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Renewable energy in North Africa: A policy road-map for 2050

Final Activity Report

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I. FINAL NARRATIVE REPORT

Final Narrative Report

Organization Name: International Institute for Applied Systems Analysis (IIASA)
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I. Background

The purpose of the project was to support academic research into social, institutional, environmental, and economic aspects of renewable energy development, and concentrated solar power in particular, that would be of importance to North African policy makers and the Europeans with whom they interact. The expressed aim was to produce a number of papers for publication in the peer-reviewed literature, as well as policy reports, that would both support policy-making directly and find its way into the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

II. Results to Date

In the first half of the grant period, the main activities were the preparation, in coördination with PriceWaterhouseCoopers (PwC), of the policy report "100% renewable electricity: a roadmap to 2050 for Europe and North Africa," and the initiation of research to lead to several different papers. In the second half of the grant period, the main activities were the completion of work on those papers, and the organization of a workshop, in coördination with the World Wildlife Fund (WWF). I list each of these in turn, beginning with the workshop.

2.1 Workshop

In collaboration with WWF, IIASA organized the workshop "Renewable energy in North Africa: a policy roadmap for 2050," held in Hammamet, Tunisia, 22 – 23rd June 2010. The final agenda for the workshop is attached in the annex.

The broad purpose of the workshop was to gain perspectives from stakeholders in North Africa on potentially controversial issues associated with a regional scale-up of renewable energy, and where possible to contrast those perspectives with those of Europeans working on the same issue. The stakeholders included technology developers, project developers, government regulators in the environmental and energy sectors, sources of private and public finance, and NGO's. As inputs for discussion, representatives from IIASA and WWF made a number of presentations, in places based on their respective scientific investigations.

The workshop was a mixed success. On the positive side, there were some particularly interesting presentations:

- First Solar: This technology developer described the conditions under which they would enter a market, with the most important thing being a package of national level legislation supporting their technology for at least the next five years.

- Nur Energie: This project developer described their interactions with the Tunisian government, and highlighted that the government seemed relatively unconcerned with potential public opposition to new development. Instead, the government appeared focused on job creation and export revenues.

- Moroccan Renewable Energy Development Centre: This local NGO confirmed the opinions of Nur Energie, and illustrated the factors driving the Moroccan government to undertake a planning effort for substantial scale-up of solar and wind.

- World Bank: The World Bank representative illustrated the package of project financing that they were hoping to get to work, including for the Moroccan plans. It was clear that an essential piece of the puzzle would be support from European countries, either in terms of project finance, or guarantees to purchase renewably generated power at above market rates.

On the less successful side, there was a noticeable absence of many participants from the region, in particular from Tunisia and Egypt, who had previously indicated their intention to attend and to make presentations. In the case of both countries, there were indications that the government had specifically taken action to block the participation of their experts; one explanation for this action was the inclusion on the agenda of government corruptions as a discussion topic.

In retrospect, all of these features of the workshop highlight the importance of the Arab Spring, and fill the air with uncertainty about where development will now go, with new governments to be formed in Tunisia, Egypt, and potentially other countries. All of the observations from the workshop have been documented and reflected upon in a recent policy report, again prepared by PwC in cooperation with IIASA and the Potsdam Institute for Climate Impact Research (PIK), to be released on 31 May 2011 in Brussels.

2.2 Corruption and the resource curse

During the first half of the project, the researchers submitted a paper on the perceived risks of project developers in North Africa, which was published online by the journal *Energy Policy*. In the second half of the project, we turned worked on disseminating these results to the policy community, as well as conducting an additional piece of analysis. In terms of the former, we summarized the results in the Global Corruption Report: Climate Change, a book edited by Transparency International and published by Earthscan. In terms of the latter, we supervised a Master's student at Central European University, who constructed a model of the resource curse, and analyzed whether or not renewable energy development, like mineral extraction, could be a trigger. Both pieces of research highlight the need to pay attention to the problem of corruption in the renewable energy sector, something that has so far largely not happened.

2.3 Sustainable water use and solar energy development

The second piece of research associated with this project was the modeling of water use from solar energy development expansion in North Africa, comparing that to water availability, and modeling the sensitivity of the results to differences in technology, and expectations of changes in weather due to climate change. The results of the research showed that concentrated solar power (CSP) when developed with the least expensive cooling technology would create a major problem in terms of its water use, if expanded to levels consistent with a transition to renewable energy. Solving the problem through the application of dry cooling technology is an option, though one that at first glance appears expensive. Further investigation, however, suggests that the costs of dry cooling to be quite modest in comparison with overall development costs, and would have a barely perceptible impact on the competitiveness of CSP. We explained these results in a paper that we submitted, at the conclusion of the project, to the journal *Energy Policy*. Now in press, the uncorrected page proofs appear in the Annex to this report.

2.4 Employment creation from CSP development

The third piece of research was the modeling of employment creation in North Africa from an expansion of CSP. There were three main findings. First, CSP has the potential to be a major job creator in the region, with exact numbers varying by country. Second, most of the jobs created would be indirect, in the service sectors of the economies, resulting from the influx of cash from project developers and export revenues. Third, the greatest sensitivity in job creation comes from the exact terms of technology transfer, and whether CSP project development relies on local manufacturing for major components, or imports these components from Europe and elsewhere. The results have been submitted to the journal *Energy Policy*. Informally, we have heard that two reviewers have judged the article positively, as suitable for publication, but because their reviews were so brief and so positive, the journal has sought out a third review. The submitted draft is in the Annex.

III. Next steps

We have already moved on from this project, in several ways. First, we have continued to push forward on the research themes, with research underway on the issues of energy security, water use from CSP compared to fossil fuels, and the potential for geographically distributed CSP in North Africa to provide baseload power. Funding for this work has come from a number of sources, including the European Commission, IIASA core funding, and the Smart Energy for Europe Platform (SEFEP), the latter of which is directly supported by ECF. Second, with funding from SEFEP, we have again collaborated with PwC to prepare a second policy report, already mentioned. We are currently in the process of writing proposals to several additional funding sources, including the Austrian Climate Research Programme and the United Nations Industrial Development Organization, to support further research on CSP development in North Africa, South Africa, and India.

We would certainly welcome further discussions with ECF related to support for our research on renewable energy. We believe that we have been successful in completing high quality research, and moving that research into both the peer-reviewed literature and the policy community.

ANNEX I

Final Agenda from Hammemet Workshop

IIASA – WWF Workshop

Renewable energy in North Africa: a policy road-map for 2050

Hammamet, Tunisia, 22-23rd of June

During this 2-day workshop participants will discuss regional renewable energy related issues at a new level of detail. Reports from WWF and IIASA will be presented to feed the debates.

Topics will include policy roadmaps creating an environment conducive to business; job creation, resource curses and other socio-economic issues; water use and other environmental issues; and financing.

