De-risking Investment into Concentrated Solar Power in North Africa: Impacts on the Costs of Electricity Generation

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Abstract:

A low-carbon energy transition on the basis of renewable energy sources (RES) is of crucial importance to solve the interlinked global challenges of climate change and energy security. However, large-scale deployment of RES requires substantial investments, including the participation of private capital. Scientific evidence shows that the economic feasibility of a RES project hinges on the availability of affordable project financing, which itself depends on risk perceptions by private investors. Since financing costs tend to be particularly high for capital-intensive RES projects and in developing countries, we investigate the impacts of addressing these perceived risks on electricity prices from semi-dispatchable concentrated solar power (CSP) in four North African countries. By employing a levelized cost of electricity (LCOE) model we find that comprehensively de-risking CSP investments leads to a 39% reduction in the mean LCOE from CSP. However, this reduction is still not sufficient to achieve economic competitiveness of CSP with highly subsidized conventional electricity from fossil fuels in North Africa. Hence, our results suggest that de-risking reflects an important strategy to foster the deployment of CSP in North Africa but additional measures to support RES, such as reconsidering fossil fuel subsidies, will be needed.

Key words: concentrated solar power, risks for investment, risk perception, North Africa

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1. Introduction

Energy generation contributes to more than 60% of Green House Gas (GHG) emissions (OECD/IEA, 2013) globally; hence significant reductions in the level of GHG emissions are only possible with a fundamental reconfiguration of the global energy system (Riahi et al., 2012). Deployment of renewable energy sources (RES) is one of the possible options to satisfy the interlinked goals of climate policy and energy security. By generating low carbon energy from abundantly available natural resources, RES deployment contributes to the mitigation of GHGs in the global energy system. Additionally, a RES based energy system could improve a country's energy security by contributing to the diversification of the energy mix, geographical diversification and reduction of the exposure of the energy mix to fossil fuel price volatilities (Francés et al., 2013).

The involvement of private capital is essential to achieve the scale of investments needed to make a RES based energy transition happen. The estimations here vary, for example to achieve a scenario that reaches the 2°C climate stabilization goal, the IEA (2014) estimates that cumulative global investments of USD 53 trillion in energy supply and energy efficiency will be necessary over the period to 2035. The World Bank and the United Nations argue that 600-800 billion USD per year is needed to double the share of RES by 2030 (Business Standard, 2013). According to the IEA's new policy scenario (IEA, 2014) non-OECD countries have to invest on average annually USD 1,200 billion in the energy supply infrastructure. Compared to the historical investments of USD 708 billion, there remains a financing gap of almost USD 500 billion. The public sector alone or even supported by funds from multinational financial institutions, such as the World Bank, will not be able to raise all of the required capital. Nevertheless, volumes of private investment into RES are still low (Frankfurt School-UNEP Centre/BNEF, 2014) and especially developing countries are struggling to attract the required private investment into RES.

To harness the full potential of RES deployment for the mitigation of GHGs, the IPCC argues in its recent 5th Assessment Report that significantly more attention should be given to decision-making processes regarding the deployment of RES, in general, and on risk perceptions[1] of different stakeholders involved into this decision-making process, in particular (IPCC, 2014). Mobilizing private investments into RES technologies in developing countries will require substantial efforts to reduce perceived risks and uncertainties associated with these investments (Schmidt, 2014; UNDP, 2013).

[1] The concept of risk perception refers to peoples' subjective judgments of the characteristics and severity of a risk and is related with how much risk people are willing to accept (Slovic, 2000).

Among other factors, the economic efficiency and hence the realization of RES investment projects depends on the availability of affordable project financing (Schmidt, 2014). The cost of capital itself and more generally, the decision whether or not to invest into a certain technology[2] (Douglas, 1985; Kann, 2009; Lüthi and Prässler, 2011), depend on the perceived risks by investors associated with specific investment projects (Brearly and Myers, 2013; Varadarajan et al., 2011; Komendantova et al., 2011 and 2012).

Perceived risks by investors (Komendantova et al., 2011 and 2012) as well as financing costs for capital-intensive RES projects (UNDP, 2013) are found to be particularly high in developing countries (Shrimali et al., 2013). Due to high upfront investment costs but low operational costs, low-carbon energy technologies are particularly sensitive to perceived financing risks and the related financing costs. In addition, financing costs are also influenced by characteristics of the regional risk environment. Due to the existence of different barriers to private investments, the cost of capital for RES investments is usually higher in developing countries than in industrialized countries (UNDP, 2013).

While perceived risks by RES investors in developing countries have mainly been addressed qualitatively (Komendantova et al., 2012; Shrimali, 2013), only few studies have investigated how these risks translate into higher cost of capital or have analyzed the direct effects of a financial de-risking strategy to RES investments on the cost of electricity (UNDP, 2013; Schmidt, 2014; Frisari and Stadelmann, 2015). The UNDP report on "De-risking Renewable Energy Investments" (UNDP, 2013) develops a framework to identify (1) investment barriers and their contribution to higher financing costs and eventually to higher RES life-cycle costs and (2) to identify and evaluate public instruments to promote RES investment. Employing this framework, the report analyzes investment risks' impact on financing costs for large scale, onshore wind energy projects in four selected countries: Kenya, Panama, Mongolia and South Africa. Based on interviews with wind energy investors and developers, the cost of equity for large-scale onshore wind energy projects in the current risk environment is found to be 15.0% for South Africa and Panama and 18.0% for Mongolia and Kenya. The cost of debt is found to be 7.5% for South Africa, 8.0%

[2] Private investors base their investment decisions on the risk-return profile of any particular investment projects. Hence, the higher the risk for investment, the higher is the rate of return demanded by investors. Conversely, if investors seek high returns, they have to accept higher risks. The combination of two elements determines the downside risk of an investment: the likelihood of the occurrence of a negative event and the associated seriousness, i.e. the level of financial impact (Schmidt, 2014). The perception of these elements for a specific investment influences the financing costs (or cost of capital) for that project. Equity investors will raise their expected rate of return (cost of equity) and banks will raise the interest rate (cost of debt) for projects with a higher perceived risk (ibid.).

for Panama and Mongolia, and 8.5% for Kenya. Furthermore, the UNDP (2013) report finds that de-risking policy, which is effective in reducing RES financing costs to a certain extent, may eventually decrease the LCOE from large scale onshore wind energy below the LCOE of a baseline power generation activity in two of the four considered case study countries (Panama and Kenya).

However, evidence on impacts of de-risking policy in other regions, such as North Africa, and other RES technologies, such as CSP, is still limited. As developing countries differ with respect to their current energy systems (e.g. the prevailing energy generation mix and electricity price), (renewable) energy strategies, RES potentials as well as financing risk environments and as RES technologies are characterized by differences in e.g. engineering characteristics, production cost structures and lengths of their track-records, a detailed case by case analyses is crucial to derive realistic conclusions with respect to the impacts of perceived risks by investors on financing costs and eventually on life-cycle electricity costs of RES projects as well as the needed de-risking policy.

