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No. 1891 | January 2014

Web: www.ifw-kiel.de

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Desert Power 2050: Regional and sectoral impacts of renewable electricity production in Europe, the Middle East and North Africa *

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Abstract:
"Desert Power 2050" is probably the world's most ambitious strategy report towards the decarbonization of the power sector in Europe, the Middle East and North Africa (EUMENA). The report inspired by the Desertec vision aims at providing clean energy from MENA's desert regions to the entire MENA region as well as exporting electricity to Europe. The report shows that an integrated EUMENA power system based on more than 90 percent renewables is technically feasible and economically viable. We use a combination of a global general equilibrium model (DART) and a multiplier analysis to evaluate the economic effects behind "Desert Power 2050" from a broader perspective, including not only the energy activities but also the repercussions in other sectors of the economies. The results show that the extent of the costs and benefits for both regions depend on the type of strategy adopted to finance the build-up of the power plants and the expected development of the levelised cost of electricity for the different technologies. Furthermore, the viability of a transition towards renewable energy as proposed by "Desert Power 2050" depends to a great extent on the international climate policy.

Keywords: Computable General Equilibrium, Multiplier Analysis, Renewable Energy, Climate Policy, Europe-North Africa-the Middle East

JEL classification: C68, C67, Q42, Q58, O52, O55

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* This article was funded by the Desertec Industrial Initiative.

1 Introduction

"Within six hours deserts receive more energy from the sun than humankind consumes within a year" (Trans-Mediterranean Renewable Energy Cooperation, TREC). This statement reveals the enormous potential of deserts for power generation and plays a central role in ambitious concepts like Desertec[1] or Gobitec[2]. According to the German Aerospace Center, one percent of the area of the Sahara desert covered by solar thermal power plants would be enough to meet the world's annual electricity consumption (DLR 2005). This abundant, unlimited and clean energy can be tapped to supply to a large part of the world with sustainable power.

With a special focus on Europe, the Middle East and North Africa (EUMENA), the Desertec Industrial Initiative (Dii)[3] has established ambitious goals towards providing clean energy from MENA's desert regions to the entire MENA region as well as exporting electricity to Europe. By 2050, Dii aims at establishing a power system in MENA based on 97 percent renewables, dominated by wind power that accounts for 53 percent of all electricity produced. Solar technologies are expected to contribute by around 44 percent (Dii 2012). This implies to install around 1 terawatt (TW) of renewable power capacity, which is equivalent to today's installed capacity in Europe. Most of the electricity produced will cover the growing energy demand in MENA countries and up to 20 percent will be exported to Europe.

A transition of this magnitude will definitively have a great economic impact on the MENA region. Hundreds of wind and solar power plants need to be constructed requiring to mobilize huge economic resources which may compete with uses in other sectors of the MENA economies. Job opportunities will be created during the construction, operation and maintenance phase of power plants. An annual production of 2 gigawatt hour (GWh) may create between 11 to 26 jobs depending on the technology (wind or solar) and phase of the power plant (DLR 2005). Moreover, the Dii's strategic framework intends to reinforce MENA's industry to enable self-production of many renewable energy technology components.

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[1] The Desertec concept aims to generate sustainable power from the sites where renewable sources of energy are most abundant. This also contributes to combat climate change, ensure a reliable energy supply and promote security and development (online resources, www.desertec.org).

[2] Similar to Desertec, the Gobitec concept aims to produce energy in the Gobi desert in Mongolia and China and brought via high-voltage lines to the industrial centers in Korea, Japan and Eastern China (online resources, www.gobitec.org).

[3] The Desertec Industrial Initiative (Dii) is a private industry consortium that aims to achieve the objectives of the Desertec vision in Europe, the Middle East and North Africa.

Accessibility to energy, and electricity in particular, is crucial for economic development and poverty reduction; it is the engine for industrial development and enhances the economic competitiveness (Bartels 2007). The development of wind and solar power in MENA will also contribute to the mitigation of climate change by significantly reducing the carbon dioxide (CO_2) emissions from the electricity sector. Thus, electricity trade between MENA and Europe will also help to achieve Europe's commitments on energy-climate targets set out in the National Renewable Energy Action Plans.

Clearly, such an ambitious transition requires substantial economic resources. The yearly investment in renewable power capacity in the whole MENA region reaches gradually up to 10 percent (around 2030) of the total investment in the region. In addition, even if solar and wind potentials are ideal in the desert regions of MENA, solar and wind power production are in many cases currently still more expensive than fossil fuel based technologies and require subsidies to be competitive on the electricity markets in MENA and the EU. Based on current projects and using the levelised cost of electricity (LCOE)[4], IRENA (2013) reports that only wind onshore technologies are cost competitive with fossil fuel based technologies.

The purpose of this article is to evaluate the overall economic impact of the Dii's strategy report "Desert Power 2050" under different scenarios of the realization of the transition and under different international policy scenarios. In particular, we assess the potential economic costs and benefits for the MENA and EU regions, identifying the economic impacts across sectors and across countries. The analysis is carried out using our global computable general equilibrium model DART[5] which we complement with a multiplier analysis in order to quantify potential employment effects.

2 A vision towards 2050

Dii's goals and implementation strategies are presented in the report "Desert Power 2050" (Dii 2012). The report proposes a shift towards a renewable-based power system in MENA and Europe to pursue the 2 degree target. It focuses on technologies widely used nowadays: concentrating solar power (CSP), photovoltaic (PV) as well as on-shore and off-shore wind

[4] A clear identification of the cost for each technology is not always possible because it depends on specific regional conditions such as resource availability and local cost structure. The levelised cost of electricity allows a comparison of different power generation technologies. It is the ratio between the cost of electricity generation (installation costs plus lifetime operation and maintenance costs) and the electricity generated by the system over its operational lifetime.

[5] A short summary is given in Annex A.

(WIND). The report compares a scenario where MENA and Europe pursue a renewable energy system but independently of each other (reference scenario), with a scenario where the power system in MENA and Europe are interconnected (connected scenario). Based on the PowerACE[6] software that optimizes the power system costs, the report shows that integrating the power systems across the Mediterranean is a win-win strategy for both MENA and Europe. The report estimates that the average system cost for the EUMENA as a whole region can be reduced from 65€/MWh in the reference scenario to 61€/MWh in the connected scenario. This implies around €33 billion cost savings per year (Dii 2012). European countries benefit from importing low-cost renewable energy from MENA while costs in MENA countries remain essentially flat when more electricity is produced for exporting to Europe.

The report describes a future power system scenario almost fully based on solar and wind energy in MENA. In fact, only three percent of the total electricity produced in 2050 is expected to be based on conventional technologies (Figure 1, upper graph). This requires a fast development in the mid and long term of solar and wind power plants (Figure 1, middle graph), which are expected to be dominated by wind technologies, since their levelised cost of electricity is lower compared to CSP and PV technologies. The lower cost of wind technologies combined with the higher potential of wind along the costal lines in North Africa favour wind technologies in the energy mix of Morocco, Egypt, Algeria and Libya. Contrary, high solar irradiation in the Middle East enables solar technologies to play a dominant role in Saudi Arabia.

Solar and wind technologies in MENA are not only expected to replace conventional power plants, they will also meet the increasing electricity demand in the region (annual growth between 6 to 8 percent) and cover part of the electricity demand in Europe. Compared to current numbers, power generation in MENA countries is expected to triple by 2050 to meet their own demand and to quadruple when exports to Europe are considered. Countries inside MENA develop differently according to their geographical and natural conditions. Morocco, Algeria and Libya will become main power producers, generating five times more power than they consume.

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[6] The PowerACE software, developed at the Fraunhofer Institute for Systems and Innovation Research, optimizes the construction and dispatch of power plants, storage facilities, transmission grids between countries and renewables generation technologies through linear optimization. Based on detailed data on potentials for renewables generation technologies and hourly generation profiles, the electricity system is optimized 24 hours a day, 7 days a week for all 365 days of the year. This means that demand in every country has to be met in every hour of the year by the selected technology mix (Dii 2012).

