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Governance of risks in financing concentrated solar power investments in North Africa

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Contents

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. To transform the global energy system, substantial investments will be needed and private participation will very likely be required to achieve the scale of new investment. Yet, especially developing countries are struggling to foster private RES investments. The literature argues that the economic feasibility and hence the realization of a RES investment project hinges on the availability of affordable project financing, which itself depends on perceived risks by investors. Since financing costs are found to be particularly high for capital-intensive RES projects and in developing countries, we investigate the impacts of a financial de-risking approach on electricity prices from concentrated solar power (CSP) in four North African countries and derive the following three conclusions. (1) By employing a levelized cost of electricity (LCOE) model we find that a comprehensive de-risking approach leads to a 32% reduction in the regional mean of LCOE from CSP. (2) To capture potential macroeconomic feedback effects of a de-risking strategy to CSP investments, we employ a Computable General Equilibrium (CGE) model. By considering a 5% CSP target by 2020, the model results indicate that an ambitious de-risking strategy is still not sufficient to achieve cost competitiveness between CSP and subsidized conventional electricity but has the potential to reduce the required subsidy to stimulate CSP deployment in 2020 by 0.03 USD/kWh which would increase GDP on average by 0.15% or 327 million USD. (3) By conducting expert interviews with RES investors we learn that investors are aware of different investment risks associated with RES projects in North Africa and of private risk transfer measures to mitigate these risks. Our results suggest that given the potential for substantial electricity cost reductions and overall economic benefits, financial de-risking – incorporating both public and private measures – reflects an important strategy to foster the deployment of RES.

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Thomas Schinko

1 Introduction

To avoid the most severe and catastrophic impacts of climate change, global warming has to be limited to 2°C above the pre-industrial average temperature (IPCC, 2013). There is a broad scientific consensus that climate change is mainly triggered by anthropogenic Greenhouse Gas (GHG) emissions, which are to a large extent generated by the combustion of fossil fuels (IPCC, 2013). In September 2013, the IPCC reported in its 5thAssessment report (IPCC, 2013) that if temperatures were to stay below the critical 2C° threshold with a probability >66 percent, the world could only emit further 1,000 $GtCO_2$.Other studies indicate that an even more stringent cap to anthropogenic GHG emissions is necessary, since the release of additional 1,000 $GtCO_2$ would eventually result in a warming of 3-4°C due to so-called "slow feedbacks" (Hansen et al., 2013).

There are several regulatory instruments in place, which aim at reducing anthropogenic GHG emissions. On a supra-national level, the United Nations Framework Convention on Climate Change (UNFCCC) set a non-binding target to reduce anthropogenic CO_2 emissions to 1990 levels by 2000. However, the process has so far not achieved meaningful progress with respect to effective reductions of anthropogenic GHG emissions. In fact, humanity has rather accelerated than controlled anthropogenic climate change, since global GHG emissions have been steadily rising since 1994 (with a brief dent in 2008 and 2009 due to the global economic crisis) when the UNFCCC entered into force (UNEP, 2014). Furthermore, the only legally binding international treaty for the reduction of anthropogenic GHGs, the Kyoto Protocol, is currently in a state of limbo with respect to its future, since the 195 parties to the convention are still struggling to agree on a comprehensive, legally binding global climate agreement as a successor to the Kyoto Protocol by 2015 at COP 21 in Paris and for it to be implemented in 2020 (UNFCCC, 2013).

To establish more effective policies for dealing with climate change, the IPCC's Working Group III argues in its contribution to the 5th Assessment Report (IPCC, 2014) that the consideration of risk perception[1] and decision processes is pivotal. Furthermore, any effective

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[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).

climate change mitigation strategy has to put an emphasis on the global energy system, since it is the source of two thirds of global greenhouse gas emissions (OECD/IEA, 2013). Altvater (2008) argues that the stabilization of the global climatic system will only be possible with a fundamental reconfiguration of the global energy system. In addition, Francés et al. (2013) point out the potential contribution of RES deployment to energy security. They find that renewable electricity, whether domestically produced or imported, could improve energy security by contributing to the diversification of the energy mix, geographical diversification, and reducing the exposure of the energy mix to fossil fuel price volatilities.

Hence, to tackle these interlinked global challenges of climate change and energy security, a transformation of the global energy system on the basis of renewable energy sources (RES) is needed. To achieve this goal, substantial investments in RES generation and electricity transmission and distribution infrastructure will be necessary. The World Bank together with the United Nations argues that 600-800 billion USD a year will be needed to meet the target of universal access to electricity, doubling energy efficiency and doubling the share of renewable energy by 2030 (Business Standard, 2013). The IEA (2014) estimates, that in a scenario which reaches the 2°C climate stabilization goal, cumulative global investments of USD 53 trillion in energy supply and energy efficiency will be necessary over the period to 2035. Given these high investment requirements and the limited public funds, which are currently constrained even further by strict austerity programs as a disputed response to the global financial crises, private participation is inevitable.

Due to the increasing maturity of renewable energy technologies, especially solar energy (indicated by constantly falling unit production costs), the private sector (investment companies like Goldman Sachs) is beginning to get interested in solar power projects (LaCapra, 2012). Nevertheless, especially developing countries struggle to stimulate the required private investments in renewable energies. The literature argues that the economic efficiency and hence the realization of a renewable energy investment project hinges on the availability of affordable project financing (Schmidt, 2014; UNDP, 2013). The cost of capital itself depends 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; Schmidt, 2014; UNDP, 2013).

Perceived risks by investors (Komendantova et al., 2011 and 2012) as well as financing costs for capital-intensive renewable energy projects (UNDP, 2013) are found to be particularly high in developing countries (Shrimali et al., 2013). However, developing countries would particularly profit from a low-carbon energy transition by improving the living standards for the 1.3 billion people that currently do not have access to electricity (IEA, 2012). The UNDP (2007) argues that without an adequate access to modern energy services, the full achievement of the Millennium Development Goals will not be possible. Hence, potential risks for investments have to be identified and carefully managed to establish attractive conditions for private renewable energy projects in developing countries (Schmidt, 2014; UNDP, 2013).

Previous research has identified risk perception by investors as being closely connected to an investor's decision whether or not to invest in a certain technology (Douglas, 1985; Kann, 2009; Lüthi and Prässler, 2011) and at which cost financing is made available (Varadarajan et al., 2011). In addition, specific risk categories associated with renewable energy investments in developing countries have been classified. Komendantova et al. (2012) conducted three stages of interviews with stakeholders to learn their perceptions of risks most likely to affect renewable energy projects, focusing on concentrated solar power (CSP) in North Africa. They find that regulatory and political risks are of highest concern to investors and suggest that sound regulations have to be implemented and enforced, and complexities in bureaucracy and the legal system have to be reduced to mitigate these risks. A UNDP report on "De-risking Renewable Energy Investments" (UNDP, 2013), which focuses on investment risks' impact on financing costs for wind energy projects in South Africa, Panama, Mongolia, and Kenya identifies several risk categories for renewable energy investments. While this previous literature focuses mainly on public policy instruments to reduce these perceived risks by investors, in the present paper we rather want to identify private financial de-risking measures by investors to address the different risk categories in a developing countries context.

By looking at four concrete North African countries – Algeria, Egypt, Morocco, and Tunisia – we set out to address the demand for more concrete case study analyses of perceived risks by renewable energy investors (Schmidt, 2014). 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. Even though the events of the Arab spring in 2011 and the subsequent political instabilities have slowed down the progress in achieving proclaimed renewable energy targets in the North African region, there is still a strong commitment to a low-carbon energy transition. The Egyptian finance minister for example has reaffirmed Egypt's efforts to use renewable energy and achieve substantial fossil fuel savings (PV magazine, 2014). With respect to renewable energy technologies, we consider in our case study CSP, which has already become a proven solar power technology for large-scale applications. Due to the optional feature of low-cost thermal energy storage and the potential for the equipment of CSP plants with conventional back-up systems, CSP systems are well suited to provide dispatchable renewable electricity to satisfy intermediate- and base-load demand (IRENA, 2013). Therefore, at present, CSP appears most promising for large-scale energy generation in the North African region.

While perceived risks by renewable energy 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[2] or have analyzed the direct effects of a financial de-risking strategy to RES investments on the cost of electricity (UNDP,

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[2] Using financial models, Varadarajan et al. (2011) examined the impact of various policy impact pathways on financing costs for RES projects in developed countries (US and Europe) and found that higher perceived risks by investors may lead to 3-9% higher financing costs.

2013; Schmidt, 2014). For an illustrative South African case study UNDP (2013) finds that the implementation of a package of de-risking instruments reduces the levelized costs of electricity (LCOE) for wind energy from 9.6 USD cents per kWh to 8.9 USD cents per kWh. Moreover, macroeconomic impacts of a de-risking strategy to RES investments in developing countries have neither in a developed nor in developing country context been comprehensively analyzed. Komendantova et al. (2011) estimate financial benefits of reducing financing costs for CSP projects in North Africa in terms of the amount of public subsidy required to stimulate investment. Since this analysis is done in a sectoral model it can only capture direct financial benefits from reducing the cost gap between CSP electricity and the marginal power plant it replaces. By applying a multi-sector, multi-region computable general equilibrium (CGE) model in addition to a sectoral LCOE model, we set out to capture not only direct financial benefits but also those benefits arising from macroeconomic feedback effects to reduced CSP electricity prices and lower public subsidy requirements. To our best knowledge, no such macroeconomic analysis of risk perceptions and of a financial de-risking strategy has been carried out so far.

The remainder of the paper is structured as follows. First, we provide detailed background information on the North African case study region, the role of private investments in renewable energy projects, and investor's perceptions of risks. Second, we introduce the methods applied in our analysis. Third, we present the results of our analysis of the influence of risk perceptions by investors and a de-risking strategy to tackle these risks on financing costs and in turn on CSP electricity prices. Based on the sectoral analysis we will then consider the overall macroeconomic benefits of a de-risking strategy to renewable energy investments in the North African region. Before discussing our results and concluding the paper, we will present concrete private risk mitigation measures and public policy options from the perspective of investors to tackle investment risks.

2 Background

The large-scale application of solar power constitutes a promising strategy for the diversification of energy and electricity sources and for fostering human development and economic growth in the North African region. Especially Photovoltaics (PV) has received a lot of attention during the last few years, since the technology has been subject to substantial and to some extent unexpected cost decreases. This led to an annual growth rate of PV electricity generation of about 47% over the period 2000-2011. With respect to CSP, the annual growth has not been as explosive and amounted to about 20% in 2000-2011 (IEA, 2013a). Nevertheless, we regard CSP, at least in the short to medium run, as the most attractive renewable energy source for large-scale applications in the North African region and as a complementary renewable energy technology to wind and PV rather than a rivaling technology.

While PV already now has the potential to provide low-cost, low-carbon electricity in decentralized applications, it is the already established concept of CSP plants that will dominate the utility-scale solar power sector at least in the next few years. This is due to its longer track record and its ability to provide dispatchable clean energy by storing energy in low-cost thermal energy storages to cancel out short-term fluctuations and the day-night cycle (GIZ, 2013). Unlike the direct storage of electricity, storage of thermal energy, for example in molten salt tanks, is already technically and economically feasible today (World Bank and ESMAP, 2011).

Within CSP, solar towers are an especially promising technology for efficient solar energy generation including storage. Solar towers can achieve very high operating temperatures with negligible losses by using molten salt as a heat transfer fluid. This allows for higher operating temperatures and hence a higher steam cycle efficiency (IRENA, 2013). Furthermore the high temperature differentials will reduce the costs of thermal energy storage. Overall capital costs for a solar tower power plant, which is the most influential determinant of total CSP electricity costs, are between USD 6,300 and USD 10,500/kW when the capacity for energy storage is between 6 and 15 hours. In combination with high capacity factors of 0.4 to 0.8, depending on the amount of storage capacity, solar towers can produce electricity in a competitive price range of 0.17 to 0.29 USD/kWh (*ibid.*). Furthermore, the option of storing energy qualifies CSP plants to satisfy peak demand and hence to profit from high peak load prices. Hence, solar towers with sufficient thermal energy storage capacities might become the solar technology of choice for utility size applications in the future. Given this potential of solar towers for economically and energy efficient power production, we will focus in our analysis on this technology, even though most of the currently operational and planned CSP plants utilize other CSP technologies (see Table A-1 in Appendix A).

2.1 CSP Potentials and RES Targets in North Africa

The storage potential of CSP plants is especially relevant for regions like North Africa with a less developed electricity grid. The North African grid is currently not designed for the large scale feed-in of intermittent renewable energy sources (Brand and Zingerle, 2011). Therefore, the weaknesses in the electricity grids of the North African region, which currently limits the exploitation of the region's renewable energy potential, can be counterbalanced by providing storage at the CSP plant site. At the same time, the North African region is particularly well suited for solar energy generation, since its countries are situated in the so called Earth's Sunbelt (Mason and Kumetat, 2011). This area stretches roughly across latitudes between 40° North and 40° South (i.e. between South Spain and South Africa) and is characterized by considerable solar energy resources. In Figure 1 we present a map of direct normal irradiation (DNI)[3] for Africa. It can be seen that especially North African countries have relatively high levels of DNI, ranging from 4,000 to 8,000 Wh/m^2/day.

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[3] 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).

The Sunbelt regions and especially North Africa cover big desert areas, which offer large amounts of currently unused land potential. The usage of desert areas as locations for CSP plants thus reduces the potential conflict for land between energy and food production. Nevertheless, traditional and regionally specific laws and customs concerning land ownership and access to land, which can be very different to the western tradition, have to be respected (Schinke and Klawitter, 2011). Furthermore, at the moment not all parts of North African deserts are equally viable locations for large-scale CSP generation, as the required high and ultra-high voltage grid connection cannot be provided at all potential locations. Therefore, in a first step and given the current grid infrastructure, the most appropriate locations for CSP projects are in unused desert areas close to city centers and the existing high voltage grid. Figure 1 displays the CSP projects, which are currently in the development, construction or operational phase in North African countries. It can be seen that these projects are all located close to cities and economic centers in the respective countries and close to the African continent's borders where the current high voltage grid is situated. Since there are currently no CSP projects in the development, planning or implementation phase in Libya and given the current unstable political situation in Libya, which is not supportive for the implementation of CSP projects in the near future, we will only look at the four North African countries Morocco, Algeria, Tunisia and Egypt in the present analysis.

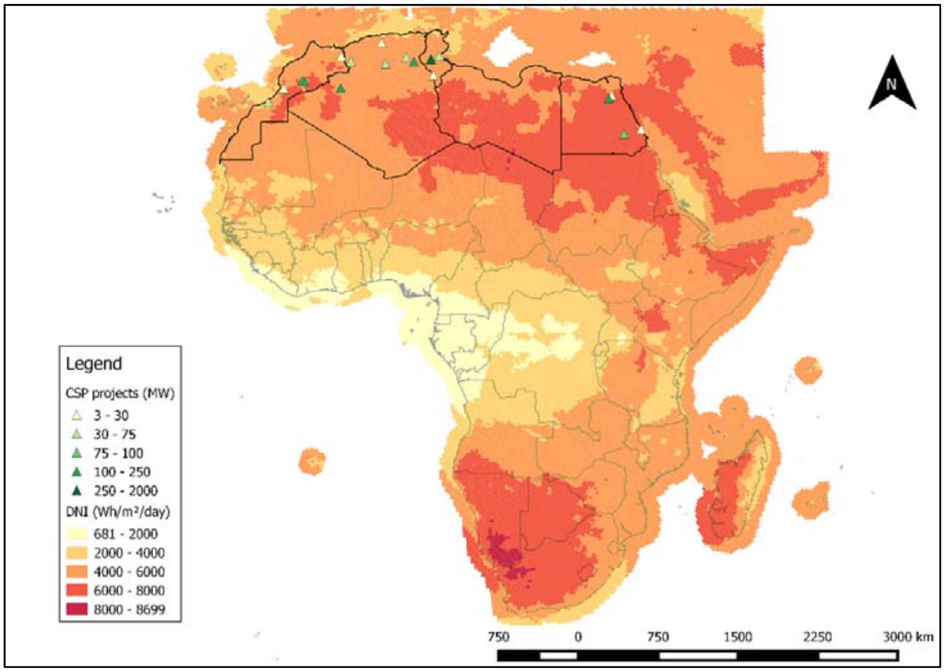

Figure 1: Direct normal irradiation (DNI) values [Wh/m²/day] for Africa and CSP projects [MW] in the North African region. Source: DNI from NREL (2011); CSP projects from CSP Today (2014) and CSP World (2014).