Agenda

Day 1

10.30 – 11.00 **Welcome & Tea**

11.00 – 11.45 **Introduction and presentation of REN vision**
Jean-Philippe Denruyter, WWF
Anthony Patt, IIASA

11.45 – 3.45 **Roadmap towards a sustainable energy mix**

11.45 – 12.15 EU & Mediterranean Roadmaps
Gus Schellekens, Pricewaterhouse Coopers
Adel Mourtada, Consultant

12.15 – 12.30 Moroccan roadmap
Said Mouline, Moroccan Renewable Energy Development Centre

12.30 – 2.00 **Lunch**

2.00 – 2.15 Business perspective of Tunisian renewables investment context & roadmap
Till Stenzel, Nur Energie

2:15 – 2.20 Response
TBA, Regional Centre for Renewable Energy and Energy Efficiency

2.20 – 3.15 Discussion

3.15 – 3.45 **Break**

3.45 – 5.30 **Socio-Economic Development**

3.45 – 4.00 CSP related jobs and resources curse
Nadejda Komendantova, IIASA

4.00 – 4.15 International perspectives on renewables & socio-economic impacts
Robert Kelly, UNDP

4.15 – 4.30 Business Perspective
Ali Kanzari, Solar Energy Systems

4.30 – 4.35 Response
Rafik Missaoui, Consultant

4.35 – 5.30 Discussion

Day 2

8.30 – 9.00 **Tea**

9.00 – 11.30 **Environment & Natural Resources**

9.00 – 9.15 CSP & Water
Kerstin Damerau, IIASA

9.15 – 9.30 NGO Perspective
Andrea Athanas, IUCN

9.30 – 9.45 Governmental Perspective
TBA

9.45 – 9.50 Response
Tahar Abdessalem, Tunis University (to be comfirmed)

9.50 – 11.00 Discussion

11.00 – 11.30 **Break**

11.30 – 1.00 **Financing of renewable energy**

11.30 – 11.45 Multi-lateral financial institution perspective
Mohamed Hassan, African Development Bank

11.45 – 12.00 The Business Perspective
TBA

12:00 – 12.05 Response
Philippe Roos, World Bank

12.05 – 1.00 Discussion

1.00 – 2.00 **Lunch**

2.00 – 3.30 **Critical Next Steps**

3 short presentations to be invited from the private sector, an NGO, and a government about the next steps they believe are needed, based on the 2 days of discussion.

3.30 – 4.00 **Conclusions**

4.00 **End of workshop**

ANNEX II

Chapter from Global Corruption Report

13. *Guardian* (UK), 'Green advertising rules are made to be broken', 23 March 2010.
14. See www.americanprogress.org/issues/2009/03/big_oil_misers.html/#2.
15. See www.treehugger.com/files/2008/12/greenwash-watch-shell-net.php and http://business.timesonline.co.uk/tol/business/industry_sectors/natural_resources/article5927869.ece.
16. *Guardian* (UK), 'Dong Energy: "clean" Denmark's dirty secret', 17 September2009.
17. See www.rwe.com/web/cms/mediablob/en/315844/data/17906/56684/rwe/responsibility/performance/energy-climate/security-of-supply/power-generation-structure/RWE-Factbook-Renewable-Energy-December-2009-.pdf.
18. See www.audi.co.uk/audi-innovation/concept-cars/detroit-showcar-audi-etron.html and *Guardian* (UK), 'Has Audi's electric dream already run out of gas?', 21 January 2010.
19. *Guardian* (UK), 'Supermarkets get cold feet over fridge doors', 1 October 2009.
20. *Guardian* (UK), 'Sir Richard Branson's green claims are running on hot air', 27 August 2009.
21. See www.easyjet.com/EN/Environment/carbon_emissions_calculator.asp. This reasoning also sidesteps the carbon footprint of the most likely alternative: the train journey will almost certainly have a substantially lower carbon footprint than the car or plane.
22. *Guardian* (UK), 'Lamborghini emits some V12-powered nonsense', 11 June 2009.
23. See www.newstatesman.com/pdf/copenhagen.pdf.
24. *Guardian* (UK), 'Are EDF trying to cut our use of energy? Surely, some mistake', 2 July 2009.
25. The carbon dioxide would be gathered into pipeline networks and buried far from the atmosphere in old oil wells or salt mines. The system and its required infrastructure, which would have a large carbon footprint of its own, is untested and several decades away from becoming commercially viable, however. Even pilot systems have not yet been built.
26. See ec.europa.eu/environment/air/transport/co2/co2_cars_regulation.htm.
27. See www.energylabels.org.uk/eulabel.html.
28. See www.fern.org/sites/fern.org/files/FERN_PindoDeli-final_0.pdf and *Guardian* (UK), 'The deflowering of the EU's green logo', 15 April 2010.
29. GAO, *Energy Star Program: Covert Testing Shows the Energy Star Program Certification Process Is Vulnerable to Fraud and Abuse* (Washington, DC: GAO, 2010), pp. 7–15.
30. See www.greenwashingindex.com.
31. Rina Horiuchi et al., *Understanding and Preventing Greenwash: A Business Guide* (Washington, DC and London: BSR and Futerra, 2009), p. 23.
32. AccountAbility, *What Assures Consumers on Climate Change? Switching on Citizen Power* (London: AccountAbility, 2007), p. 9.

4.7

Could corruption pose a barrier to the roll-out of renewable energy in North Africa?

Nadejda Komendantova and Anthony Patt[1]

Considerable attention has turned to North Africa as a promising location for the development of renewable energy sources (RES). Egypt, Morocco and Tunisia already produce energy from renewable sources[2] and are eager to increase this share.[3] The European Union (EU) has also committed itself to sourcing 20 per cent of its energy from RES by 2020, part of which is expected to come from solar and offshore wind installations located in North Africa.[4]

Several scientific studies have demonstrated the technical feasibility of developing renewable energy projects in the Sahara Desert for import into Europe,[5] and it is estimated that installations of concentrated solar power (CSP)[6] covering less than I per cent of the desert could meet all of Europe's power needs.[7]

RES projects require significant private and public investment, however. The large-scale deployment of CSP in North Africa, including the costs of electricity transmission lines to Europe, would require nearly €400 billion until 2050 to import 700TWh/y (terawatt-hours per year) of solar electricity.[8] Currently, the combination of financing from national budgets and multilateral organizations contributes the major share of investment into renewable energy development in North Africa, focused mainly on wind and solar installations and concentrated in Egypt, Morocco and Tunisia. While private companies have won deals to supply components or to construct plants, significant amounts of financing come from national governments.[9] The involvement of private capital is crucial, however; past experience suggests that, when infrastructure projects reach a large scale, governments may lack the fiscal resources needed to continue funding them.[10]

Unfortunately, European foreign direct investment (FDI) in North Africa remains minimal compared to other regions.[11] According to the World Investment Prospects Survey 2010–2012, after sub-Saharan Africa it was North Africa that was predicted to be the lowest-priority region for FDI in 2010 and 2012.[12] Where it is present, FDI is often linked to the extraction of natural resources.[13]

Some of the challenges for attracting capital have been identified in World Bank studies of regulatory risks in North Africa. One assessment evaluated the business environment across the region and found regulatory shortcomings relating to enforcing contracts, starting a business or dealing with construction permits.[14] In another survey, over 45 per cent of companies involved in FDI in Egypt and Algeria found corruption to be a major constraint.[15]

The International Institute of Applied Systems Analysis (IIASA) conducted research to identify barriers to private investment in RES, focusing on North Africa and on determining the cost of these barriers in terms of investment volumes. IIASA used qualitative methods of research based on structured, semi-structured and in-depth interviews, and quantitative modelling.[16]

Gathering stakeholder perspectives

During the first round of interviews with experts,[17] 52 per cent of all respondents named complexity and corruption in bureaucratic procedures as significant barriers to the deployment of RES in North Africa (figure 4.6). In this context, experts understood corruption primarily as the existence of nepotism, the expectation of hidden payments or gifts to officials as the cost of doing business, or long delays in bureaucratic procedures unless bribes were given.

