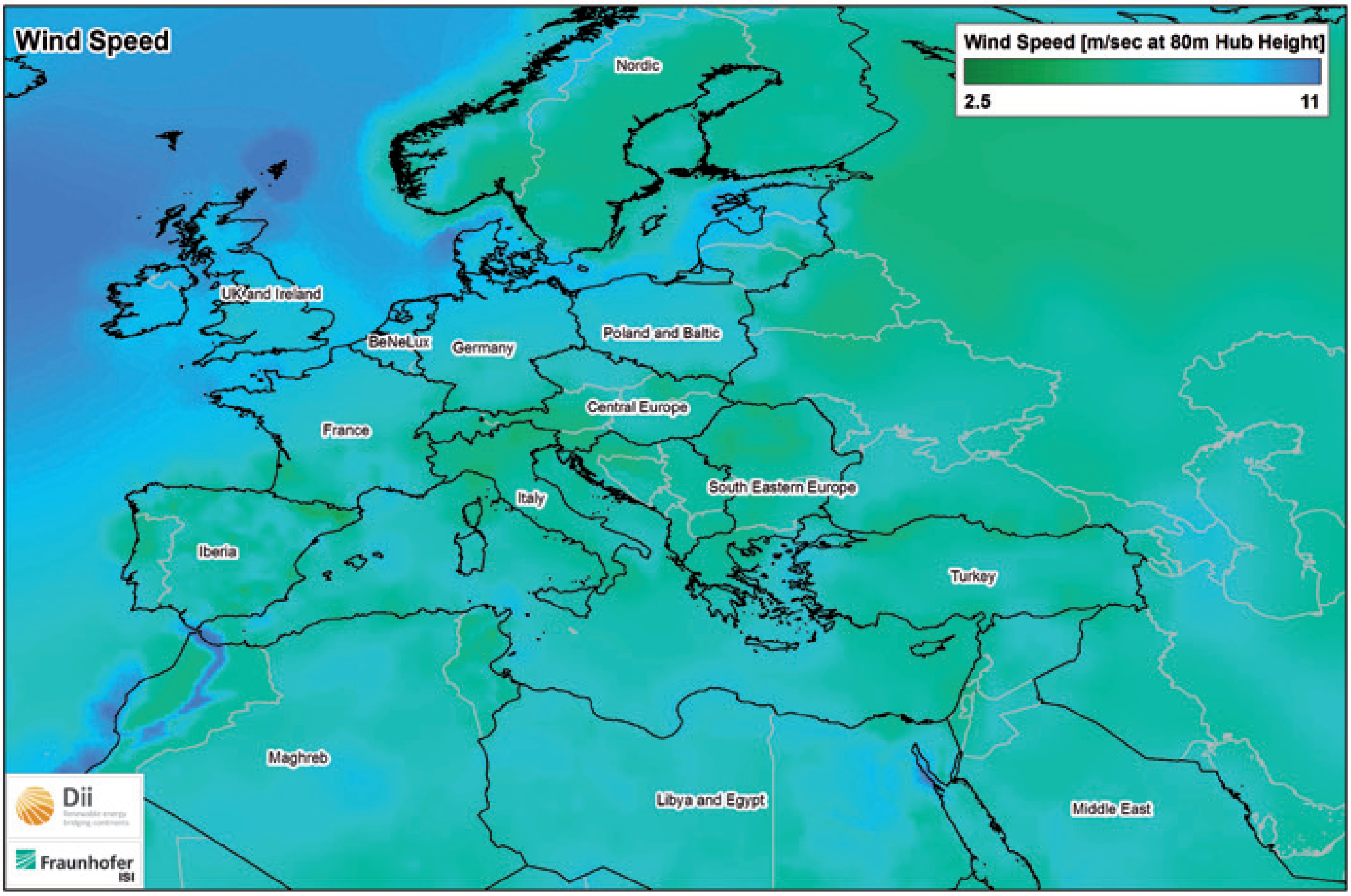


Figure 2: Wind resources in the EUMENA region

Of course, the mere abundance of renewables resources does not automatically translate into a power system that works reliably 24 hours a day, 365 days a year. Therefore, Dii has joined forces with Fraunhofer ISI to model the EUMENA power system in high time and spatial resolution. The continuous involvement of industry experts, particularly from Dii's network of 56 partner companies across the EUMENA region, was equally important for the whole analysis. Using ISI's proven PowerACE model, we demonstrate the potential of Solar and Wind[1] technologies to affordably supply demand across the entire EUMENA region in every single hour of a whole year. ***Figure 3*** shows the basis for these analyses: compared to power demand, the Solar and Wind potential in EUMENA is virtually infinite e.g. Wind and Solar potential costing less than 50€/MWh (in 2050) amounts to 10,000TWh.

[1] Please note that "Solar", "Wind", etc. refer to the respective technologies, while "solar", "sun" and "wind" refer to the naturally occurring phenomena