Due to its high solar resource potential and the vast areas of unutilized desert land, the North African region is particularly well suited for large-scale solar energy generation. To foster the deployment of RES, North African countries settled ambitious targets, with a strong role for solar power[3]. Even though the events of the Arab spring in 2011 and the subsequent political instabilities have slowed down the progress in achieving proclaimed RES targets in the North African region, politicians in the North African countries are continuing to express their commitment to the deployment of RES (Brand, 2015).

In a detailed case study analysis of two large-scale CSP projects in Morocco and India, Falconer and Stadelman (2015) comprehensively discuss the role of international financial institutions (IFI) in de-risking CSP in emerging markets. They find that due to the provision of substantial concessional loans, IFIs can play an important role in enabling CSP projects in developing countries where public and private finance would be too expensive due to high (perceived) risks of investment. Given the limited availability of IFI finance compared to the substantial investment needs to de-carbonize developing countries' energy

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[3] Algeria foresees installing of 12GW of RES until 2030 to cover 40% of domestic electricity demand (MEM, 2011). The bigger portion of this RES based electricity share is planned to be generated by CSP. Egypt plans to reach 20% of RES in its energy mix by 2020 (GIZ, 2014). Morocco has one of the most ambitious targets in the MENA region, expecting 42% of its installed power generation capacity be based on RES by 2020. This amounts to 6 GW, consisting of 2GW of solar capacity, 2 GW of wind capacity and 2GW of hydro capacity (IEA, 2013c). Tunisia established a long-term target for its electricity sector to achieve 25% of RES by 2030, broken down into an installed capacity of 4,700 MW: 2,700 MW wind, 1,700 MW solar and 300 MW other RES technologies (Harrabi, 2012).

systems, Falconer and Stadelman (2015) point out that a significant scale-up of private investment will be needed. This requires addressing perceived risks by private investors and assessing these risks' impacts on financing costs and in turn on CSP generation costs as well as the potential cost reductions of de-risking CSP investments.

By looking at four specific North African countries – Algeria, Egypt, Morocco, and Tunisia – and at a particular RES technology, namely CSP with thermal storage, which has already become a proven solar power technology for large-scale applications (Pitz-Paal et al., 2012) and the generation of semi-dispatchable electricity with a high capacity value[4], we contribute to the existing literature on de-risking CSP in North Africa and set out to address the demand for further concrete case study analyses, both in the regional as well as the technological dimension, of perceived risks by RES investors (Schmidt, 2014).
By investigating the current financing environment for CSP in the North African region we are addressing the following question within the frame of this research: What is the influence of different risk categories on the overall cost of capital for CSP? Furthermore, by employing a Levelized Cost of Electricity (LCOE) model, we set out to analyze the direct impacts of a de-risking approach on the cost of electricity from CSP in the North African region.

The remainder of the paper is structured as follows. First, we provide detailed background information on the North African case study region, the CSP technology, and a motivation for the need for a de-risking policy. Second, we introduce the LCOE method and discuss its applicability in the present context. Third, we present the results of our analysis of the influence of risk perceptions by investors on financing costs and in turn on CSP electricity prices and a de-risking strategy to tackle these risks. Before the final section concludes and derives policy implications, we discuss our results in relation to the existing literature.

2. Background on the North African region and CSP

The North African region is particularly suitable for solar energy generation, since its countries are situated in the so-called Earth's Sunbelt, which is

[4] The marginal economic value of a variable electricity generation technology consists of four components (Mills and Wiser, 2012; the percentage share of each component in the total marginal economic value for CSP generation with 6 hours thermal storage at 20% penetration in 2030 in parentheses): (1) Capacity value: Short run profits earned during peak load hours with scarcity prices (28%) (2) Energy value: Short run profits earned during hours without scarcity prices (74%) (3) Day-ahead forecast error: net earnings from real time deviations from the day ahead forecast (-3%) (4) Ancillary services: Net earnings from selling ancillary services in the market from variable electricity generation and paying for increased ancillary services due to increased short-term variability and uncertainty from variable electricity generation (1%).

characterized by considerable solar energy resources[5] (Mason and Kumetat, 2011). The current structure of electricity generation in the four North African countries is dominated by conventional fossil fuel technologies. While natural gas makes up for the biggest share in electricity generation in Algeria, Egypt and Tunisia, coal dominates in Morocco (IEA, 2013b). Furthermore, the demand for electricity is growing steadily in all of these North African countries, driven by rapid population growth, a decaying infrastructure and hence a diminishing rate of energy self-sufficiency (IEA, 2013b; Brand and Zingerle, 2011).

While the four North African countries considered in our analysis share a heavy dependence on hydrocarbons for their energy supply, there is considerable diversity in resource endowment across them. Algeria, as a significant producer of fossil fuels, can be considered as large energy exporting country, with net exports amounting to 104 ktoe (IISD, 2014). Egypt, with net exports of 10 ktoe can be classified as a small energy exporting country. Tunisia and Morocco are net energy importing countries, with net imports of 16 ktoe and 102 ktoe, respectively (ibid). Particularly for net energy importing countries, providing energy security in the face of growing demand is an increasing concern. Moreover, net importers are facing a high fiscal vulnerability to changes in international prices. By diversifying electricity generation, countries could mitigate this vulnerability and in addition free up domestic fossil fuel resources from power generation for higher value-added applications and energy exports as a pivotal source for foreign exchange.

A switch to low carbon energy generation technologies could reduce the detrimental effects of the widespread fossil energy subsidies in the North African region (IMF, 2014). For decades, countries in the North African region have been relying on energy subsidies as a major tool for providing social protection and redistributing the wealth generated by fossil fuel resources. While fossil energy subsidies do support less well-off consumers to some degree, they tend to be regressive in nature, with the main benefits eventually going to the better-off. Moreover energy subsidies narrow governments' fiscal space for important investments to improve human wellbeing, such as investments in the health system or a country's infrastructure. The IMF (2014) estimates the value of pre-tax subsidies as a share of GDP amounting to 0.5% in Morocco, 3% in Tunisia, and 11% in Egypt as well as in Algeria.

[5] The North African countries experience high levels of direct normal irradiation (DNI), ranging from 4,000 to 8,000 Wh/m^2/day (NREL, 2011). Unlike PV cells and flat plate solar thermal collectors, CSP power plants cannot utilize diffuse solar irradiation, since it cannot be concentrated and hence not converted into usable thermal energy (World Bank and ESMAP, 2011).

Concentrated solar power (CSP) could become an attractive energy generation option for the North Africa region as a complementary to wind or solar PV in the medium term (Trieb et al., 2011). This is due to its longer track record and its ability to provide semi-dispatchable clean energy by allowing for the storage of energy in thermal storages to cancel out short-term fluctuations and the day-night cycle (GIZ, 2013). The annual growth of CSP amounted to about 20% in 2000-2011 (IEA, 2013a). The bulk of installed CSP capacity as well as of the CSP projects in the development pipeline (see Table 1) is dominated by parabolic trough collector (PTC) systems; solar towers, however, could potentially gain a significant market share in the future, if costs can be reduced and operating experience gained. While both CSP technologies can be equipped with efficient thermal energy storage systems (Kuravi et al., 2013), the key advantage of solar towers is their higher operating temperatures. The high operating temperatures allow for low-cost energy storage due to negligible losses by using molten salt as a heat transfer fluid-and hence higher steam cycle efficiency (IRENA, 2013).