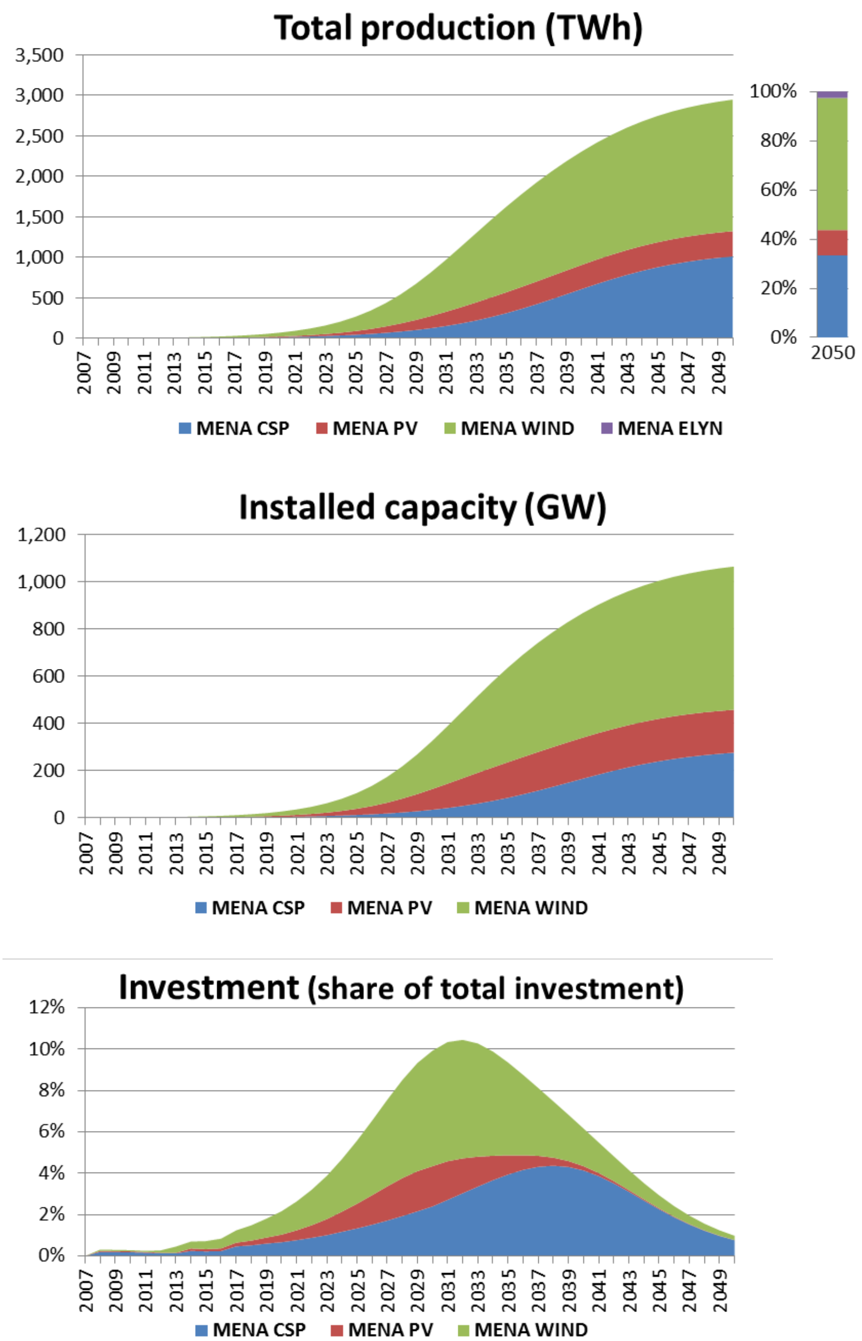

Figure 1. Electricity production, installed capacity and investment in solar and wind energy in MENA

Note: CSP = concentrating solar power, PV = photovoltaic, ELYN = electricity generation from conventional sources (fossil fuels, hydroelectric, nuclear, geothermal, tide, wave, biomass and waste).

Source: Own calculations based on Dii's connected scenario. Total investment according to the *current policy scenario* (DART model).

The scenario for the solar and wind energy development in the EU is based on the low-carbon economy framework set in the European Commission's "Energy Roadmap 2050"[7]. Thus by 2050 more than two-thirds of the electricity produced in Europe will come from solar and wind power plants. Wind energy will also play a crucial role in Europe providing more than half of the total electricity produced (Figure 2, upper graph). This implies a gradual substitution of fossil fuel based technologies with solar and wind technologies. In fact, to meet these requirements the current European installed capacity of solar and wind electricity generation needs to grow 20 times by 2050, when power markets are not connected in Europe and MENA, and up to 15 times in the case of interconnection (Figure 2, middle graph).

The decarbonization of the power sector in EUMENA proposed by the Dii's report has several challenges. First, it implies that huge amounts of resources must be allocated to the installations of solar and wind generation capacities. In MENA the annual investment behind Dii's plans grows gradually up to more than 10 percent of the total investment in the region (Figure1, lower graph). In Europe, even if the required installed capacity of solar and wind power plants is 50 percent higher, it represents as a maximum only one percent of the total investment in the region (Figure 2, lower graph). The investment peak for PV technologies in the early years is mainly driven by Germany's promotion of PV installations with high feed-in tariffs through the National Renewable Energy Law. As shown in the next section, the financing mechanisms for renewable energy investments and their impact on other sectors of the economy are crucial for the extent to which the countries can benefit from the build-up of renewable electricity installations.

Second, there is also a need to finance the costs of solar and wind energy production. Nowadays, subsidies are needed for renewables to compete with fossil fuel based technologies. The LCOE behind the Dii's report shows that only wind technologies in MENA are cost competitive with conventional technologies[8] (Figure 3). Electricity from wind energy in Morocco could be produced as cheap as 3.5 euro cents per kilowatt hour (kWh). On the other hand, electricity produced from PV utilities in Germany is 5 times more expensive (18 euro cents/kWh). The combination of more than 10 years of PV promotion in Germany and its high LCOE are resulting, according to Frondel et al. (2012), to about 100 billion euros in

[7] European Commission (2011).
[8] Conventional technologies in this study include fossil fuels, hydroelectric, nuclear, geothermal, tide, wave, biomass and waste.

subsidies. Only about 16 percent of this burden has already been paid, the rest will be paid over the next two decades, as feed-in tariffs in Germany are legally guaranteed for 20 years. It is clear that the viability of a transition towards renewable energy in EUMENA depends to a large degree on the development of the LCOE of the three renewable electricity technologies over the next years.