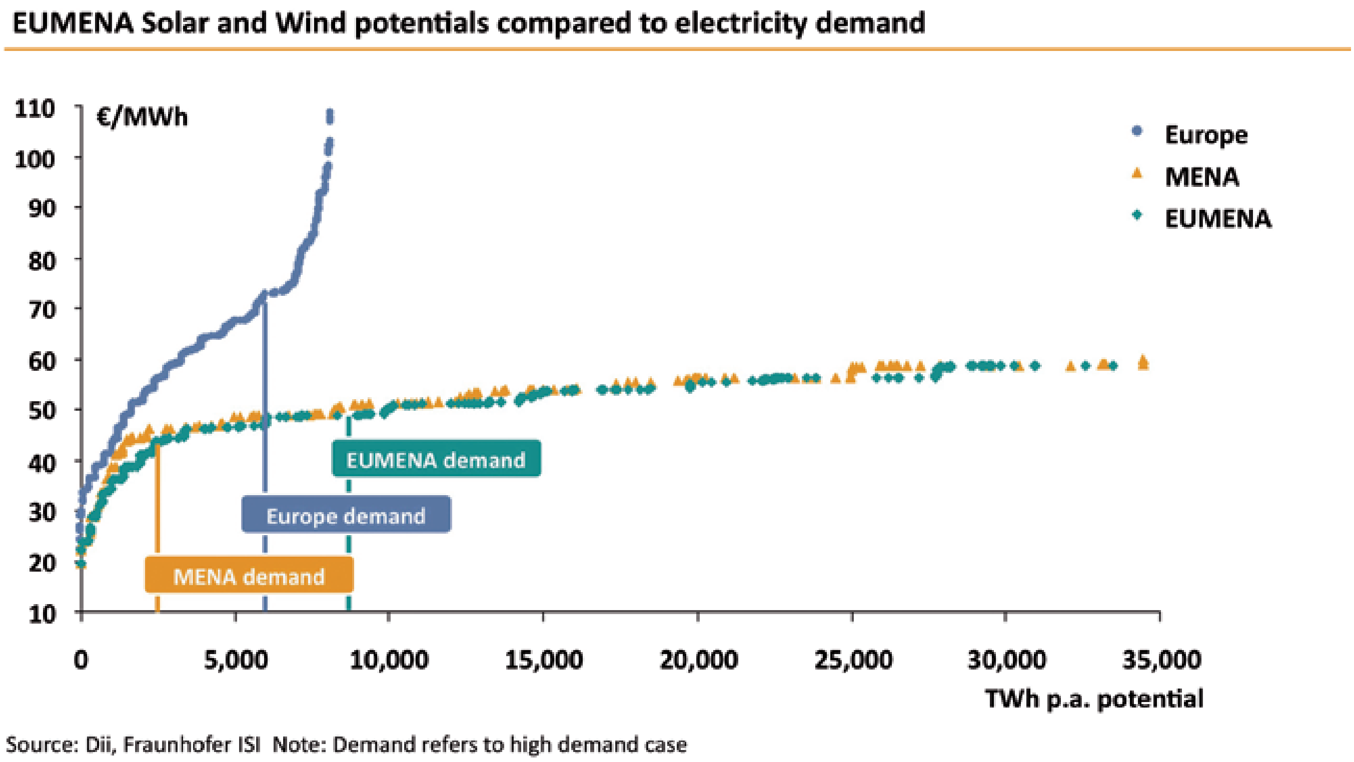


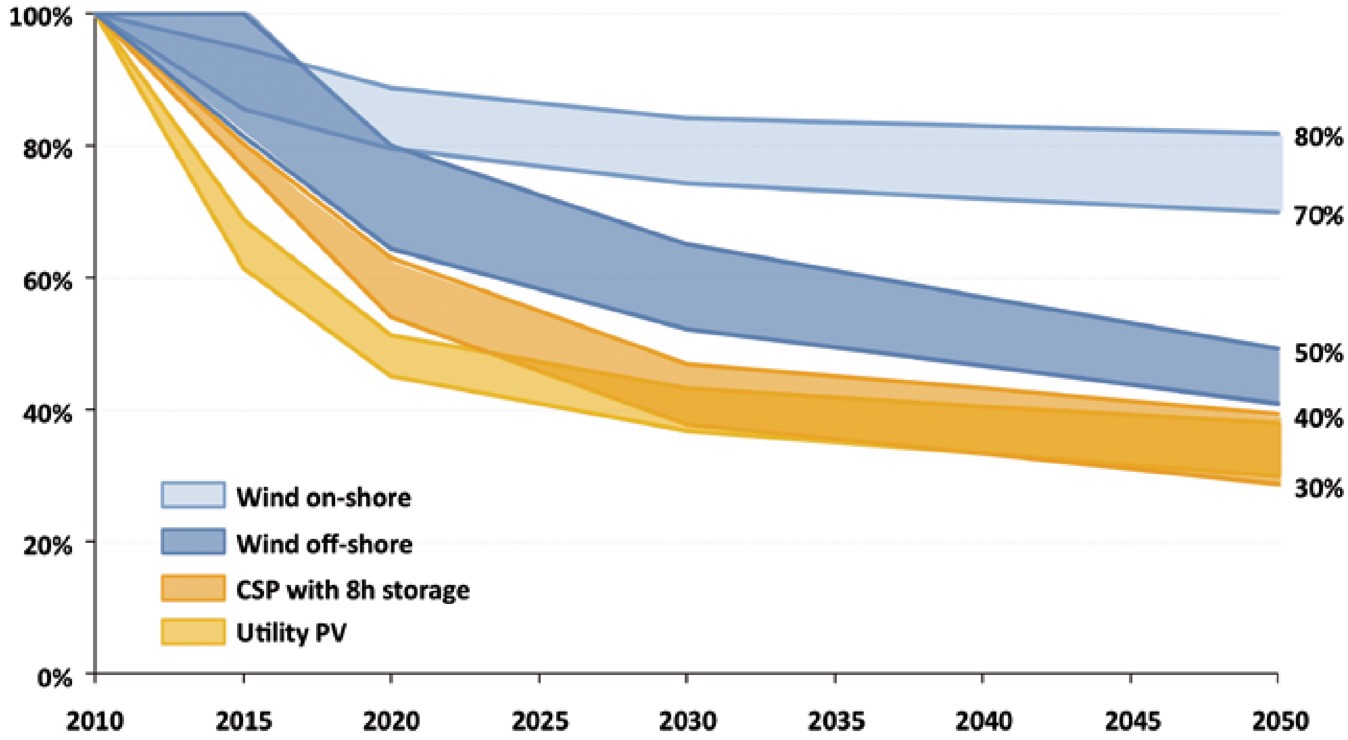
Figure 3: Renewable energy potentials and electricity demand in 2050 in MENA and Europe

The use of proven technologies will ensure the technical feasibility of a sustainable power system. The focus technologies of this report are all widely used today – utility scale photovoltaic (Utility PV) and concentrating solar power (CSP) technologies as well as on-shore and off-shore Wind. Their worldwide installed capacity has reached gigawatt (GW) scale, with installations that have been in continuous use for more than two decades.

Economic viability, however, has not yet been achieved on a sufficiently broad scale. Renewables have shown impressive cost reductions in the past years. Yet they have not yet reached full cost competitiveness with conventional power technologies in many markets. One of the key aims of this study is to show how desert power optimizes cost and helps make a renewable energy-based power system economically viable.

With 2050 as a time horizon, we aim to understand the design of an optimized target picture based on cost projections for the four technologies under consideration. As ***Figure 4*** shows, significant cost reductions of around 50% or more are expected for all technologies, except for Wind on-shore costs, which are estimated to decline by 20-30%, since this technology is already mature and cost competitive today. Just a few years ago, these projections may have appeared aggressive, but recent developments in PV and on-shore Wind show they are possible. Moreover, cost developments depend on market developments. This report will show that supporting the growth of such markets for Solar and Wind is in the interest of governments that seek to provide a competitive, sustainable and secure energy supply.

System cost development per kW¹ in percent of 2010 cost estimate



Source: Dii 1. Refers to nameplate capacity, i.e. kW_p (kW peak) for Utility PV and Wind and kW_e (kW electric) for CSP

Figure 4: Cost reduction pathways for Wind and Solar technologies until 2050

In order to assess the added value of power system integration across the Mediterranean, we compare two scenarios. The 2050 target picture in the **Connected Scenario** examines a power system with full, EUMENA-wide integration. The **Reference Scenario**, meanwhile, depicts a situation where each region, Europe and MENA, is fully optimized in itself but without co-operation between the two systems. In other words, both Desert Power 2050 scenarios assume a paradigm shift to a renewables-based power system, with considerable investment in grids and renewable energy generation. Both the Connected and Reference Scenarios are optimized for minimum system cost under a EUMENA carbon emission cap of 0.25Gtonnes p.a., i.e. approx. 30g per kWh of demand[2]. Thus, in the Reference Scenario, the European part alone is similar to the optimized power systems analyzed in the European Commission's Roadmap 2050; the main difference is that it still profits from a common carbon cap with MENA.

[2] The minimum system cost includes the cost of power generation and transmission but not the cost of carbon emissions

BENEFITS OF DESERT POWER

Desert Power 2050 adopts the three main pillars of European energy policy to assess the study's key findings.

It shows how an integrated EUMENA power system is beneficial to the competitiveness of the EUMENA region, makes a signal contribution to affordable sustainability, and improves overall security of supply in EUMENA.

COMPETITIVENESS

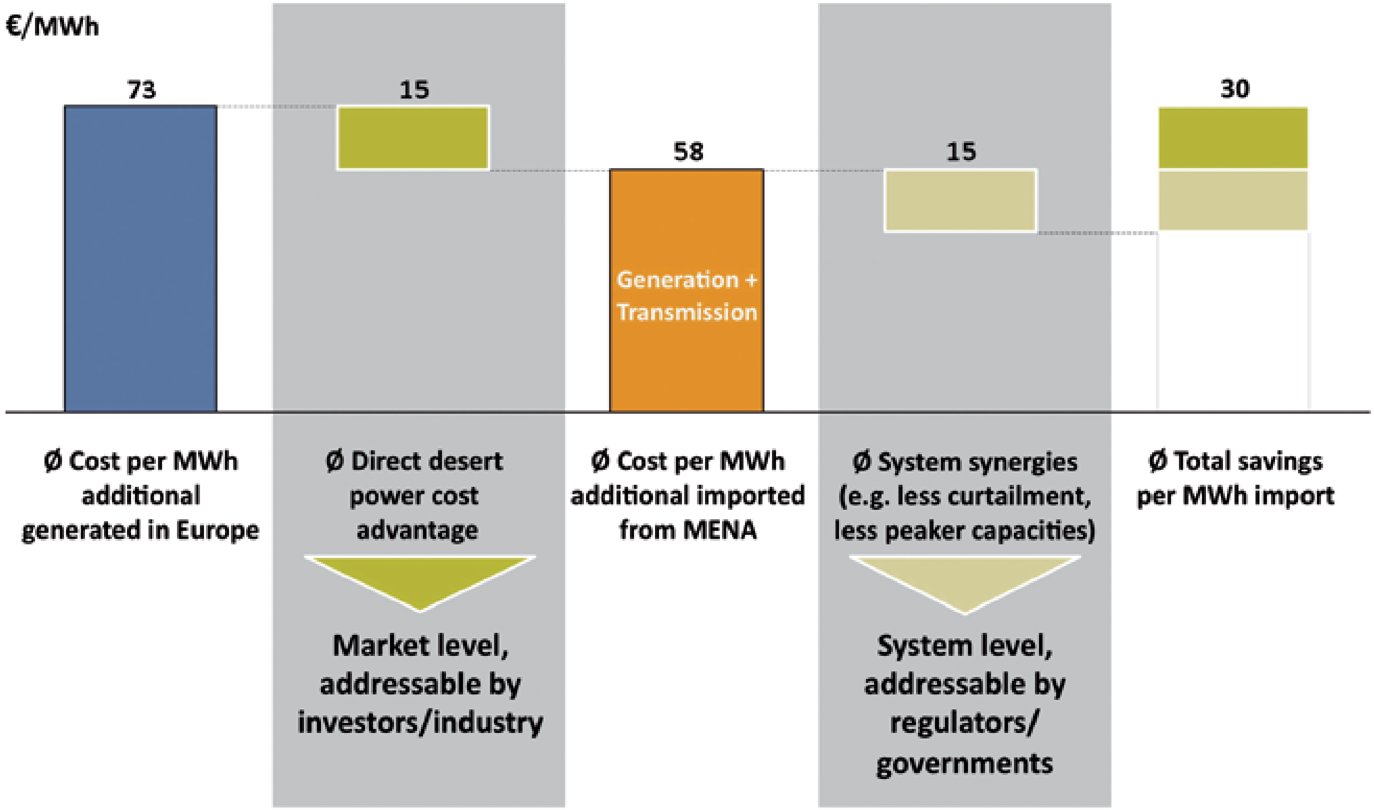
Desert power helps improve the competitiveness of the EUMENA power system by making the achievement of ambitious CO_2 reduction goals more economic. The competitive advantage of an EUMENA-wide power system results from a total of 1110TWh of annual power exchange, thereof 1087TWh from MENA to Europe and 23TWh from Europe to MENA[3]. Thus, the trade balance amounts to 1064TWh of annual net exports from MENA to Europe. The Connected Scenario saves €33bn. per year in system cost. For the approx. 1110TWh of annual power exchange between MENA and Europe, this amounts to approx. 30€/MWh.