The storage potential of CSP plants is especially relevant for regions like North Africa with a less developed electricity grid, which is not designed for the large scale feed-in of intermittent RES electricity (Brand and Zingerle, 2011). Despite high upfront investment costs, a characteristic CSP shares with most other RES technologies, solar towers can produce electricity in a competitive price range of 0.17 to 0.29 (USD/kWh) (IRENA, 2013). Among other factors, these prices are viable because of high capacity factors of solar tower plants with thermal storage of 0.4 to 0.8, depending on the amount of storage capacity (IRENA, 2013). Hence, by offering the option of energy storage, CSP plants are able to maintain a high capacity value (by generating flexible electricity to satisfy peak demand and hence by profiting from high peak load scarcity prices) up to penetration levels of 15% and beyond (Mills and Wiser, 2012). Hence, solar towers with sufficient thermal energy storage capacities might become the solar technology of choice in the near to medium future. In the longer term, investments into CSP capacities will also allow for the export of CSP electricity and, given the establishment of local value chains, export of CSP technology (World Bank and ESMAP, 2011). Several CSP power stations are currently in the planning phase across the North African region (Table 1).

Table 1. CSP projects announced/planned, in development, under construction or in operation in the North African region

Country and project title	Status	Power MW (solar only)	Technology
Algeria			
Hassi R'mel ISCC	Operational	25.00	Parabolic trough - ISCC
DLR - Algeria CSP tower pilot plant	Development	7.00	Central receiver (power tower)
Naâma	Announced/planning	70.00	Parabolic trough - ISCC
Meghaier	Announced/planning	75.00	Parabolic trough - ISCC
Hassi-R'mel	Announced/planning	70.00	Parabolic trough - ISCC
El Oued	Announced/planning	150.00	Tower
Beni Abbes	Announced/planning	150.00	Tower
Egypt			
Kuraymat ISCC	Operational	20.00	Parabolic trough - ISCC
Kom Ombo CSP project	Development / hold	100.00	Parabolic trough
TAQA CSP Plant	Planned	250.00	Central receiver (power tower)
Marsa Alam	Announced/planning	30.00	Parabolic trough
Aïn Beni Mathar ISCC	Operational	20.00	Parabolic trough - ISCC
Morocco			
Ouarzazate	Under construction	160.00	Parabolic trough
Ouarzazate 2	Development	100.00	Central receiver (power tower)
Ouarzazate 3	Development	200.00	Parabolic trough
Airlight Energy Ait Baha CSP Plant	Under construction	3.00	Parabolic trough
CNIM eCare Solar Thermal Project	Development	1.00	Fresnel
Tan Tan CSP-Desal Project	unconfirmed	50.00	Undecided
Tunisia			
TuNur	Development	2 000.00	Central receiver (power tower)
Akarit / TN-STEG CSP plant	Planned	50.00	Parabolic trough
El Borma ISCC	Planned	5.00	Tower - ISCC
Elmed CSP project	announced / hold	100.00	Undecided

Source: CSP Today (2014) and CSP World (2014).

To date three CSP power plants are operating in the North African region. They all utilize the Integrated Solar Combined Cycle (ISCC) technology (Hassi R'mel in Algeria and Kuraymat and Aïn Beni Mathar in Egypt). Komendantova et al. (2012) point out that all three realized CSP projects were initially planned by the government to be built and operated as independent power producers (IPP). Eventually, private investors in all three projects withdrew due to detrimental changes in the project framework, which led to a shift to World Bank supported state financing. This suggests that factors like regulatory changes in one Egyptian case create risks, which private investors tend to avoid (*ibid.*).

In contrary to other investments into low-carbon technologies and other RES, like wind, CSP projects do not possess an extensive track record yet. This creates additional uncertainty to investors and raises expectations on interest rates and rates of return due to higher perceived risks. Financing costs do not only tend to be higher because of a high capital intensity and a shorter track-record of CSP but also because of regionally specific barriers for investment in North Africa (Komendantova et al., 2012). The specific risk profile motivates the comprehensive analysis of CSP projects in North Africa to eventually inform the development of de-risking strategies to foster the deployment of RES.

3. Methodology

The LCOE approach is regularly used to compare the overall competitiveness of alternative power generation technologies and cost structures (EIA, 2014; Kost et al., 2013; Branker et al., 2011; Short et al., 1995). The basic idea of the LCOE approach is to relate cumulated lifetime costs to cumulated lifetime power generation of a specific power plant[6]. The resulting average electricity price per kWh, the LCOE, is the price, which is necessary for a project to break even across the whole project lifetime.

It is important to note that the LCOE method is an abstraction from reality in order to make energy technologies, which might differ quite substantially in their specific characteristics (e.g. the scale of operation, investment and operating time periods) comparable to each other (Kost et al., 2013). Even though there is criticism that the LCOE approach is not the appropriate tool to assess the competitiveness and the social costs of non-dispatchable RES generation, such as wind, solar PV and solar thermal without storage (e.g. Hirth, 2013; Ueckerdt et al., 2013; Joskow, 2011), we argue that the LCOE approach is indeed applicable for analyzing semi-dispatchable CSP generation including thermal storage at low penetration rates. It is argued that LCOE comparisons, which do not take into account integration costs[7], tend to overvalue intermittent

[6] The LCOE approach is based on the net present value method. The net present value of electricity generation from any specific technology is calculated by dividing the discounted monetary values of initial investment and accumulated annual variable costs by the discounted monetary value of electricity sales during the whole project lifetime.

[7] According to Hirth (2012), integration costs are consisting of profile costs (linked to the intermittency of variable RES generation), balancing costs (based on day-ahead forecast errors) and grid related costs (if RES capacity is located differently than average conventional plants).

generation technologies compared to dispatchable base load generation technologies. Adding these integration costs to the LCOE might indeed dramatically change the picture for truly non-dispatachable variable RES generation technologies such as PV and wind, particularly at high penetration rates (Hirth, 2013; Ueckerdt et al., 2013). CSP in combination with thermal storage can, however, achieve capacity factors up to 0.8 (IRENA, 2013) and hence has the potential to provide high value semi-dispatchable electricity. Integration costs for CSP with storage will therefore be substantially lower than for non-dispatchable RES generation technologies, particularly at low levels of penetration in the early stages along a pathway to a de-carbonized electricity system. Mills and Wiser (2012) find that while the marginal economic value of PV and CSP without storage drops considerably once the penetration of solar increases beyond 30%, the value of CSP with thermal storage drops substantially less as penetration increases. The higher marginal economic value of CSP with thermal storage compared to other variable RES generation rests on the high capacity value of CSP with thermal storage up to penetration rates of 15% and beyond (Mills and Wiser, 2012). Given that in our analysis we focus on CSP with thermal storage and by considering proposed energy strategies by North African countries, which set out to reach penetration rates around or below 20%, we consider the LCOE approach as appropriate for our assessment.