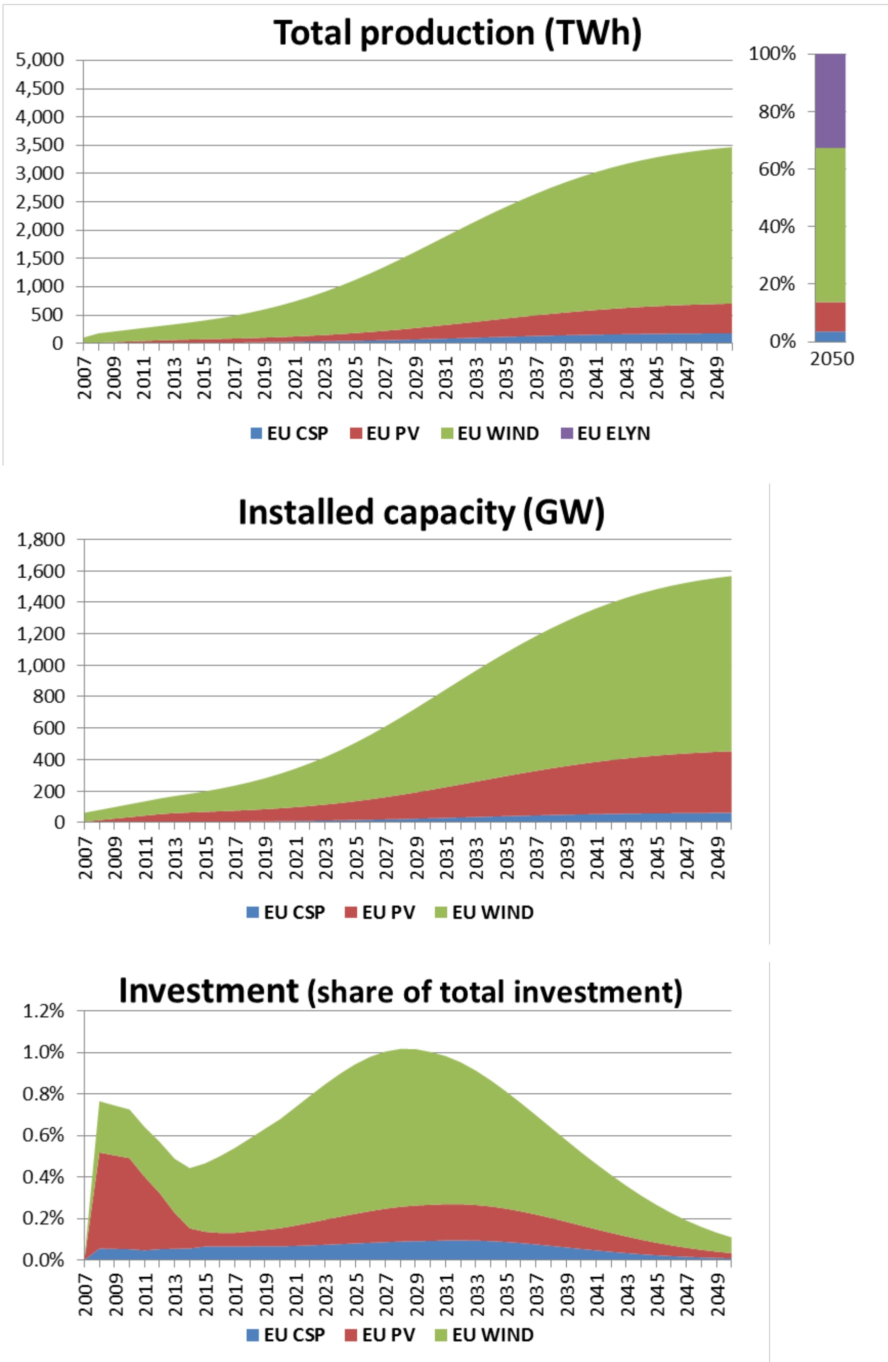

Figure 2. Electricity production, installed capacity and investment in solar and wind energy in Europe

Note: CSP = concentrating solar power, PV = photovoltaic, ELYN = electricity generation from conventional sources (fossil fuels, hydroelectric, nuclear, geothermal, tide, wave, biomass and waste).

Source: Own calculations based on Dii's connected scenario. Total investment according to the *current policy scenario* (DART model).

In the last few years the cost of producing renewable power has been falling drastically. For example, in two years the prices of Chinese PV modules have fallen by more than 65 percent (IRENA 2013). The LCOE for CSP and wind are also declining and there is still a substantial potential for cost reductions in all three renewables technologies (IRENA 2013). The cost projections for solar and wind technologies in the Dii report include learning curves which reflect these significant cost reductions in the short and medium term (Figure 4). Cost reductions for solar technologies of around 50% are expected by 2025 and for wind off-shore technologies by 2050. As wind on-shore technologies are already well developed and cost competitive, their costs decline to a lesser extent.

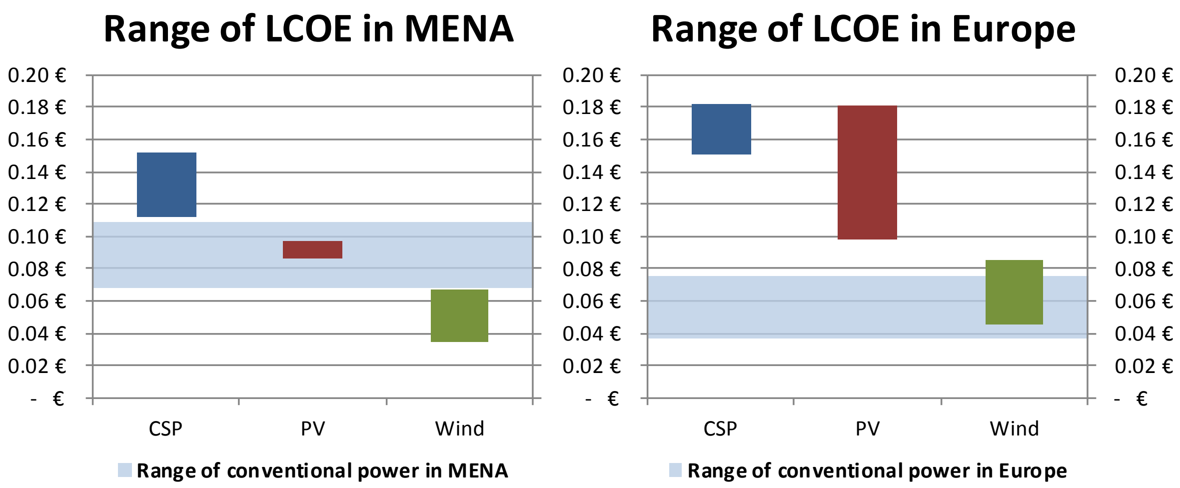

Figure 3. Range of LCOE for different technologies in MENA and Europe (€/kWh)
Note: CSP = concentrating solar power, PV = photovoltaic, ELYN = electricity generation from conventional sources (fossil fuels, hydroelectric, nuclear, geothermal, tide, wave, biomass and waste).
Source: Own calculations based on Dii's report.

A third challenge is related to the submarine transmission lines across the Mediterranean Sea to connect European and MENA countries. While technically feasible, the construction of a high voltage direct current (HVDC) power lines will increase the cost of the project and the consumer electricity price in Europe. According to Dii, an additional 130 billion euros in grid investments are necessary for an interconnected system. Furthermore, the cost of electricity produced in MENA for export to Europe increases from 4.3 to 5.8 euro cents/kWh when transmission costs and costs of transmission losses are taken into account.

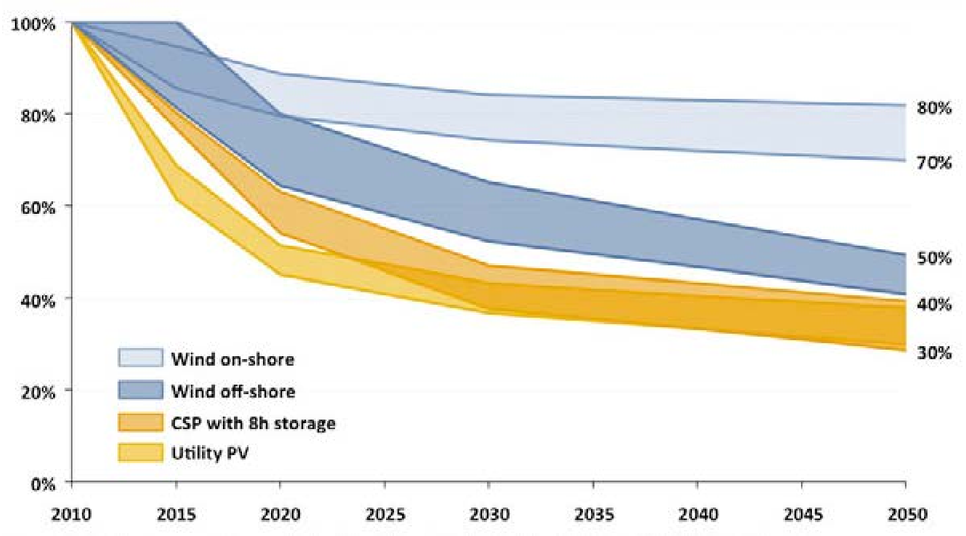

Figure 4. System cost development per kW in percent of 2010 cost estimate
Note: kW peak for PV and wind; and kW electric for CSP.
Source: Dii's report.

"Desert Power 2050" is a detailed technical report, its motion is the cost optimization of envisioned energy mix but it lacks the analysis of the effects on the overall economic system. Dii's strategy report needs to be studied from a broad perspective including not only the relevant energy activities but also other sectors of the economy. It also needs to be addressed from an international perspective to capture the economic interactions across regions and across sector. The next section evaluates the economic impacts of Dii's vision in the whole economy from a country, regional and global perspective.

3 Economic and employment impacts of "Desert Power 2050"

The economic and employment assessment of Dii's vision to decarbonize the electricity sector in MENA and Europe is carried out using two different economic techniques that provide useful insights. To capture the economy-wide impacts across sectors and across regions, we use a global computable general equilibrium (CGE) model. This CGE analysis is complemented by a multiplier analysis which allows the assessment of the employment effects during the construction and operation phases of the renewable energy power plants.