The following round of interviews presented stakeholders with a list of nine possible risks: regulatory, political, revenue, technical, 'force majeure' (including natural catastrophes and terrorism), financial, construction, operating and environmental. Participants were asked to value these according to the seriousness of their concern and the likelihood of occurrence. As figure 4.7 shows, three types of risk were evaluated as being a high level of concern, with 78 per cent of respondents identifying regulatory risk – defined as complexity or corruption relating to bureaucratic procedures – as a high-level concern.[18]

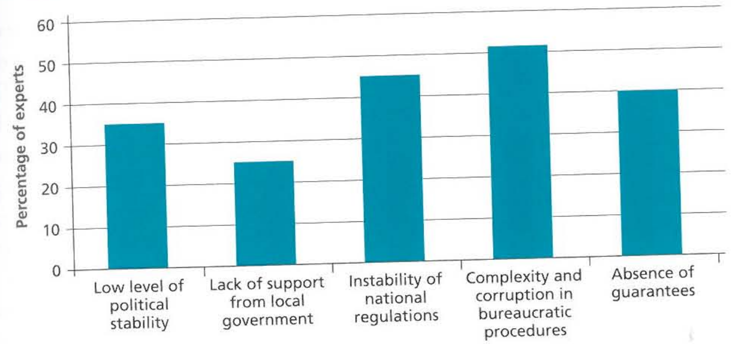

Figure 4.6 Barriers to investment in renewable energy in North Africa

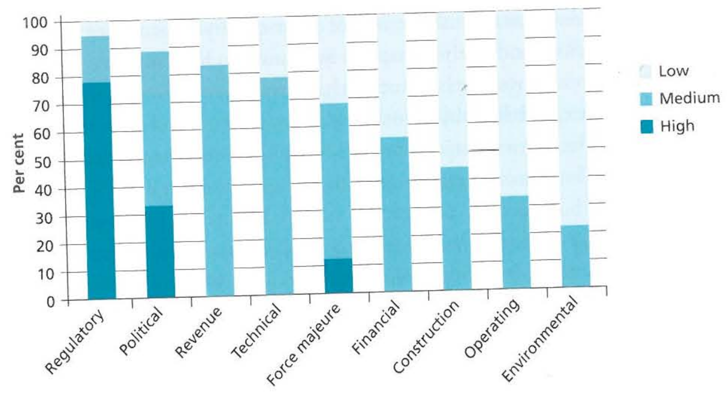

Figure 4.7 Risks perceived as most serious in relation to RES investment in North Africa

Furthermore, 67 per cent of all interviewed stakeholders considered that regulatory risk was very likely to be present in North Africa, while the likelihood of political risk and force majeure was considered to be less (figure 4.8).

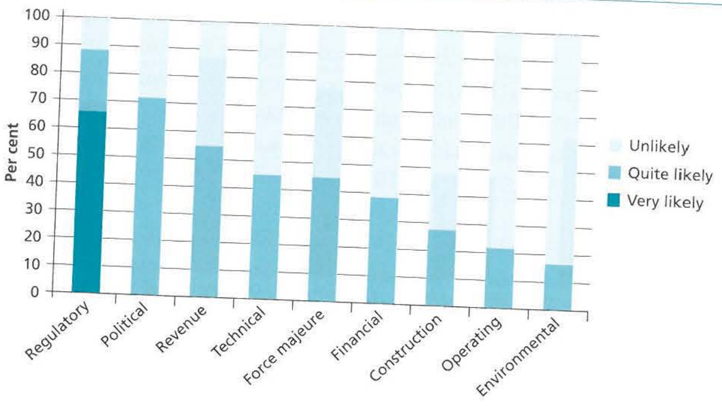

Figure 4.8 Risks perceived as most likely to happen in relation to RES investment in North Africa

Both evaluations demonstrate that the risk of poor-quality bureaucratic procedures was perceived as serious and likely to happen in relation to RES investment in North Africa. Many respondents further noted that investment often does not occur because of complex and lengthy bureaucratic procedures and uncertainty as to whether public officials will expect bribes. Such risks can create difficulties for calculating project budgets and put projects at risk of cost overruns.

The quality of bureaucratic procedures is also a concern for investors in the conventional energy sector, but here the costs of capital are lower, since banks perceive projects with pre-existing track records as less risky and therefore require lower risk premiums for their capital.[19] This is not the case with North African RES projects, and particularly not with CSP, which has no established track record.

The cost of investment

For the second stage of its research, the IIASA used its Mediterranean Area Renewable Generation Estimator (MARGE) to quantify the economic cost that risks of complex or corrupt bureaucratic procedures have on the internal rate of return (IRR).[20] The MARGE model estimated the annual cost of constructing CSP plants, using data from studies on CSP technology and variables input by users, including interest rates and industry growth rates.[21] Investors will generally require a higher IRR for projects they perceive as high-risk because of the technology or the region of operation. MARGE examined the cost of these risks in terms of the overall

investment needed between now and 2025 by inputting different IRRs commonly associated with varying levels of risk.

Project developers of conventional thermal power stations generally guarantee an IRR in the range of 6–10 per cent, while developers of large renewable power plants – such as CSP plants in Spain – need to guarantee 15 per cent, due to banks' apparent view that the technology may not yet be commercially viable. Taking into account the perception of bureaucratic risks, it is reasonable to consider that private developers of CSP projects in North Africa could face IRRs as high as 20 per cent.

Taking an IRR of 20 per cent, the MARGE model suggests that the overall investment required by European and North African governments, multilateral organizations and the private sector to develop CSP capacity (including the construction of installations and electricity grids, insurance, operation and management costs) until 2025 could reach €1600 billion (US$2000 billion) with a 20 per cent IRR,[22] in comparison to less than €100 billion (US$130 billion) with a 5 per cent IRR and €580 billion (US$750 billion) with a 15 per cent IRR.

Both the MARGE calculations and the findings of the initial interviews will need to be supported by further research to determine the extent to which perceptions of regulatory risks and complicated bureaucratic procedures reflect concerns over corruption as opposed to legal, though inconvenient, regulatory complications or bureaucratic delays. Nevertheless, the World Bank finding that a substantial percentage of companies operating in the region[23] found corruption to be a significant problem suggests that it could indeed prove an obstacle to the roll-out of renewable energy in the region.

If this is true, a failure to address corruption will result in higher quantities of investment being required for CSP deployment in North Africa. This is just one possible result; another is that investors will simply seek other regions for investment. Given the region's singular potential for solar development, however, this outcome should be avoided. By taking steps to reduce corruption and streamline bureaucratic procedures, North African governments may both fuel their economies and contribute significantly to the reduction of global emissions.

Notes

1. Nadejda Komendantova is a research scholar and Anthony Patt is a team leader of the Decisions and Governance Group at the International Institute of Applied Systems Analysis (IIASA) in Austria.
2. Observatoire Méditerranéen de l'Energie (OME), *Mediterranean Energy Perspectives 2008* (Paris: OME, 2009).