As the south to north power flows clearly dominate the power trade balance, Europe imports up to 20% of its electricity from North Africa. A minimum 70% self-supply rate has been imposed on a national basis to ensure that no country becomes overly reliant on imported power. Europe clearly benefits from its role as a net importer, due to system cost savings of €30 per MWh of its net imports, see ***Figure 5***. Half of these system cost savings, 15€/MWh, stem from the direct cost advantage of desert power, as shown in ***Figure 5***: the average cost of each additional MWh generated in MENA in the Connected Scenario is 58€/MWh by the time it arrives in Europe[4]. This is compared to the average cost of 73€/MWh for each additional MWh produced by Europe in the Reference Scenario. The other half of the savings results from the fact that a larger system offers more options to balance the load and the output of Solar and Wind power plants. Fewer gas peakers for balancing need to be built and less excess production by renewables, i.e. curtailment, occurs. This reduction in capacity leads to savings of an additional €15 per MWh of MENA exports to Europe.

It is crucial to differentiate between these two forms of cost savings. Producing power in MENA that arrives in Europe at a cost of approx. 20% below domestic European alternatives provides a viable business model: it can be realized by market players and investors. Thus, this part of the cost benefits will be addressed by industry once carbon emission limits are in place and renewables technologies have moved down the cost curve.

[3] The power trade figures refer to the power arriving in either Europe or MENA, i.e. transmission losses have been subtracted from these figures

[4] 58€/MWh includes the cost of power production, power transmission and transmission losses



Source: Dii, Fraunhofer ISI Note: Cost of MENA exports arriving in Europe includes cost of transmission losses

Figure 5: System cost savings per MWh of net power exports from MENA to Europe

On the other hand, no market player can do business by delivering benefits to the system that are based on system-wide synergies, such as the 220TWh of electricity that no longer need to be produced in the Connected Scenario. These synergies are, however, a major economic benefit that, among other advantages, can add to the EUMENA region's competitiveness in the global economy. These system-level advantages therefore should be addressed by governments and regulators: public institutions need to provide the appropriate structures and incentive schemes for the market to realize these economic benefits.

Overcoming this situation, a classic Nash equilibrium, is a challenging task in a market-based economy. It is part of the reason why grid extensions are making such slow progress in Europe today, despite widespread agreement that more grids are needed. Thus, well-designed, reliable and purposeful policies for both renewables technologies and grids are urgently required to achieve system integration. The engagement of governments and regulators in this area would, in turn, trigger greater investment.

The resulting benefits for both Europe and MENA are significant: Europe achieves cost savings of approx. €33bn. p.a., while MENA acquires an export industry for renewable electricity worth up to €63bn. p.a. – more than all of the current exports of Egypt and Morocco combined.

SUSTAINABILITY

Our analyses confirm that a power system based on more than 90% renewable energy is technically possible and economically viable. The effect of EUMENA-wide system integration on the marginal cost of carbon emission reductions in the power sector is impressive: it drops by 40% from 192€/tonne in the Reference Scenario to 113€/tonne in the Connected Scenario. Power system integration can thus play a major role in creating a robust and cost effective pathway towards decarbonization. This lower cost of carbon emission reduction is achieved through an optimized mix of renewables technologies, whereby power from the sun and wind is produced in the most favorable locations throughout EUMENA.

The Desert Power 2050 electricity mix is made up of 91% renewables and 9% natural gas. Wind contributes 53% to the mix, of which 48% on-shore and 5% off-shore Wind, and is installed everywhere in EUMENA, see ***Figure 6***[5]. Solar contributes another 25%, with a concentration of installations in southern Europe and MENA. While the 16% share of CSP in the power mix is almost entirely allocated in MENA, the 9% share of Utility PV production is installed in MENA as well as in southern Europe[6]. Solar installations further north, especially in Germany, are based on the NREAPs[7] of the respective EU member states. In short, a cost optimized, sustainable EUMENA power system requires the installation of hundreds of gigawatts of the four focus Solar and Wind technologies: Utility PV, CSP, on-shore Wind and off-shore Wind. The rest of the power mix consists of hydro power, biomass, geothermal and a few other renewables technologies.

This cost optimized power mix relies heavily on the use of a high voltage direct current transmission grid. Without such a grid, it will be impossible to bring power from the best solar, wind and hydro sites in the sparsely populated north and south to high demand regions in the center of the system, see ***Figure 7***.

The Maghreb and Libya are the southern “powerhouses” of the region, while Scandinavia, especially Norway, plays the same role in the far north. Power flows from the south reach Europe via seven sub-Mediterranean transmission corridors and are then passed on north from Spain, France, Italy and Greece to the UK, the BeNeLux countries, Germany, Austria, and the Czech Republic. In the belt from BeNeLux to the Czech Republic, desert power then meets the power flows from Norway via Denmark, Sweden and Poland. An eighth south-north corridor brings power from Egypt and Saudi Arabia on to Turkey.

An aspect emphasized by our study is the strong need for power in the south eastern part of the system. Indeed, Turkey and Egypt could well have the largest population and highest power demand in the region in 2050. Due to high per capita consumption, Saudi Arabia will likely be of a similar size in terms of power demand. These three countries, together with Jordan and Syria, contribute approx. 33% of total EUMENA demand – as much as the four largest EU economies Germany, France, the UK and Italy together. Unlike most of the major economies in the center of Europe, the region enjoys good solar and wind conditions and does not rely on imports. Due to the high demand in the Middle East and Egypt, most of the desert power produced there will be consumed locally. Given their relatively small populations and abundant renewables resources, the Maghreb countries and Libya export large quantities of power to Europe.

[5] Off-shore Wind is only considered for Europe, since the conditions in MENA are not attractive enough

[6] Distributed PV installations are not addressed by the methodology used to analyze the benefits of a large-scale power system integration. That said, widespread Distributed PV can contribute to a scenario of low demand in the grid, which is the lowest cost scenario analyzed in Desert Power 2050