Both analyses are based on the GTAP 8 dataset, which reproduces the global economy in 2007. We focus on 6 MENA countries/regions (Egypt, Morocco, Tunisia, Saudi Arabia, Rest of North Africa and Rest of Western Asia), 9 European countries/regions (Germany, France, Italy, Spain, UK, Switzerland, Norway, Turkey and the Rest of EU27) and the rest of the world is aggregated in 2 broad regions (BRIC plus and Rest of OECD).

3.1. Computable general equilibrium analysis

To evaluate the economic impact of renewable electricity development in MENA and Europe, the Dynamic Applied Regional Trade (DART) model has been extended to explicitly account for CSP, PV and wind electricity production. Thus, the DART model assesses the direct and indirect effects of the annual Dii's investment strategies up to 2050. Moreover, its dynamic structure is appropriated to evaluate differences during the transition period to a decarbonized power sector. A short description of the DART model and the main changes in its data and structure for the current analysis is presented in Annex A.

We assess the Dii "Desert Power 2050" report in several scenarios. They incorporate two dimensions: unilateral actions in MENA and the EU versus a regional cooperation and a scenario without international climate policy versus a scenario of global climate protection. Thus, we can define 4 scenarios associated to these two dimensions (see Figure 5). All scenarios incorporate the investment and production strategies for renewable electricity production as in "Desert Power 2050". The *self-financing scenario* reflects a situation where both regions aim to independently decarbonize their power sector and use national resources to invest in the renewable power plants. The *EUMENA financing scenario* incorporates a capital transfer mechanism by which all regions support the MENA countries by financing 70 percent of their investment costs (the external financing in the rest of Western Asia is only 30 percent). We assume that the regional contribution is set according to the regional GDP. In both scenarios there is no agreement on controlling greenhouse gas emissions such that fossil fuel prices are at a level that does not include the external cost of emissions.

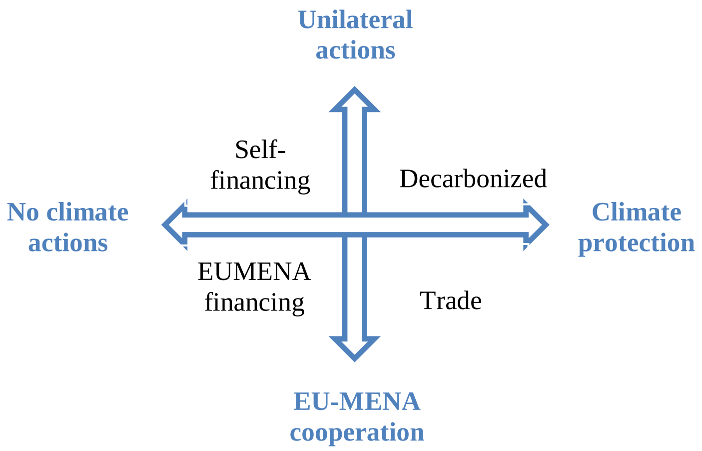

Figure 5. Schematic representation of the policy scenarios

The scenarios with climate protection are based on the assumption that a contraction and convergence[9] strategy is followed which is intended to reduce greenhouse gas emissions and limit climate change to roughly 2 degrees by the end of this century. For the climate protection scenarios we assume a global reduction of carbon dioxide emissions by 30 percent relative to 1990 levels until 2050. Emissions will start to fall by 2015 and will continue in a linear fashion until 2050. Thus, the *decarbonized scenario* assesses the investment program of “Desert Power 2050” under the assumption that all regions support the MENA countries to finance their investment costs and there is no electricity trade. All this happens in the contraction and convergence scenario, i.e. fossil fuel prices rise considerably in order to limit CO_2 emissions. The *trade scenario* includes the electricity trade between MENA and Europe and the financial support for MENA investments as in the EUMENA financing scenario, but again in a world of global climate policy.

First, in a world without climate mitigation the unilateral decarbonization of the EUMENA region is faced with low fossil fuels prices which require substantial subsidies to the renewable electricity sources. Compared to a business as usual situation[10], the overall costs of the transition to a decarbonized power sector in MENA and Europe, when both regions act independently, leads to a decrease in real income[11]. On average, real income decreases by up to 5 percent in MENA and 3 percent in Europe (Figure 6, blue lines) depending on the amount of renewable electricity produced and the investment that is drawn from the overall macro-economic investment budget. The real income effects vary strongly between the different countries as shown in the shaded area of Figure 6. The major drivers of these differences are the total amount of solar and wind power as well as their composition. The more CSP and PV technologies are introduced the higher is the need to subsidize the sales of electricity since those technologies are initially more expensive than electricity produced from wind power.

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[9] The contraction and convergence strategy (Meyer 2000) consists of reducing overall emissions of greenhouse gases to a safe level (contraction) where the global emissions are reduced because every country brings emissions per capita to a level which is equal for all countries (convergence).

[10] All policy scenarios are evaluated by comparing them to a reference scenario. Here we use two reference scenarios. The “current policy scenario” represents a business as usual situation where only current policies are taken into account for future economic trends. The economic development behind the current policy scenario is set to be in accordance with OECD projections. The “climate policy scenario” includes in addition the contraction and convergence strategy as a climate policy. Thus it represents a world with climate protection but without Dii’s renewable energy investment plans.

[11] We use welfare as a measure of real income. Welfare in DART is defined as the Hicksian equivalent variation. That is, the change in regional household income to obtain the new level of utility at initial prices and expenditure.

The *EUMENA financing scenario* takes into account that the build-up of the renewable energy infrastructure in the MENA region requires a very large investment volume, especially when it is compared to the overall investment that is available within the region. The losses in real income are less marked in MENA when international support is received (Figure 6, red lines). In fact, as 70 percent of the cost of the transition in MENA is financed by international sources, the domestic investment is not drawn from other sectors as much as in the self-financing case and the foreign capital promotes economy growth that partially offsets real income losses caused by subsidies. For European countries, the financing mechanism implies a slightly larger decrease in real income (Figure 6), because in addition to finance their own transition, they provide financial support for the transition in MENA.

In fact, several MENA countries already experience real income gains. The members of the EU, on the other hand, experience only a small change if the EU participates in financing MENA investment. In Europe strong differences occur as real income losses vary between less than 1 percent and 12 percent in the 2040s. Real income losses are particularly large in Turkey, which is expected to have the largest installed capacity of solar and wind technologies. Renewable power production in Turkey is expected to reach around 600 TWh by 2050.

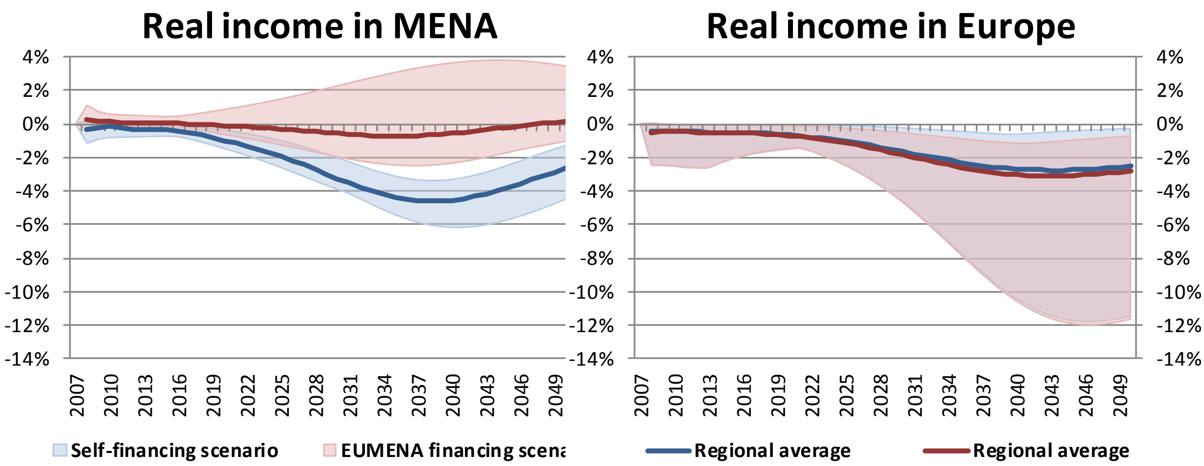

Figure 6. Changes in real income under a current policy background (percentage change with respect to the *current policy scenario*)
Source: DART model results.