3. For example, the governments of Egypt and Morocco have committed themselves to achieving 20 per cent and 42 per cent shares of renewable energy by 2020, respectively. Climate Investment Funds (CIFs), *Clean Technology Fund Investment Plan for Concentrated Solar Power in the Middle East and North Africa Region* (Washington, DC: CIFs, 2009), p. 6.
4. Reuters (UK), 'EU sees solar power imported from Sahara in five years', 20 June 2010.
5. Gregor Czisch, *Szenarien zur zukünftigen Stromversorgung: kostenoptimierte Variationen zur Versorgung Europas und seiner Nachbarn mit Strom aus erneuerbaren Energien* (Kassel: University of Kassel, 2005).
6. Concentrated solar power is a promising method of energy generation that uses mirrors to focus sunlight, which heats a transfer liquid that, in turn, generates the steam necessary to power a turbine.
7. World Bank, *World Development Report 2010: Development and Climate Change* (Washington, DC: World Bank, 2009), p. 221.
8. By way of comparison, in 2000 Europe's total electricity demand was about 3500 TWh/y for all energy sources. Franz Trieb, *Trans-Mediterranean Interconnection for Concentrating Solar Power* (Stuttgart: German Aerospace Center, 2006), pp. 34 and 102.
9. UN Environment Programme (UNEP), *Global Trends in Sustainable Energy Investment 2009: Analysis of Trends and Issues in the Financing of Renewable Energy and Energy Efficiency* (Nairobi: UNEP, 2009), p. 56.
10. Clive Harris, *Private Participation in Infrastructure in Developing Countries: Trends, Impacts, and Policy Lessons.* Working Paper no.5 (Washington, DC: World Bank, 2003), p. 40.
11. Marion Mühlberger and Marco Semmelmann, *North Africa: Mediterranean Neighbours on the Rise* (Frankfurt: Deutsche Bank Research, 2010), p. 7.
12. UN Conference on Trade and Development (UNCTAD), *World Investment Report 2010: Investing in a Low-Carbon Economy* (Geneva: UNCTAD, 2010), p. 25.
13. UNCTAD, *World Investment Report 2008: Transnational Corporations and the Infrastructure Challenge* (Geneva: UNCTAD, 2008), p. 43.
14. World Bank, *Doing Business 2008* (Washington, DC: World Bank, 2007), at www.doingbusiness.org.
15. World Bank, 'Enterprise surveys', at www.enterprisesurveys.org. Full survey data are available for Algeria (2007) and Egypt (2008).
16. A more in-depth discussion of the research can be found at Nadejda Komendantova et al., 'Perception of Risks in Renewable Energy Projects: The Case of Concentrated Solar Power in North Africa', *Energy Policy* (forthcoming).
17. Interviews were conducted with participants at an international conference on CSP development that was held in Madrid in 2008; a meeting for the Mediterranean Solar Plan held in Paris in 2009; and a special workshop on barriers to CSP development organized by the IIASA in Austria in 2008.Twenty-three experts were interviewed: five from industry, two from government ministries, seven from the financial sector and nine from the social scientific community. All interviewees worked in Europe and were actively involved in the analysis of CSP projects in North Africa or in the realization or management of these projects.
18. The research assumed that the European feed-in-tariff would be available to support investment into CSP in North Africa for a period of 20 years.
19. See, for example, Edward Kahn, *Comparison of Financing Cost for Wind Turbine and Fossil Powerplants* (Berkeley: University of California, 1995).

20. The internal rate of return means the return on investment capital. It is closely connected with the costs of capital and risk premiums, when investors or banks require higher risk premiums or interest rates for their capital for projects that they perceive as more risky.
21. See www.iiasa.ac.at/Research/RAV/Presentations/MARGE/dist/The_MARGE_Model.html.
22. This investment does not include investment by distribution companies and governments in the purchase of RES electricity.
23. Based on figures from World Bank 'Enterprise surveys': Algeria (64 per cent in 2007), Egypt (45 per cent in 2008) and Morocco (27 per cent in 2007).

ANNEX III

Uncorrected page proofs

Energy Policy ▮ (▮▮▮▮) ▮▮▮–▮▮▮

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Costs of reducing water use of concentrating solar power to sustainable levels: Scenarios for North Africa

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ABSTRACT

Concentrating solar power (CSP) has the potential to become a leading sustainable energy technology for the European electricity system. In order to reach a substantial share in the energy mix, European investment in CSP appears most profitable in North Africa, where solar potential is significantly higher than southern Europe as along with sufficient solar irradiance, however, the majority of today's CSP plants also require a considerable amount of water, primarily for cooling purposes. In this paper we examine water usage associated with CSP in North Africa, and the cost penalties associated with technologies that could reduce those needs. We inspect four representative sites to compare the ecological and economical drawbacks from conventional and alternative cooling systems, depending on the local environment, and including an outlook with climate change to the mid-century. Scaling our results up to a regional level indicates that the use of wet cooling technologies would likely be unsustainable. Dry cooling systems, as well as sourcing of alternative water supplies, would allow for sustainable operation. Their cost penalty would be minor compared to the variance in CSP costs due to different average solar irradiance values.

1. Introduction

About eight tons of CO_2 are emitted each year on average by every citizen of the European Union (U.S. Energy Information Administration (EIA), 2009). This is the result of an energy-intensive lifestyle, mainly relying on burning fossil fuels for energy generation. The consequences are experienced by the whole planet as global climate change (Solomon et al., 2007). An increase in average air temperatures and hence the frequency and intensity of extreme weather events, such as floods or droughts, will threaten human life more and more during the upcoming decades (Parry et al., 2007). One way to counteract this development efficiently is to restructure the energy sector by replacing fossil energy resources with renewable ones, making energy generation sustainable and reducing CO_2 emissions substantially (Metz et al., 2007).

There are many visions of how Europe could obtain its energy sustainably. While their time horizon, emission goal and technology preferences can differ widely, there is relative consensus that if we want to achieve a sustainable energy market by the mid-century, transformation must begin over the next few years (Knopf et al., 2010; Van Vuuren et al., 2010). One energy technology that could play a major role in a fast and efficient transformation to renewables is concentrating solar power (CSP). Already in commercial operation today and equipped with affordable energy storage capacities for either peak or baseload power generation, CSP has the economic and technological potential to become a leading energy technology in future (Khosla, 2008; Lorenz et al., 2008; Pitz-Paal, 2005). But to make the most efficient use of solar energy, deserts are the preferred location for CSP plants. Several researchers have suggested that for CSP to supply sufficiently large amounts of power to the energy mix, the European electricity grid would need to expand southwards to the Sahara, allowing new cooperation and transition possibilities for both North Africa and Europe (Battaglini et al., 2009; MacKay, 2009; Patt, 2010). Two recent political and private sector initiatives in this direction are the Mediterranean Solar Plan (2008) and the Desertec Industrial Initiative (2009), respectively. This increasing interest of European energy policy leads to the need of proactive investigation of potential adverse environmental consequences of such large-scale projects, making local resource studies from North Africa of interest for Europe.