[7] National Renewable Energy Action Plans

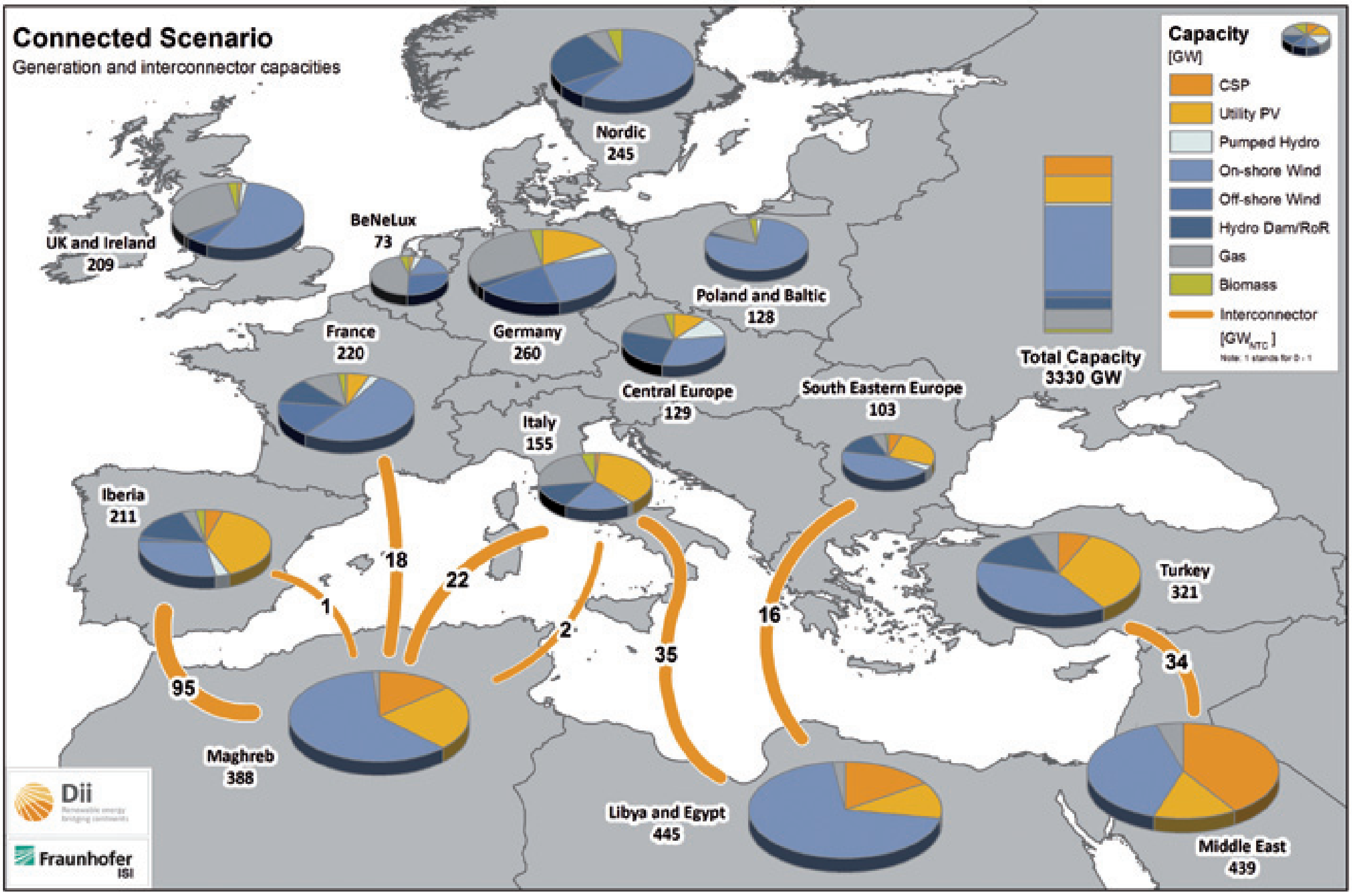


Figure 6: Generation and interconnector capacity, Connected Scenario

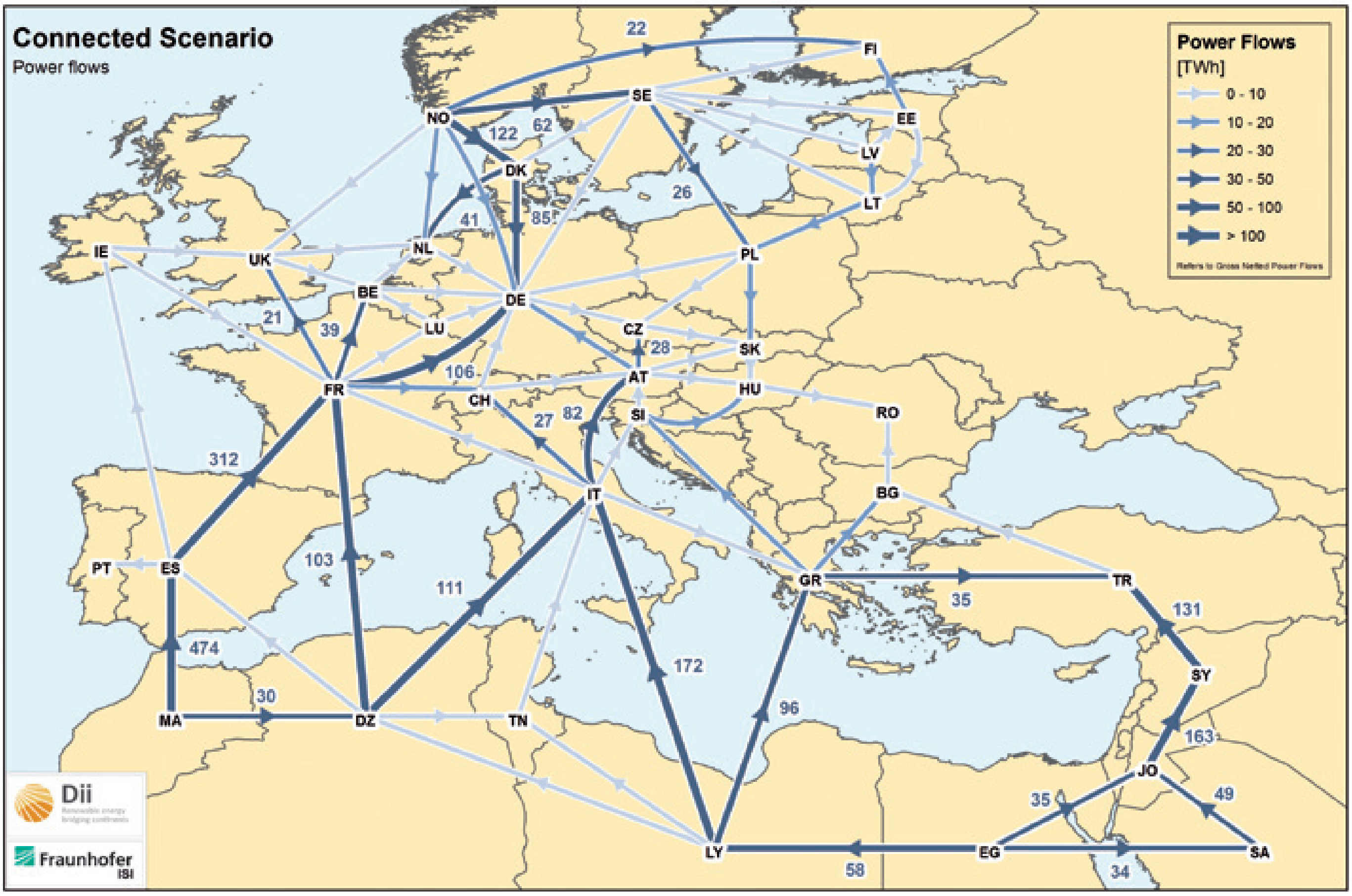
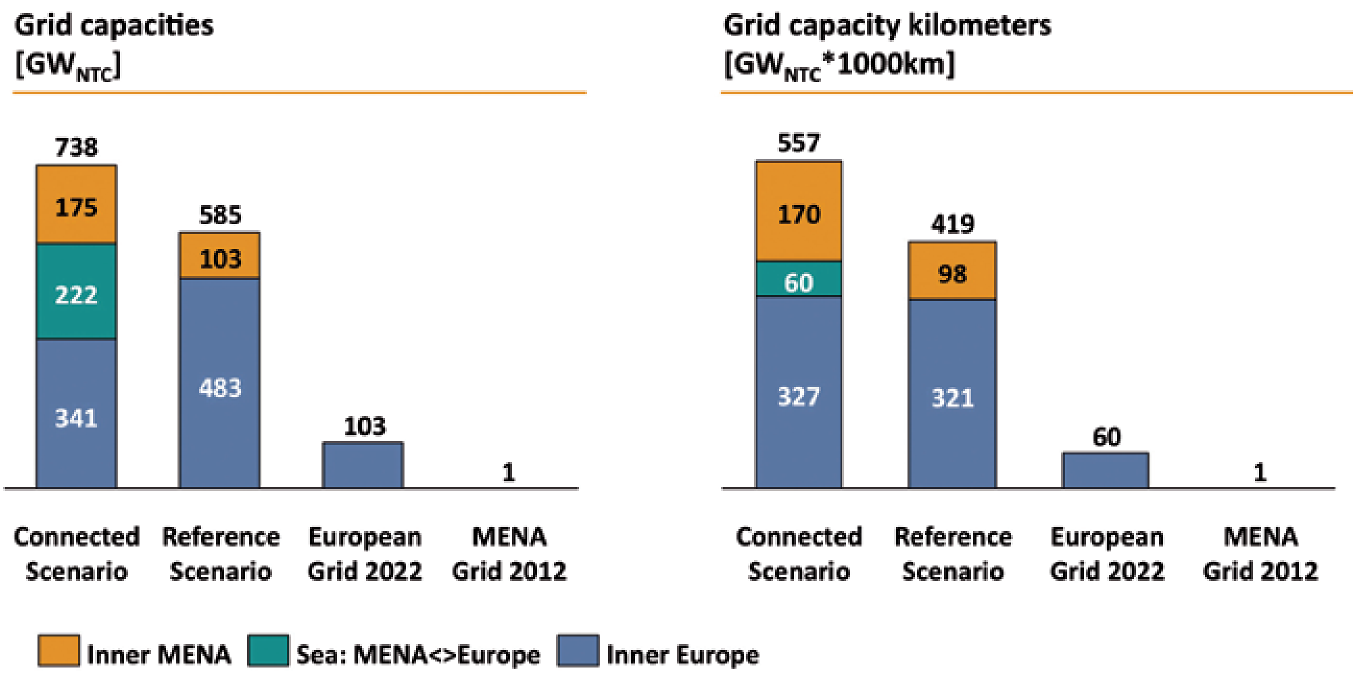


Figure 7: Power flows in the Connected Scenario

The total capacity of the sub-Mediterranean connections and the Syria-Turkey overland connection amounts to 222GW_{NTC}[8], see the left part of ***Figure 8***. Around 1100TWh of electricity per year flows through these connections between MENA and Europe. Due to these interconnectors' high utilization rates, power transmission across the Mediterranean is affordable.

The 557GW_{NTC}*1000km capacity needed are not only much larger than the ones currently connecting the south and the north of the system[9] but are also far larger than any existing within Europe and MENA today. In comparison to the Reference Scenario of two separate cost optimized systems, most additional overland transmission infrastructure (measured in capacity kilometers) is needed in MENA, not the densely populated European mainland, as shown in the right part of ***Figure 8***.

Europe needs to build grids in order to enable a cost efficient power system based on renewables – no matter whether such a system ends at Europe's borders or goes beyond them. The benefit to Europe of such grid expansion is a sustainable, affordable and reliable power supply; the further the integration of the grid reaches, the larger the benefits become.