Even with the fast cost reduction of the renewable energy technologies as shown in Figure 4, substantial subsidies are required in MENA and Europe to support the sales of renewable electricity. Figure 7 shows that subsidies increase gradually up to 3.5 percent of the GDP in MENA and 1.5 percent in Europe. These levels of subsides are associated to production levels that satisfy only domestic demand. When the power system in MENA and Europe is interconnected subsidies are larger in MENA and smaller in Europe, because electricity production in MENA increases substantially to cover part of the European power market. Again, the most important driver of these subsidies is the lack of an international climate policy and hence the lack of a sufficiently high carbon price that should be added to the market price of fossil fuels.

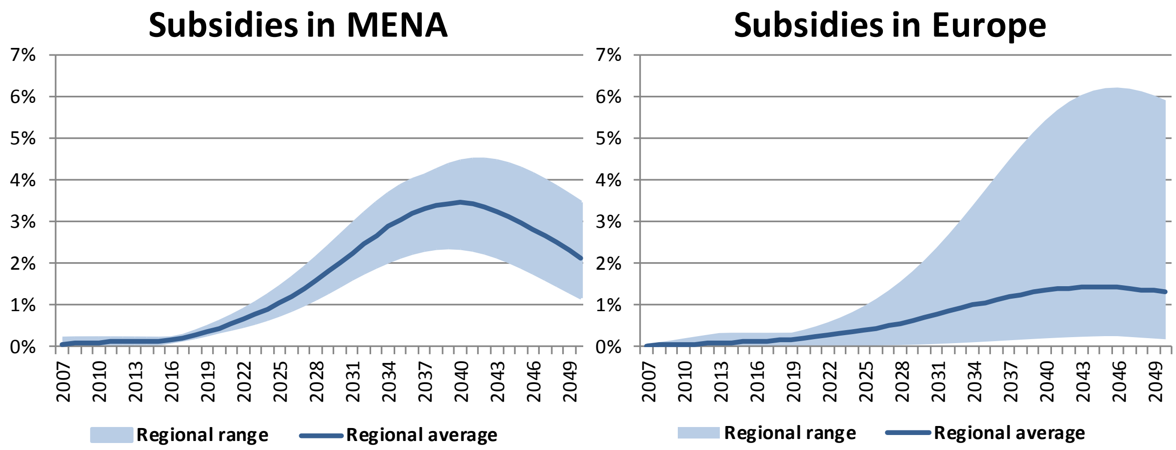

Figure 7. Total subsidies in solar and wind electricity production (share of GDP)
Source: DART model results. *Self-financing scenario*.

The financial mechanism by which a large part of the build-up of the renewable energy infrastructure is financed through foreign direct investment implies that the MENA countries receive up to 1.6 percent of the total investment in the economy (Figure 8, left chart). The sources of these net capital transfers are not only Europe but also the rest of the world. As the investment is substantially larger in MENA if its power system is integrated across the Mediterranean region, the capital transfers to MENA countries go up to 3.3 percent of the total investment of the MENA region (Figure 8, right chart).

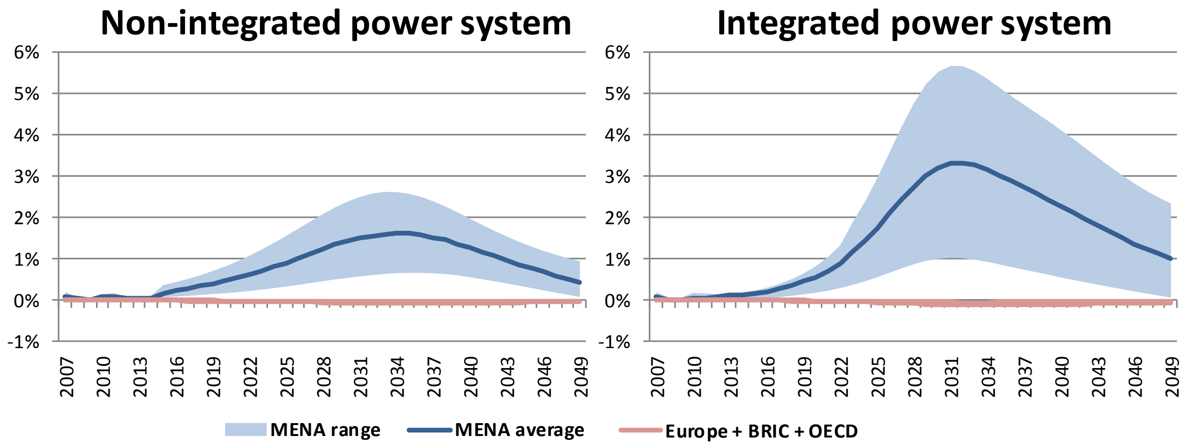

Figure 8. Net capital transfers (share of total investment)
Source: DART model results. Total investment according to the *current policy scenario*.

The scenarios presented so far contain no international climate policy framework. As a consequence the conversion of the power sector in the Europe and the MENA countries towards a complete decarbonization takes place in a world economy where unilateral climate mitigation suffers from carbon leakage and a loss in competitiveness of the energy intensive sectors. In addition, the relatively low fossil fuel prices make it necessary to subsidize renewable electricity to a much larger extent than it would be the case if a carbon price would be added to the fossil fuels. The results of the simulation exercise change significantly if the "Desert Power 2050" vision is assessed against a scenario with an international agreement of the reduction of CO_2 emissions.

In the *decarbonized scenario* fossil fuels prices rise steadily and fast because of the limits on CO_2 emissions. As a consequence, real income in MENA remains unchanged during the first two decades of the transition and increases afterwards by up to 2.5 percent (Figure 9, blue lines). In Europe, the average decrease in real income is comparable to the case without climate action. However, the decrease in real income is very small in most European countries whereas the average is influenced by larger real income losses in Norway. In fact, as electricity imports from MENA replace European production, energy exporting countries like Norway lose part of their market share and face a reduction in revenues from electricity exports.

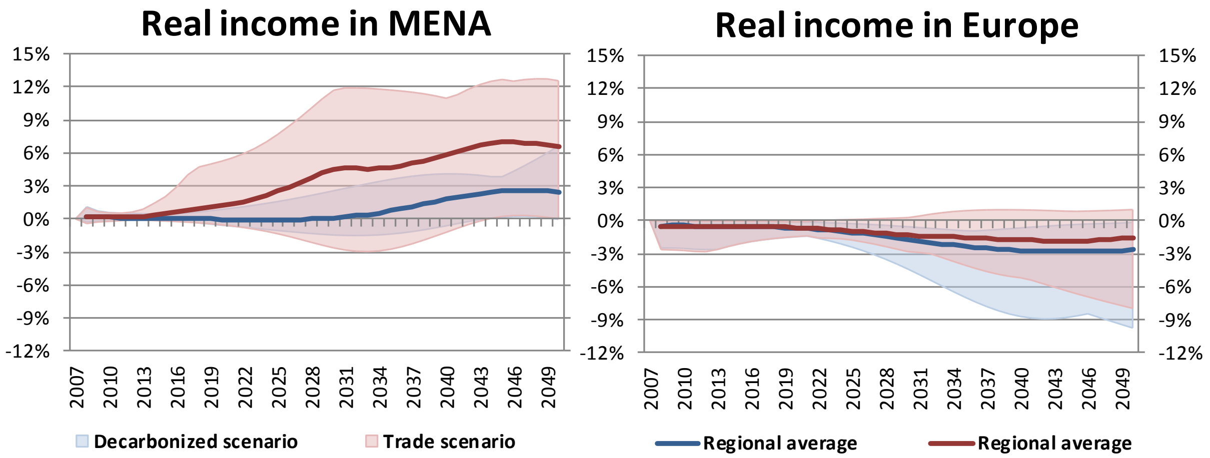

Figure 9. Changes in real income under a climate policy background (percentage change with respect to the *climate policy scenario*)
Source: DART model results.