While CSP has great potential, one issue that has arisen in its development, especially in the United States, is its sustainability in the very desert environments to which it is most suited (Pitz-Paal, 2005). In contrast to other renewable technologies like photovoltaic (PV) or wind, CSP requires a considerable amount of water, mainly for cooling purposes, when using recirculating wet

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cooling, a characteristic this technology shares with other thermal power technologies. While coal or nuclear power plants show a similar water demand, natural gas plants require only up to a fourth of that (cf. DOE, 2006, 2009). Some renewable energy experts argue that this water demand constrains the large-scale development of wet-cooled CSP in desert regions; either they would consume too much water in an area with by definition very low water resources, or, when using more expensive alternative cooling systems, like dry cooling, CSP could not become cost-competitive with other energy technologies (Carter and Campbell, 2009; Hogan, 2009; Woody, 2009; Patel, 2010).

We investigate the validity of this argument for the case of large-scale investment in CSP in the Sahara, starting with four case studies from Morocco to Egypt, and then scaling up to a regional level where CSP could meet a substantial part of the future electricity demand of both regions, North African and Europe. We focus on growth scenarios that include power production for the European market because here the potential social and political ramifications of unsustainable water use are the most acute.

2. Background

Concentrating solar power technologies use an assembly of mirrors that reflect and concentrate solar thermal energy to heat up a fluid that then impels a conventional steam power cycle for electricity generation. Heat storage capacities, mostly involving the use of molten salt, allow running the steam turbine after the sun goes down, and during periods of cloudiness. Parabolic trough (PT) and central tower (CT) are the most mature technologies at present, with CT showing highest thermodynamic efficiencies. Both will be compared in this paper. Other technologies are Fresnel collectors or dish/engine systems (which use Stirling engines). Interested readers can find a detailed overview of the four main CSP technologies in the IEA Technology Roadmap (2010).

2.1. Cooling technologies

Most of today's CSP plants have recirculating wet cooling systems that require a constant supply of freshwater. But water is also needed for mirror cleaning, as make-up water for the steam cycle, and for personnel needs. A representative wet-cooled parabolic trough plant located in the Mojave Desert, California, consumes about 3000 m^3/GWh, while a representative wet cooled central tower plant consumes somewhat less, about 2100 m^3/GWh (DOE, 2009). This is due to the higher concentration ratio and improved thermal efficiency possible in the CT plant type and represents a similar level of condensing water as used in a coal fired power plant. With dry cooling systems, this amount can be reduced to about 300–340 m^3/GWh (DOE, 2009), of which about 75 m^3/GWh is used for mirror cleaning (Turchi and Kutscher, Q2 2010). Depending on local ground and wind conditions this latter amount may vary widely, and industry experts suggest that the application of new techniques currently being experimented with may substantially reduce the water consumption for mirror Q3 cleaning (Burgaleta, 2010).

There are several alternative technologies for dry cooling. The oldest is direct dry cooling using air-cooled condensers (ACCs). With this technology, the steam from the closed-loop turbine cycle passes through a device similar in design to a car radiator, with large fans blowing air across a lattice of pipes. A second technology, known as the Heller system, uses indirect dry cooling. In this case, the heat of the turbine cycle steam is transferred to a much larger body of water. That water, in turn, is circulated through an air-cooled heat exchanger at the bottom of a large cooling tower. Either a fan system or temperature differentials from the tower's height generates convective air currents that draw cool air through a radiator. Finally, there are hybrid technologies, utilizing some water. To hybridize a principally air-cooled system, it is common to combine its use with a separate, wet cooling system. Another option is to evaporate water spray on the hot surfaces of the condenser or into the hot ambient inlet air, also increasing their cooling rate (Micheletti and Burns, 2002). This proves to be effective at high ambient air temperatures and low humidity conditions.

Dry cooling systems have a few disadvantages. First, the projected costs of installing dry instead of wet cooling systems for large CSP plants, with capacities from 500 to 1000 MW, are higher; the overall investment costs would likely increase by about 2%, and for hybrid cooling systems by 3%. It is important to note the speculative nature of these estimates; they are based on literature data (California Energy Commission (CEC) (2002)), personal information (Burgaleta, 2010) and calculations with the Mediterranean Area Renewable Generation Estimator (MARGE) model (Williges et al., 2010). Second, the power output of dry-cooled plants of comparable size located in similar environmental conditions remains somewhat below that of wet-cooled plants due to the difference between the wet and dry bulb temperatures. In addition, the higher the average ambient temperature of a plant location, the higher the efficiency loss, primarily due to thermodynamic losses in the power cycle but also to the cooling system's energy demand. Based on annual mean temperatures, the difference from wet to dry cooling amounts to about 3% annual output loss in southern Spain (Burgaleta, 2010; Szabó, undated) and on average 4.5% in the Mojave Desert (DOE, 2009; Szabó, undated). In North Africa, with annual mean temperatures between 23 and 30 °C in the Sahara and 20 °C at coastal sites, the annual output loss would be 5–10% (see Fig. 1). The value of hybrid cooling systems, which are more expensive to install and which increase water usage about that of pure dry systems, is to reduce these efficiency losses at high ambient temperatures (Kutscher and Costenaro, 2002; California Energy Commission (CEC), 2003).

Based on Szabó (undated), wet cooling systems show an almost linear increase in water consumption with increasing ambient temperatures, while the auxiliary energy need for the cooling system levels off for increasing air temperatures from 0 °C. Direct and Heller dry cooling systems do not require water for evaporation. The auxiliary power required stays constant for natural-draft Heller systems for temperatures above 2 °C. Direct air-cooled condensers have an increasing power demand until 10 °C, from this point it decreases again slightly. For hybrid

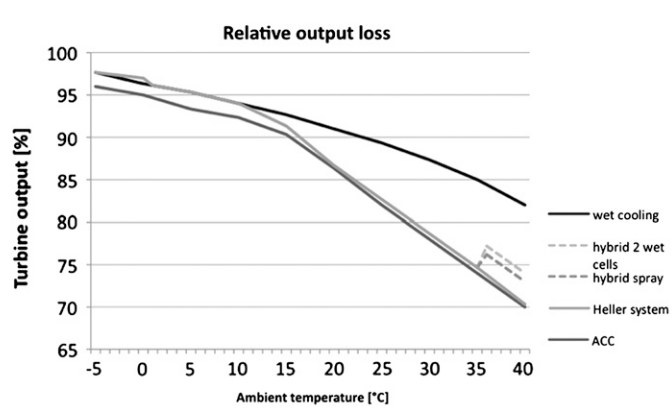

Fig. 1. Relative output loss due to thermodynamic losses and auxiliary power needed for the cooling system. Approximation based on Szabó (undated).

cooling systems the added wet cells show a steeply increasing water demand if continuously used with rising air temperatures, while their power demand stays constant from temperatures above 15 °C. A threshold temperature can be set from which wet cooling will enhance the dry cooling system. Hybrid Heller systems show a constant water and energy demand.