Source: Dii, Fraunhofer ISI Note: European grid 2022=NTC as of 2012 plus NTC increase based on ENTSO-E TNYDP2012

Figure 8: Transmission grid capacities in the Connected Scenario and the Reference Scenario

[8] GW_{NTC} refers to GW of net transfer capacity

[9] 250MW Turkey/Syria (not synchronized) and 900MW Spain/Morocco

SECURITY OF SUPPLY

Security of supply comprises both technical and political complementarities. As our analysis suggests, system integration makes a sustainable power system not only more affordable but also more reliable. In order to show how this occurs, we look first at technical complementarities and then proceed to examine the mutual reliance created by an integrated system.

Intuitively, the larger a connected system is, the higher the probability that the sun shines and the wind blows somewhere in the area covered. This is essential for a power system based on 90% renewables, since avoiding blackouts means ensuring that there are sufficient Solar and Wind resources to meet demand 24 hours a day, 365 days a year. ***Figure 9*** shows that this intuition is not only correct, but that the natural correlation of sun and wind is favorable from a power supply point of view. In order to understand power supply over time, one needs to look at daily changes as well as seasonal variations.

Figure 9 shows an average summer and an average winter day in EUMENA in terms of power demand and supply in hourly resolution. On the daily time scale, sun and wind fit well: the least Wind is in the system during the midday sunlight hours when demand is high. However, during these hours Solar is able to provide the necessary power. On a seasonal time scale, Wind production is higher in winter while Solar is stronger in summer.

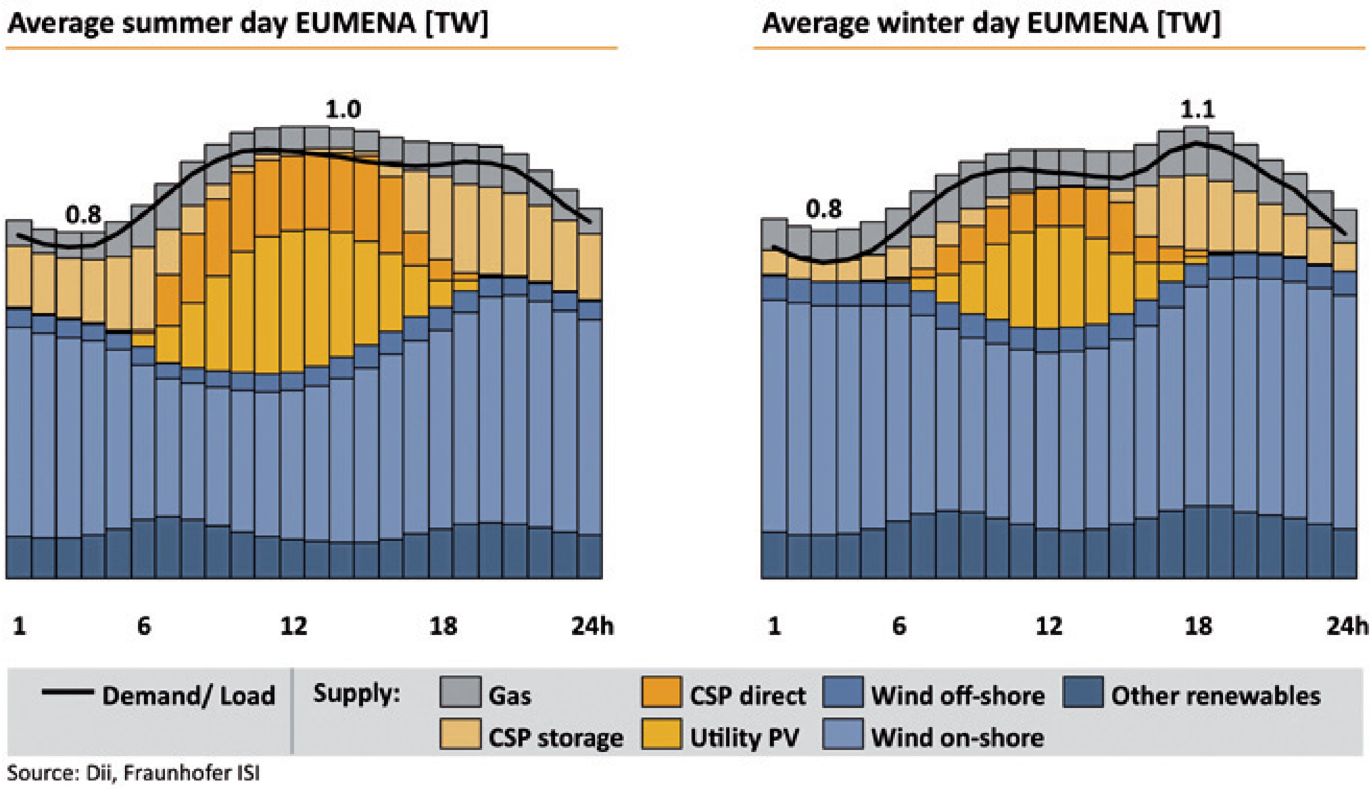
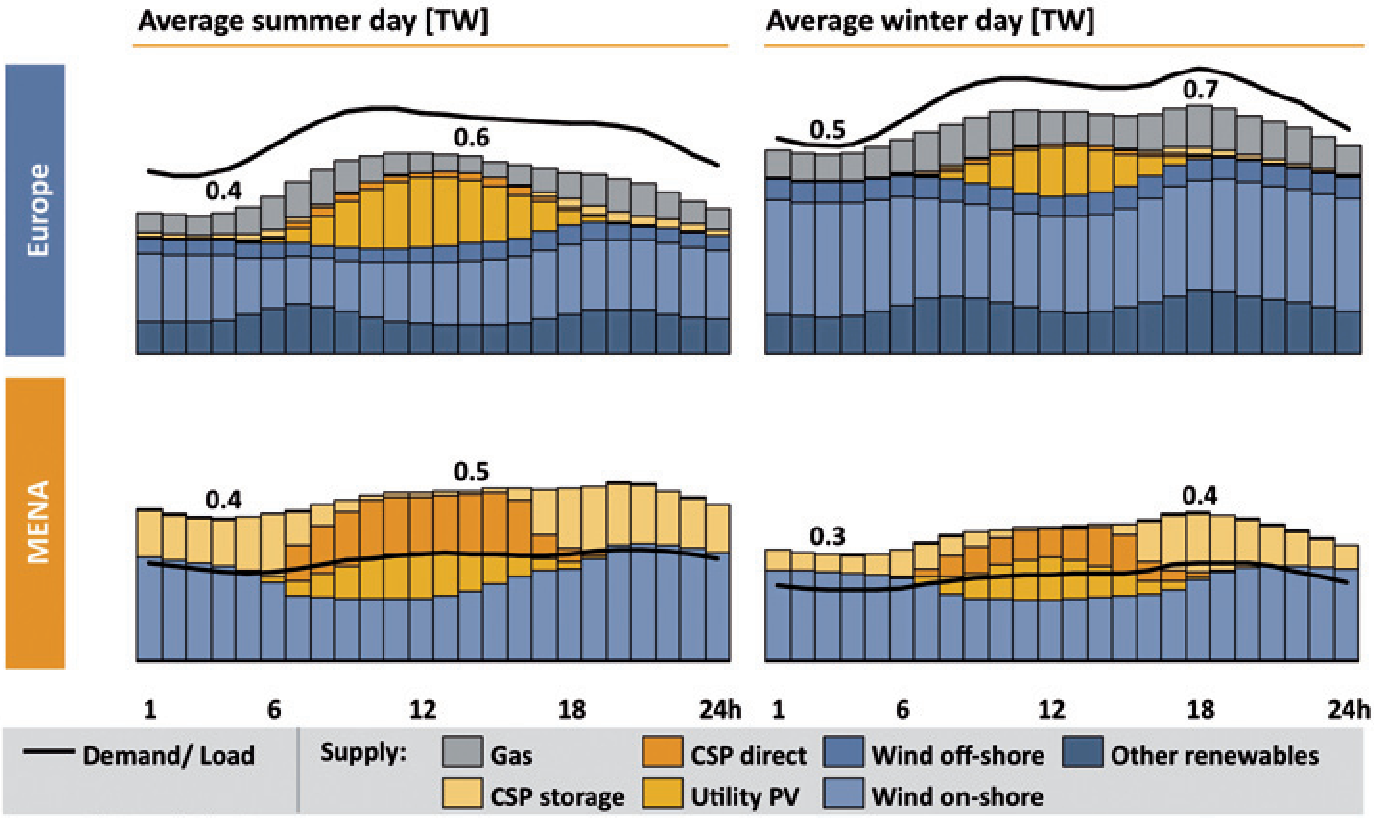


Figure 9: Daily and seasonal demand and supply in EUMENA



Source: Dii, Fraunhofer ISI

Figure 10: Daily and seasonal demand and supply in Europe and MENA

Figure 10 reveals that the good fit of demand, sun and wind shown in ***Figure 9*** is the result of complementary demand and supply conditions in MENA and Europe. While load is higher in winter than in summer in Europe, the opposite is the case in MENA, where more extreme weather conditions prevail during the hot summer as opposed to Europe's cold winter. Also, while Wind production is higher in winter in Europe, it is stable throughout the year in MENA. Due to its high Solar yield, MENA is able to provide Europe with the power it needs during the summer, following the daily demand curve with the help of the CSP storage. Availability of gas generation is strictly limited by the common carbon emission cap for MENA and Europe. The strong allocation of gas generation to Europe not only ensures a well-functioning power system; it is also the reason for the 40% decrease in the marginal cost of carbon emission reduction.