The impact of the "Desert Power 2050" vision becomes even more positive if the power systems of both regions are interconnected. Given the ideal conditions for solar and wind energy production in MENA and the falling cost of especially PV panels, both MENA and Europe benefit from trading renewable electricity. On average, real incomes in the MENA countries increase by up to 7 percent under the *trade scenario* (Figure 9, red lines); some countries such as Morocco, Tunisia, Algeria and Libya experience income increases of up to 12 percent. In Europe, importing renewable electricity from MENA slightly reduces the real income losses to around 2 percent in the 2040s. The *climate policy scenario* indicates that the real income gain in most MENA countries comes more from the reduced need to subsidize solar and wind power than from their comparative advantage in renewable electricity vis-à-vis Europe due to their better wind and solar radiation conditions.

3.2. Employment effects of the "Desert Power 2050" program

There have been many reports in recent years attempting to analyse local, national, or regional job effects of energy scenarios and energy policy.[12] Most of these studies focused on developed countries and on direct jobs created in fuel production, manufacturing, construction, and operations and maintenance, while neglecting indirect job creation[13] ─ both national and international ─ that results from the domestic and import demand of renewable energy sectors for equipment and intermediate goods (backward linkages and trade linkages).

[12] See Wei et al. (2010) for a review of 15 recent studies.
[13] See, e.g., Rutovitz and Atherthon (2009) and Ulrich et al. (2012) for assessments, which take indirect employment effects into account.

Yet, neglecting indirect jobs may lead to a significant underestimation of possible employment effects of renewable energy initiatives, such as "Desert Power 2050", especially in lower middle-income countries like Egypt and Morocco, which are characterized by huge amounts of surplus labour and labour-intensive modes of production.

Thus, in our comparative analysis of the potential employment effects of renewable energy capacity installation and renewable electricity production in selected MENA countries (Egypt, Morocco, and Saudi Arabia) and European countries (Germany and Spain), we focus on these indirect employment effects of PV, CSP, and wind energy.

Under the assumptions of the multiplier model described in Annex B, the investment in PV, CSP, and wind behind "Desert Power 2050" will create between 400,000 and 600,000 jobs during the investment phase and an additional 160,000 to 380,000 jobs during the production phase (see Figure 10), depending on whether MENA countries use European or local modes of production in the manufacturing of renewable equipment and production of renewable electricity.

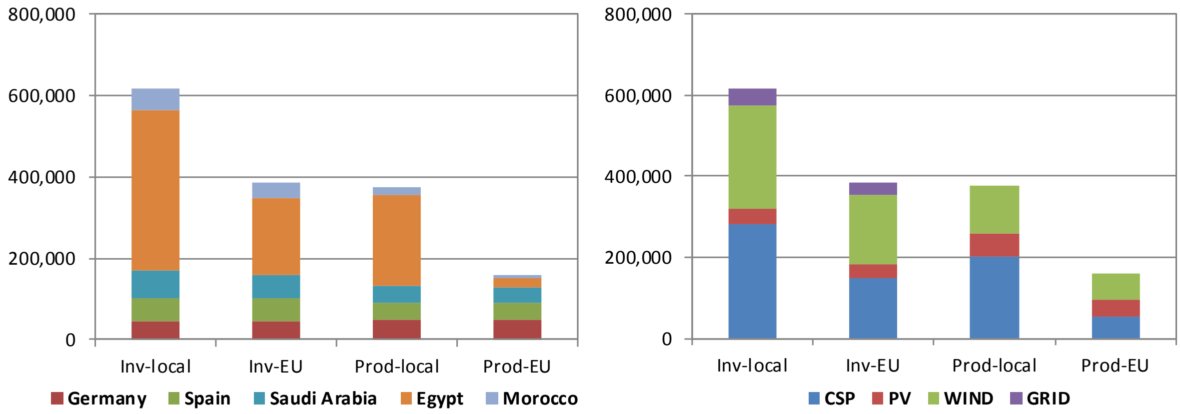

Figure 10. Total job creation of renewable equipment manufacturing and renewable electricity production by country and technology, 2010-50
Note: inv = investment in energy infrastructure, prod = electricity production, local = MENA.
Source: Multiplier model results.

Regardless of whether European or local modes of production is used, most jobs will be created in Egypt and in CSP and WIND technologies, which results from (i) high planned investment in these technologies (about 80 percent of the total investment volume), (ii) high investment in Egypt (25 percent of the total investment volume and 33 percent of total CSP and WIND investment), and (iii) labour intensive production technologies in non-renewable sectors. Although planned investment in Saudi Arabia is comparable to investment in Egypt, capital intensive modes of production, less integration of domestic production, and high import dependence on manufactured goods significantly reduce the number of jobs that will be created (see below).

In addition to local job effects, MENA's import demand for renewable equipment and intermediate inputs will add to significant job creation in Europe too (about 14,000 jobs), at least in the short to medium-term. These induced employment effects are similar in Germany and Spain as a result of similar production technologies; they are strong in the period 2010-20, when many components of energy power plants and intermediate inputs are imported by MENA; they increase in the period 2020-30 despite lower import dependence of MENA as a result of higher investment in the region; and they are weak in the long-term, when investment in MENA is increasingly phased out.

Beside the distribution of investment across countries and renewable energy technologies discussed above, country-specific structural characteristics determine the job creation potential of renewable investment in Europe and MENA. Table 1 summarizes the major results on job creation of €1 billion investment in CSP, PV, and wind power plants.

Investment in renewable energies in MENA will have a significant impact on employment, at least in lower-middle income countries, such as Morocco and Egypt, with a huge amount of surplus labour and labour-intensive modes of production. An identical investment volume of €1 billion will yield significantly more additional jobs in these two countries than in Europe or Saudi Arabia. Investing for example in wind technology in Morocco generates between 36,000 and 47,000 jobs if renewable equipment is produced with European and local technology, respectively, while the same investment would create only 11, 000 jobs in Germany. In general, the number of jobs generated in Morocco and Egypt is at least almost twice those created in Europe; the number is significantly lower in Saudi Arabia. The primary reason for these differences is of course differences in labour intensities. On a national level, labour intensities range from about 9 workers per €1 million output for Germany and Spain to 17 for Saudi Arabia, and 70 and 110 for Morocco and Egypt, respectively (see Annex Table A2). Another reason is differences in production technologies of equipment manufacturing. The underlying data base (GTAP8-SAMs) suggests that the production of components for PV, CSP and WIND requires inputs from many other sectors in Morocco and Egypt, while it is more concentrated in a few (integrated) sectors in Germany, Spain and Saudi Arabia. Finally, business services like any other services are typically highly labour intensive sectors in developing countries.

High labour intensities in non-renewable sectors imply that the indirect employment effects are generally significantly larger in Morocco and Egypt and in early phases of capacity installation, when a large share of imported components limit direct local employment creation. Table 1 indicates that the number of total jobs that can be created is larger in Egypt than in Morocco, and in both countries it is larger in Wind than in CSP and PV technology. Yet, indirect job creation is largest in PV.

Most of the jobs that may be created by renewable investment will be jobs for blue-collar workers in both regions (see Table 1). Yet, since the share of blue-collar jobs is significantly larger in Morocco and Egypt than in the other three countries, investment in the former may lead to a stronger trickle-down of income. Indeed, the underlying database suggests that relative income effects for blue-collar workers are significantly higher in Egypt and Morocco than in Germany, Spain, and Saudi Arabia.

Finally, the results in Table 1 indicate that investment in renewable energy in MENA leads to significant additional employment opportunities in Europe, especially in sectors producing electronic equipment and machinery & other equipment. Thus, though Germany does not produce any CSP technology, investment in this technology in MENA would create about 2,000 jobs in other export-oriented manufacturing sectors. Moreover, additional jobs will be created in Europe if the required engineering, business and insurance services also need to be imported. Additional results from the multiplier analysis (not shown in Table 1) suggest, that a €1 billion investment in, for example, CSP technology in Morocco would induce an additional import demand for services worth €0.16 billion thereby creating jobs in exporting European countries.