2.2. Available water resources

As we have shown, all CSP technologies require a certain amount of water. In arid regions like the Sahara, water is an extremely rare resource, and those requirements may compete with the region's other water uses, mainly for agricultural purposes. Today, the annual freshwater withdrawal in North Africa—94 billion m^3—is already twice the internal renewable freshwater resources (Food and Agriculture Organization of the United Nations (FAO), 2010). With growing populations, economic development, as well as increasing temperatures and coastal inundation due to climate change, the future availability of water will further decrease (Abou-Hadid, 2006; Elsharkawy et al., 2009; Bakir, 2001). De Wit and Stankiewicz (2006) project in their scenario a decrease in rainfall of 10–20% by the end of the century, while a drying of 20% along the African Mediterranean coast under a A1B scenario can be found in the regional climate projections of the fourth IPCC report (Christensen et al., 2007). Arnell (1999) assumes a decrease in surface runoff up to 25 mm/yr for major parts of the region until the 2050s. Changing hydrological patterns are to be especially expected in the drainage area of the Atlas Mountains (Boulet et al., 2008; Born et al., 2008). Recent climate models do not provide conclusive results regarding the catchment area of the Nile River, which provides 90% to Egypt's current water demand.

This means that sustainable water use by CSP plants in North Africa likely demands alternative sources to surface water. Most of the regional groundwater resources are fossil aquifers that are already over-pumped, so they would not be a sustainable option either. Seawater cooling would be an option, though such cooling towers and water transport systems require special alloy and more intensive cleaning. Since all plants need a certain amount of freshwater, e.g. for mirror cleaning and periodic replacement of steam within the power cycle, we considered meeting the entire supply of water with freshwater sources as the most efficient solution for plants that are not located directly at the coast. Thus, treating wastewater or desalinating seawater and transporting it, if necessary, to the plant's location can be a possible solution for meeting the water demand of CSP. Zhou and Tol (2004) present a survey of cost development for water treatment over the last 40 yr. As most of today's desalination plants are located in the Middle East and North Africa (MENA), the study's results seem suitable for our approach. At the time unit costs are about 1.1 €/m^3 for desalination, 0.9 €/m^3 for wastewater treatment and 0.7 €/m^3 for brackish water (€2000). Further, Zhou and Tol (2004) discuss water transport costs based on estimations from Egypt. Transporting a water volume of 100 million m^3/yr in a canal costs 6.5 ¢/100 km horizontal transport and 5.5 ¢/100 m vertical transport with a capacity elasticity of 0.92, as pipeline costs increase by 271%. We considered those figures to be adequate as well.

3. Methods

As the water demand of a plant depends on its precise location, its access to water resources as well as its climate, we examine four representative locations for CSP plants in North Africa. For each location, we identify appropriate cooling technologies for both central tower and parabolic trough plants. We compare wet cooling systems with dry cooling (integrating direct and indirect technologies) as well as with hybrid (two wet cells added to the dry cooled condenser) and spray cooling systems. We then use the results of those case studies to estimate and compare the amount of water that would be required on a regional level by sketching scenarios of a high share of CSP in the future European and North African energy mix. We choose a background storyline presented in a roadmap to 2050 for Europe and North Africa (PricewaterhouseCoopers (PwC), 2010) with the target of a 100% renewable electricity market. This is reached through an inter-regional smart energy grid that connects and distributes various renewable energy resources while making use of CSP as a peak and baseload technology, and implies a large scale-up of this technology during the next four decades.

3.1. Case studies

Despite the sheer vastness of the Sahara, not every site appears suitable for the installation of a CSP plant. In order to achieve highest potential efficiencies throughout the year, Ummel (2010) suggested that a minimum solar radiation of 4.7 kWh/m^2/day is required. This condition is met in parts of the central and southern Sahara. Other criteria are stable and flat ground conditions (slope $\leq$ 3%), and access to infrastructure as well as to planned electricity grid corridors towards Europe. We chose four representative sites that would likely be attractive locations for CSP plant construction, shown in Fig. 2. Showing differing climatic and water profiles, Aswan, Egypt, is the most southern and also hottest site but has respectable water resources. Ghadames, Libya, lies further north but still shows very good annual insolation records. Tataouine, Tunisia, slightly fails the 4.7 kWh/m^2/day threshold, but is located close to the Mediterranean coast with unlimited salt water availability. Tan Tan, Morocco, lies southwards of the last two locations, but shows a lower and unique annual irradiance curve due to its proximity to the Atlantic Ocean. Combining the characteristics of all four locations, they represent a good overview of potential future CSP sites, including coastal site characteristics only to a small extent due to land-use and climatic constraints, and focusing on the inland of North Africa, the Sahara desert, with excellent solar radiation conditions and smooth climate variations.

All sites show higher average temperatures than plant environments examined for a United States Department of Energy (U.S. DOE, 2009) report on CSP plants primarily located in the Mojave Desert.[1] In order to meet these differing climatic conditions, we apply

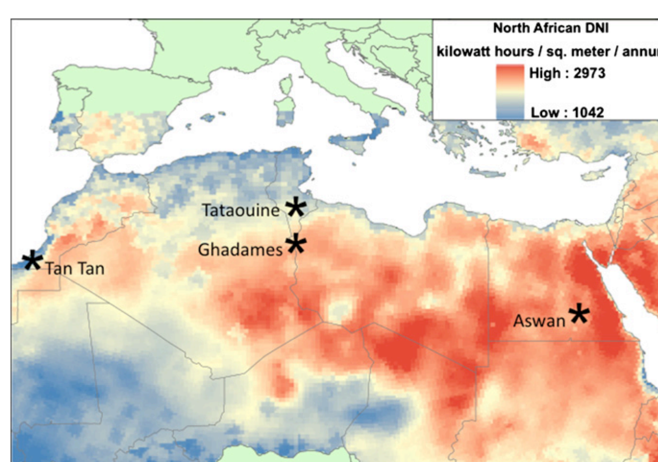

Fig. 2. Annual direct normal irradiance (DNI) in North Africa (National Renewable Energy Laboratory (NREL), 2006) and case study locations.

DOE data only as basic water demand of 2100 to 3000 m^3/GWh, respectively, to our wet cooled CT and PT plants. For each hour in the range from 35 to 50 °C an auxiliary water and parasitic power demand is added. This approach may underestimate the real water demand of a CSP plant in North Africa as not only average temperatures but also seasonal climatic variance differs in both regions. We set a 35 °C threshold temperature, above which hybrid cooling options are applied. So, by extrapolating data linearly up to 50 °C, wet and hybrid (from 35 °C) cooling systems cause an output loss of 0.8%/°C. Dry cooling, by contrast, shows a loss of 0.95%/°C (see Fig. 1). The higher the number of hot hours above 35 °C, the higher the additional efficiency loss of the CSP plant, irrespective of the cooling system installed. Of course, absolute losses diverge for all systems. The loss of net turbine output that we present is due to both decreasing thermodynamic efficiency and the auxiliary energy need of the cooling system. However, we further assumed that a typical condenser temperature is held constant for each plant type, leading to the same theoretical losses for all power cycles. In reality though most plants show condenser temperatures inline with the ambient temperature, viz. depending on the specific thermodynamic efficiency of a power cycle, the efficiency loss can differ, leading to somewhat higher efficiency losses for parabolic trough plants than for central tower when ambient temperatures rise.

With climate change, mean temperatures in North Africa will further increase (Meehl et al., 2007). For calculating the impact this rise would have on prevalent cooling technologies and thus plant performance, we take (uncorrected) temperature data of the ECHAM climate model for the A1B scenario path. Three climate periods were set. First, 1976–2005 is our base period, and observational data were used. Because observation data cover only a part of the basic climate period, results remain to some extent questionable. We then examine two subsequent periods, from 2006 to 2035, and from 2036 to 2065. For these, we add the calculated change signal, from the model, to our observation data. As Fig. 3 shows, we project mean temperatures to increase, especially during the third period, in all locations. The projected rise is the greatest in the Aswan and Ghadames locations.