Moreover, also in the case of conventional dispatchable generation technologies, such as coal and gas fired power plants, the LCOE approach does not depict the true social costs of electricity generation (for a comparative review of external cost estimates see Kitson et al., 2011).

The LCOE of a CSP investment project in country n is calculated by dividing the sum of initial investment costs $I_{n,0}$, discounted cumulated operation and maintenance (O&M) costs $O_{n,t}$ and decommissioning costs net of scrap value $D_{n,T}$ by the discounted rated annual electricity production $S_{n,t}$ over the project lifetime T, taking into consideration the annual degradation factor d. For the discount rate r_n we apply the weighted average cost of capital (WACC) approach (see section 3.1). For further details on the LCOE model as well as the parameter values employed see the Appendix A.1.

We account for regional differences in the solar power potential, by relying on country specific DNI values taken from Breyer and Gerlach (2010). However, we do not differentiate technological assumptions such as the economic lifetime of the CSP projects, the concrete technology and the associated overnight investment costs and variable O&M costs and performance ratio across the four North African countries. To take into account the effects of changes in these technological parameters on the LCOE from CSP, we carry out a sensitivity analysis (see Appendix A.2).

$$LCOE_n = \left(I_{n,0} + \sum\nolimits_{t=1}^{T} \frac{O_{n,t}}{(1+r_n)^t} + \frac{D_{n,T}}{(1+r_n)^T}\right) \Big/ \left(\sum\nolimits_{t=1}^{T} \frac{S_{n,t}(1-d)^t}{(1+r_n)^t}\right)$$

$LCOE_n \ldots levelized\ cost\ of\ electricity\ in\ country\ n$ (in USD/kWh)
$T \ldots economic\ operational\ lifetime\ of\ investment\ project\ (in\ years)$
$t \ldots year\ of\ lifetime\ (1,\ 2, \ldots T)$
$n \ldots country$
$I_{n,0} \ldots initial\ investment\ cost\ in\ period\ 0$ (in USD/kWp)
$O_{n,t} \ldots Operation\ expenditures\ (variable\ and\ fixed)\ in\ counutry\ n\ and\ in\ period\ t$ (in USD/kWp)
$D_{n,T} \ldots Decomissioning\ costs\ (net\ of\ scrap\ value)\ in\ country\ n\ and\ in\ period\ T$ (in USD/kWp)
$r_n \ldots real\ interest\ rate\ (i.e.\ WACC)\ in\ country\ n\ (in\ percent)$
$S_{n,t} \ldots rated\ annual\ electricity\ production\ in\ country\ n\ and\ in\ perios\ t\ (in\ kWh)$
$d \ldots annual\ degradation\ factor\ (in\ percent)$

3.1. The weighted average costs of capital (WACC)

Besides some first attempts to assess the effect of financing costs on the LCOE of RES technologies (Ondraczek et al., 2015) and the role of IFIs in bringing down the financing costs of RES investments in developing world regions (Frisari and Stadelmann, 2015), LCOE assessments regularly do not take into account investment risks and differences in financing methods (Branker et al., 2011). Typically, the discount rate used in the LCOE method reflects the return on invested capital in the absence of investment risks (IEA, 2010). However, the cost of capital varies widely across countries and alternative energy technologies. This is mainly due to very different risk profiles of each individual technology and country and how these risks are perceived by investors (Oxera, 2011). Eventually, LCOE assessments should employ an idiosyncratic discount rate for each generation technology (Awerbuch, 2000).

In our analysis of CSP projects in the North African region we go beyond the notion of discount rates representing risk free interest rates and introduce investment risks by employing higher financing costs, i.e. weighted average cost of capital for CSP projects in the North African region. To analyze the effects of a de-risking strategy on the competitiveness and cost effectiveness of CSP power plants in the North African region, we reduce the weighted average cost of capital until it equals financing costs in a reference region[8] (UNDP, 2013).

[8] The reference region, or the reference investment environment, reflects a theoretical best-case situation for investors with respect to the cost of capital when all project risks are effectively

To explicitly include project specific characteristics of financing costs, such as the share of equity and debt in external funding and the respective interest rates into the analysis we apply the WACC approach (see Appendix A.1; Breyer and Gerlach, 2010).

4. Results

4.1 WACC in the North African region

With respect to financing costs for CSP projects in the North African region, there is currently very limited relevant information available. This is mainly because only few CSP projects are already in the operational stage and even less projects make their data available to the public. Due to the limited availability of data, we have to rely on debt and equity interest rate estimates for CSP projects in the MENA region in the existing literature (Kulichenko and Wirth, 2011) to establish reference financing costs, or WACC, representing the current risk environment for CSP projects in the North African region[9]. Applying the WACC approach presented in the previous section, the resulting financing costs for a reference CSP project in North Africa amount to 10.2%, compared to a Euro area WACC of 4.1% (Table 2).

Table 2: Financing cost structure of a reference CSP project in the North African region and the theoretical best-case Euro area financing environment

	Reference CSP project North Africa*	**Euro area****
Share of equity in financing	20.0%	30.0%
Equity rate of return	15.0%	4.8%
Share of debt in financing	80.0%	70.0%
Debt interest rate	9.0%	3.9%
Weighted average cost of capital	**10.2%**	**4.1%**

*Source: *Kulichenko and Wirth (2011); **Dimson et al. (2011) and ECB (2014)*

underwritten by an institution. The German feed-in scheme, for example, mitigates regulatory and political risks for RES investors and revenue risks (consisting of price and volume risks; Mitchell et al., 2006) are effectively underwritten by the German electricity consumer, eventually reducing overall investment risks substantially.

[9] Kulichenko and Wirth (2011) base their assumptions regarding prevailing financing costs on information provided by developers, financial assumptions made for a World Bank internal analysis for an IBRD co-financed CSP development in the MENA region, and informed assumptions by World Bank staff.

4.2. The financing cost gap for the North African region

The differences in financing costs between the North African region (10.2%) and the Euro area (4.1%) – the financing cost gap – can be explained by the existence of different categories of investment risks (UNDP, 2013). The financing cost gap between the North African region and the Euro area, as well as the relative contribution of different risk categories to this gap, as identified by Komendantova et al. (2012), are depicted in Figure 1.