The roles of individual countries in this integrated system are essential to understand how the system becomes stable as well as competitive. We distinguish between three main types of countries: renewables super producers, importers, and countries with balanced renewables and demand. While each of these three types profits from system integration in a different way, they all benefit from being part of a large sustainable power system. At the same time, their complementary roles lead to a situation of mutual reliance, in which no one country is dependent on another but instead each country is reliant on the system as a whole.

> **Super producers** are countries with excellent renewables resources and relatively low demand. Thus, they have enough excess in cheap renewables potentials for significant exports. Examples of super producers are the Maghreb and Libya in the south and Norway in the north. The super producers profit from system integration in two ways: from a large renewable electricity export industry and from a reliance on the overcapacities of renewables (compared to domestic load) as a means of ensuring their own security of supply at all times of the year.

> Importers have high demand and, compared to demand, limited potentials of good renewables resources. This group of countries includes Germany, Italy, and – though less pronounced – also France and Turkey. These countries import cheap renewable power throughout the day and year in order to ensure an affordable sustainable power supply. They benefit not only from the cost advantage of the imported electricity, but also from the optimized allocation of the remaining conventional gas generation. Since gas, and thereby carbon emissions, are allocated under a common cap to where they are needed most, the countries with limited renewables can use more gas than in an isolated system.

> Balancers have levels of demand and renewables resources that are largely proportionate to each other. They include Egypt, Saudi Arabia, Syria, Spain, the UK and Denmark. As mentioned, an assessment of renewables potentials must not only be based on the levelized cost of electricity but also on their fit with the load that needs to be satisfied at every point in time. This is why the balancers also profit from system integration: they build just as much renewables capacity as is economic to cover most of their domestic load. Covering the remaining minor share of the load with domestic renewables becomes less economical, since curtailment of excess energy would occur. Consequently, these countries import power when needed and export it when their production exceeds domestic demand. They thereby avoid building the final segment of domestic renewables, which would make the sustainable power system more expensive due to high curtailment.

Having addressed the different country roles in an integrated power system, it becomes clear that such a system is heavily interlinked and has advantages for all participating parties. This mutual reliance and interdependence is one of the reasons why an integrated sustainable power system enhances security of supply not only from a technical but also from a political and geopolitical point of view.

Desert power contributes to security of supply in several ways. First, most European and many MENA countries currently rely on fossil fuel imports for their electricity. Desert power facilitates an affordable shift across the region to a clean, renewables-based power system. This transition will make these countries independent of fossil fuels and their volatile price developments: in a sustainable power system with more than 90% renewables, less than 7% of system costs are fuel costs. In comparison, in today‘s gas plants almost 70% of all costs are fuel, in coal plants 30% and in nuclear plants about 15%. Thus, the reduced exposure to fuel price volatility leads to more stable power prices as a basis for a more stable and more competitive economy.

An integrated system also leads to a more diversified power supply for all countries. Importers in Europe, for example, buy power from several different countries; unlike today, no single exporter makes up more than 10% of European supply. Furthermore, being part of the same system leads to a situation of mutual reliance between importers and exporters. Exporters in North Africa, for example, rely on importers in Europe for the balancing effects of European gas capacity.

By making a paradigm shift to a renewables-based power system more affordable, desert power makes an important contribution to energy autonomy for countries throughout EUMENA. In an integrated system, even the importers in Europe will supply more of their own power in 2050 than they do today. Without such a paradigm shift, the negative effects of fossil fuel dependency will worsen for EUMENA as a whole, and for fossil fuel importers in particular. An integrated EUMENA system, on the other hand, will encourage a transition that benefits all parties, promotes mutual reliance across the region, and has the potential to extend beyond the power sector. Such increased cooperation with neighboring regions is already an explicit target of EU energy policy[10].

[10] See, for example, the European Commission communication *The EU Energy Policy: Engaging with partners beyond our borders* (2011), which highlights the importance of an EU-Southern Mediterranean Energy Partnership with a special focus on renewable energy

PERSPECTIVES ON DESERT POWER

As Niels Bohr, physicist and Nobel Prize laureate put it, “Prediction is difficult, especially about the future”.

Analyzing the design of a power system built to include more than 90% renewables 40 years into the future is necessarily subject to major uncertainties on a range of assumptions. The only way to address these uncertainties is to analyze so-called sensitivities, or perspectives, to show how the results react to changed parameters.

Beyond the Connected and the Reference Scenarios, we have analyzed a total of 16 additional perspectives on the EUMENA power supply in 2050, see ***Figure 11***. They cover a wide range of major impact factors on the attractiveness of power system integration.