We now set a prototype of a parabolic trough as well as a central tower plant at all four locations. Table 1 gives an overview of the plant's key characteristics at each site. It also presents the rising number of hours above 35 °C, which require additional water and power use in our case study.

Based on these characteristics, we calculated the annually required amount of water as well as the output loss for each CSP plant when equipped with wet, dry or hybrid cooling systems, and the corresponding costs. To do so, we used the MARGE model presented in Williges et al. (2010), which permits the development of site-specific CSP scenarios, and projects annual costs based on a component-by-component breakdown of each plant and the associated intercontinental transmission costs via high-voltage direct current (HVDC) lines. For the current analysis, we expanded MARGE to the MARGE *CCL* (Cost of Cooling Load) model by elaborating the cooling component in greater detail. We estimated the site-specific costs of water treatment and transport for assuring a sustainable water supply at the least costs. Concerning treatment costs, we expect a further drop of unit costs over the next decades as North Africa is already today strongly investing in the capacity extension of desalination plants. We assumed a half of unit costs until 2050. Sites in Ghadames and Tataouine are supplied with desalinated water from the coast, while for Ghadames a pipeline (as part of the Great Man-made River Project) already exists and could be used inversely (Algharíani, 2003). Plants around Aswan and Tan Tan use treated wastewater from the cities.

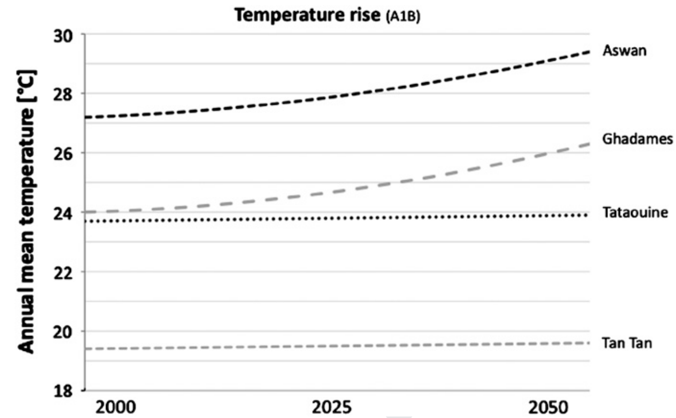

Fig. 3. Local rise of annual mean temperatures.

3.2. Scenarios

For the year 2050, energy scenarios project a doubling of the European[2] electricity demand, while the North African demand rises eight-fold (World Energy Council, 2007; European Commission, 2006). This means that the electricity demand rises to annually 7800 TWh in Europe and 1500 TWh in North Africa. For CSP to meet 15–50% of this demand, consistent with the PricewaterhouseCoopers (PwC) (2010), renewable energy vision for Europe would require installation of 200–700 GW of current CSP technologies. Starting in 2010 with almost no capacity installed in North Africa, CSP would entail an annual growth rate of 21–25% until 2050, depending on the capacity goal.

For our scenario calculations with MARGE *CCL* we assume a strong development of CSP technologies only in the Mediterranean region. We set a hypothetical learning rate of 15%, 5% discount rate, and project internal rates of return starting at 15% and declining to 10% as the technology matures and risk diminishes. With these parameters we calculate the effects of different cooling systems on the levelized electricity cost (LEC), the year of price parity with the fossil resources coal and gas, and finally the total amount of discounted subsidies that would be required to reach this price parity. For the latter two calculations we assume European gas and coal prices consistent with the World Energy Outlook 2008 (IEA, 2008); all costs are given in € (2000). As several of our base data and scenario assumptions differ substantially from the cost scenarios presented by Williges et al. (2010), our study also leads to considerably distinct results.

4. Results

4.1. Case study results

Water demand at all four sites averages 2240 (CT) or 3180 m^3/GWh (PT) with the hottest sites showing highest water demands. Hybrid systems require about 360–380 m^3/GWh on average and naturally dry-cooled system stay stable at 300/340 m^3/GWh. Until 2050 these requirements increase with climate change under an A1B scenario on average by about 2% (45 [CT]–60

[1] The Mojave Desert shows average temperatures of about 16–18.5 °C (61–65 °F).

[2] Europe includes EU27, Belarus, Bosnia-Herzegovina, Croatia, Macedonia, Montenegro, Norway, Serbia, Switzerland, Turkey and Ukraine.

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Table 1
Key characteristics of CSP prototypes.

Location	Aswan	Ghadames	Tan Tan	Tataouine
Generation capacity (MW)	1000			
Storage capacity (h)	14			
Operation (h/yr)	7000			
Capacity factor	80%			
Theoretical maximum output (GWh)	7000			
Solar-to-electricity efficiency CT	20% (IEA, 2010)			
Solar-to-electricity efficiency PT	15% (IEA, 2010)			
Mean annual irradiance (kWh/m^2/yr)	2430	2250	1230	1790
Mirror field size CT (ha)	1440	1560	2850	1960
Mirror field size PT (ha)	1920	2080	3800	2610
Yearly sum of hours above 35 °C (2000)	1710	1220	20	1260
Yearly sum of hours above 35 °C (2050)	2450	1740	25	1310

Table 2
Case study results representing the local water demand of different CSP technologies in 2010 and 2050 as well as the associated LEC when targeting a share of 15%, 30% or 50% in the energy mix in 2050.

	Central tower			Parabolic trough		
	Wet cooling	Dry cooling	Spray/hybrid	Wet cooling	Dry cooling	Spray/hybrid
Aswan						
m^3/GWh 2010	2330	340	380–410	3290	300	350–380
m^3/GWh 2050	2430	340	390–440	3410	300	370–420
LEC ¢/kWh 2010	14.50	16.11	15.84	18.36	20.45	20.10
LEC ¢/kWh 2050 (15% share)	3.95	4.33	4.25	4.58	5.04	4.95
LEC ¢/kWh 2050 (30% share)	3.49	3.81	3.74	4.02	4.42	4.34
LEC ¢/kWh 2050 (50% share)	3.10	3.38	3.32	3.56	3.90	3.83
Ghadames						
m^3/GWh 2010	2270	340	370–390	3200	300	330–360
m^3/GWh 2050	2340	340	380–410	3290	300	350–390
LEC ¢/kWh 2010	16.32	17.76	17.33	20.75	22.62	22.06
LEC ¢/kWh 2050 (15% share)	4.37	4.77	4.68	5.09	5.58	5.48
LEC ¢/kWh 2050 (30% share)	3.84	4.19	4.11	4.46	4.88	4.79
LEC ¢/kWh 2050 (50% share)	3.41	3.70	3.63	3.70	4.30	4.22
Tan Tan						
m^3/GWh 2010	2100	340	340	3000	300	340
m^3/GWh 2050	2100	340	340	3000	300	340
LEC ¢/kWh 2010	17.49	18.53	18.70	22.30	23.64	23.86
LEC ¢/kWh 2050(15% share)	4.74	4.90	4.94	5.42	5.74	5.79
LEC ¢/kWh 2050 (30% share)	4.07	4.19	4.43	4.74	5.02	5.06
LEC ¢/kWh 2050 (50% share)	3.60	3.79	3.82	4.17	4.41	4.45
Tataouine						
m^3/GWh 2010	2270	340	370–390	3,210	300	330–360
m^3/GWh 2050	2280	340	370–390	3,240	300	340–370
LEC ¢/kWh 2010	18.44	19.52	19.34	23.55	24.95	24.72
LEC ¢/kWh 2050 (15% share)	4.85	5.11	5.08	5.68	6.00	5.97
LEC ¢/kWh 2050 (30% share)	4.26	4.47	4.45	4.97	5.24	5.21
LEC ¢/kWh 2050 (50% share)	3.76	3.94	3.92	4.37	4.60	4.58

[PT] m^3/GWh) for wet-cooled systems and 1.5–3% (5–15 m^3/GWh) for hybrid-cooled CT systems or 2–3% (7–15 m^3/GWh) for PT.