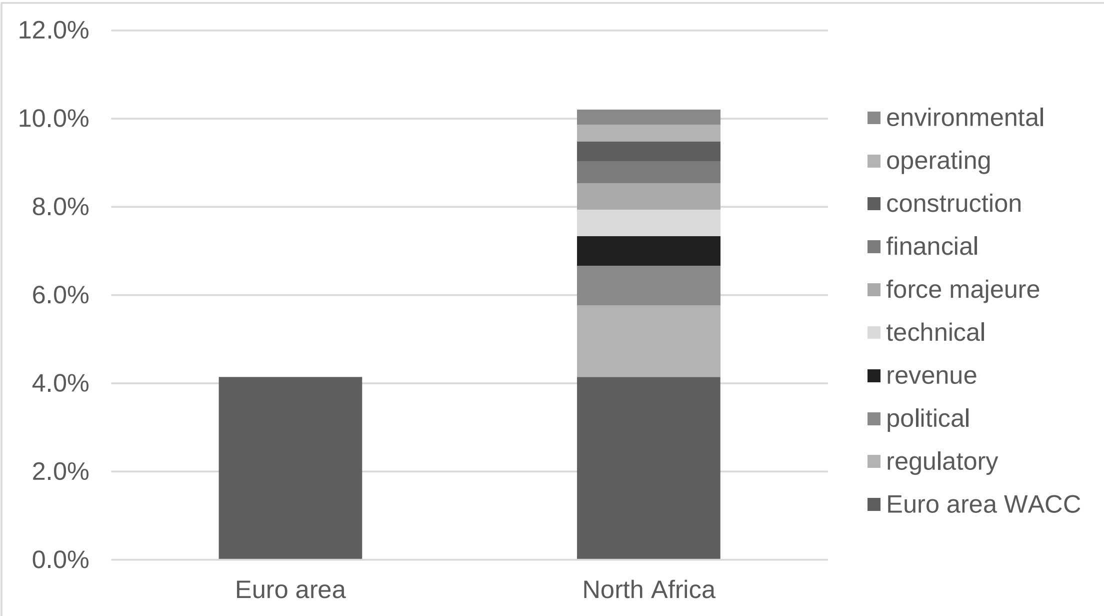

Fig. 1. The financing cost gap between the Euro area and the North African region, split up into different risk categories. Source: Financing costs: Kulichenko and Wirth (2011); Dimson et al. (2011); ECB (2014); Risk assessment and categories: Komendantova et al. (2012)

For the present analysis of financing costs in the North African region we rely on the risk assessment carried out by Komendantova et al. (2011 and 2012), which focuses explicitly on CSP investments in the North African region. By carrying out stakeholder workshops, structured and unstructured expert interviews and case studies, Komendantova et al. (2012) identify nine risk categories: regulatory, political, revenue, technical, financial, force majeure, construction, operating, and environmental. The respective strength of each risk component (Figure 1) depends on the combination of the seriousness of the financial impact and the likelihood of it to happen. Regulatory and political risks are the most serious risks for investment into CSP in the North African region and the most likely to happen (Komendantova et al., 2012). Other important risks contributing to the financing cost gap, include revenue, technical, force majeure and financial risks. Risks related to construction and operation as well as environmental risks are perceived as being least serious and least likely to happen (Komendantova et al., 2012).

Not all components of investment risks for RES projects in the North African region will be avoidable in reality and the best-case financing costs have to be seen as a theoretical lower bound for CSP financing costs in less developed world regions. Each individual technology and region is characterized by a unique risk profile, with RES technologies regularly being subject to higher innate risks (e.g. due to their variability and shorter track records), which is then reflected in differences in the cost of capital for different technologies.

4.3. LCOE from CSP in the North African region

The LCOE from CSP solar tower plants in the North African countries, based on the WACC presented in Table 2, representing reference financing costs in the region (Kulichenko and Wirth, 2011), are depicted in Fig. 2. As we do not assume regional differences in the CSP technology, the variations in the LCOE across the North African countries result from differences in the countries' solar potentials. The lowest required average electricity price to break even across the whole economic lifetime of a CSP project is achievable in Egypt, represented by LCOE of 0.227 USD/kWh, followed by Algeria with LCOE of 0.236 USD/kWh, Morocco with LCOE of 0.244 USD/kWh, and Tunisia with LCOE of 0.255 USD/kWh.

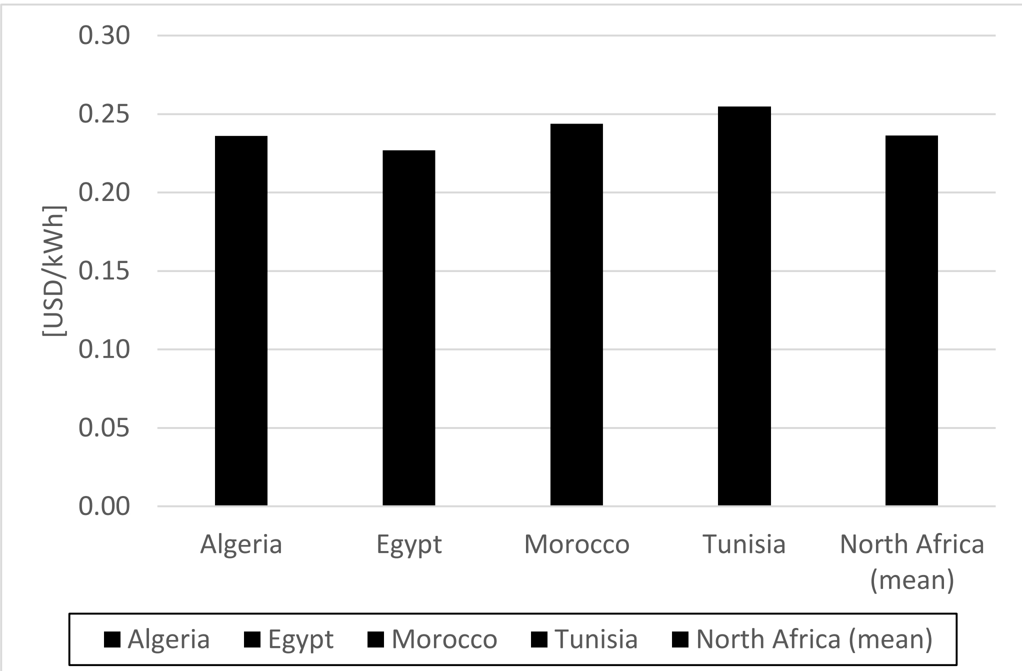

Fig. 2. *LCOE for CSP electricity generation in the four North African regions and the resulting mean (in USD/kWh)*

By comparing the LCOE for CSP electricity generation between North Africa and Europe (Fig. 3) we find that even though North Africa has a substantially higher solar potential than Europe (see DNI values in Table A.1 in the Appendix A.1), the resulting LCOE for Europe (0.245 USD/kWh) is only slightly higher than the mean for North Africa (0.236 USD/kWh). This is due to substantially lower financing costs in Europe than in the North African region.