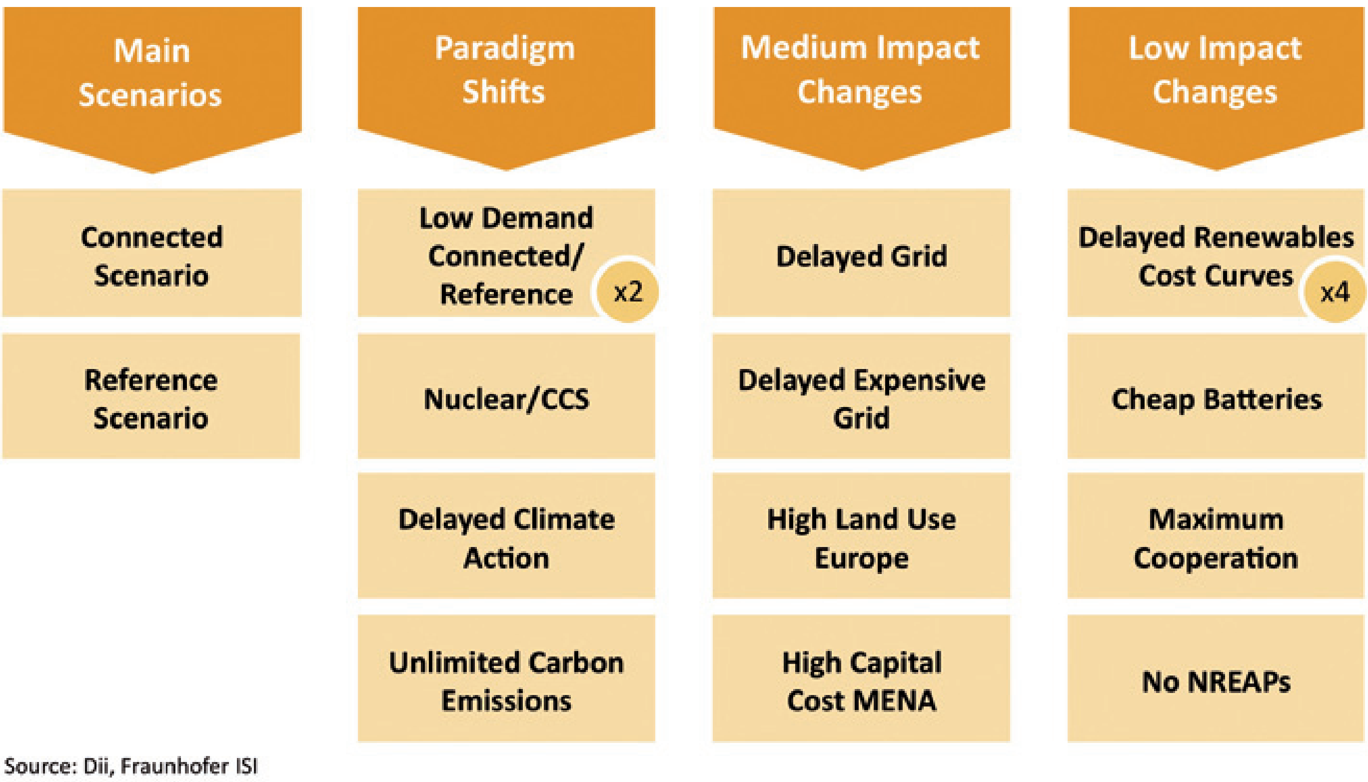


Figure 11: Scenarios assessed for robustness of EUMENA system integration

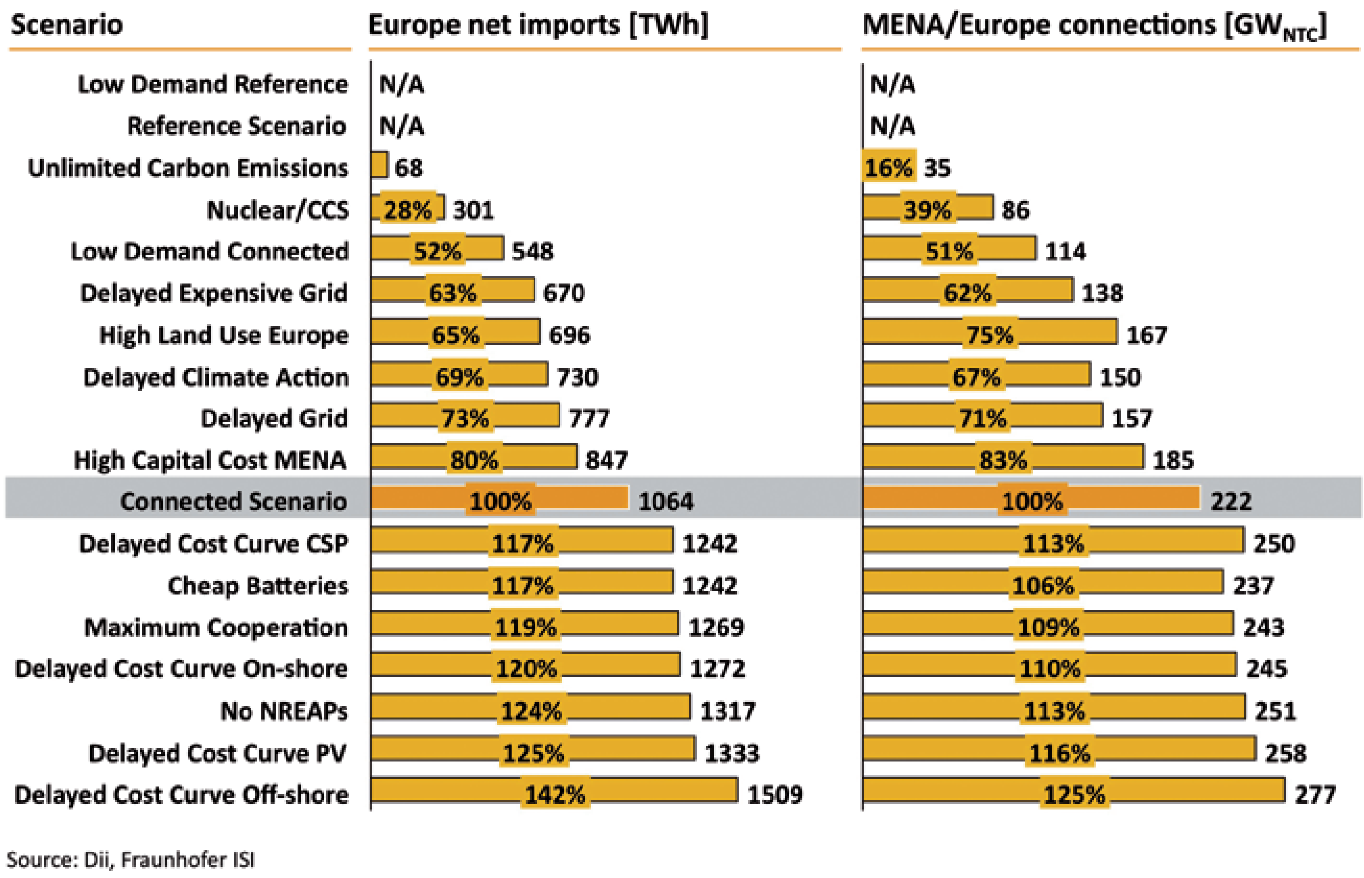


Figure 12: European net imports and interconnector capacities

The sensitivities have been clustered into three categories. The first category, paradigm shifts, is dedicated to four substantially different pathways in shaping tomorrow's power system. Among all sensitivities, the Low Demand Connected Scenario is of special importance. The other sensitivities show the impact of society's success in establishing favorable prerequisites for an integrated sustainable power system in EUMENA. These eleven scenarios have been clustered according to how strongly they affect the attractiveness of EUMENA-wide power system integration. We now turn to summarizing the overall conclusions, and highlighting key details of the sensitivity analysis.

The main message from the analysis of these different cases could not be clearer: grid integration across the Mediterranean is valuable under all foreseeable circumstances. Even in the **Unlimited Carbon Emissions Scenario**, with a power mix dominated by coal and carbon emissions 2.5 times higher than today, a total of 35GW$_{NTC}$ of interconnector capacities across the full east-west width of the Mediterranean is built, see the right part of ***Figure 12***. In all scenarios with a carbon emission cap, it is cost optimal to build at least 86GW$_{NTC}$ of Mediterranean interconnectors. At least 301TWh net of desert power is exported by MENA to Europe, see the left part of ***Figure 12***.

The **Low Demand Connected Scenario** assumes that Europe manages to keep the portion of its power demand supplied by utility scale power generation flat at today's levels, e.g. by successful energy efficiency measures or through decentralized power generation and storage. It shows that, even with 40% lower demand of 4900TWh per year for EUMENA, 114GW$_{NTC}$ of interconnectors are built and 548TWh of annual net exports to Europe are optimal from a cost point of view. This scenario thereby demonstrates that energy efficiency and decentralized power generation, on the one hand, and EUMENA wide power system integration, on the other, are not mutually exclusive alternatives but instead complement each other extremely well. The Low Demand Connected Scenario is also the scenario with the lowest cost of all analyzed cases, including the Unlimited Carbon Emissions Scenario, which is €97bn. p.a. more expensive.

It would be a major step in the right direction if Europe manages to exploit its best renewables potentials to a very high degree. A scenario based on this assumption, called **High Land Use Europe**, would mean for example that Germany alone installs 180GW of on-shore Wind in the most favorable half of its potential Wind sites. The result is that the cost optimal solution in this scenario includes approx. 700TWh of annual net exports from MENA to Europe. Thus, maximizing European effectiveness in renewables installations does not eliminate the benefits of desert power imports. Instead, both efforts should be combined to achieve the best possible sustainable power supply for EUMENA.

Solar and Wind technologies have consistently met or exceeded expectations concerning cost reductions and market growth. Unfortunately, this cannot yet be said for the extension of the transmission grid in Europe. Despite all efforts to overcome this major challenge in building the electricity system of the future, it seems only prudent to analyze the impact of **Delayed Grids**. Already the cost assumptions of the Connected Scenario are based on the assumption that by 2050, 50% of all installed overland transmission in Europe will be HVDC underground cables. This takes into account cost increases related to public acceptance issues of overhead lines. The Delayed Grid Scenario assumes that no connection between two countries throughout EUMENA can exceed $20GW_{NTC}$. This assumption severely limits the most attractive sub-Mediterranean interconnectors compared to the Connected Scenario. It has no impact, though, on the grid within Europe except for the connection between Spain and France. In the Delayed Expensive Grid Scenario, the $20GW_{NTC}$ limit is maintained and the cost of transmission lines increases by 50% above the costs deemed realistic by industry experts. This causes only a minor drop in interconnector capacity across the Mediterranean, from $157GW_{NTC}$ to $138GW_{NTC}$. The result of this scenario is that those sub-Mediterranean interconnectors not used to the limit in the Connected Scenario are expanded to the allowed maximum. This replaces the lost import capabilities, see ***Figure 13***. In other words, the attractiveness of desert power does not depend on the success of using a few interconnectors. Instead, all interconnectors can substantially contribute to lowering the cost of sustainable power supply for Europe.