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 all of these North African countries have in common a substantial increase in demand for electricity driven by rapid population growth, decaying infrastructure and hence a diminishing rate of energy self-sufficiency (IEA, 2013b; Brand and Zingerle, 2011). Furthermore the high subsidies for conventional electricity, with the Middle East and North Africa (MENA) region accounting for about half of global energy subsidies, weigh on federal budgets at the expense of vitally needed investments in health care, education, and infrastructure (IMF, 2014; Energypedia, 2014). Therefore the governments of these countries introduced ambitious renewable energy and energy efficiency targets to tackle these issues.

By diversifying electricity generation, the North African countries can also free up domestic fossil fuel resources from power generation for higher value-added applications and energy exports as a pivotal source for foreign exchange. In the longer term, investments in 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).

The establishment of CSP projects is part of these existing efforts by North African States to expand the utilization of renewable energy. The Algerian government introduced an ambitious renewable energy and energy efficiency program in 2011 (MEM, 2011). The program consists of installing up to 12,000 MW of renewable power generation technology until 2030 (2,600 MW until 2020). In 2030 renewable energy is expected to supply 40% of domestic electricity demand. Solar power should satisfy more than 37% of domestic electricity demand by 2030. This requires an increase of the installed capacity of solar energy amounting to 10,000 MW by 2030 (2,300 MW by 2020). The lion's share of solar power, about 6,500 MW, is expected to be supplied by CSP plants in 2030.

Already in 1986 the New & Renewable Energy Authority (NREA) was established to become Egypt's main authority in the development and introduction of renewable energy technologies on a commercial scale (Croker, 2013). The Supreme Council for Energy, which was set up to support the NREA in the development of policies to foster the use of renewable energy, adopted in 2008 Egypt's present energy strategy. The strategy sets the target to increase the share of renewable energy from currently 9% to 20% (around 12.000 MW) of Egypt's energy mix by 2020 (Croker, 2013; GIZ, 2014). A five year plan spanning the timeframe from 2012 to 2017 sets the target of implementing a solar thermal capacity of 100 MW in Egypt (Energypedia, 2014).

Given its high import dependency with respect to fossil fuels, amounting to 97% in 2011 (IEA, 2013b) and the promising availability of wind and solar resources, Morocco implemented a number of strategies to foster the promotion of renewable energy in order to increase and diversify its power supply. In 2009 the Moroccan Ministry of Energy and Mines (MEMEE) presented the National Energy Strategy, which is the most ambitious renewable energy program in the MENA region. The strategy expects 42% of its installed power generation capacity to be based on renewable energies 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). The ambitious targets for solar power manifested in the 2009 Moroccan solar plan and the establishment of the Moroccan Agency for Solar Energy (MASEN), a public-private agency founded to implement the plan.

In 2008, Tunisia's National Agency for Energy Conservation released the Renewable Energy and Energy Efficiency Plan. The plan set out to achieve a 10% share or RES in total electricity production and a 20% reduction of energy demand by 2020 (Energypedia, 2014). Both ambitious targets could not be achieved by now. In 2009, Tunisia issued the Tunisian Solar Plan, which set targets for solar and wind power. Tunisia plans to install 1,000 MW of renewable energy projects, thereof 505 MW wind, 253 MW solar and 242 MW other renewable sources until 2016. The share of RES in the total capacity is planned to be 16 % in 2016. Furthermore Tunisia sets itself a long-term target of achieving a 25% RES share in electricity production by 2030 (amounting to an installed capacity of 4,700 MW: 2,700 MW wind, 1,700 MW solar and 300 MW other renewable sources) (Harrabi, 2012).

These country specific RES strategies led to the establishment of several CSP projects indicated in Figure 1 and listed in detail in Table A-1 in Appendix A. Besides three operational CSP projects, which utilize the Integrated Solar Combined Cycle (ISCC) technology (Hassi R'mel in Algeria and Kuraymat and Aïn Beni Mathar in Egypt), most of these projects have only been announced or are currently in their planning and development phase. Amongst other circumstances, their eventual realization crucially hinges on the availability of private project financing.

2.2 The Role of Private Investments

The involvement of private investors is essential to achieve the required energy investments to meet the world's energy needs. The required investments in power infrastructure and energy efficiency measures amount to USD 48 trillion over the period to 2035 in the IEA's main scenario (IEA, 2014). Aiming for a scenario which 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. Especially in developing countries the public sector will not able to finance this scale of required infrastructure investments on its own.

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. Therefore multilateral financing agencies largely support private participation in infrastructure investment projects.

Nevertheless, privatization of crucial public infrastructure is often criticized in the public (Birdsall and Nellis, 2003) and the literature (Araral, 2009; Quiggin, 2010). In the cases of privatization of public infrastructure with strong natural monopoly characteristics, such as railway systems or telecommunications and of core areas of the welfare state, such as health, education, pension systems, and criminal justice, poor outcomes have been observed all across the world (Quiggin, 2010). In some cases of public infrastructure where it is possible to separate competitive components of the overall system, privatization or private participation may be feasible (Quiggin, 2010). For the electricity supply system this would suggest that private participation in electricity generation, which is, in contrast to transmission and distribution, the competitive component of the overall system, privatization may indeed lead to increased economic efficiency via unit cost reductions in the sectors under consideration. However, there is still a need for appropriate regulations and competition enhancing policies to sustain a competitive electricity market.

Despite of short-term improvements in the federal budget balances and increased profitability of formerly state owned sectors, the long-term societal and economic impacts of privatization are not per se positive. If the increase in profitability of privatized infrastructure services eventually leads to a net benefit for society, depends on how these efficiency gains are realized. If the profitability gains arise from improvements in operating efficiency or from an increase in the quality of goods and services, privatization not only leads to private and fiscal benefits but also to net social benefits (Quiggin, 2010). However, there is a net social cost associated with the efficiency gains from privatization if they come at the cost of lower wages, higher unemployment, higher prices for consumers, and a decrease in the quality of infrastructure services (Birdsall and Nellis, 2003). Therefore, also in the case of private participation in renewable energy projects in the North African region, the overall impacts on economic and human development have to be considered and the best for society has to be envisioned at all stages of the investment project.

The way markets are restructured after privatization, competition is introduced and maintained, and which regulatory structure is implemented, determine whether privatization is eventually beneficial for a society as a whole or if only some stakeholders profit in the short term (Estache et al., 2001). A potentially viable way to achieve individual business interests and at the same time societal interests, such as reliable, clean energy at reasonable prices, are public private partnerships (PPP).

Komendantova et al. (2012) point out that all three realized CSP projects to date where initially planned by the government to be built and operated by 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*.).

2.3 Investors’ Perceptions of Risk in North African CSP Projects

The willingness of private investors to invest in CSP projects in the North African region depends on the associated risks and returns, since private investors base their investment decisions on the risk-return profile of any particular investment projects. To undertake a high-risk investment, the investor demands a higher rate of return. Conversely, if investors seek high returns, they have to accept higher risks.

The downside risk of investments influences the decisions of investors. It is a combination of two elements: 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 this risk associated with a specific investment opportunity is then reflected in the financing costs (or cost of capital) for that project. Equity investors will raise their expected rate of return (cost of equity) and banks the interest rate (cost of debt) for projects with a higher perceived risk (ibid.).

Due to high upfront investment costs but low operational costs, low-carbon energy technologies such as CSP, are particularly sensitive to perceived financing risks and the related financing costs. Since CSP projects do not possess a track record as long as the one of high-carbon investment alternatives, investors associate higher risks with this sort of low-carbon technology investment and hence demand higher interest rates or rates of return.

Financing costs do not only tend to be higher because of shorter track records of capital intensive, low-carbon energy technologies but also because of regional characteristics. The cost of capital for renewable energy investments is usually higher in developing countries than in industrialized countries (UNDP, 2013). These higher financing costs in developing countries reflect a range of risk categories, which create perceived barriers for investments.

Risk categories for large-scale renewable energy investments in developing countries have been identified in the existing literature. The UNDP (2013) argues for a case-by-case risk assessment and does so for wind energy projects in South Africa, Panama, Mongolia and Kenya. 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 stake holder 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 (see Appendix B for a detailed description of these risk categories).

2.4 Research Questions

Mobilizing private investments in renewable energy technologies in developing countries will require substantial efforts to reduce perceived risks and uncertainties associated with these investments. A financial de-risking approach reduces the barriers to renewable energy investments and hence the associated financing costs (Schmidt, 2014; UNDP, 2013).

Since investment risks are perceived quite differently by investors across different countries and renewable energy technologies, the current research sets out to analyze in detail the situation for CSP investment projects in the North African region and addresses the following closely related research questions:

1) What is the impact of a financial de-risking strategy on the cost of electricity from CSP in the North African region?
2) What are the macroeconomic benefits of a de-risking strategy for North African CSP investments?
3) Which public policy instruments and private measures can contribute to a de-risking of private investment?

3 Methods

In the following sections we present the methods, which we employ in our multi-stage research approach (Figure 2) to answer the research questions stated in the previous section. First, we investigate the current risk environment and quantify the influence of each risk category, as identified by Komendantova et al. (2012), on the overall cost of capital by applying the financing cost waterfall approach (UNDP, 2013). Second, we analyze the direct impact of a de-risking approach via the channel of lower financing cost on the cost of electricity from CSP in a Levelized Cost of Electricity (LCOE) model. Third, based on this detailed sectoral analysis we then derive macroeconomic effects of de-risking measures for CSP investments in the North African region by applying a Computable General Equilibrium (CGE) model. Fourth, by carrying out expert interviews, we identify public policy instruments which are needed from the point of view of investors and measures that can be fostered by the investors themselves to de-risk private investments in North African CSP projects.

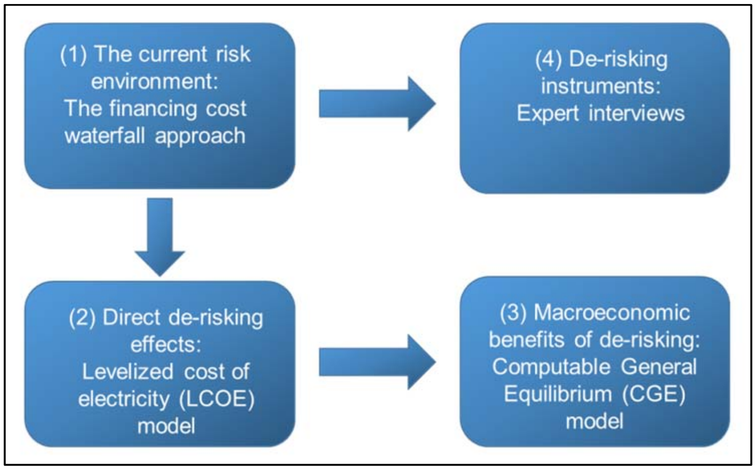

Figure 2: The multi-stage research approach

3.1 The Financing Cost Waterfall Approach

We employ the financing cost waterfall approach (UNDP, 2013) to quantify the contribution of different categories of investment risks to the financing cost gap between a given developing region and a reference investment environment (Figure 3). This quantification informs about the importance of specific investment risk components for the financing cost gap and can in turn be used to establish a hierarchy of public policy instruments and private measures to tackle these risks.

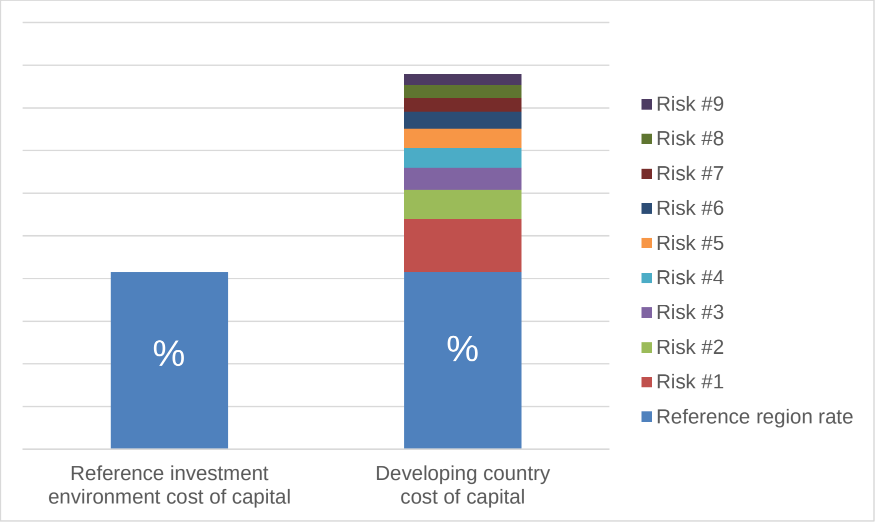

Figure 3: The financing costs waterfall

In our analysis we analyze the contribution of different investment risks to higher financing costs in four North African countries and the reference region Europe. The reference investment environment sets a theoretical lower bound for CSP financing costs in North Africa, being aware of the fact, that these financing costs might not be fully achievable in reality due to other factors than just perceived risks by investors.

The difference between the European financing costs and the financing costs in the four North African countries is broken down into nine different investment risk components as identified by Komendantova et al. (2012) for CSP projects in the North African region (see Table A-2 in Appendix B). The respective strength of each risk component depends on the combination of the seriousness of the financial impact and the likelihood of it to happen.

We distinguish between two options investors generally have to raise the funds required for the investment projects: getting credit from a bank (debt financing) and selling shares in the project to capital market participants (equity financing). The risk for lenders is different in the two cases. Due to a higher seniority in the case of bankruptcy, more stable interest payments and a more difficult access for the borrower in the first place, debt lenders face a relatively lower risk. Equity lenders on the other hand are not only directly participating in the profits but also in the downside-risk of any particular investment. Hence, in the case of bankruptcy, equity is lost

(IEA, 2010). Therefore lower-risk debt financing requires lower interest rates than higher-risk equity financing. Since most investment projects rely on both forms of project financing, it is the weighted average cost of capital (WACC), which eventually determines the overall financing cost of a project (see Appendix C for details on the calculations of the WACC).

3.2 Levelized Cost of Electricity (LCOE) Model

The levelized cost of electricity (LCOE) method is a commonly used approach to compare the overall competitiveness of different power generation technologies and cost structures (EIA, 2014; Kost et al., 2013; Branker et al., 2011). The basic idea of the LCOE approach is to relate cumulated lifetime costs to cumulated lifetime power generation of a specific power plant. 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.

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.

It is important to note that the LCOE method is an abstraction from reality to make energy technologies, which might differ quite substantially in their specific characteristics, comparable to each other (Kost et al., 2013). The LCOE approach is often used as benchmarking or ranking tool for cost effectiveness of alternative power plant technologies, which, for example, differ with respect to the scale of operation, investment and operating time periods (Short et al., 1995).

The LCOE approach can be criticized, as it does not consider the issue of intermittency of RES electricity generation. While conventional power plants can provide dispatchable intermediate- and base-load electricity, RES technologies, such as PV and wind, are dependent on the availability of the natural resources wind and sunshine. Since these resources are intermittent, RES electricity generation tends to fluctuate significantly and is often not appropriate to satisfy intermediate- and base-load electricity demand. Hence, intermittency limits the comparability of the LCOE from conventional technologies and RES technologies. To address this issue, we consider in the present analysis a CSP technology with integrated thermal heat storage (a solar tower with molten salt storage), which allows the CSP power plant to supply dispatchable electricity (IRENA, 2013).

The LCOE method usually does 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. Mainly this is due to differences in investment risks ant how they are perceived by investors (Oxera, 2011).

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, regionally different, financing costs, i.e. weighted average cost of capital for CSP projects (see previous section and Table A-3 in Appendix D). 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 the reference region (UNDP, 2013).

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, variable O&M costs, and performance ratios (see Appendix E for details on the calculations of the LCOE).

3.3 Computable General Equilibrium (CGE) Model

While the LCOE approach is suitable to derive the direct effects of financing costs on electricity prices, we are also interested in the macroeconomic effects of de-risking CSP investments in the North African region, which arise due to indirect feedback effects across the other economic sectors. To analyze the effects on GDP and welfare, we rely on an established static, multi-region, multi-sector CGE model of global trade, energy use, and CO_2 emissions. The model is based on the CGE model developed in Bednar-Friedl et al. (2012a, b) and Schinko et al. (2014). In Appendix F we provide a non-technical summary of the basic model structure and in Appendix G a detailed algebraic representation of the core model logic and the parameters employed.