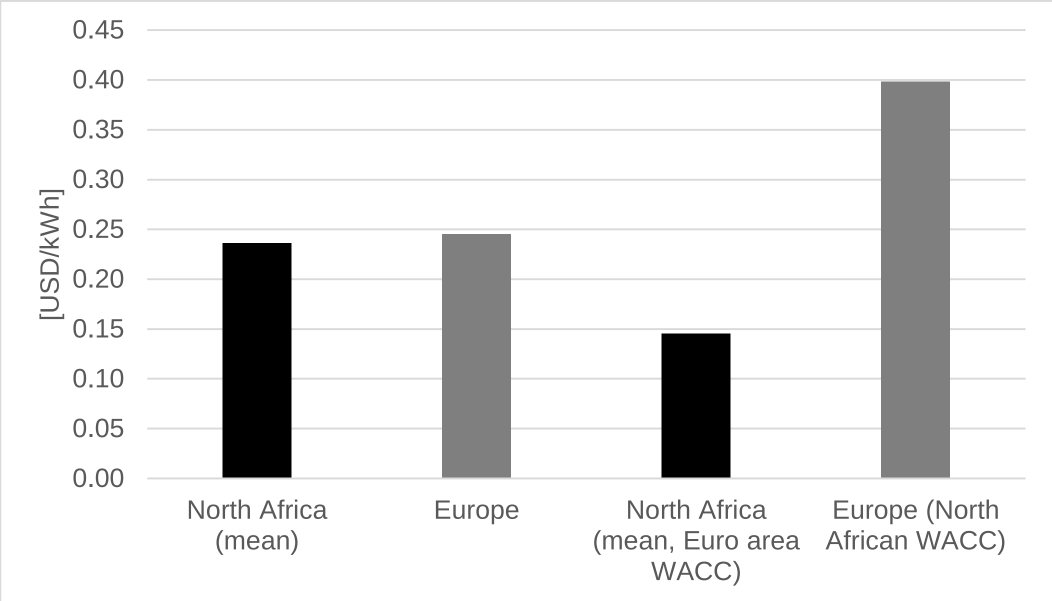

Fig. 3. *LCOE for CSP electricity generation in the North African region (mean) and Europe (in USD/kWh): the Status quo financing environment (first and second column) and for alternative financing cost (third and fourth column).*

By de-risking investments into CSP projects in the North African region, which leads to reduced financing costs , LCOE associated with CSP projects could be substantially reduced (Fig. 3). If a CSP investor in North Africa could acquire project financing at a cost equivalent to that in Europe, the LCOE could be reduced from 0.236 USD/kWh to 0.145 USD/kWh or by 39%. On the other hand, if we consider in a thought experiment the reciprocal situation and employ North African reference financing costs (Kulichenko and Wirth, 2011) in the calculation of the LCOE from CSP in Europe, LCOE would increase from 0.245 USD/kWh to 0.371 USD kWh or by 51%.

As RES technologies, such as CSP, are in principle highly capital intensive, investment risks reflected in higher financing costs are very significant for these technologies. The LCOE break-down which is presented in Fig. 4 confirms this reasoning. It can be seen that in a pre-de-risking environment the cost of capital is the by far most influential component of the overall LCOE. Hence, a reduction in financing costs, which translates into a reduction of the cost of capital, has a decisive impact on the competitiveness of CSP. Still, even a full financial de-risking of CSP investments in North Africa, reflected by financing costs in the four North African countries equalizing those in Europe, does not lead to the achievement of cost competitiveness of electricity from CSP in comparison to the respective prevailing subscribed demand weighted average electricity prices, ranging from 0.048 USD/kWh in Egypt to 0.133 USD/kWh in Morocco, (see Fig. 4; UPDEA, 2009). Currently Morocco has the highest electricity prices in the region (even though prices are less subsidized than in other North African countries) since its electricity generation is currently based up to 95% on energy imports. This situation is completely different in Egypt or Algeria, which are both fossil fuel rich, net energy exporting countries.

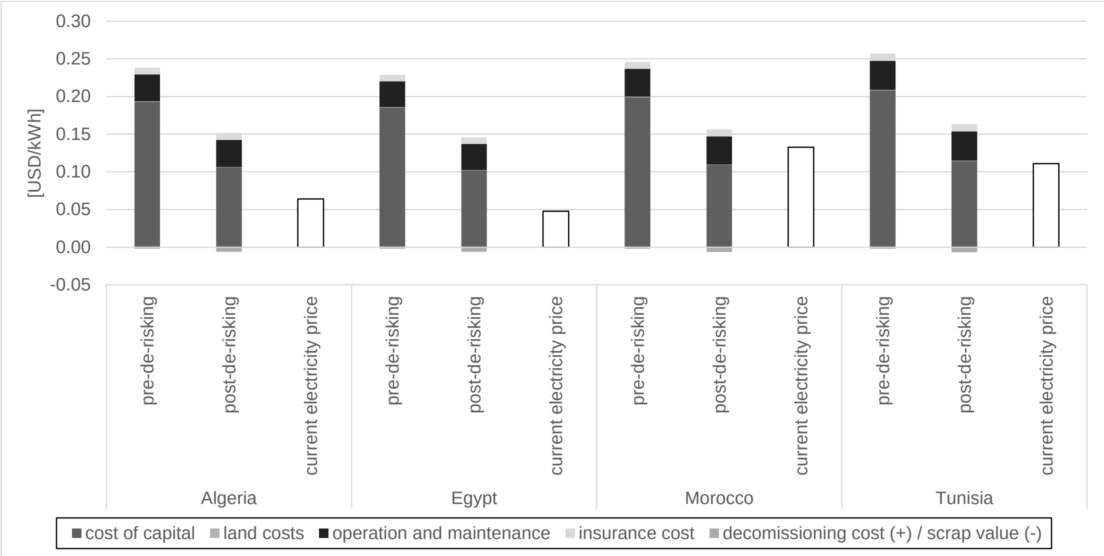

Fig. 4. *Breakdown of LCOE for CSP electricity generation in North African countries in a pre-de-risking and a post-de-risking financing environment, compared to current electricity prices based on the current energy mix (in USD/kWh). Source of current electricity prices: UPDEA (2009)*

5. Discussion and Conclusions

While the question about how perceived risks by investors impact LCOE remained long time without attention in the literature on the economics of RES technologies, now scientific evidence shows that perceived risks can be a crucial determinant of the economic feasibility of a RES project. In this paper we analyze the impact of specific perceived risks by investors on the financing costs of CSP projects in four North African countries (Algeria, Egypt, Morocco, and Tunisia). Our research suggests the following new insights.

A reform of the current energy subsidy scheme is crucial to level the playing field for CSP and to foster its deployment in the North African region. Based on reference financing costs for CSP projects in North Africa, we find that the WACC in the North African region is on average 6.1 percentage points higher than in the European region. Given these financing costs, the average LCOE from CSP in the North African region is 0.236 USD/kWh, which is at the moment uncompetitive with the prevailing electricity prices in the four North African countries. This price gap between CSP and conventional electricity does, on the one hand, result from higher financing and production costs for CSP, compared to conventional power generation, but is, on the other hand, also based on high subsidies for conventional fossil fuel power generation in the North African countries (IMF, 2014).