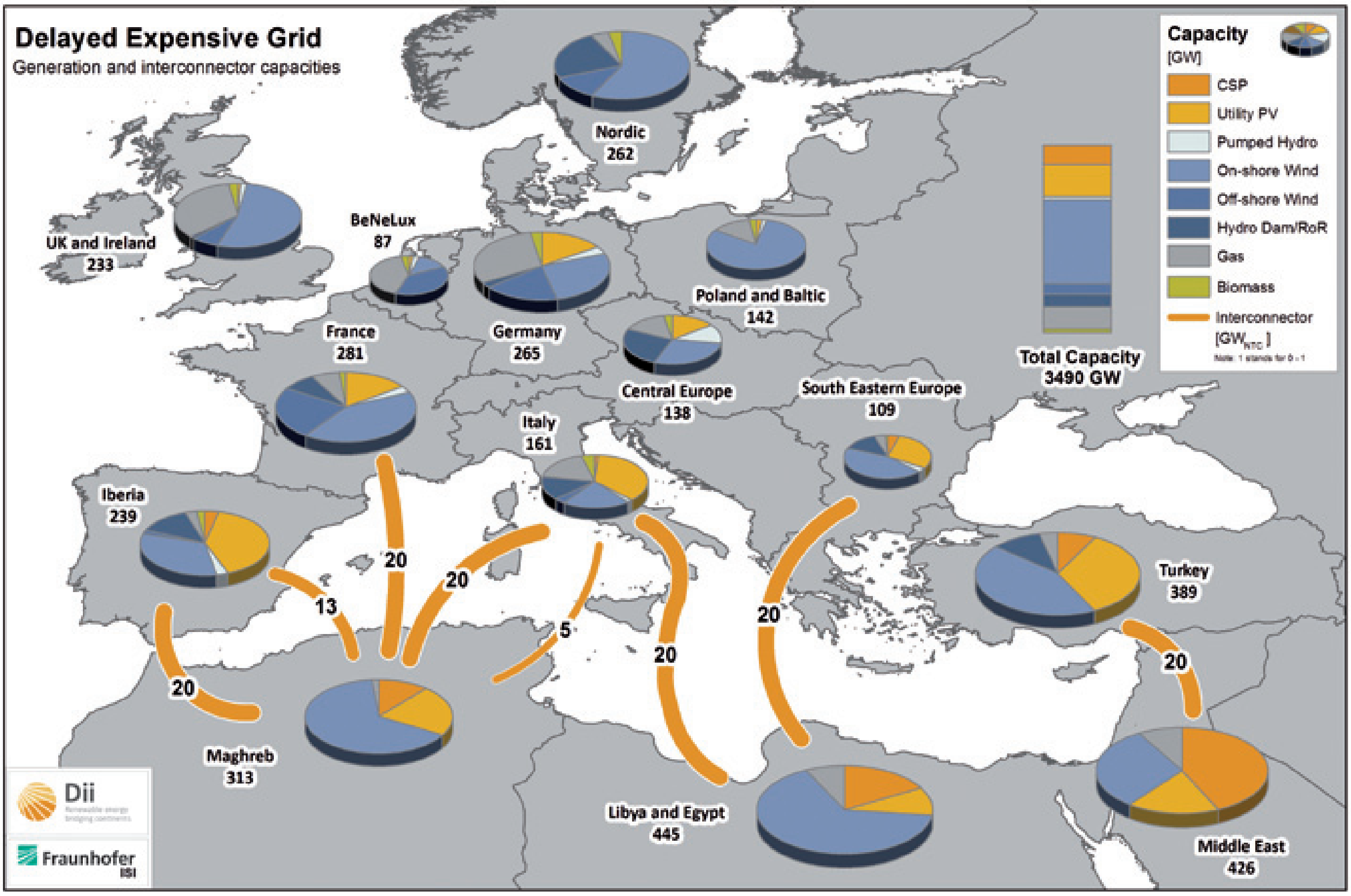


Figure 13: Generation and interconnector capacity, Delayed Expensive Grid Scenario

Another well-known obstacle to the faster diffusion of renewable power technologies is the financing needed for the construction of these capital intensive types of power plants. Financing depends on risk perception among investors, who ask for increased returns on capital for investments in renewables and in developing countries. The **High Capital Cost MENA** scenario analyzes the impact of 9% p.a. weighted average cost of capital for installations in MENA while the standard 7% p.a. still suffices for Europe. Despite the effect of higher capital costs in MENA on desert power's attractiveness in Europe, 847TWh or 80% of the annual net exports in the Connected Scenario remain. Thus, even if investments in MENA renewables continue to be perceived as high risk, the case for EUMENA-wide system integration remains strong.

Nuclear and CCS[11] are often considered alternative options for the decarbonization of the power sector. Thus, it is important to examine the interplay of these technologies and renewables. The result of the **Nuclear/CCS** scenario is that 55% of all power is produced from renewables and 301TWh imports of desert power to Europe are a cost optimal choice. Furthermore, neither Nuclear nor CCS are cost competitive with renewables in all of North Africa, which continues to rely on a mix of Solar and Wind power.

Despite their limited impact on the system, the conclusion from the **Low Impact** scenarios is still highly relevant: the attractiveness of EUMENA system integration and desert power for Europe does not depend on any of the technologies' ability to fully achieve the predicted cost reductions. Also, the impact of cheap daily storage with utility batteries is low. Finally, in the **Maximum Cooperation** scenario no lower limit on self-supply rates is imposed. The limited impact of removing this restriction shows that many countries' cautious attitudes towards electricity imports have only a limited impact on the value of desert power. The **No NREAPs** scenario underlines that current European policy on renewables is not in stark contrast to the case for desert power, although of course not optimal from a system cost point of view.

Given the robustness of the case for desert power under the full range of perspectives considered, the next question necessarily is what needs to be done to make it actually happen.

[11] Carbon capture and storage

CONCLUSION: TIME TO GET STARTED

Desert Power 2050 proves why the objective of an integrated, sustainable EUMENA power system is valuable.

In addition to this long-term strategy, Dii is also developing individual country strategies, which in turn form the basis for concrete Reference Projects. These country studies present analyses on sites, grids, regulation, markets and socio-economic aspects that are decisive for the success of renewables in individual MENA countries. The long-term outlook of Desert Power 2050 ensures that this short- to medium-term focus contributes to a sustainable EUMENA power system.

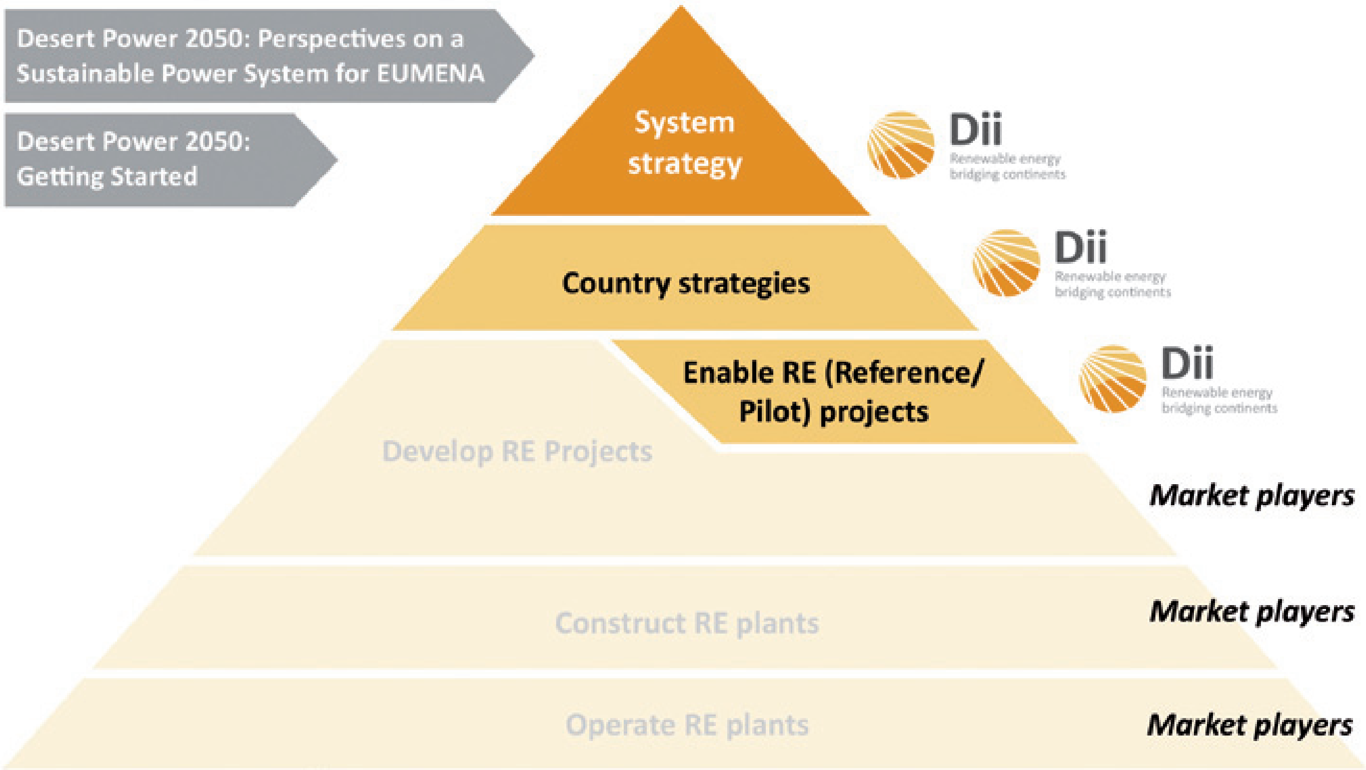
In the power sector, 2050 is only one to two investment cycles away. Therefore, the policy choices made today will determine whether the path to a sustainable system can be pursued. With its next study, **Desert Power 2050: Getting Started**, Dii aims to formulate recommendations on the appropriate technology and policy choices to be made now.

Desert Power 2050: Getting Started will offer a closer look at the technology and geography of the first gigawatts of desert power leading to the hundreds of gigawatts shown in this study in a step-by-step process. We will also assess the action needed on grids and Europe-MENA interconnectors. This analysis aims to provide input for ten year development plans, such as that of the European Network of Transmission System Operators for Electricity (ENTSO-E).

Furthermore, it is crucial to show how these technical prerequisites for desert power can be implemented politically. In Desert Power 2050: Getting Started, Dii will model the impact of different support schemes over time in order to ensure that they provide value to stakeholders. This quantitative analysis will be combined with a qualitative assessment of the political feasibility of support scheme designs. Combined, the two will result in concrete and actionable recommendations for policymakers today.

Both parts of Desert Power 2050 reflect Dii's conviction that desert power is about more than electricity. To this end, Desert Power 2050: Getting Started will present the results of Dii's socio-economic assessment. Not only will desert power provide affordable, stable electricity – the key to economic growth – it could also create up to one million jobs by 2050. Understanding the GDP and labor market effects of desert power is another key input to policymakers that Dii is working on.

Reaching the goal of an integrated sustainable EUMENA power system will require combined efforts from all the countries involved. Today, we can choose to take the first step towards a common market for renewable energy in EUMENA – a vision of EUMENA supplying itself with sustainable and affordable power for future generations.



Source: Dii Note: RE=Renewable energy

Figure 14: Dii strategy pyramid

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