Table 1. Jobs created by €1 billion investment in and production of renewable energy power, 2010-50

	Investment in renewable energy power plants									Production of renewable electricity		
	2010-50			2010-20			2030-50			2010-50		
	PV	CSP	WIND	PV	CSP	WIND	PV	CSP	WIND	PV	CSP	WIND
No. of jobs (1,000) [1,2]												
Germany	9(22)	NA	11(35)							4(26)	NA	2(58)
Spain	8(21)	10(16)	10(34)							4(21)	3(44)	2(50)
Morocco				15-24(65)	25-35(42)	36-47(34)	19-29(67)	37-56(49)	42-56(37)	4-18(51)	4-13(71)	3-6(76)
Egypt				17-42(59)	33-59(36)	44-82(34)	19-52(54)	41-101(42)	48-88(36)	3-43(16)	2-27(32)	2-11(47)
Saudi Arabia				4(37)	5(31)	6(37)	4-5(41)	7-9(36)	7(37)	3-4(18)	2(35)	1(55)
Share of blue-collar workers (percent)												
Germany	81	NA	83							58	NA	83
Spain	80	80	81							58	61	82
Morocco				85	87	88	85	86	87	55	58	84
Egypt				90	92	92	90	91	92	65	71	88
Saudi Arabia				80	84	83	79	81	83	67	73	84
Induced jobs in Europe	*730*	*2116*	*656*							*833*	*1600*	*1032*
Minerals and mineral products	53	286	0							0	0	0
Chemicals, rubber, and plastic products	0	311	0							0	0	0
Electronic equipment	677	0	0							312	0	0
Machinery and other equipment	0	1143	649							0	521	830
Financial services	0	0	0							0	0	0
Insurance services	0	0	0							521	919	0
Business services	0	377	7							0	160	202

[1] Constrained output multipliers in parentheses, assuming fixed output in services sectors.
[2] Percent share of indirect jobs in parentheses.
NA = not applicable.
Source: Multiplier model results.

The maximum number of jobs that could be created by renewable energy production sales also varies greatly across countries and technologies (see Table 1, last 3 columns). The total job creation of €1 billion production ranges between 1,000 jobs for Wind energy in Saudi Arabia and 4,000 jobs for PV in Europe and PV and CSP in Morocco, if all countries use German production technologies. If MENA countries use local production technologies, job creation increases drastically, especially for PV and CSP production in Morocco and Egypt, largely as a result of job creation in the highly labour-intensive services sectors. As expected, the share of indirect jobs is for all countries and all technologies higher than the respective share of capacity installation. All renewable energy production technologies are highly capital-intensive, implying low direct employment effects, but do have strong backward linkages to labour-intensive production of intermediates. Finally, as in the case of equipment manufacturing, strong induced employment effects can be expected in Europe from MENA imports of intermediate goods used in renewable electricity production. For example, production of €1 billion worth of CSP in MENA would create about 1,600 working places in Europe.

4 Conclusions

The idea behind "Desert Power 2050" is relatively simple and based on the principle of comparative advantage: produce renewable energy in areas with relatively abundant natural resource endowments and export it to regions with high electricity demand. However, the extent proposed by the report to bring this idea in practice is very ambitious and challenging. Pursuing the 2 degree target, the report "Desert Power 2050" aims at a power system in EUMENA almost fully based on wind and solar technologies. The electricity produced in MENA will not only cover the growing electricity demand in MENA countries, it will also be exported to cover part of the European electricity market.

Achieving this EUMENA energy vision requires substantial economic resources. To fulfil Dii's vision, MENA requires annual investments that may grow up more than 10 percent of the total investment in the region. Besides financing the build-up of the renewable energy infrastructure, there is also a need to finance renewable production—in many cases wind and solar power production are currently still more expensive than fossil fuel based technologies.

Therefore, the extent of the overall costs and benefits for both regions and particularly for individual countries depend on the type of strategy adopted to finance the build-up of the power plants and the expected development of the LCOE for the different technologies. In fact, without foreign investment MENA countries need to finance the build-up of the renewable infrastructure with their own resources which restricts investment (and growth) in other energy and non-energy sectors. Likewise, the LCOE of renewable energy relative to conventional electricity production is highly influenced by the international energy price framework which in turn strongly depends on the global climate policy architecture. Without a climate policy to control greenhouse gas emissions, fossil fuel prices are low because they do not include the external cost of emissions such that higher subsidies for renewable energy are required.

In a world without climate mitigation the decarbonization of the power sector in the EUMENA countries leads to real income losses in both regions. Indeed, with low fossil fuel prices substantial subsidies are required to make renewable electricity cost competitive with conventional power generation. For some MENA countries the situation is somewhat better if the renewable energy infrastructure in MENA is financed through foreign direct investment. However, even with international financial support the effect on real income is on average still negative for MENA.

The results change significantly if the “Desert Power 2050” vision is assessed against a scenario with an international agreement of the reduction of CO_2 emissions. In fact, with a climate policy in effect fossil fuel prices rise steadily and fast because of the limits on emissions. This reduces the need to subsidise renewable technologies and thus lowers the cost of the transition towards a renewable energy system. Real income in MENA remains constant during the first two decades and increases afterwards. In Europe, the decrease in real income is small in most countries. The results are even more positive if the power systems of both regions are interconnected. Trading electricity benefits both regions, MENA and Europe.

The viability of a transition towards renewable energy as proposed by “Desert Power 2050” depends to a great extent on the international climate policy. Real income gains in most MENA countries depend more on the reduced need to subsidize solar and wind power in a global climate policy scenario than from their comparative advantage in renewable electricity vis-à-vis Europe due to their better wind and solar radiation conditions.

Although renewable energy initiatives, such as “Desert Power 2050” are promoted primarily for their environmental attributes, policy makers are increasingly embracing such policies based on their perceived strength as engines of job creation. Despite the questions surrounding predictions of green job growth, estimates for Egypt and Morocco indicate the potential for significant positive employment effects. Job growth in these two countries is one of the most promising benefits of the EUMENA initiative because these economies are more labour intensive than Saudi Arabia and Europe and have a higher demand for less-skilled labour, especially in non-renewable sectors. Thus, indirect employment effects are potentially large. However, many segments of the renewable energy sector, such as solar photovoltaic technology, require technically skilled labour. The dearth of skilled workers in Egypt and Morocco is a major constraint on the feasibility of these green jobs predictions.

Acknowledgements:

This article was funded by the Desertec Industrial Initiative. We gratefully acknowledge the financial support for the joint project "Economic Impacts of Desert Power" and the access to the scenarios database behind their strategic framework "Desert Power 2050".

Disclosure statement:

The opinions expressed in this article are the sole responsibility of the authors and do not necessarily reflect those of the Desertec Industrial Initiative. The authors report no financial interests or potential conflicts of interest in the context of this work.

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Annex A: The renewable energy version of the DART model

The DART model, developed at the Kiel Institute for the World Economy, is a multi-sectoral, multi-regional dynamic computable general equilibrium model of the world economy. It has been designed primarily for the analysis of international climate policies. The model is based on microeconomic theory. In each region, the economy is modelled as a competitive economy with flexible prices and market clearing conditions. Agents represented in the model are consumers, who maximise utility, producers, who maximise profits and regional governments. The regions are connected via bilateral trade flows.

The dynamic framework of DART is recursively-dynamic meaning that the evolution of the economies over time is described by a sequence of single-period static equilibria connected through capital accumulation, changes in labour supply and sector specific technical progress. The economic structure of DART is fully specified for each region and covers production, investment and final consumption by consumers and the government. Policy instruments in DART are taxes, subsidies, or quantity constraints in factor markets, product markets, and in international trade. The model results show relative changes to a reference scenario that also needs to be defined.

Although renewable electricity capacity and generation has substantially increased in the last years, its share in the energy mix is still modest or inexistent in most of the countries. To model the energy transition plans of Dii, we split the electricity sector to include CSP, PV, wind, and conventional technologies. For countries currently producing electricity from renewable sources, we use statistical information from the International Energy Agency. For countries without renewable power production, we assume that a small amount of solar and wind electricity is generated by a standard power plant running at the minimum capacity.[14]

The production technology of solar and wind power plants is defined according to the Dii' industry survey[15] and it is assumed to be identical for all countries. There is not enough information to model grid operation independently; therefore we use the same assumption as the original electricity sector in GTAP. That is, each electricity sector accounts for electricity generation, collection and distribution. In addition to the 4 electricity sectors, DART models 4 energy sectors (coal, oil, gas and petroleum products) which help us to represent the complete interaction of different energy sources on the global energy market. DART also

[14] This assumption does not distort the energy mix because a small production is added for solar and wind technologies. It also allows us to model future development of solar and wind power production in countries where production is currently inexistent.