Currently, electricity prices in the four North African countries are regarded as a part of social contract and electricity itself as a "public good" that should be provided by the government (Fattouh and El-Katiri, 2012). Hence, the generation – directly and indirectly via fossil fuel intermediate inputs –, as well as the consumption of electricity are strongly subsidized in the North African region (Bridle et al., 2014; IMF, 2014 and 2013; Fattouh and El-Katiri, 2012). The resulting administered prices are regularly below market prices and cost-recovery prices. The presence of these subsidies bestows a cost advantage on fossil fuel generation technologies and renders electricity from CSP uncompetitive at the moment. Bergasse et al. (2013), relying on data from IEA, IMF, World Bank and individual national statistics, report subsidy levels (as % of the final electricity price) amounting to 35% in Algeria, 44% in Tunisia and 10% in Egypt. As Bergasse et al. (2013) do not present an effective subsidy rate for Morocco, we take the average of the subsidy rates in Algeria, Tunisia and Egypt, resulting in an effective subsidy rate of 30% in Morocco. Adding these effective direct subsidies to the current electricity prices, Fig. 5 gives a more realistic picture of actual production costs of the conventional electricity mix in the North African region than Fig. 4. We find that considering subsidies could even change the economic viability of RES electricity generation in one of the four North African countries considered in our analysis: For Morocco, a de-risking strategy could be effective in achieving cost competitiveness with conventional fossil electricity at its effective production cost without relying on any additional RES subsidies[10].

[10] It is important to note that these subsidies do not cover indirect (or implicit) subsidies for conventional electricity generation through the subsidy of fossil fuels (IMF, 2014), nor do they cover post-tax subsidies, such as the non-existence of corrective taxes to capture negative environmental and other externalities due to fossil energy use (IMF, 2013). Taking also these additional indirect and post-tax subsidies into consideration would change the picture even further, potentially resulting in cost competitiveness of CSP with the current generation mix in other countries as well or requiring lower levels of de-risking in a country like Morocco, where considering direct subsidies alone would already result in cost competitiveness.

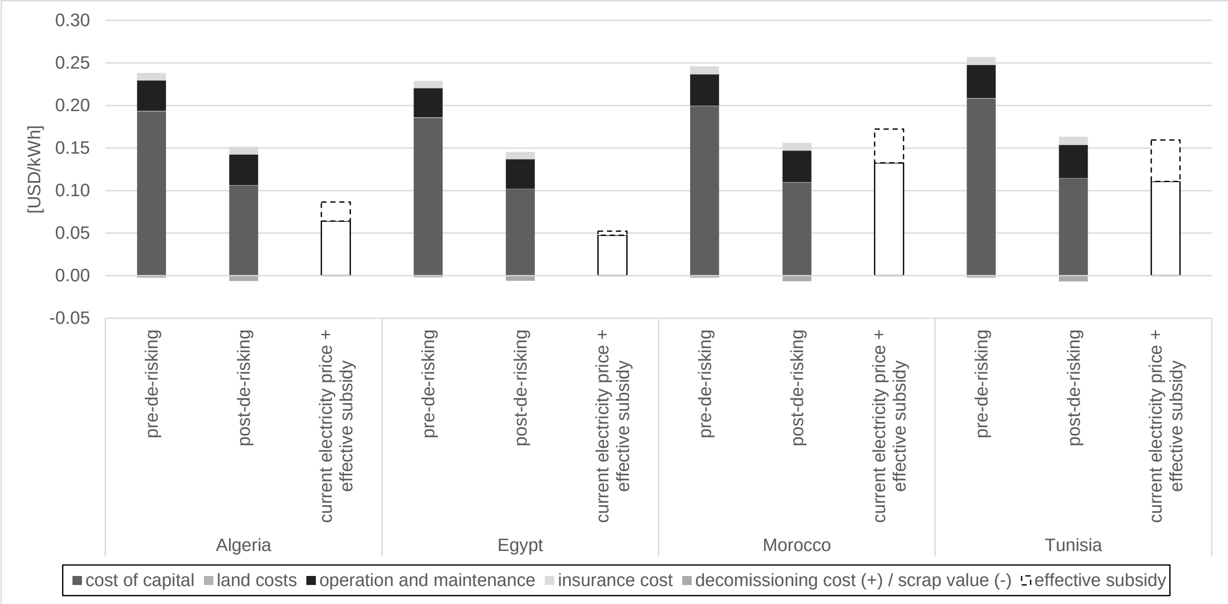

Fig. 5. Breakdown of LCOE for CSP electricity generation in North African countries in a pre-de-risking and a post-de-risking financing environment, compared to current electricity prices based on the current energy mix plus effective direct subsidies (in USD/kWh). Source of current electricity prices: UPDEA (2009); Source of subsidy levels: Bergasse et al. (2013).

De-risking CSP investments is needed to attract the levels of private investments required to foster the anticipated deployment of CSP (and RES in general) in the North African region. Focusing on a specific CSP project in the North African region, Ouarzazate I in Morocco, Frisari and Stadelmann (2015) point out that the relatively low financing costs compared to benchmark rates are due to very favorable financing conditions in this very specific project. The public-private partnership with government guarantees addressed investment risks in the case of the Ouarzazate I project to some degree and led to a reduction in the equity rate of return to 13.1% against a benchmark return of 15% (Kulichenko and Wirth, 2011). Furthermore, the highly concessional finance provided by IFIs resulted in a very low blended, i.e. weighted average interest rate for the overall debt financing of approximately 3.1% compared to a benchmark commercial loan interest rate of 9% (Kulichenko and Wirth, 2011). Compared to a best in class reference investment environment, in our case the Euro area, the WACC of the Ourzazate project, amounting to 5.1% is only 1 percentage point higher than the theoretical lower bound represented by the Euro area's WACC of 4.1% (Table 2).

Hence, the Ourzazate 1 financing costs have to be seen as an exception rather than a rule, given the current risk environment in developing world regions such as North Africa. Comparing the limited funds managed by IFIs with the large sum of investments required to achieve a substantial scale-up of RES deployment in developing countries, a stronger mobilization of private investments will be needed, which would eventually lead to a further reduction of equity rates of return. This, in turn, requires an even stronger attention on perceived risks by private investors and the development of policies to tackle these perceived risks.

The effect of de-risking on the cost competitiveness of RES electricity generation with conventional electricity generation depends strongly on the particular RES technology under consideration. In relation to the quantitative assessment of impacts of investment risks on RES financing and life-cycle costs by the UNDP (2013), our findings differ quite substantially. While the UNDP (2013) de-risking report finds that in the case of large-scale onshore wind energy projects a de-risking strategy may eventually decrease the LCOE from wind energy below the LCOE of a baseline activity in two of the four case study countries (Panama and Kenya). We find that reducing financing costs of CSP projects in the North African regions to the European level will indeed lead to a 39% reduction in LCOE; however, this reduction will still not be sufficient to reach economic competitiveness of CSP in North Africa with prevailing electricity prices[11]. Only when taking into consideration estimates of effective production and consumption subsidies for conventional electricity production in North Africa, CSP appears to become competitive in one of the four case study countries (Morocco) after implementing a de-risking strategy that reduces financing costs to European levels.

This relative advantage of large scale onshore wind over large scale CSP might lead to the conclusion that investing in large-scale onshore wind energy is economically more feasible than investing in large scale CSP projects. However, the results of our analysis and of UNDP (2013) are not directly comparable as the two technologies, wind and CSP, are not directly comparable either. Differences in the maturity of technologies, their respective market penetration rates and lengths of their track records may constitute technology parameters influencing financing costs for a specific RES technology. Moreover, given the current situation of the grid infrastructure and electricity storage potentials, large scale deployment of wind energy might eventually not be technically feasible in the North African region in the short to medium run. CSP in combination with heat storage capacities might therefore represent an important complementary technology in the transition to a RES based energy system.