On the regional level, the model differentiates between four North African countries and five other world regions (see Table A-6 in Appendix F) that are linked through bilateral trade flows. For our analysis of a de-risking approach to CSP investments in the North African region we assume that only the North African countries are implementing CSP targets and technologies, while all other regions do not foster any energy or climate policies. On the sectoral level, we differentiate between 15 economic sectors (see Table A-7 in Appendix F).

Electricity production in the model is characterized by a region specific aggregate technology. To allow for the specific analysis of CSP investments in the North African region we have to explicitly include the CSP technology in the model. This is done by translating the production cost information from the LCOE model into the sectoral structure of the CGE model. The shares of the specific cost components in the overall LCOE from CSP in the four specific North African countries, as visualized in Figure 7, are employed to derive the unit cost production function for CSP power generation. To account for the differences in the current region specific conventional electricity price and the LCOE from CSP, we add a markup to the capital input cost of the CSP technology, since capital costs are the main driver of electricity prices of capital intensive renewable energy technologies (see Table A-19 in Appendix H for the unit cost functions of CSP power plants after taking into account the regionally specific electricity price markups).

The CGE model allows for the analysis of risk perceptions by investors by changing the WACC associated with CSP investments in the North African region. The WACC reflects the internal rate of return that investors seek to achieve with new CSP projects. The internal rate of return also affects the annualized cost of capital, which is a primary factor in the production functions employed within the CGE framework. Hence, the markup applied to capital costs in the CSP production function varies according to the risk scenario, since lower perceived risks of investment translate into lower capital costs and hence in a lower spread between conventional and CSP electricity prices.

For our empirical assessment we use the GTAP8.1 database (Narayanan et al., 2012), which includes detailed national accounts on production and consumption together with bilateral trade flows for the base year 2004 and 2007. The data base also provides information on international energy markets derived from the International Energy Agency's (IEA) energy volume balances converted into monetary values (McDougall and Aguiar, 2007, McDougall and Lee, 2006, Rutherford and Paltsev, 2000), as well as on energy related CO_2 emissions (Lee, 2008). The GTAP8.1 database can be flexibly aggregated to a composite dataset representing the model regions and sectors described above.

With respect to model parameterization we follow the standard procedure in the CGE literature. We calibrate the free parameters of the model's functional forms (production and aggregate demand functions) to the 2007 benchmark prices and quantities derived from the GTAP8.1 database. In combination with exogenous price elasticities, which are applied to determine the representative agents' response behavior to price changes triggered by exogenous policy shocks, we define technologies and preferences in the CGE model.

Since we analyze CSP targets for the year 2020 we calibrate the model baseline to economic growth factors and fossil fuel price forecasts consistent with the literature on energy modeling. This literature often relies on the IEA's World Energy Outlook scenarios' assumptions. In the present analysis we employ real GDP growth rates and fossil fuel price assumptions in the WEO 2009 reference scenario (OECD/IEA, 2009, p. 62 and p. 64). To account for technological improvements until 2020, we employ cost reduction potentials for CSP technologies from the literature. Hinkley et al. (2011) assume that for solar tower CSP plants capital costs can be reduced by 28% until 2020. In addition, Turchy et al. (2010) predict a 23% cost reduction potential for O&M costs by 2020. For all other economic sectors we assume a constant autonomous energy efficient improvement factor of 1% per year to represent all non-price driven improvements in technology (Löschel, 2002).

The CGE model is programmed and implemented in MPSGE (mathematical programming system for general equilibrium analysis) (Rutherford, 1999), a subsystem of GAMS (general algebraic modeling system) (Rosenthal, 2013). Algebraically, the model is set up as MCP (mixed complementary problem), which is numerically solved by employing the PATH solver (Ferris and Munson, 2000).

3.4 Expert Interviews

The nine risk categories and their comprising barriers for investments in RES in the North African region that we analyze in this study are based on previous research on the understanding of perceived risks by investors (Komendantova et al., 2011 and 2012; UNDP, 2013). These studies identified risk categories by carrying out structured and unstructured interviews with experts from industry, ministries, the financial sector, and the social scientific community at various stakeholder workshops (Komendantova et al., 2011). The workshops and interviews took place at Laxenburg, Austria in 2008 and 2013, Potsdam, Germany in 2010, and Hammamet, Tunisia, 2010.

Based on these predefined risk categories and their concrete barriers for investment, we set out to identify public policy instruments and private measures investors can take to mitigate these risks. We carried out structured interviews with renewable energy investors at Kommunalkredit Austria AG in July 2014. During the interviews the nine different risk categories were individually addressed and potential public policy instruments and private measures to mitigate each investment risk category were identified from the perspective of these investors.

4 Results

4.1 The Influence of Investors' Perceptions of Risks on CSP Financing Costs

A prerequisite for the identification and assessment of public policy instruments to reduce financing costs and eventually overall life-cycle costs of renewable energy from CSP power plants in the North African region is the understanding of the current investment risk environment. In this section we evaluate how perceived risks by investors result in higher financing costs for CSP projects in developing countries compared to investments in Europe, the reference region for our analysis.

The financing cost gap between the North African countries and the Euro area and the relative contribution of different risk categories to this gap are depicted in Figure 4[4]. There is very limited information on financing costs for concrete CSP projects in the North African region, because not many projects are currently in a stage of development where such data is publically available. Therefore, for our analysis, we have to rely on data from two concrete North African

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[4] For the calculation of WACC in Europe we use the average monthly borrowing interest rates for the Euro area over the time span 01/2003 - 04/2014 (ECB, 2014) and the geometric mean of the equity rate of return for Europe over the time span 1900-2010 (Dimson et al., 2011).

system CSP projects: Hassi R'Mel in Algeria and Ouarzazate I in Morocco. Financing costs (Table A-3 in Appendix D) for the Hassi R'Mel project is available from SolarPaces (2003) and for the Ouarzazate I project from Frisari and Falconer (2013).

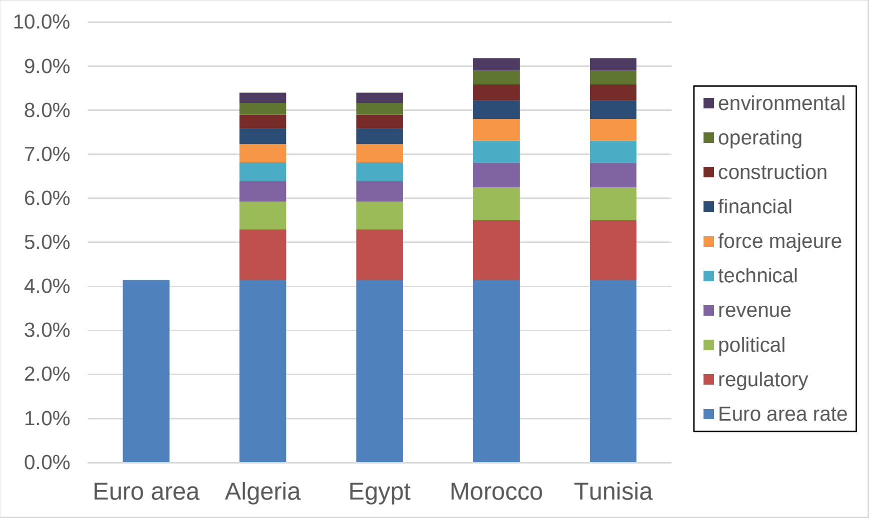

Figure 4: The WACC financing cost waterfall

Since there is no concrete financing cost information available for CSP projects in Egypt and Morocco but the credit ratings of Algeria and Egypt as well as of Morocco and Tunisia are very similar (Wikirating, 2014), we assume that also financing costs for CSP projects will be similar in Algeria and Egypt and respectively in Morocco and Tunisia. Therefore we apply the financing cost structure of Algeria (based on the Hassi R'Mel) project also for CSP projects in Egypt and the financing cost structure of Morocco (based on Ouarzazate I) on Tunisian CSP projects.

Applying the same relative contribution of risk categories on the difference between North African and Euro area WACC for each of the four North African case study countries[5], we learn that investors perceive regulatory and political risks as the most serious and most likely risks associated with CSP investments in the North African region. Further risk categories, which contribute less strongly to the financing cost gap, include revenue, technical, force majeure and financial risks. Perceived as least critically by investors with respect to their impact on the downside risk of investments in CSP projects are the risk categories construction, operating and environmental (Komendantova et al., 2012).

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[5] Komendantova et al. (2012) carried out stakeholder interviews in order to derive perceived risks by investors for CSP projects in the whole North African region. Therefore, the resulting risk category matrix based on the financial impact and the likelihood of any risk to happen is applicable to all four case study regions in the present paper.

4.2 The Relevance of Financing Costs for LCOE from CSP in North Africa

Financing costs, or the weighted average cost of capital as analyzed in the previous section, have a substantial role in the determination of overall costs of electricity from a specific energy source. In this section we employ the LCOE model (see Appendix E for model details) to analyze the effects of a high financing cost scenario and a financial de-risking scenario on the eventual electricity costs from CSP power plants in the North African region.

The LCOE from CSP solar tower power plants in the North African countries based on current financing costs are depicted in Figure 5. The lowest required average electricity price to break even across the whole economic lifetime of a CSP project is achievable in Egypt, represented by a LCOE of 0.20 USD/kWh, followed by Algeria with a LCOE of 0.21 USD/kWh. Even though Egypt shares the assumption for WACC with Algeria, it has a higher potential annual solar energy output than Algeria, resulting in the lower LCOE. Morocco and Tunisia are confronted with a higher WACC (9.2%) than Algeria and Egypt. Hence the LCOE from CSP is higher in these two countries than in the former two, amounting to 0.23 USD/kWh in Morocco and 0.24 USD/kWh in Tunisia. Again, the country with a larger solar potential, Morocco, has the lower LCOE. In contrast to the prevailing electricity prices based on the current energy mix in the four countries[6], we find that in all countries electricity from CSP is uncompetitive at the moment, given the high level of financing costs (Figure 5).

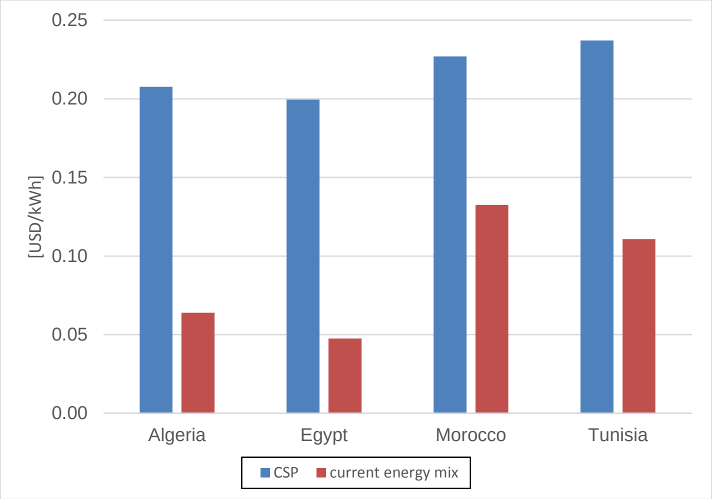

Figure 5: Status quo electricity prices based on the current energy mix and LCOE for CSP electricity generation in the four North African regions (in USD/kWh)

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[6] The electricity prices are based on a comparative study of electricity prices in Africa by UPDEA (2009). By defining five standard categories, the study shows that electricity tariffs vary widely across different consumer categories and their respective prescribed demand levels. For our analysis we calculate a subscribed demand weighted average across these five consumer categories.

By comparing the LCOE for CSP electricity generation between North Africa and Europe (Figure 6) we find that even though North Africa has a substantially higher solar potential than Europe (see DNI values in Table A-4 in the Appendix), the resulting LCOE for Europe (0.25 USD/kWh) is not dramatically higher than the mean for North Africa (0.21 USD/kWh). This is due to substantially lower financing costs in Europe than in the North African region.

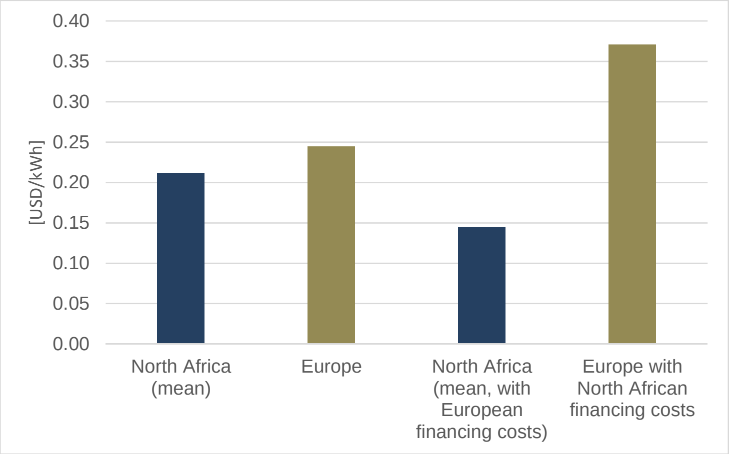

Figure 6: LCOE for CSP electricity generation in the North African region (mean) and Europe (in USD/kWh): the Status quo (first and second column) and for alternative financing cost

Considering a financial de-risking strategy, which aims at reducing financing costs for CSP projects in North African countries, the LCOE associated with CSP renewable energy projects can be substantially reduced (Figure 6). 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 0.21 USD/kWh to 0.15 USD/kWh or by 32%. On the other hand if we consider the reciprocal situation and employ North African financing costs (in our case the Moroccan WACC) in the calculation of the LCOE from CSP in Europe, LCOE would increase from 0.25 USD/kWh to 0.37 USD kWh or by 51%.

As renewable energy technologies such as CSP are highly capital intensive, investment risks reflected in higher financing costs are also very significant for these technologies. The LCOE breakdown, which is presented in Figure 7, confirms this reasoning. It can be seen that in the 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 North Africa equalizing those in Europe, does not lead to the achievement of cost competitiveness.

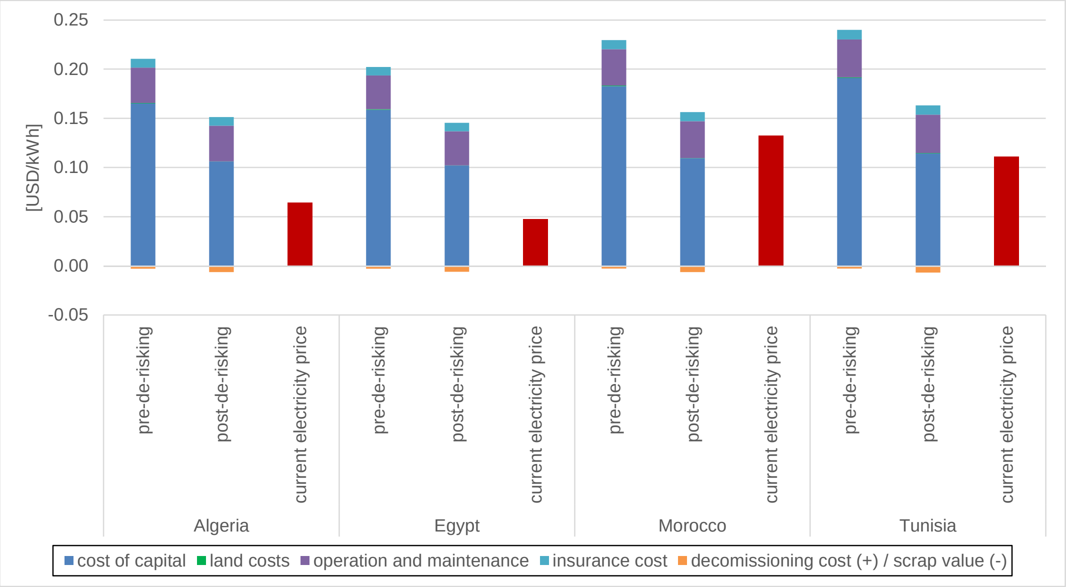

Figure 7: Breakdown of LCOE from CSP power plants in North African countries in a pre and a post financial de-risking environment and current electricity prices based on the current energy mix (in USD/kWh)

4.3 Macroeconomic Benefits of a De-Risking Strategy to CSP Investments in North Africa

For North African countries to achieve their renewable energy targets (see background section) the cost of power generation from renewable sources, such as CSP, has to become cost competitive with current market prices for electricity. By applying our LCOE model we have shown that a financial de-risking approach does in fact increase cost competitiveness of CSP electricity generation in North Africa. However, RES subsidies will still be necessary to achieve full cost competitiveness (Figure 7).