[15] Dii's internal study.

includes 16 different sectors in agriculture, industry and service to capture production synergies during the construction and operation phase. See Table A1 for the regional, sectoral and factoral aggregation used in DART.

Table A1. Regional, sectoral and factoral aggregation in DART

17 Regions		**24 Sectors**	
DEU	Germany	AGR	Agricultural and food products
FRA	France	COL	Coal
ITA	Italy	CRU	Oil
ESP	Spain	GAS	Gas
GBR	United Kingdom	MIN	Minerals and mineral products
CHE	Switzerland	TEX	Textiles leather paper
NOR	Norway	OIL	Petroleum coal products
TUR	Turkey	CRP	Chemical rubber plastic products
XEU	Rest of EU27	MET	Metals and metal products
EGY	Egypt	VEH	Motor vehicles and transport equipment
MAR	Morocco	ELE	Electronic equipment
TUN	Tunisia	MAC	Machinery and other equipment
XNF	Rest of North Africa	OTS	Other services
SAU	Saudi Arabia	**CSP**	**Concentrating solar power**
XWS	Rest of Western Asia	**PV**	**Photovoltaic**
BRIC	BRIC plus	**WIND**	**Wind**
OECD	Rest of OECD	**ELYN**	**Electricity from conventional sources**
		WTR	Water
5 Factors of Production		CON	Construction
LND	Land	TRN	Transport
UnSkLab	Unskilled labour	CMN	Communication services
SkLab	Skilled labour	FIS	Financial services
CAP	Capital	ISR	Insurance
RES	Natural Resources	BUS	Business services

In the *current policy scenario*, renewable electricity production in DART is mainly driven by fossil fuel prices and competitiveness. High fossil fuel prices make expensive the production of electricity from conventional sources incentivising the production of electricity from renewable sources. Competitiveness, on the other hand, is determined by the LCOE and the learning curve. High LCOE and poor reduction costs are directly linked to production subsidies in the model, which makes its production unattractive.

The electricity produced by each type of power plant is sold to domestic markets and part of it could also be exported. The distribution to intermediate demand and final demand of renewable electricity is assumed to be similar to the conventional electricity. Therefore, we use a high elasticity of substitution between CSP, PV, wind, and conventional electricity, which characterize a very homogeneous good.

Annex B: The multiplier model

To assess the employment effects of Dii's projected renewable electricity development in selected MENA and European countries (Egypt, Morocco, Saudi Arabia, Germany, and Spain), the extended GTAP 8 data set for year 2007 described in Annex A has been combined with ILO data[16] on employment by sector and occupation to calculate sector and skill specific labour coefficients for all non-renewable sectors. Labour coefficients for the manufacturing of renewable equipment and the production of renewable energy are taken from the Dii's industry survey[17].

The resulting Input-Output model is completely demand driven emphasizing inter-industry linkages between renewable energy (RE) sectors and other sectors and therefore allows for an assessment of employment creation along the RE value chain (see Figure A1). It completely ignores issues of resource allocation, which are the focus of the CGE analysis. Moreover, with its fixed coefficients, the model ignores substitution possibilities in production, imports and exports triggered by changes in relative prices. Thus, results from the multiplier model provide an upper bound on the maximum possible direct and indirect skill-specific employment effects of the annual Dii's investment strategies up to 2050.

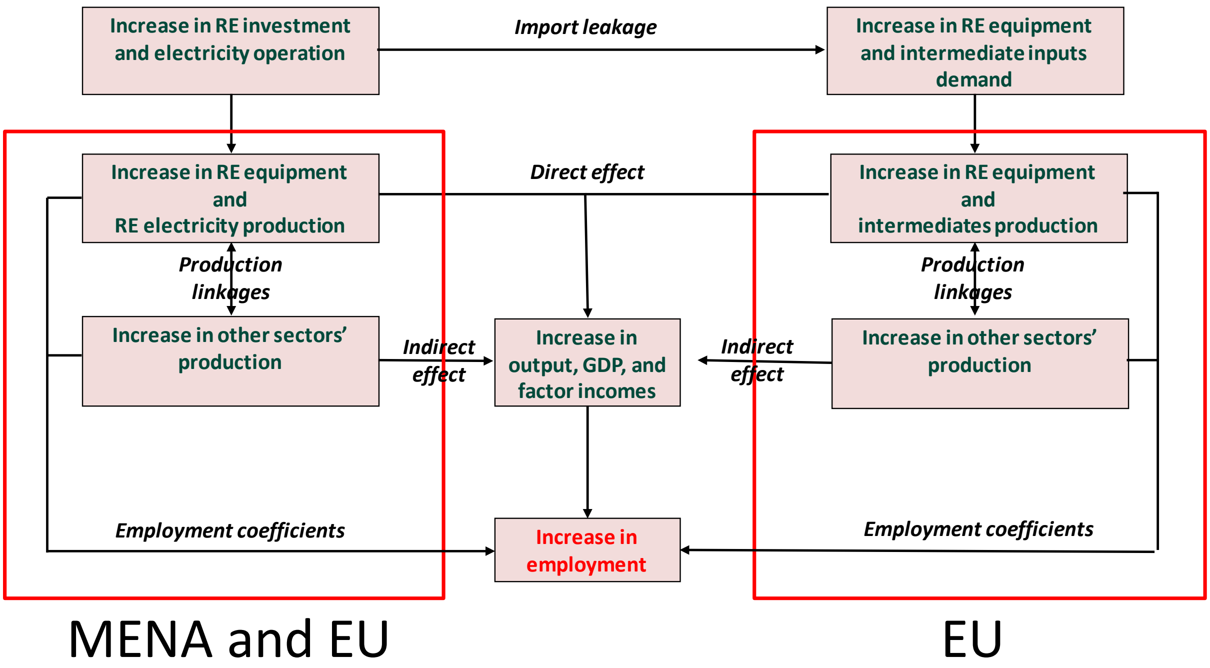

Figure A1. Direct and indirect production and employment effects

[16] http://kilm.ilo.org/kilmnet/.
[17] Dii's internal study.

Differences in job creation between the selected countries are driven by

(i) Differences in the volumes and distribution of RE investment over technologies and time (see Figures 1 and 2);

(ii) Differences in import intensities of RE equipment: These are generally higher in MENA countries than in Europe − implying lower output and employment effects − but decrease over time − implying lower import leakages and higher output and employment effects in MENA, and lower induced employment effects in the EU.

(iii) Differences in input coefficients: These are generally higher in the EU than in MENA implying higher indirect employment effects in the EU. Input coefficients are lowest in Saudi Arabia.

(iv) Differences in labour coefficients: These are significantly higher on a macroeconomic scale in Egypt and Morocco than in EU and Saudi Arabia and much higher for blue-collar than white-collar workers in all countries (see Table A2) but are assumed to converge slightly over time as a result of higher labor productivity growth in Egypt and Morocco than in the other three countries.

These significant differences in macroeconomic labour intensities between Germany, Spain, and Saudi Arabia on the one hand, and Egypt and Morocco on the other are largely attributable to very labour intensive modes of production in agriculture and services. We therefore also calculated constrained output and employment multipliers, which assume that the insurance and business services used in RE equipment manufacturing and electricity production are not delivered by domestic supply but need to be imported from the EU.

Table A2. Selected macroeconomic indicators, 2007

	Germany	Spain	Saudi Arabia	Egypt	Morocco
Output [bn. €]	4,489.0	1,950.4	446.0	189.7	126.3
GDP [bn. €]	2,258.1	994.6	282.5	96.1	55.6
GDP per economically active person (€)	55,944.2	54,089.3	36,422.7	4,596.5	6,350.6
Economically active population ('000 persons)	40,364.0	18,388.0	7,755.4	20,913.9	8,761.9
Blue collar	31,946.0	13,902.1	5,733.9	19,102.8	7,935.3
White collar	8,400.0	4,486.1	2,021.5	1,811.1	826.5
Labor coefficient (persons/mil. € output)	9.0	9.4	17.4	110.2	69.4
Blue collar	7.1	7.1	12.9	100.7	62.8
White collar	1.9	2.3	4.5	9.5	6.5

Source: Own calculations based on GTAP 8 data set and ILO (2011).