Based on these insights we suggest a dual strategy for North Africa's RES policy to promote RES deployment in the region: (1) the introduction of a comprehensive de-risking strategy with private and public measures to tackle

[11] In our analysis we consider the average electricity prices prevailing in the respective countries while the UNDP report considers marginal baseline activities as points for comparison with the RES technology that tend to be higher than average prevailing electricity prices.

the higher financing costs associated with CSP projects and to eventually reduce the LCOE from CSP complemented by (2) additional policy instruments directly (e.g. by introducing feed-in-tariffs or green quotas) and indirectly (e.g. by lowering fossil fuel subsidies) supporting RES.

Given the regional differences in the legal and political systems, the cultural environments, the existing energy systems and energy infrastructure, as well as the (renewable) energy policies and strategies in North Africa, investors have to deal with the concrete situation in a host country case by case and upfront to anticipate potential risks and barriers in particular RES investment projects. Therefore, the analysis of additional case studies will be a fruitful and important area of future research and we strongly encourage the research community to put their joint effort in the establishment of a comprehensive data base collecting baseline financing costs, the impacts of perceived risks on financing costs and the potential of de-risking related to concrete RES projects.

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Appendix

A.1. LCOE model details and parameter values employed

The annual electricity production S_n is calculated by multiplying the DNI value in country n by the performance ratio of the CSP power plant and the tracking factor. Following Hernández-Moro and Martínez-Duart (2013) the tracking factor TF is assumed to be 1 for the technology we consider in our analysis: a power tower system with a double axis tracking system. The performance ratio PR converts the DNI value for country n into the actual amount of electricity produced by the system after including the tracking factor TF. The value of the performance ratio of CSP plants is mainly determined by the amount of storage capacity. Since we consider a power tower plant with thermal storage for 7.5h in our analysis, the performance ratio PR is assumed to be 1.602 m²/kWh (ibid.).

$$S_{n,t} = DNI_n * TF * PR$$

$S_{n,t}$ ... $rated\ annual\ energy\ output\ \ in\ country\ n\ (in\ kWh/year)$

$DNI_{n,t}$ ... $maximum\ direct\ normal\ irradiation\ value\ in\ country\ n\ (in\ kWh/m^2\ /year)$

TF ... $tracking\ factor$

PR ... $Performance\ ratio\ (in\ m^2/kWh)$

The decommissioning costs net of scrap value d are assumed to be negative for CSP projects. This means that at the end of the economic project lifetime the scrap value of the power plant components exceed the decommissioning costs. This is motivated by the assumption that in the case of RES technologies such as wind and solar power, the power plant is usually not fully decommissioned, which would imply high costs, but rather refurbished with new equipment (IEA, 2010).

In the calculation of the WACC, the equity rate of return i_{E_n} and the debt interest rate $i_{D_n}$for a CSP project in a North African country are weighted by their respective shares in overall external funding of the project.

$$WACC_n = i_{E_n}\left(\frac{E_n}{E_n + D_n}\right) + i_{D_n}\left(\frac{D_n}{E_n + D_n}\right)$$

$WACC_n$ ... $Weighted\ average\ cost\ of\ capital\ in\ country\ n\ (in\ percent)$

n ... $country$

i_{E_n} ... $equity\ rate\ of\ return\ in\ country\ n\ (in\ percent)$

E_n ... $Share\ of\ equity\ used\ in\ investment\ project\ in\ country\ n\ (in\ percent)$

i_{D_n} ... $debt\ interest\ rate\ in\ country\ n\ (in\ percent)$

D_n ... $Share\ of\ debt\ used\ in\ investment\ project\ in\ country\ n\ (in\ percent)$

Table A.1. Parameter values for the LCOE model

Parameter description	**Parameter**	**Unit**	**Value**	**Source**
Economic life of CSP project	T	Years	30	IRENA (2013)
Initial investment cost of in country n in period t=0	$I_{n,t=0}$	USD/kWp	7,000	IRENA (2013)
Land cost	L	USD/kWp	24	Hernández-Moro and Martínez-Duart (2013)
Operation expenditures in country n in period t	$O_{n,t}$	% of initial investment	2.5	Hernández-Moro and Martínez-Duart (2013)
Operation and maintenance cost in country n in period t		% of initial investment	2.0	Hernández-Moro and Martínez-Duart (2013)
Insurance cost in country n in period t		% of initial investment	0.5	Hernández-Moro and Martínez-Duart (2013)
Decommissioning cost (+) / Scrap value (-)in country n in period t=T	$D_{n,t=T}$	% of initial investment	-20	IEA (2010)
Annual module degradation factor	d	%	0.2	Hernández-Moro and Martínez-Duart (2013)
Direct Normal Irradiation (DNI) in country n in period t	$DNI_{n,t}$	kwh/m^2/a		Breyer and Gerlach (2010)
Algeria		kwh/m^2/a	2,488	Breyer and Gerlach (2010)
Egypt		kwh/m^2/a	2,589	Breyer and Gerlach (2010)
Morocco		kwh/m^2/a	2,410	Breyer and Gerlach (2010)
Tunisia		kwh/m^2/a	2,306	Breyer and Gerlach (2010)

A.2 LCOE sensitivity analysis

The main focus of this article is on the assessment of the impacts of variations in financing costs on the LCOE from CSP in the North African region. In this sensitivity analysis we assess the impact of altering other important parameter values in the calculation of LCOE from CSP.

Table A.2. Sensitivity analysis of key LCOE parameter values

Parameter description	Parameter	Unit	-10%	base	+10%
Initial investment costs	$I_{n,t=0}$	USD/kWp	6,300	7,000	7,700
LCOE		*USD/kWh*	*0.221*	*0.240*	*0.260*
Operation and maintenance cost	$O_{p,n,t}$	USD/kWp/a	157.5	175	192.5
LCOE		*USD/kWh*	*0.236*	*0.240*	*0.245*
Rated annual energy output	$S_{n,t}$	kWh/kWp/a	3,530	3,922	4,314
LCOE		*USD/kWh*	*0.219*	*0.240*	*0.267*
Project life	T	a	27	30	33
LCOE		*USD/kWh*	*0.239*	*0.240*	*0.241*

Table A.2 depicts the sensitivity of LCOE from CSP in the North African region due to variations (-10% and +10%) in key parameter values: Cost overruns, expressed in higher or lower initial investment costs and operation and maintenance costs; deviations in the rated annual energy output due to uncertainty in DNI forecasts or variations in the performance factor; variations in the project life. Due to the high capital intensity of CSP projects, the LCOE metric is particularly sensitive to deviations in initial investment costs. Moreover, we find that a -/+10% deviation in the assumption regarding the rated annual energy output of a CSP project has an even stronger impact on the LCOE from CSP than a comparable deviation in the initial investment costs. Variations in the assumed project life as well as in the operation and maintenance expenditures have considerably less impact on the LCOE results.