By applying the CGE model presented in the methods section (for more details see Appendix F and Appendix G) we set out to analyze (1) the required subsidies for CSP power generation to achieve cost competitiveness with conventional technologies in the year 2020, given the respective level of financial de-risking and (2) the implications of de-risking CSP investments on GDP and welfare after taking into account macroeconomic feedback effects. For our analysis we assume that the four North African countries pursue a 5% CSP target by 2020[7] and do not implement any other mitigation policies such as carbon taxes or a cap and trade scheme. The level of financial de-risking indicated on the X-axis in Figure 8 refers to the percentage

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[7] The targets for the implementation of CSP projects in the North African region are very different across the four case study countries (see the background section on CSP Potentials and RES Targets in North Africa 2.1 CSP Potentials and RES Targets in North Africa). However, to make macroeconomic effects of a de-risking approach to CSP investments across specific North African countries comparable, we use a uniform CSP target in the CGE simulation amounting to 5% of total electricity production by 2020.

reduction in the financing cost gap between the North African countries and the European reference financing costs.

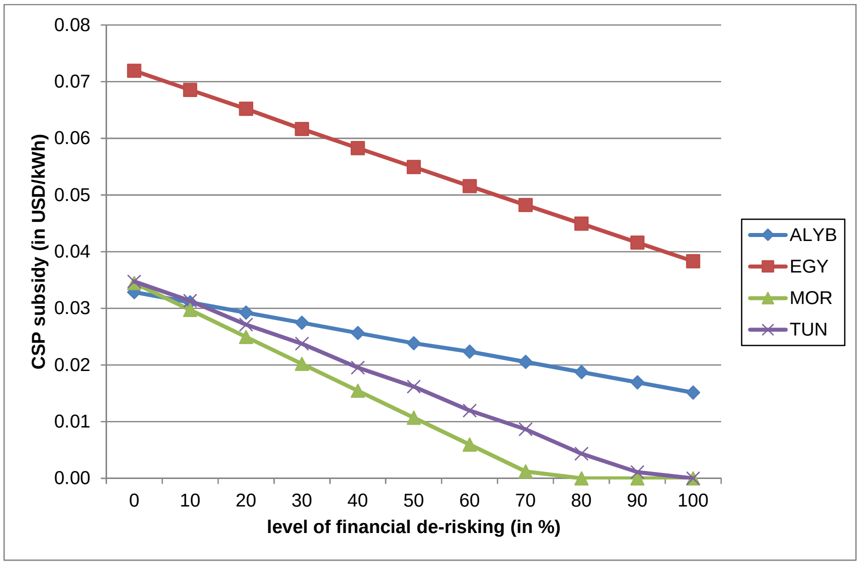

Figure 8: Cost competitiveness trajectories for a 5% CSP target in total electricity production by 2020 in North African countries. The required level of CSP subsidy (in USD_{2007}/tCO_2*) for the price of electricity from CSP to brake-even with the price of conventional electricity, given the level of financial de-risking*

We find that for each of the four countries the required subsidy to CSP electricity producers to break even with conventional electricity in 2020 is highest for the case of pre-de-risking financing costs, i.e. at a 0% level of financial de-risking. Due to technological improvements for solar tower CSP plants (we assume that capital costs can be reduced by 28% (Hinkley et al., 2011) and O&M costs by 23% (Turchy et al., 2010) by 2020)), the required subsidies in 2020 are lower than the current cost gap between CSP electricity and conventional electricity indicated in Figure 7.

While the required subsidy for CSP in Egypt decreases from 0.072 USD/kWh to 0.038 USD/kWh along the cost competitiveness trajectory depicted in Figure 8, CSP production in Morocco does not require a subsidy to break even anymore as soon as an 80% level of financial de-risking can be achieved. The same holds true for 100% financial de-risking of CSP investments in Tunisia. Algeria, whose cost competitiveness trajectory starts below the ones from Morocco and Tunisia, still has to pay a subsidy of 0.015 USD/kWh to their CSP electricity producers in order to level the playing field.

The slope of the trajectory as well as the absolute level of the required subsidies depends on the initial price differential of CSP and conventional electricity, which is reflected in the unit cost functions of the CSP technology (see Table A- in the Appendix) in the respective countries. The two countries with relatively higher cost gaps, Egypt and Algeria, require a positive subsidy throughout the cost competitiveness trajectory. The two countries with the relatively lower initial cost gaps, Morocco and Tunisia, do not only require lower subsidy rates throughout the cost competitiveness trajectory but can even achieve cost competitiveness of CSP without having to pay subsidies, if the perceived risks of investment can be sufficiently reduced (by 80% in Morocco and by 100% in Tunisia).

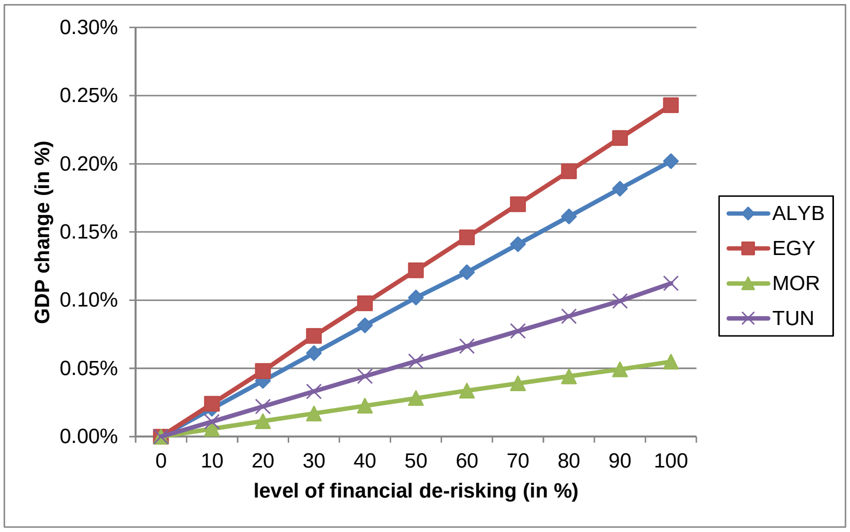

Figure 9: GDP gains along the cost competitiveness trajectories for a 5% CSP target in total electricity production by 2020 across North African countries.

The reduction in the required levels of subsidies for CSP electricity to break even with conventional electricity by 2020 and the reduced price of electricity due to de-risking of CSP investment projects eventually translate into overall economic benefits. Figure 9 and Figure 10 present the GDP gains, respectively the welfare gains, relative to the pre de-risking financing cost situation along the cost competitiveness trajectories for a 5% CSP target in total electricity production by 2020 across the four North African countries. We find a linear trend for GDP and welfare increases along the pathway to a 100% financial de-risking scenario, i.e. a situation in which North African countries are assumed to be subject to the same financing costs as in Europe. At the point of full financial de-risking, GDP is by 0.05% (Morocco), 0.11% (Tunisia), 0.20% (Algeria), and 0.24% (Egypt) and welfare by 0.06% (Morocco), 0.13% (Tunisia), 0.25% (Algeria), and 0.27% (Egypt) higher than under pre de-risking financing costs.

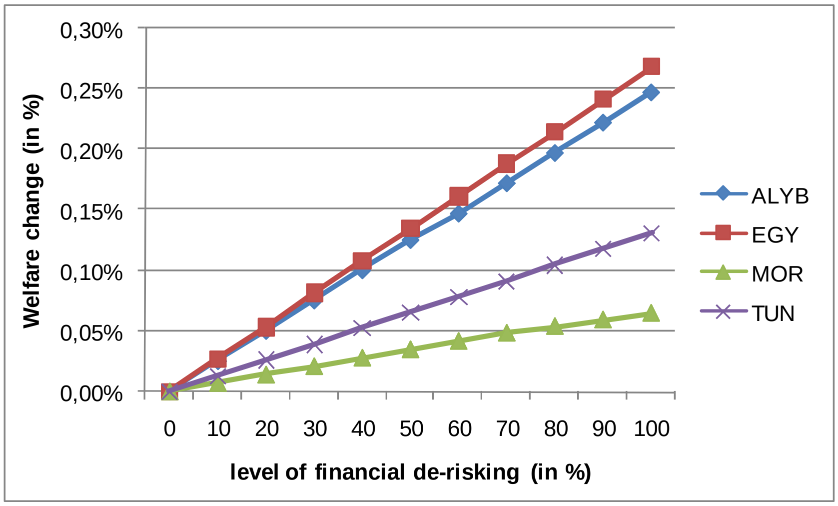

Figure 10: Welfare gains along the cost competitiveness trajectories for a 5% CSP target in total electricity production by 2020 across North African countries.

4.4 Public Policy Instruments and Private Measures to Reduce Perceived Risks by Investors in North African CSP Projects

Given the importance of perceived risks by investors in the determination of financing costs for renewable energy projects in developing countries, which are eventually decisive for the economic feasibility and hence the implementation of a particular project, a de-risking strategy is conceivably a powerful policy option to foster renewable energy investments. By lowering financing costs with various public policy instruments and private measures, a financial de-risking approach eventually increases the competitiveness of renewable energy generation against conventional high-carbon alternatives and thus supports the achievement of the 2°C climate stabilization target.

Different measures to reduce the perceived risks by investors can be introduced either by the government or by the investors themselves. Each of the risk categories and their comprising barriers for investment listed in Table A-2 in Appendix B require different approaches to reduce their impacts on financing costs for RES investments in the North African region. These impacts, which might eventually lead to the economic infeasibility and hence to the termination of a RES project, cover amongst others construction and O&M cost increases, construction delays, instability of revenue streams, and reduced utilization rates. In the following we present, in contrast to the existing literature, which is chiefly focusing on public instruments, primarily private strategies for project developers to deal with investment risks, which are based on expert interviews at Kommunalkredit Austria AG.

Regulatory risk

To deal with *regulatory risks*, investors seek the involvement of the public sector as an active partner in the project company. Investors try to minimize regulatory risks by setting up stipulated terms for governmental action when regulations or the legal situation changes. For example, a contract could be negotiated that if additional costs arise due to regulatory changes the government has to compensate investors for these incremental costs. From a public policy perspective, renewable energy support schemes, such as feed-in tariffs or tax credits, can lower regulatory risk. A feed-in tariff system guarantees project developers a fixed price at which they can sell RES electricity over a certain period of time. Hence, a feed-in tariff reduces the uncertainty for the project company whether it will be able to sell electricity at the price, which is necessary to amortize fixed investment costs and hence increases the project company's planning security. Important parameters in this policy instrument are the level of the tariff, the duration over which the tariff is guaranteed, and the indexation of the tariff rate. In addition to RES support instruments, also national and regional renewable energy strategies increase planning security for RES investors.

Political risk

Increasing the federal and the local governments' commitment to and its support of a RES project is important to tackle the dimension of *political risk*. To stimulate the interest of the government, benefits for the local communities have to be generated by the RES project. These benefits can take the form of electrification of regions currently without access to electricity, the support of local value chains, creation of employment, and transfer of know-how. The involvement of local business partners and, especially important for the North African region, of prominent families which are very well connected to the local governments, in the form of participatory investments, is crucial to strengthen the political support in the host country. The history of energy trade and exports as well as abilities of national governments to satisfy their commitments in energy exports towards partners plays also a crucial role. Investors perceive political risks as being lower in countries, which applied necessary efforts to guarantee their energy exports without interruptions and despite any political circumstances. A strong and well-constructed local network is decisive for a sustainable project outcome in the long run. Eventually, investors also try to mitigate political risks by establishing contracts with national and regional governments. Private-public partnerships (PPP) are one way to institutionalize the collaboration of the public and the private sector and to reduce uncertainty regarding the political commitment of the government to the RES project.

Revenue and market risk

Investors in RES projects in North Africa have to carry out a comprehensive upfront market and demand analysis, taking into consideration such issues as demographic changes, in order to learn about concrete *revenue and market risks*. This upfront analysis involves rigorous financial modeling of different best, worst, and middle-of-the-road scenarios to analyze the effect of different risk components, such as currency risks and tariff related revenue risks. Energy markets in the North African region are often characterized by limitations to liberalization and regulation, market distortions such as high subsidies for fossil fuels, and uncertainties related to market access and price stability. To increase planning security for RES investors it is crucial to establish transparent and long-term renewable energy strategies and a well-regulated energy market.

The establishment of long-term offtake agreements with municipalities or local firms is a potential measure for RES investors to reduce revenue risks. An offtake agreement may take the form of a barter agreement, which guarantees the local offtake of electricity in exchange for a guaranteed purchase of local goods and services by the RES project company. The establishment of PPPs can provide additional security with respect to perceived revenue risks, if governments agree to cover revenue risks by committing to the purchase of RES electricity output at a guaranteed price.

Technical risk

A comprehensive planning phase resulting in a viable plant layout is a necessity to reduce potential *technical risks* associated with CSP projects in the North African region. A comprehensive plant layout not only takes into consideration the technical aspects of the plant itself but also aspects of the plant's environment, such as the grid infrastructure and climatic conditions. The compatibility of the technical components, which in the case of CSP are mainly built in Europe, with the North African grid infrastructure and local environmental conditions (e.g. UV radiation, sand, weather) has to be evaluated upfront. The clarification of technical connection conditions, the evaluation of the reliability of the upstream grid, and the early establishment of a grid connection contract reduces the uncertainty regarding grid integration and marketing of the produced electricity. Through "full service" long term O&M contracts with the manufacturer of the equipment, the risk of a degradation of the quality of the plant and hence an increase in the electricity production costs can be mitigated by passing it on to the prime contractor. Such contracts are typically concluded with the manufacturer of the project, as concluding such a contract with a 3rd party service company would increase complexities and risks by including another player in the field. The manufacturer can and should then include local sub-contractors to support the local economy and hence increase the public acceptance of the CSP project.

Force majeure

The risk category *force majeure* covers risks, which have a potentially high impact but a low probability to occur. If a natural disaster happens or human made disasters such as war, terrorism, or sabotage occurs, the result can be a partial or complete destruction of the plant, triggering very high costs for rebuilding. Investors trying to mitigate the risk posed by natural and human made disasters strive to transfer the risk to the manufacturer via an availability warranty. With the warranty of availability, the manufacturer of the power plant guarantees a certain amount of full load hours. If this guaranteed availability is not met, due to technical reasons or complications triggered by natural and human made disasters, the manufacturer has to compensate the project company for the foregone revenues.

With respect to human made disasters, personnel identification of local communities with the project increases public acceptance for the project and reduces the risk of sabotage and theft of equipment. To increase personnel identification, the project company has to make sure that the local communities benefit from the investment project, support the long run inclusion and involvement of local communities, and establish local security concepts.

Financial risk

For problem developers to mitigate *financial risks* it is important to carefully select project partners based on their solvency and their past performance, familiarity, and capacity regarding RES investments projects. Investors can try to hedge against financial risks with appropriate instruments such as swaps. With respect to risks associated with re-financing issues, for example if one source of financing opts out or a bank goes bankrupt, investors should carry out upfront scenario analyses with rigorous financial modeling approaches.

Construction risk

A lack of reliable local construction services or uncertainties regarding land ownership in the North African region are barriers in the category of *construction risks*. Construction risks and barriers may eventually lead to the unreliability of installed equipment, reduced operating hours, and hence to a reduction in electricity sales revenues. Project companies can mitigate construction risks by selecting a prime contractor with a sound reputation and a long experience in conducting RES projects. Furthermore support of the local value chain and education of local staff is crucial to increase the quality of local equipment and construction services. Investors frequently pass on construction risks to the prime contractor or manufacturer via an availability clause in the service contract. Regarding the unclear situation of landownership in the North African region, adjustments in the local property law are necessary to guarantee clear property rights.

Operating risk

To tackle uncertainties regarding O&M costs or costs for recycling and disposal, which constitute concrete barriers in the *operating risk* category, project developers strive to transfer the risk to operators of the power plant. To pass on operating risks, long-term PPP-operator contracts are established, which guarantee stable O&M costs. By choosing a prime contractor with long experience and a solid reputation in the field of RES projects, the risk of unstable costs and quality of services can be reduced. A continuous monitoring of options for innovation, optimization, and improving energy efficiency helps to minimize O&M costs over the whole project lifetime. To increase the quality of the required O&M services, the education of local employers and know-how transfer to local industries is decisive. With respect to end of lifetime costs and revenues, it is important to already develop upfront strategies for re-use of the site and to maximize the residual value of the equipment by continuously carrying out maintenance, repair, and operations work.

Environmental risks

Investors at Kommunalkredit Austria AG perceive *environmental risks* as less relevant in the case of RES projects such as CSP in North Africa compared to conventional fossil fuel plants, nuclear power, or large-scale hydro. Nevertheless, they suggest it is important to carry out an upfront analysis of potential environmental impacts of the RES power plant during all its project phases and after its lifetime. For an environmental impact analysis project developers obtain expert assessments in the planning phase. A concrete risk that might occur in the construction phase of CSP projects is an unexpected contamination of the construction site. Therefore project developers are encouraged to obtain an assessment of the land quality of the envisaged construction site.

5 Discussion

While perceived risks by investors remained for a long time without attention in the literature on the economics of renewable energy technologies, perceived risks are now seen as a crucial determinant of the economic feasibility of a RES project and the associated macroeconomic effects. 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) and the macroeconomic benefits of a financial de-risking strategy to CSP investments in North Africa. Our research suggests the following new insights.

First, we address the need for more specific information on financing costs across countries and technologies (Schmidt, 2014). Based on financing costs for concrete CSP projects in Algeria and Morocco, we find that the weighted average cost of capital in the North African region is on average 4.7 percentage points higher than in the Euro area. Given these financing costs, the average LCOE from CSP in the North African region is 0.21 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 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). Even though it is very difficult to gather concrete information on electricity subsidies for specific African countries, the African Development Bank Group (AFDB, 2013) estimated that the average electricity subsidy for Africa amounts to 0.04 USD/kWh. Adding this average subsidy to the current electricity prices depicted in Figure 7, we find that this could change the economic viability of RES electricity generation in one North African country (Figure 11). For Morocco, a financial de-risking could be effective in achieving cost competitiveness with conventional fossil electricity at its effective production cost without any RES subsidies.

Second, we go beyond the previous literature on the economics of financial de-risking of RES investment projects, by linking a qualitative analysis of the current risk environment for CSP projects in four North African countries, a quantitative but only sectoral economic LCOE analysis, and a quantitative multi-sector multi-region CGE approach to derive the overall economic benefits of a financial de-risking strategy. Our findings show that overall economic benefits can be substantial. By lowering the cost of capital, financial de-risking can decrease the CSP electricity costs in the four North African countries, which we assume in our scenario are pursuing a 5% CSP target in overall electricity production, by several USD cents per kWh by 2020. However, this cost reduction is still not sufficient to achieve cost competitiveness of CSP electricity with conventional electricity in the four North African regions, since conventional fuels are in some cases highly subsidized. Currently the subscribed demand weighted average electricity prices in North Africa are ranging from 0.048 USD/kWh in Egypt to 0.133 USD/kWh in Morocco (see Footnote 6 for details).

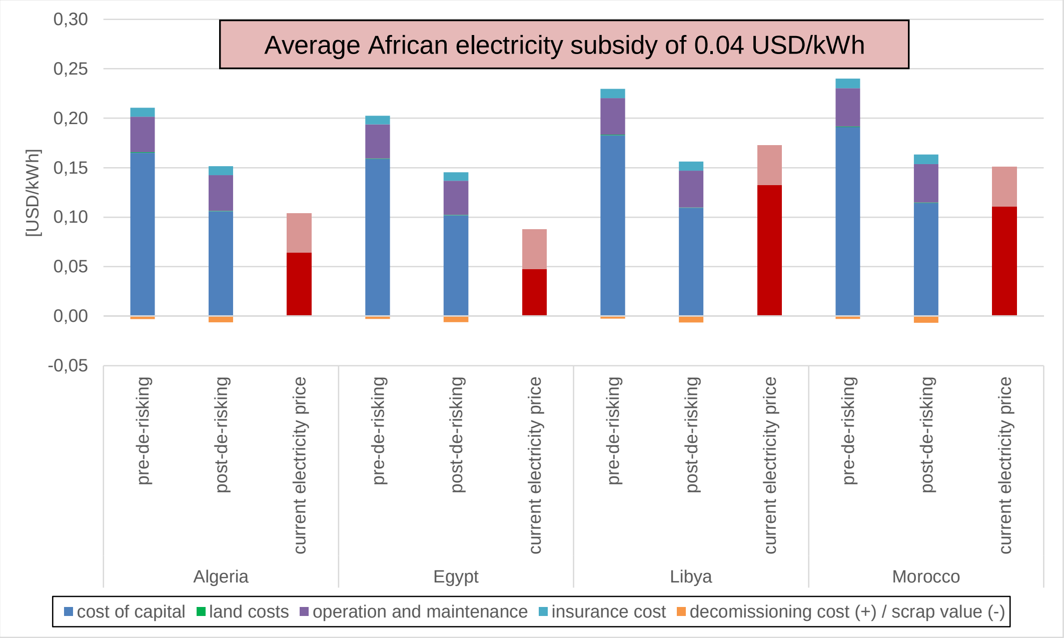

Figure 11: Breakdown of LCOE from CSP power plants in North African countries in a pre and a post financial de-risking environment and current electricity prices based on the current energy mix including the average African electricity subsidy (AFDB, 2013) (in USD/kWh)

Therefore subsidies for electricity from CSP will still be necessary to foster CSP deployment in North Africa. Nevertheless, the CSP electricity cost reductions induced by financial de-risking eventually reduce the required levels of RES subsidies for CSP electricity to break even with conventional electricity. This reduction in required financial support for CSP electricity in turn translates into substantial average economic benefits across the four North African countries of up to 0.15% or 327 million USD in 2020.

Third, expert interviews at Komunalkredit Austria AG have pointed out that broadly discussed (e.g. UNDP, 2013) public policy instruments to tackle investment risks, such as long term energy strategies and renewable energy support schemes (e.g. feed-in-tariffs), the establishment of a harmonized, unbundled, and well regulated energy market, and a reduction in bureaucratic complexities by a streamlining of permit and licensing processes and the establishment of contract enforcement and recourse mechanisms are needed to address risk perception. Additionally, the interviews suggest that private RES investors mainly foster private risk mitigation strategies, which strive to transfer risks associated with a RES investment project to third parties. Examples are the establishment of long term offtake agreements with municipalities or local firms to reduce revenue risks, or “full service” long-term O&M contracts with the prime contractor or the manufacturer of the equipment to transfer technical risks. Furthermore, as has been pointed out in the previous literature (e.g. Schinke and Klawitter, 2011), private investors regard it as crucial to increase public acceptance for the project by generating benefits for the local communities, increasing the political interest in the project by getting the (regional) government on board of the project company, and by involving local business partners and important local families at early project stages.

Given these findings, we suggest a dual strategy to promote RES deployment in North Africa: (1) A modification of the current energy subsidy schemes, i.e. a reduction of subsidies for conventional technologies or an additional subsidy for renewable energy technologies, complemented by (2) the introduction of a comprehensive de-risking strategy with private and public measures to tackle the higher financing costs associated with CSP projects and to eventually reduce the LCOE from CSP.

Despite the broad scope of our analysis, there are two important aspects, which have not been explicitly addressed in this research, since they go beyond the scope of the present analysis but should be analyzed in more detail in future research. First, we did not analyze in detail the potential effectiveness of financial de-risking measures and hence the achievable level of financial de-risking until 2020, the time horizon of our macroeconomic analysis. As we have pointed out before, a full financial de-risking in the North African region, which would result in equal financing costs with Europe, may not be achievable, at least not by 2020. The implementation of public policy instruments and private measures which we identified as being crucial to mitigate perceived risks of investment will require some lead time. Especially public policy instruments, such as renewable energy support schemes or energy strategies, as well as the reduction in bureaucratic complexities or of corruption are strongly disputed issues and will not be easy to implement or to achieve in the short run. In contrast, we reckon measures which could be actively pursued by the private investors themselves to reduce investment risks, such as risk transfer to contractors or the active engagement of the local communities, as more likely to become implemented by 2020. Based on this analysis of the effectiveness of potential measures to mitigate investment risks as identified in the interviews with practitioners and in combination with the increasing maturity of the CSP technology, we assume that financial de-risking up to 50% and based on private de-risking measures is plausible until 2020.

Second, it is important to note that we do not consider any costs associated with a financial de-risking approach and the implementation of the necessary public policies and private measures. Hence, the GDP gains along the cost competitive trajectories can be regarded as the upper limit for policy implementation costs. If this limit is not exceeded, a financial de-risking strategy can be achieved without net economic costs. However, in addition to the direct effects of a financial de-risking strategy on CSP investments which we explicitly analyze in this study, there will be de-risking spillover effects for other renewable energy and infrastructure investments in the North African region, leading to further economic benefits in these sectors and to even higher net economic benefits than obtained in our macroeconomic analysis. Furthermore, we do not monetize the environmental benefits associated with a solar-based energy system compared to a conventional fossil fuel based energy system. Given the potentially severe economic impacts of climate change, the economic benefits of a financial de-risking strategy to foster renewable energy investments have to be scaled up accordingly. Therefore, our results represent conservative estimates for potential macroeconomic benefits of a financial de-risking strategy. Because of these indirect effects and since we have shown that reducing perceived risks and hence the cost of capital will have a substantial impact on LCOE for CSP plants in the North African region, we argue that the costs of achieving this goal will likely stay below the economic benefits.

6 Conclusions

We demonstrate in this case study analysis of CSP projects in the North African region the importance of dealing with perceived risks by investors to increase the economic feasibility of RES investments. We show that a financial de-risking strategy could reduce the LCOE from CSP plants in North Africa by several USD cents per kWh. By pointing out the potential macroeconomic benefits, we demonstrate that tackling perceived risks by investors not only leads to electricity cost reductions but eventually has overall positive economic effects. In addition we identify concrete private risk transfer measures for investors to de-risk investments into RES projects in the North African region.

Given the differences in the legal and political systems and the cultural environments in the North African region, investors have to deal with the concrete situation in a host country case-by-case and upfront to anticipate potential risks and barriers in their RES investment projects. Therefore, the analysis of additional case studies could be a fruitful and important area of future research. Moreover, as we do not explicitly focus on implementation costs and the effectiveness of public and private de-risking measures, further research is necessary to delineate the costs and benefits of financial de-risking. In addition, our results imply further research of the political science aspects of effective de-risking and institutional arrangements and capacities.

Even though it is clear that financial de-risking alone will not reduce all political, social, and economic risks which are currently present in the North African regions and that there is still a long way to go to achieve a full financial de-risking of RES investments in the North African region, we find a substantial feasible potential for financial de-risking, eventually leading to overall economic benefits. This is a reassuring conclusion, since without de-risking RES investments, the stimulation of the required levels of private investment for a RES based energy transition to mitigate climate change, increase energy security, and foster economic and human development in developing countries will not be attainable.

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Appendix

Appendix A: CSP projects in the North African region

Table A-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: http://social.csptoday.com/tracker/projects/map?world-region[]=151 *and* http://www.csp-world.com/cspworldmap

Appendix B: Risks associated with CSP investments in North Africa

Table A-2: Risk categories and their comprising barriers for investment associated with large-scale CSP projects in the North African region

Risk category	Comprising barriers for investment	Potential impacts on investors
Regulatory	• Complexity, instability and corruption of bureaucratic procedures • Complex processes and long time frames for obtaining permits and licenses for renewable energy projects • Instability of national regulations (feed in tariffs, renewable energy targets, etc.) • Instability of bureaucratic processes and of the legal situation	• Cost increases • Construction delays • Instability of revenue streams • Eventual infeasibility and termination of investment project
Political	• Low level of political stability • Lack of support from local government • Poor rule of law and institutions • Poor governance	• Cost increases • Construction delays • Instability of revenue streams • Eventual infeasibility and termination of investment project
Revenue	• Uncertainty regarding (or absence of) governmental energy strategies • Limitations to energy market liberalization • Uncertainty related to access, the competitive environment and price outlook for renewable energy • Market distortions such as high subsidies for fossil fuels • Uncertainty due to unstable exchange rates • Uncertainty regarding long term electricity purchase • Potential cost increases due to plant degradation	• Cost increases • Reduced revenues • Reduced utilization
Technical	• Inaccuracies in early stage assessment of renewable energy potential • Suboptimal plant design • Lack of standards for the integration of renewable electricity sources into the grid • Differences in standards between Europe and North Africa • Inadequate or antiquated grid infrastructure, e.g. lack of transmission lines from the renewable power plant to load centers • Limited access to the grid	• Cost increases • Construction delays • Reduced revenues

	• Instability of the grid • Uncertainty over the construction of new transmission infrastructure • Uncertainties regarding the reliability of the equipment in the North African environment (weather, UV radiation, sand (storms) etc.)	
Force majeure	• Natural and human made disasters including war, terrorism and sabotage	• High costs for rebuilding the plant • Complete loss of the plant • Reduced revenues
Financial	• Limited availability of local or international capital for renewable energy investments due to: underdeveloped local financial sector, policy bias against renewable energy investments… • Lack of information, assessment skills and track-record for renewable energy projects amongst the investor community • Lack of familiarity and skills with project finance structure • Uncertainty regarding the long term solvency of project partners • Uncertainty with respect to re-financing due to e.g. bankruptcy of an investor	• Losses for investors • Construction delays • Increase in financing costs • Termination or delay of project
Construction	• Lack of reliable local firms offering construction services • Lack of skilled and experienced local staff • Lack of local industrial presence and experience with hardware • Limitations in civic infrastructure • Uncertainties regarding land ownership	• Unreliability of equipment • Reduced operating hours • Reduced revenues • Limited access to land and unclear land ownership
Operating	• Lack of local firms offering maintenance services • Lack of skilled and experienced local staff • Limited experience of grid operator with renewable electricity sources • Uncertainty regarding O&M expenditures • Uncertainty regarding the costs for recycling and disposal and the scrap value	• Reduced revenues • Higher than expected O&M costs
Environmental	• Actual or potential threat of adverse effects on living organisms and the environment by effluents, emissions, wastes, resource depletion, etc., arising out of an organization's activities • Potential contamination of construction site	• Construction delay • Cost increase

Source: Komendantova et al. (2011 and 2012); UNDP (2013); Schmidt (2014); expert interviews

Appendix C: The weighted average cost of capital (WACC)

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 weighted average cost of capital (WACC)approach (Breyer and Gerlach, 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 SCP project in a North African country are weighted by their respective shares in overall external funding of the project.

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

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

$n \ldots country$

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

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

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

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

Appendix D: Financing cost structure of CSP projects in North Africa

Table A-3: Financing cost structure of the Hassi R'Mel (Algeria) and Ouarzazate I (Morocco) CSP projects

	Hassi R'Mel (Algeria)	**Ouarzazate I (Morocco)**
Share of equity in financing	40.0%	20.0%
Equity rate of return	6.0%	13.1%
Share of debt in financing	60.0%	80.0%
Debt interest rate	10.0%	8.2%
Weighted average cost of capital	**8.4%**	**9.2%**

Source: Frisari and Falconer (2013)

Appendix E: The levelized cost of electricity (LCOE) model

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 country specific WACC as presented in Table A-3 in Appendix D. The calculation of the rated annual electricity production $S_{n,t}$ is presented in the following (for results see Table A-4). For other parameter values refer to Table A-5.

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

$LCOE_n$ ... $levelized\ cost\ of\ electricity\ in\ country\ n$ (in USD/kWh)

T ... $economic\ operational\ lifetime\ of\ investment\ project\ (in\ years)$

t ... $year\ of\ lifetime\ (1,\ 2, \dots T)$

n ... $country$

$I_{n,0}$ ... $initial\ investment\ cost\ in\ period$ 0 (in USD)

$O_{n,t}$ ... $Operation\ and\ maintenance\ \big(variable\ and\ fixed\big)\ costs\ in\ period\ t$ (in USD)

$D_{n,T}$ ... $Decomissioning\ costs\ (net\ of\ scrap\ value)\ in\ period\ T$ (in USD)

r_n ... $real\ interest\ rate\ (i.e.\ WACC)\ for\ country\ n\ (in\ percent)$

$S_{n,t}$ ... $rated\ annual\ electricity\ production\ in\ country\ n\ (in\ kWh)$

d ... $annual\ degradation\ factor\ (in\ percent)$

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 7.5hin our analysis, the performance ratioPR is assumed to be 1.602 m^2/kWh (ibid.).

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

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

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

$TF \ldots tracking\ factor$

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

Table A-4: Results for the rated annual energy output from CSP projects and parameter values for direct normal irradiation (DNI) in North African countries

	Rated annual energy output of CSP project in country n	Maximum direct normal irradiation (DNI) value in country n
	$[S_{n,t}] = kWh/year$	$[DNI_{n,t}] = kWh/m^2/year$
Algeria	3,986	2,488
Egypt	4,148	2,589
Morocco	3,860	2,410
Tunisia	3,694	2,306
Europe	2,363	1,475

The decommissioning costs net of scarp 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 derived from the assumption that in the case of renewable energy 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).

Table A-5: 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 and maintenance cost 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)

Appendix F: Non-technical CGE model description

Figure A-1 illustrates the diagrammatic structure of the CGE model (for a detailed algebraic overview and information on the applied elasticities of substitution see the following section). We assume perfect commodity and factor markets. The model distinguishes three classes of primary factors. Labor L_r (which itself distinguishes between skilled and unskilled labor) and capital K_r which are assumed to be mobile across sectors *i* within each region *r* but not internationally mobile. The third class comprises of resource-specific factors $R_{reu,r}$, each used exclusively in one of the five extraction sectors *reu*. Again, the resource factors of production are assumed to be internationally immobile.

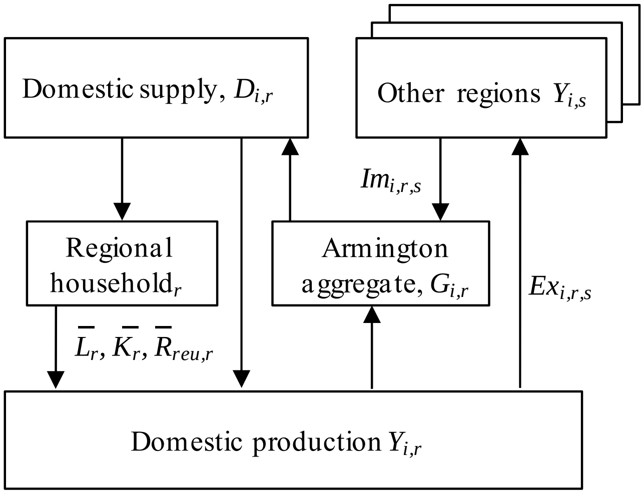

Figure A-1: Diagrammatic model structure

Producer behavior is characterized by profit maximization. For each domestic production sector $Y_{i,r}$, the production technology of a representative producer is described by a multi-level nested constant elasticity of substitution (CES) production function. The CES functions specify the substitution possibilities in domestic production between the primary inputs (capital, labor, and natural resources), intermediate energy and material inputs as well as substitutability between energy commodities (primary and secondary). We implement different CES nesting structures according to the respective production techniques and factor and input substitution possibilities of the different production sectors *i*. Figure A-2 depicts the nesting structure for those sectors not requiring a specific resource input *Non-Res-Using*$_r$. At the top nesting level a material input CES aggregate $D_{esc,r}$ is used with an aggregate of energy and value added $(KL)E_r$ at a constant elasticity of substitution. This aggregate itself consists at the second CES nesting stage of a value added aggregate KL_r and an energy aggregate E_r. The value added aggregate is a CES function of capital K_r and labor L_r, where labor itself is a CES composite of skilled SL_r and unskilled labor UL_r. The energy aggregate is produced by means of a CES function trading off against each other electricity, P_C, and a primary energy aggregate $OIL/GAS/COL_r$. The primary energy aggregate can further be represented by a CES function comprising of a liquid primary energy aggregate OIL/GAS_r and a COL_r fraction. Combustion CO_2 emissions are linked in fixed proportions to the use of fossil fuels in all economic activities, differentiated by the specific carbon content of fuels. In three production sectors, i.e. in the I_S, CRP and the NMM sectors we also include industrial process emissions. They are nested in a Leontief style CES function at the top level of the nesting tree with all other inputs in the production process.

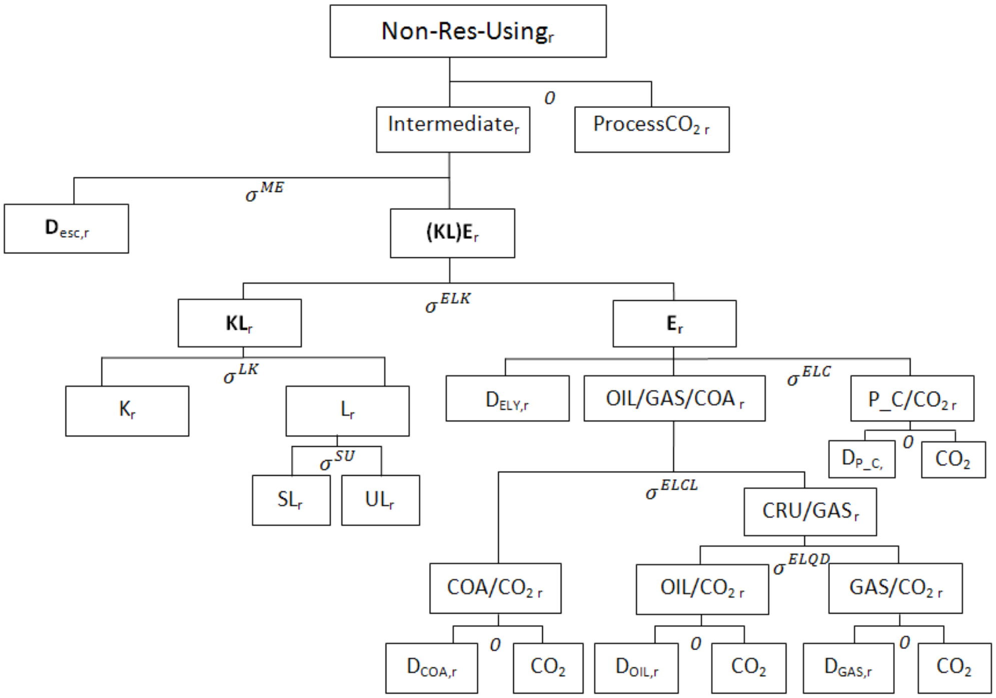

Figure A-2: Nesting structure of non-resource using production sectors

For the natural resource-using sector EXT, the nesting structure is identical to the one in Figure A-2 with the exception that instead of industrial process emissions the sector-specific natural resource is traded off in a fixed proportion with an intermediate aggregate at the top nesting level. In the three other resource using sectors, the fossil fuel production sectors OIL, COL, and GAS, all inputs except of the sector-specific resource are characterized by a Leontief fixed-proportion aggregation. This Leontief aggregate of all other inputs trades off at the top level with the sector specific resource at a constant elasticity of substitution, calibrated to an exogenous own price elasticity of fossil fuel supply. Finally, the production in sector P_C differs from all other non-resource using sectors, such that in this sector fossil inputs OIL, COL, and GAS are Leontief type inputs at the top nesting level to all other inputs (i.e. they are characterized by zero elasticity of substitution) such that production cannot substitute away from energy inputs.

Following the Armington trade assumption of product heterogeneity (Armington 1969), goods of the same variety but produced in different regions are not perfectly substitutable. As visualized in Figure A-1, the Armington aggregation activity $G_{i,r}$ corresponds to a CES composite of domestic output and imported goods $IM_{i,r}$ as imperfect substitutes. The resulting

Armington supply $G_{i,r}$ enters the domestic supply $D_{i,r}$ satisfying final demand and intermediate demand in production activities. The domestic output is also exported to satisfy the import demand of other regions $X_{i,r}$. Further, the imports of any particular world region consist of imports from all other model regions, traded off at a constant but sectorally differentiated elasticity of substitution.

The so-called "Regional Household" is an aggregate of private and public households and thus represents total final demand in each region r (Figure A-1). This regional household provides the primary factors capital K_r, labor L_r, and natural resources R_r for the domestic production sectors, and receives total income including various tax revenues. The regional household redistributes this stream of income with a unitary elasticity of substitution between the private household and the government for private consumption and public goods provision, respectively.

Final demand in region r is determined by consumption of the private household and the provision of public goods by the government. Both the private household and the government maximize utility subject to their disposable income received from the regional household with fixed investment. Consumption of private households in each region is characterized by a constant elasticity of substitution between a material consumption bundle and an energy aggregate. Public goods provision is modeled as a Cobb Douglas aggregate of an intermediate material consumption bundle.

Sectors and regions in the CGE model

Table A-6: Regional dimension of the CGE model

Aggregated Region	**Model code**
North African countries	EUR
Algeria[8]	ALYB
Egypt	EGY
Morocco	MOR
Tunisia	TUN
Other world regions	NPOL
Rest of Africa and Middle East	AFME
Europe	EUR
North America and South America	AMER
Asia	ASIA
Rest of the world	ROW

---

[8] The GTAP8 database covers Algeria, Libya and Western Sahara in the regional aggregate "Rest of North Africa". Since we focus on Algeria in the present paper but a further disaggregation of this data set is not possible, we refer in the following to the "Rest of North Africa" region as Algeria.

Table A-7: Sectoral dimension of the CGE model

Aggregated Sectors	**Model Code**
Energy sectors	
Primary energy	
Crude oil	OIL
Coal	COA
Natural gas	GAS
Secondary energy	
Refined oil products	P_C
Electricity[9]	ELY
Conventional electricity	CON
CSP	CSP
Energy intensive and trade exposed sectors	
Iron & steel	I_S
Non-metallic mineral products	NMM
Paper and pulp	PPP
Chemical products	CRP
Other industries and services	
Other extraction and mining	EXT
Transport (air, water, and other transport)	TRN
Agriculture	AGRI
Non-energy intensive sectors	TEC
Food and textile industries	FTI
Services and utilities	SERV
Capital goods	CGDS

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[9] The distinction between conventional electricity and electricity from CSP is only applied in the four North African countries, as we assume that only these countries implement CSP targets.

Appendix G: Algebraic model formulation

The computable general equilibrium is formulated as a system of non-linear inequalities. Three classes of conditions characterize the competitive equilibrium of our model: (i) zero profit conditions, (ii) market clearance conditions, and (iii) the income balance. The first class determines activity levels, the second one determines price levels and the third class defines income levels. In equilibrium each of these variables is linked to one inequality condition. In terms of notation we use i (aliased with j) as an index for economic sectors and r (aliased with s) as an index for regions (for more details on notation see Tables A-8 to A-18). Initial benchmark data refers to the base year 2007.

(i) Zero profit conditions

In our algebraic formulation, the notation of Π_{ir}^{Z} is used to denote the unit profit function of sector *i* in region *r* for the production activity *Z*. The zero profit conditions require that any activity, produced at positive values, has to earn zero profit. Thus, the value of inputs must be equal or greater than the value of outputs. Activity levels are the associated complementarity variables.

1. Production of non resource using domestic goods (i $\notin$ RES and i $\neq$ P_C):

$$\begin{aligned}
\Pi_{ir}^{Y} = {} & p_{ir}^{D}\,(1-\bar{t}_{ir}^{D}) \\
& -\frac{\bar{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{Y}}}{\bar{\mathrm{Y}}_{\mathrm{ir}}}\Bigg\{\theta_{ir}^{EP}\left(\frac{p_r^{CO}}{\bar{p}_r^{CO}}\right) \\
& +(1-\theta_{ir}^{EP})\Bigg[\theta_{ir}^{ME}\Bigg(\theta_{ir}^{ELK}\left(\frac{p_{ir}^{LK}}{\bar{p}_{ir}^{LK}}\right)^{1-\sigma_i^{ELK}}+(1-\theta_{ir}^{ELK})\left(\frac{p_{ir}^{E}}{\bar{p}_{ir}^{E}}\right)^{1-\sigma_i^{ELK}}\Bigg)^{\frac{1-\sigma_i^{ME}}{1-\sigma_i^{ELK}}} \\
& +(1-\theta_{ir}^{ME})\Bigg(\sum_{\mathrm{j\in MG}}\theta_{jir}^{MG}\left[\left(\frac{p_{jr}^{G}}{\bar{p}_{jr}^{G}}\right)(1+\bar{t}_{ir}^{C,j})\right]^{1-\sigma_i^{INT}}\Bigg)^{\frac{1-\sigma_i^{ME}}{1-\sigma_i^{INT}}}\Bigg]^{\frac{1}{1-\sigma_i^{ME}}}\Bigg\} \\
& \leq\ 0 \text{ with } \perp Y_{ir} \text{ for i} \notin \text{EXT}
\end{aligned}$$

2. Production of resource using domestic goods (i ∈ RES):

$$\begin{aligned}\Pi_{ir}^{Y} = p_{ir}^{D}\,(1-\bar{t}_{ir}^{D})&\\ &-\frac{\bar{C}_{ir}^{Y}}{\bar{Y}_{ir}}\Bigg\{\theta_{ir}^{RES}\left(\frac{\upsilon_{ir}}{\bar{\upsilon}_{ir}}\left(1-\bar{t}_{ir}^{F,R}\right)\right)\\ &+(1-\theta_{ir}^{RES})\Bigg[\theta_{ir}^{ME}\left(\theta_{ir}^{ELK}\left(\frac{p_{ir}^{LK}}{\bar{p}_{ir}^{LK}}\right)^{1-\sigma_i^{ELK}}+(1-\theta_{ir}^{ELK})\left(\frac{p_{ir}^{E}}{\bar{p}_{ir}^{E}}\right)^{1-\sigma_i^{ELK}}\right)^{\frac{1-\sigma_i^{ME}}{1-\sigma_i^{ELK}}}\\ &+(1-\theta_{ir}^{ME})\left(\sum_{\mathrm{j\in MG}}\theta_{jir}^{MG}\left[\left(\frac{p_{jr}^{G}}{\bar{p}_{jr}^{G}}\right)\left(1+\bar{t}_{ir}^{C,j}\right)\right]^{1-\sigma_i^{INT}}\right)^{\frac{1-\sigma_i^{ME}}{1-\sigma_i^{INT}}}\Bigg]^{\frac{1}{1-\sigma_i^{ME}}}\Bigg\}\\ &\le 0 \text{ with } \perp Y_{ir} \text{ for i } \in \text{EXT}\end{aligned}$$

3. Production of economic sector P_C (i = P_C)

$$\begin{aligned}\Pi_{ir}^{Y} = p_{ir}^{D}\,(1-\bar{t}_{ir}^{D})&\\ &-\frac{\bar{C}_{ir}^{Y}}{\bar{Y}_{ir}}\Bigg\{\theta_{ir}^{COP}\left(\theta_{ir}^{CC}\left[\theta_{ir}^{COA}\frac{p_{\{COA,r\}}^{G}}{\bar{p}_{\{COA,r\}}^{G}}\left(1+\bar{t}_{ir}^{C,COA}\right)+(1-\theta_{ir}^{COA})\frac{p_{r}^{CO}}{\bar{p}_{r}^{CO}}\right]\right.\\ &+\theta_{ir}^{CO}\left[\theta_{ir}^{OIL}\frac{p_{\{OIL,r\}}^{G}}{\bar{p}_{\{OIL,r\}}^{G}}\left(1+\bar{t}_{ir}^{C,OIL}\right)+(1-\theta_{ir}^{OIL})\frac{p_{r}^{CO}}{\bar{p}_{r}^{CO}}\right]\\ &\left.+(1-\theta_{ir}^{CC}-\theta_{ir}^{CO})\left[\theta_{ir}^{PC}\frac{p_{\{PC,r\}}^{G}}{\bar{p}_{\{PC,r\}}^{G}}\left(1+\bar{t}_{ir}^{C,PC}\right)+(1-\theta_{ir}^{PC})\frac{p_{r}^{CO}}{\bar{p}_{r}^{CO}}\right]\right)\\ &+(1-\theta_{ir}^{COP})\Bigg[\theta_{ir}^{ME}\left(\theta_{ir}^{ELK}\left(\frac{p_{ir}^{LK}}{\bar{p}_{ir}^{LK}}\right)^{1-\sigma_i^{ELK}}+(1-\theta_{ir}^{ELK})\left(\frac{p_{ir}^{E}}{\bar{p}_{ir}^{E}}\right)^{1-\sigma_i^{ELK}}\right)^{\frac{1-\sigma_i^{ME}}{1-\sigma_i^{ELK}}}\\ &+(1-\theta_{ir}^{ME})\left(\sum_{\mathrm{j\in MG}}\theta_{jir}^{MG}\left[\left(\frac{p_{jr}^{G}}{\bar{p}_{jr}^{G}}\right)\left(1+\bar{t}_{ir}^{C,j}\right)\right]^{1-\sigma_i^{INT}}\right)^{\frac{1-\sigma_i^{ME}}{1-\sigma_i^{INT}}}\Bigg]^{\frac{1}{1-\sigma_i^{ME}}}\Bigg\}\\ &\le 0 \text{ with } \perp Y_{ir} \text{ for i} \notin \text{ EXT}\end{aligned}$$

4. Sector specific labor - capital aggregate:

$$\Pi_{ir}^{LK} = p_{ir}^{LK} - \frac{\bar{C}_{ir}^{LK}}{\overline{LK}_{ir}}\left\{\theta_{ir}^{LK}\left(\frac{\nu_r}{\bar{\nu}_r}\left(1+\bar{t}_r^{\,F,K}\right)\right)^{1-\sigma_i^{LK}} + (1-\theta_{ir}^{LK})\left[\theta_{ir}^{US}\left(\frac{\omega_r^{U}}{\bar{\omega}_r^{U}}\left(1+\bar{t}_r^{\,F,U}\right)\right)^{1-\sigma_i^{SU}} + (1-\theta_{ir}^{US})\left(\frac{\omega_r^{S}}{\bar{\omega}_r^{S}}\left(1+\bar{t}_r^{\,F,S}\right)\right)^{1-\sigma_i^{SU}}\right]^{\frac{1-\sigma_i^{LK}}{1-\sigma_i^{SU}}}\right\}^{\frac{1}{1-\sigma_i^{LK}}} \le 0 \text{ with } \perp LK_{ir}$$

5. Sector specific energy aggregate ($\forall\ i \neq P\_C$)

$$\Pi_{ir}^{E} = p_{ir}^{E} - \frac{\bar{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{E}}}{\bar{\mathrm{E}}_{\mathrm{ir}}} \Bigg\{ \theta_{ir}^{ELY} \left(\frac{p_{\{ELY,r\}}^{G}}{\bar{p}_{\{ELY,r\}}^{G}} \left(1 + \bar{t}_{ir}^{C,ELY}\right) \right)^{1-\sigma_i^{ELC}} + \theta_{ir}^{COG} \Bigg(\theta_{ir}^{FF} \Big[\theta_{ir}^{COA} \frac{p_{\{COA,r\}}^{G}}{\bar{p}_{\{COA,r\}}^{G}} \left(1 + \bar{t}_{ir}^{C,COA}\right) +$$

$$(1 - \theta_{ir}^{COA}) \frac{p_r^{CO}}{\bar{p}_r^{CO}} \Big]^{1-\sigma_i^{ELCL}} + (1 - \theta_{ir}^{FF}) \Big[\theta_{ir}^{OG} \Big(\theta_{ir}^{OIL} \frac{p_{\{OIL,r\}}^{G}}{\bar{p}_{\{OIL,r\}}^{G}} \left(1 + \bar{t}_{ir}^{C,OIL}\right) + (1 - \theta_{ir}^{OIL}) \frac{p_r^{CO}}{\bar{p}_r^{CO}} \Big)^{1-\sigma_i^{ELQD}} +$$

$$(1 - \theta_{ir}^{OG}) \Big(\theta_{ir}^{GAS} \frac{p_{\{GAS,r\}}^{G}}{\bar{p}_{\{GAS,r\}}^{G}} \left(1 + \bar{t}_{ir}^{C,GAS}\right) + (1 - \theta_{ir}^{GAS}) \frac{p_r^{CO}}{\bar{p}_r^{CO}} \Big)^{1-\sigma_i^{ELQD}} \Big]^{\frac{1-\sigma_i^{ELCL}}{1-\sigma_i^{ELQD}}} \Bigg)^{\frac{1-\sigma_i^{ELC}}{1-\sigma_i^{ELCL}}} + \big(1 - \theta_{ir}^{\mathrm{ELY}} -$$

$$\theta_{ir}^{\mathrm{COG}}\big) \Big[\theta_{ir}^{PC} \frac{p_{\{PC,r\}}^{G}}{\bar{p}_{\{PC,r\}}^{G}} \left(1 + \bar{t}_{ir}^{C,PC}\right) + (1 - \theta_{ir}^{PC}) \frac{p_r^{CO}}{\bar{p}_r^{CO}} \Big]^{1-\sigma_i^{ELC}} \Bigg\}^{\frac{1}{1-\sigma_i^{ELC}}} \leq 0 \text{ with} \perp E_{ir}$$

6. Sector specific energy aggregate (i = P_C)

$$\Pi_{ir}^{E} = p_{ir}^{E} - \frac{\bar{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{E}}}{\bar{\mathrm{E}}_{\mathrm{ir}}} \Bigg\{ \theta_{ir}^{ELY} \left(\frac{p_{\{ELY,r\}}^{G}}{\bar{p}_{\{ELY,r\}}^{G}} \left(1 + \bar{t}_{ir}^{C,ELY}\right) \right)^{1-\sigma_i^{ELC}}$$

$$+ (1 - \theta_{ir}^{ELY}) \left[\theta_{ir}^{PC} \frac{p_{\{GAS,r\}}^{G}}{\bar{p}_{\{GAS,r\}}^{G}} \left(1 + \bar{t}_{ir}^{C,GAS}\right) + (1 - \theta_{ir}^{PC}) \frac{p_r^{CO}}{\bar{p}_r^{CO}} \right]^{1-\sigma_i^{ELC}} \Bigg\}^{\frac{1}{1-\sigma_i^{ELC}}}$$

$$\leq 0 \text{ with} \perp E_{ir}$$

7. Armington Aggregate:

$$\Pi_{ir}^{G} = p_{ir}^{G} - \frac{\bar{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{G}}}{\bar{\mathrm{G}}_{\mathrm{ir}}} \left[\theta_{ir}^{A} \frac{p_{ir}^{IM}}{\bar{p}_{ir}^{IM}}^{1-\sigma_i^{A}} + (1 - \theta_{ir}^{A}) \frac{p_{ir}^{D}}{\bar{p}_{ir}^{D}}^{1-\sigma_i^{A}} \right]^{\frac{1}{1-\sigma_i^{A}}} \leq 0 \text{ with} \perp G_{ir}$$

8. Aggregate imports from regions s to region r:

$$\Pi_{\mathrm{ir}}^{IM} = p_{\mathrm{ir}}^{IM} - \frac{\bar{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{IM}}}{\overline{\mathrm{IM}}_{\mathrm{ir}}} \left\{ \sum_{s} \theta_{\mathrm{isr}}^{IMT} \left(\theta_{isr}^{IM} \frac{p_{is}^{D}}{\bar{p}_{is}^{D}} \ (1 + \bar{t}_{\mathrm{is}}^{EX})(1 + \bar{t}_{\mathrm{is}}^{IM}) + (1 - \theta_{\mathrm{isr}}^{IM}) \frac{p^{T}}{\bar{p}^{T}} \right)^{1-\sigma_i^{IMR}} \right\}^{\frac{1}{1-\sigma_i^{IMR}}}$$

$$\leq 0 \text{ with} \perp IM_{ir}$$

9. Transport Margin:

$$\Pi^T = p^T - \frac{\bar{\mathrm{C}}^{\mathrm{T}}}{\bar{\mathrm{T}}} \left\{ \prod\nolimits_{\mathrm{r}} \left(\frac{p^G_{\{TRANS,r\}}}{\bar{p}^G_{\{TRANS,r\}}} \right)^{\theta^T_{\mathrm{r}}} \right\} \le \ 0 \text{ with } \perp \mathrm{T}$$

10. Welfare of regional household:

$$\begin{aligned} \Pi_r^{WHH} = p_r^{WHH} - \frac{\bar{\mathrm{C}}_{\mathrm{r}}^{\mathrm{WHH}}}{\overline{\overline{\mathrm{WHH}}}_{\mathrm{r}}} \Bigg\{ & \theta_r^{WHH} \left(\sum_{\mathrm{i \in MG}} \theta^{MG}_{HH,ir} \left[\left(\frac{p^G_{ir}}{\bar{p}^G_{ir}} \right) \left(1 + \bar{t}^{C,i}_{HH,r}\right) \right]^{1-\sigma^{INT}_{HH,r}} \right)^{\frac{1-\sigma_r^{WHH}}{1-\sigma^{INT}_{HH,r}}} \\ & + \left(1 - \theta_r^{WHH}\right) \left(\frac{p^E_{HH,r}}{\bar{p}^E_{HH,r}} \right)^{1-\sigma_r^{WHH}} \Bigg\}^{\frac{1}{1-\sigma_r^{WHH}}} \le \ 0 \text{ with } \perp WHH_r \end{aligned}$$

11. Household energy consumption:

$$\begin{aligned} \Pi^E_{HH,r} = p^E_{HH,r} - \frac{\bar{\mathrm{C}}^{\mathrm{E}}_{\mathrm{HH,r}}}{\bar{\mathrm{E}}_{\mathrm{HH,r}}} \Bigg\{ & \theta^{ELY}_{HH,r} \left(\frac{p^G_{\{ELY,r\}}}{\bar{p}^G_{\{ELY,r\}}} \left(1 + \bar{t}^{C,ELY}_{HH,r}\right) \right)^{1-\sigma_{\mathrm{r}}^{EHH}} \\ & + \theta^{COG}_{HH,r} \Bigg(\theta^{FF}_{HH,r} \left[\theta^{COA}_{HH,r} \frac{p^G_{\{COA,r\}}}{\bar{p}^G_{\{COA,r\}}} \left(1 + \bar{t}^{C,COA}_{HH,r}\right) + \left(1 - \theta^{COA}_{HH,r}\right) \frac{p_r^{CO}}{\bar{p}_r^{CO}} \right]^{1-\sigma_r^{PETHH}} \\ & + \theta^{OG}_{HH,r} \left[\theta^{OIL}_{HH,r} \frac{p^G_{\{OIL,r\}}}{\bar{p}^G_{\{OIL,r\}}} \left(1 + \bar{t}^{C,OIL}_{HH,r}\right) + \left(1 - \theta^{OIL}_{HH,r}\right) \frac{p_r^{CO}}{\bar{p}_r^{CO}} \right]^{1-\sigma_r^{PETHH}} \\ & + \left(1 - \theta^{COG}_{HH,r} - \theta^{OG}_{HH,r}\right) \left[\theta^{GAS}_{HH,r} \frac{p^G_{\{GAS,r\}}}{\bar{p}^G_{\{GAS,r\}}} \left(1 + \bar{t}^{C,GAS}_{HH,r}\right) + \left(1 - \theta^{GAS}_{HH,r}\right) \frac{p_r^{CO}}{\bar{p}_r^{CO}} \right]^{1-\sigma_{\mathrm{r}}^{PETHH}} \Bigg)^{\frac{1-\sigma_{\mathrm{r}}^{EHH}}{1-\sigma_{\mathrm{r}}^{PETHH}}} \\ & + \left(1 - \theta^{ELY}_{HH,r} - \theta^{COG}_{HH,r}\right) \left[\theta^{PC}_{HH,r} \frac{p^G_{\{PC,r\}}}{\bar{p}^G_{\{PC,r\}}} \left(1 + \bar{t}^{C,PC}_{HH,r}\right) + \left(1 - \theta^{PC}_{HH,r}\right) \frac{p_r^{CO}}{\bar{p}_r^{CO}} \right]^{1-\sigma_r^{EHH}} \Bigg\}^{\frac{1}{1-\sigma_{\mathrm{r}}^{EHH}}} \\ \le \ 0 \text{ with } \perp \ E_{HH,r} & \end{aligned}$$

12. Public good provision by the regional government:

$$\Pi_r^{WGOV} = p_r^{WGOV} - \frac{\bar{\mathrm{C}}_{\mathrm{r}}^{\mathrm{GOV}}}{\overline{\mathrm{WGOV}}_{\mathrm{r}}} \left\{ \frac{p^G_{GOV,r}}{\bar{p}^G_{GOV,r}} \left(1 + \bar{t}^{C,GOV}_{GOV,r}\right) \right\} \le \ 0 \text{ with } \perp \mathrm{WGOV_r}$$

(ii) Market clearance conditions

Market clearance conditions require that every commodity that has a positive price must have a balance between supply and demand. Thus, any good with excess supply has a price of zero. Differentiation of the unit profit function regarding the price gives the compensated supplied and demand quantities. The price of each quantity is the associated complementarity variable.

13. Unskilled labor market:

$$\overline{U_r} \geq \sum_i Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial \omega_{\mathrm{r}}^{\mathrm{U}}} \qquad \text{with} \perp \omega_{\mathrm{r}}^{\mathrm{U}}$$

14. Skilled labor market

$$\overline{S_r} \geq \sum_i Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial \omega_{\mathrm{r}}^{\mathrm{S}}} \qquad \text{with} \perp \omega_{\mathrm{r}}^{\mathrm{S}}$$

15. Capital market:

$$\overline{K_r} \geq \sum_i Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial \nu_r} \qquad \text{with} \perp \nu_r$$

16. Natural resource markets:

$$\overline{R_{ir}} \geq Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial \upsilon_{ir}} \qquad \text{with} \perp \upsilon_{ir}$$

17. Sector specific energy aggregate:

$$E_{ir} \geq Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial p_{ir}^{E}} \qquad \text{with} \perp p_{ir}^{E}$$

18. Aggregate household energy consumption:

$$E_{HH,r} \geq W_r^{HH} \frac{\partial \Pi_{HH,r}^{WHH}}{\partial p_{HH,r}^{E}} \qquad \text{with} \perp p_{HH,r}^{E}$$

19. Sector specific capital-labor aggregate:

$$LK_{ir} \geq Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial p_{ir}^{LK}} \qquad \text{with} \perp p_{ir}^{LK}$$

20. Regional output:

$$Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial p_{ir}^{D}} \geq G_{ir} \frac{\partial \Pi_{ir}^{G}}{\partial p_{ir}^{D}} + \sum_{\mathrm{s}} IM_{isr} \frac{\partial \Pi_{is}^{IM}}{\partial p_{ir}^{D}} \qquad \text{with} \perp p_{ir}^{D}$$

21. Import aggregate across regions:

$$IM_{ir} \geq G_{ir} \frac{\partial \Pi_{ir}^{A}}{\partial p_{ir}^{IM}} \qquad \text{with} \perp p_{ir}^{IM}$$

22. Armington aggregate:

$$G_{ir} \geq Y_{ir} \frac{\partial \Pi_{ir}^{Y}}{\partial p_{ir}^{G}} + W_r^{HH} \frac{\partial \Pi_{HH,r}^{WHH}}{\partial p_{HH,r}^{G}} + W_r^{GOV} \frac{\partial \Pi_{GOV,r}^{WGOV}}{\partial p_{GOV,r}^{G}}$$

with $\perp p_{ir}^{G}$

23. Household material consumption:

$$G_{HH,r} \geq W_r^{HH} \frac{\partial \Pi_{HH,r}^{WHH}}{\partial p_{HH,r}^{G}} \qquad \text{with } \perp p_{HH,r}^{G}$$

24. Material consumption in public goods provision:

$$G_{GOV,r} \geq W_r^{GOV} \frac{\partial \Pi_{GOV,r}^{WGOV}}{\partial p_{GOV,r}^{G}} \qquad \text{with } \perp p_{GOV,r}^{G}$$

25. Welfare of regional Household:

$$WHH_r \geq \frac{I_r}{p_r^{WHH}} \qquad \text{with } \perp p_r^{WHH}$$

26. Public goods provision by regional government:

$$WGOV_r \geq \frac{I_r}{p_r^{WGOV}} \qquad \text{with } \perp p_r^{WGOV}$$

27. Carbon emissions:

$$CO_r \geq \sum_i Y_{ir} \frac{\partial \Pi_{i,r}^{Y}}{\partial p_r^{CO}} + W_r^{HH} \frac{\partial \Pi_{HH,r}^{WHH}}{\partial p_r^{CO}} \qquad \text{with } \perp p_r^{CO}$$

28. Transport market:

$$T \geq \sum_r \sum_i IM_{ir} \frac{\partial \Pi_{ir}^{IM}}{\partial p^{T}} \qquad \text{with } \perp p^{T}$$

(iii) Income balance

The income balance condition states that the sum of the values of income of every agent must equal the sum of the values of endowments.

As such, income is defined as follows:

$$I_r \equiv \; p^G_{\{CGDS,r\}} G_{\{CGDS,r\}} + p_r^{WHH} \mathrm{WHH_r} + p_r^{WGOV} \mathrm{WGOV_r}$$

and has to equal the value of endowments:

$$I_r = \; \omega_r^U \overline{U_r} + \omega_r^S \overline{S_r} + \nu_r \overline{K_r} + \textstyle\sum_i \upsilon_{ir} \overline{R_{ir}} + p_r^{CO} CO_r + \overline{B_r} + TAX_r \;,$$

with the following tax income:

$$TAX_r = \; \omega_r^U \overline{U_r} \bar{t}_r^{F,U} + \omega_r^S \overline{S_r} \bar{t}_r^{F,S} + \nu_r \overline{K_r} \; \bar{t}_r^{F,K} + \sum_i \upsilon_{ir} \overline{R_{ir}} \; \bar{t}_r^{F,R} + \sum_i (p_{ir}^X \, \bar{t}_{ir}^{\mathrm{X}} + p_{ir}^D \bar{t}_{ir}^D) Y_{ir}$$
$$+ \sum_i p_{ir}^{IM} \, IM_{ir} \bar{t}_{ir}^{\mathrm{IM}} + \sum_i p_{ir}^G \, G_{ir} \bar{t}_{ir}^C \;,$$

and the balance of payment ($\overline{B_r}$), fixed at initial benchmark level is defined as follows:

$$\overline{B_r} = \; p^G_{\{CGDS,r\}} \; \textstyle\sum_i (X_{ir} - M_{ir}) \; + p^T T.$$

Definitions

Table A-8 Sets

*i (*alias *j)*	Economic sectors
*r (*alias *s)*	Regions
RES	Primary energy extraction sectors: COA, OIL, GAS, EXT
MG	Material intermediate inputs: *i* \ COA, OIL, GAS, P_C, ELY
F	Factors: unskilled labor (U), skilled labor (S), capital (K), and natural resources (R)
HH	Representative regional private household
GOV	Government, i.e. public good provision

Table A-9 Activity Variables

Y_{ir}	Production of sector *i* in region *r*
G_{ir}	Armington aggregate of good *i* in region *r*
IM_{ir}	Aggregate imports of good *i* in region *r*
T	International transport services
E_{ir}	Energy aggregate for good *i* in region *r*
LK_{ir}	Labor-capital aggregate for good *i* in region *r*
WHH_r	Welfare of representative private household in region *r*
$WGOV_r$	Public good provision by the government in region *r*
$E_{HH,r}$	Aggregate energy consumption by private household in region *r*
$G_{GOV,r}$	Consumption by the government in region *r*

Table A-10 Benchmark activity variables

$\overline{\mathrm{Y}}_{\mathrm{ir}}$	Benchmark production of sector *i* in region *r*
$\overline{\mathrm{G}}_{\mathrm{ir}}$	Benchmark Armington aggregate of good *i* in region *r*
$\overline{\mathrm{IM}}_{\mathrm{ir}}$	Benchmark aggregate imports of good *i* in region *r*
$\overline{\mathrm{T}}$	Benchmark international transport services
$\overline{\mathrm{E}}_{\mathrm{ir}}$	Benchmark energy aggregate for good *i* in region *r*
$\overline{\mathrm{LK}}_{\mathrm{ir}}$	Benchmark labor-capital aggregate for good *i* in region *r*
$\overline{\mathrm{WHH}}_{\mathrm{ir}}$	Benchmark welfare of household in region *r*
$\overline{\mathrm{WGOV}}_{\mathrm{ir}}$	Benchmark public good provision by the government in region *r*
$\overline{\mathrm{E}}_{\mathrm{HH,r}}$	Benchmark aggregate energy consumption by private household in region *r*
$\overline{\mathrm{G}}_{\mathrm{GOV,r}}$	Benchmark consumption by the government in region *r*

Table A-11 Benchmark cost

$\overline{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{Y}}$	Benchmark cost of item *i* in production activity Y_{ir} in region *r*
$\overline{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{G}}$	Benchmark cost of item *i* in production activity G_{ir} in region *r*
$\overline{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{IM}}$	Benchmark cost of item *i* in production activity IM_{ir} in region *r*
$\overline{\mathrm{C}}^{\mathrm{T}}$	Benchmark cost of international transport services
$\overline{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{E}}$	Benchmark cost of item *i* in production activity E_{ir} in region *r*
$\overline{\mathrm{C}}_{\mathrm{ir}}^{\mathrm{LK}}$	Benchmark cost of item *i* in production activity LK_{ir} in region *r*
$\overline{\mathrm{C}}_{\mathrm{r}}^{\mathrm{WHH}}$	Benchmark cost of WHH_r in region *r*
$\overline{\mathrm{C}}_{\mathrm{r}}^{\mathrm{WGOV}}$	Benchmark cost of $WGOV_r$ in region *r*
$\overline{\mathrm{C}}_{\mathrm{HH,r}}^{\mathrm{EHH}}$	Benchmark cost of $E_{HH,r}$ in region *r*
$\overline{\mathrm{C}}_{\mathrm{r}}^{\mathrm{GOV}}$	Benchmark cost of $G_{GOV,r}$ in region *r*

Table A-12 Price variables

p_{ir}^{D}	Price of domestic production of item *i* in region *r*
p_{ir}^{G}	Price of Armington good *i* in region *r*
p_{ir}^{IM}	Price of imports of item *i* in region *r*
p_{r}^{CO}	Shadow price of carbon in region *r*
p_{r}^{WHH}	Price of households' welfare in region *r*
p_{r}^{WGOV}	Price of public goods provision in region *r*
ω_{r}^{U}	Unskilled wage rate in region *r*
ω_{r}^{S}	Skilled wage rate in region *r*
v_{ir}	Rent on resources in region *r* ($i \in FF$)
v_{r}	Rental price of capital (price of capital services) region *r*
p_{ir}^{E}	Price of energy composite of item *i* in region *r*
p_{ir}^{LK}	Price of value-added aggregate of item *i* in region *r*
p^{T}	Price of international transport services
p_{HHr}^{E}	Price of aggregate energy household consumption in region *r*
$p_{GOV,r}^{G}$	Price of government consumption in region *r*

Table A-13 Benchmark price variables

$\bar{p}_{ir}^{D}$	Benchmark price of domestic production of item *i* in region *r*
$\bar{p}_{ir}^{G}$	Benchmark price of Armington good *i* in region *r*
$\bar{p}_{ir}^{IM}$	Benchmark price of imports of item *i* in region *r*
$\bar{p}_{r}^{CO}$	Benchmark shadow price of carbon in region *r*
$\bar{p}_{r}^{WHH}$	Benchmark price of households' welfare in region *r*
$\bar{p}_{r}^{WGOV}$	Benchmark price of public goods provision in region *r*
$\bar{\omega}_{r}^{U}$	Benchmark unskilled wage rate in region *r*
$\bar{\omega}_{r}^{S}$	Benchmark skilled wage rate in region *r*
$\bar{v}_{ir}$	Benchmark rent of resources in region *r* (*i* ∈ *FF*)
$\bar{v}_{r}$	Benchmark rental rate (price of capital services) region *r*
$\bar{p}_{ir}^{M}$	Benchmark price of material composite of item *i* in region *r*
$\bar{p}_{ir}^{E}$	Benchmark price of energy composite of item *i* in region *r*
$\bar{p}_{ir}^{LK}$	Benchmark price of value-added aggregate of item *i* in region *r*
$\bar{p}_{HHr}^{E}$	Benchmark price of aggregate energy household consumption in region *r*
$\bar{p}_{GOV,r}^{G}$	Benchmark price of government consumption in region *r*
$\bar{p}^{T}$	Benchmark price of international transport services

Table A-14 Endowments

$\overline{U_r}$	Aggregate unskilled labor endowment in region *r*
$\overline{S_r}$	Aggregate skilled labor endowment in region *r*
$\overline{K_r}$	Aggregate capital endowment in region *r*
$\overline{R_{ir}}$	Endowment of resource *i* in region *r* (i ∈ FF)
$\overline{CO_r}$	Carbon emission allowances in region *r*
$\overline{B_r}$	Initial balance of payment surplus or deficit (note: $\sum_r B_r = 0$)

Table A-15 Taxes

$\bar{t}_{r}^{F}$	Exogenous factor tax rate in region *r*; F ∈ {U, S, K, R}
$\bar{t}_{ir}^{C}$	Exogenous commodity tax in the production of item *i* on intermediate inputs C ∈ *i* in region *r*
$\bar{t}_{HH,r}^{C,i}$	Exogenous commodity tax on item *i* in the private demand in region r
$\bar{t}_{ir}^{IM}$	Exogenous import tax on item *i* in region *r*
$\bar{t}_{ir}^{X}$	Exogenous export tax on item *i* in region *r*
$\bar{t}_{ir}^{D}$	Exogenous domestic output tax on item *i* in region *r*

Table A-16 Cost shares

θ_{ir}^{ME}	Cost share of the energy-value-added composite in the production of item *i* in region *r*
θ_{ir}^{ELK}	Cost share of value added in the aggregate of energy and value added in the production of item *i* in region *r*
θ_{jir}^{MG}	Cost share of material input *j* in the production of item *i* in region *r*, for j ∈ MG (set of material goods)
θ_{ir}^{LK}	Cost share of capital within the value added aggregate in the production of good *i* in region *r*
θ_{ir}^{US}	Cost share of unskilled labor within the skilled and unskilled labor aggregate in the production of good *i* in region *r*
θ_{ir}^{EP}	Cost share of process emissions in the production of good *i* in region *r*
θ_{ir}^{COP}	Cost share of the aggregate COA, OIL, and P_C in the production of good *i* in region *r, for i = P_C*
θ_{ir}^{ELY}	Cost share of ELY in the energy aggregate in the production of good *i* in region *r*
θ_{ir}^{COG}	Cost share of the composite of COA, OIL, and GAS in the energy aggregate in the production of good *i* in region *r*
θ_{ir}^{FF}	Cost share of COA in the aggregate of COA, OIL, and GAS in the production of good *i* in region *r*
θ_{ir}^{OG}	Cost share of OIL within the composite of OIL and GAS in the production of good *i* in region *r*
θ_{ir}^{COA}	Cost share of *COA* intermediate input within the COA – CO_2 composite in the production of good *i* in region *r*
θ_{ir}^{OIL}	Cost share of *OIL* intermediate input within the OIL – CO_2 composite in the production of good *i* in region *r*
θ_{ir}^{GAS}	Cost share of *GAS* intermediate input within the GAS – CO_2 composite in the production of good *i* in region *r*
θ_{ir}^{PC}	Cost share of *P_C* intermediate input within the P_C – CO_2 composite in the production of good *i* in region *r*
θ_{ir}^{CC}	Cost share of the intermediate composite input COA – CO_2 in the production of good *i* in region *r, for i = P_C*
θ_{ir}^{CO}	Cost share of the composite input intermediate OIL – CO_2 in the production of good *i* in region *r, for i = P_C*
θ_{ir}^{RES}	Cost share of natural resources in the production of good *i* in region *r,* for $i \in RES$
θ_{ir}^{A}	Cost share of aggregate imports in the Armington aggregate of good *i* in region *r*
θ_{isr}^{IMT}	Cost share of import of good i plus transport composite from region s to region r

θ_{isr}^{IM}	Cost share of imports in the import and transport composite of good *i* from region s to region *r*
θ_{r}^{T}	Cost share of transport services of region *r* within the interregional transport composite
θ_{r}^{WHH}	Cost share of material aggregate in the demand of the representative private household in region *r*
$\theta_{HH,ir}^{MG}$	Cost share of material input *i* in the material aggregate in the demand of representative private household in region *r*, for $i \in MG$ (set of material goods)
$\theta_{HH,r}^{ELY}$	Cost share of electricity (ELY) in the household energy consumption aggregate in region *r*
$\theta_{HH,r}^{COG}$	Cost share of the COA-OIL-GAS composite in the household energy consumption aggregate in region *r*
$\theta_{HH,r}^{FF}$	Cost share of coal in the COA-OIL-GAS composite within the household energy consumption aggregate in region *r*
$\theta_{HH,r}^{OG}$	Cost share of oil in the COA-OIL-GAS composite within the household energy consumption aggregate in region *r*
$\theta_{HH,r}^{COA}$	Cost share of *COA* intermediate input within the COA – CO_2 composite of household energy consumption in region *r*
$\theta_{HH,r}^{OIL}$	Cost share of *OIL* intermediate input within the OIL – CO_2 composite of household energy consumption in region *r*
$\theta_{HH,r}^{GAS}$	Cost share of *GAS* intermediate input within the GAS – CO_2 composite of household energy consumption in region *r*
$\theta_{HH,r}^{PC}$	Cost share of *P_C* intermediate input within the P_C – CO_2 composite of household energy consumption in region *r*

Table A-17 Elasticities

σ_i^{LK}	Substitution between labor and capital in the value added nest in the production of item *i*
σ_i^{SU}	Substitution between unskilled labor and skilled labor in the labor value added nest in the production of item *i*
σ_i^{ELK}	Substitution between the energy composite and the value added nest in the production of item *i*
σ_i^{ME}	Substitution between energy and value added composite and intermediate material aggregate in the production of item *i*
σ_i^{INT}	Substitution between different material intermediate inputs in the production of item *i*
σ_i^{ELC}	Substitution between ELY, P_C, and the COA-OIL-GAS aggregate within the energy aggregate in the production of item *i,* for i ≠ P_C
σ_i^{ELCL}	Substitution between COA and the OIL-GAS nesting within the energy aggregate in the production of item *I,* for i ≠ P_C
σ_i^{ELQD}	Substitution between OIL and GAS within the energy aggregate in the production of item *I,* for i ≠ P_C
σ_i^{A}	Substitution between the import composite and the domestic input to the Armington aggregate of good *i*
σ_i^{IMR}	Substitution between imports from different regions *s* within the import composite for item *i* in region *r*
σ_r^{WHH}	Substitution between the material aggregate and the energy composite in the consumption of households in region *r*
$\sigma_{HH,r}^{INT}$	Substitution between different material intermediate inputs in the private demand in region r
σ_r^{EHH}	Substitution between ELY, the COA-OIL-GAS composite, and P_C in the energy consumption of households in region *r*
σ_r^{PETHH}	Substitution between COA, OIL, and GAS within the COA-OIL-GAS composite in the energy consumption of households in region *r*

Table A- 18 Values of elasticities in production of domestic goods and Armington elasticity σ_i^{IMR}

Sector	$\sigma_i^{ME}*$	$\sigma_i^{INT}*$	$\sigma_i^{ELK}*$	$\sigma_i^{LK}*$	$\sigma_i^{ELEC}**$	$\sigma_i^{ELECL}**$	$\sigma_i^{ELEQD}**$	$\sigma_i^{A}***$	$\sigma_i^{IMR}***$
COA	0.73	0.31	0.55	0.14	0.16	0.07	0.25	3.05	6.1
OIL	0.73	0.31	0.55	0.14	0.16	0.07	0.25	5.20	10.4
GAS	0.73	0.31	0.55	0.14	0.16	0.07	0.25	10.80	32.4
P_C	0.00	0.39	0.26	0.46	0.16	0	0	2.10	4.2
ELY	0.00	0.39	0.26	0.46	0.16	0.07	0.25	2.80	0
I_S	1.17	0.25	0.66	0.22	0.16	0.07	0.25	2.95	5.9
NMM	0.31	0.19	0.41	0.36	0.16	0.07	0.25	2.90	5.8
TEC	0.60	0.49	0.32	0.23	0.16	0.07	0.25	3.71	7.5
PPP	0.19	0	0.21	0.38	0.16	0.07	0.25	2.95	5.9
CRP	0.85	0.08	0	0.33	0.16	0.07	0.25	3.30	6.6
FTI	0.58	0.24	0.49	0.21	0.16	0.07	0.25	2.91	6.4
EXT	0.73	0.31	0.55	0.14	0.16	0.07	0.25	1.38	2.2
TRN	0.35	0.33	0.28	0.31	0.16	0.07	0.25	1.90	3.8
AGRI	0.39	0	0.52	0.02	0.16	0.07	0.25	2.50	4.9
SERV	0.58	0.5	0.48	0.29	0.16	0.07	0.25	1.91	3.8
Final Demand	0.20	1.00	-	-	0.50	1.00	-		

Source: *Okagawa and Ban (2008); **Beckman and Hertel (2009); ***Narayanan et al. (2012)

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Appendix H: CSP unit cost structures

Table A-19: CSP unit cost structure in the four North African countries

	ALYB	EGY	MOR	TUN
P_C	0	0	0	0
ELY	0	0	0	0
I_S	0	0	0	0
NMM	0	0	0	0
PPP	0	0	0	0
CRP	0	0	0	0
TEC	0	0	0	0
FTI	0	0	0	0
SERV	0.078	0.078	0.073	0.073
TRN	0	0	0	0
EXT	0	0	0	0
COA	0	0	0	0
OIL	0	0	0	0
GAS	0	0	0	0
AGRI	0	0	0	0
LAB	0.069	0.069	0.065	0.065
SKL	0.069	0.069	0.065	0.065
CAP	4.152	3.976	1.509	1.938
RES	0	0	0	0
Total Cost	4.368	4.191	1.712	2.141