Integrating the three factors, water use, efficiency loss and water costs, now and in 2050, together with differing investment costs, we then calculated the hypothetical, technology-specific levelized electricity cost at each site for a conventional local wet-cooled plant and in comparison with sustainable cooling options. It turned out that the relatively low costs for importing treated water to wet-cooled plants does not significantly affect the final LEC. Further we could not find a difference between hybrid and spray-cooled plants (see Table 2). Our results show that mainly the efficiency loss from alternative cooling systems, due to high temperatures, affects the levelized electricity costs. Higher costs for cooling technologies as well as for water treatment and transport play only a marginal role.

4.2. Scenario results

Scaling our case study results up to a level where CSP could provide between 15% and 50% of Europe's and North Africa's electricity demand; a system based exclusively on wet-cooled CT plants would require about 11 billion m^3 of water each year, while one with wet-cooled PT plants would require 15.5 billion m^3. Fig. 4 presents the total annual water demand for each wet-cooled technology and compares those results with current renewable water resources as well as the region's average freshwater withdrawal. Future renewable water resources are likely to decline, but no explicit projections can be made yet. Hence, with prevalent wet cooling systems CSP would require up to 23% as CT or even 33% as PT technology of today's renewable water resources—of which 61% are held in Morocco and another 11% in Algeria (FAO AQUASTAT, 2010).

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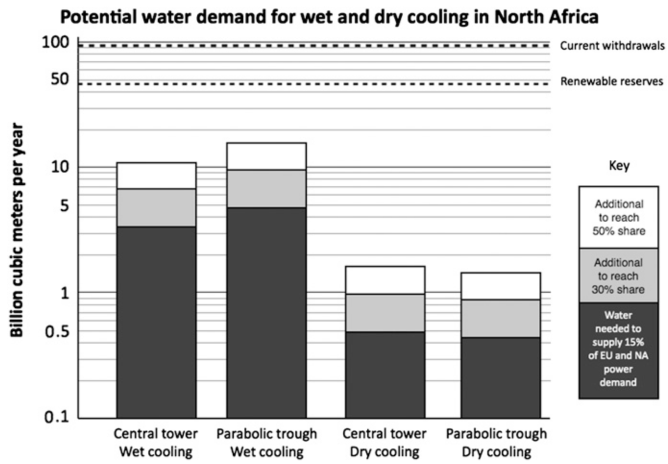

Fig. 4. Water demand of wet-cooled CSP (compare scenario from the German Aerospace Centre (DLR) for 15% CSP share from MENA (Trieb, 2006)).

Table 3
Development of average LECs depending on technology and capacity goal for 2050.

Technology	Capacity goal (%)	Levelized electricity costs (¢/kWh)				
		2010	2020	2030	2040	2050
Central tower *Wet cooled*	15	16.69	16.53	10.63	6.74	4.45
	30		16.33	9.89	6.05	3.92
	50		15.85	9.15	5.45	3.47
Central tower *Hybrid cooled*	15	17.80	17.66	11.37	7.19	4.74
	30		17.45	10.55	6.45	4.16
	50		16.93	9.78	5.93	3.67
Central tower *Dry cooled*	15	17.98	17.83	11.48	7.26	4.78
	30		17.61	10.64	6.51	4.19
	50		17.09	9.87	5.85	3.70
Parabolic trough *Wet cooled*	15	21.24	19.75	12.61	7.93	5.19
	30		19.43	11.69	7.11	4.55
	50		18.87	10.83	6.39	4.01
Parabolic trough *Hybrid cooled*	15	22.69	21.13	13.48	8.49	5.55
	30		20.79	12.52	7.61	4.85
	50		20.18	11.59	6.84	4.27
Parabolic trough *Dry cooled*	15	22.92	21.34	13.66	8.57	5.59
	30		20.99	12.64	7.68	4.89
	50		20.38	11.70	6.90	4.30

However, such wet-cooled CSP would take a substantial share of water resources that are already today exposed to strongly competing uses. Compared to that, dry cooling systems would require 1–3% of the renewable water resources, depending on the share of CSP. Hybrid cooled systems would consume between one and four percent.

An overview of the average LECs derived from the case study results is given in Table 3. Comparing these numbers, we found that alternative cooling systems lead to an average increase in the LEC of about 6% for central tower plants and about 7% for parabolic trough systems. Across alternative scenarios differing according to capacity goal and cooling technology, CT could reach price parity with gas between 2025 and 2028, PT between 2027 and 2032, and with coal between 2030 and 2035 (CT) or between 2033 and 2039 (PT). It is important to note that there is a considerable uncertainty concerning many of the costs associated with both PT and CT technologies, independent of the cooling system. For example, the ECOSTAR (Pitz-Paal et al., 2005) data on mirror field costs on which these results are partly based suggest

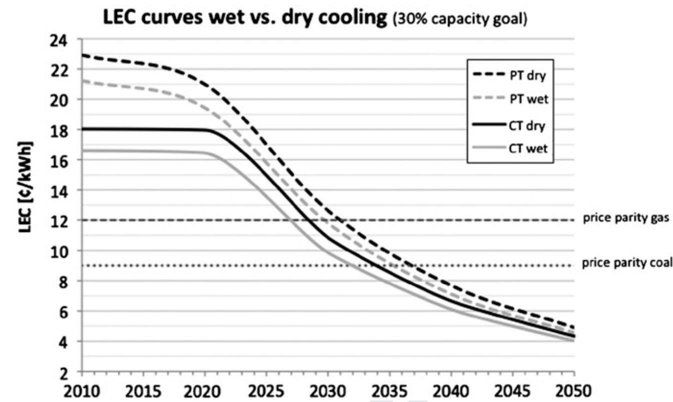

Fig. 5. LEC trend for wet and dry cooled CSP in the 30% capacity scenario, including transmission costs.

lower costs for CT systems than for PT. For each scenario goal, price parity with gas or coal of electricity from alternatively cooled CSP plants lags behind one to two years that of wet cooled ones. Fig. 5 presents an exemplary LEC trend in the 30% capacity scenario, comparing wet and dry cooling. While costs for parabolic trough remain to some extent above those for central tower, gaps between all LECs decrease with extending capacities. The total amount of discounted subsidies that would be required to reach price parity with coal amounts to about €6.7 (wet-cooled plants) to 8.8 (dry cooling) billion for central tower technologies. Parabolic trough would require €13.2–17.2 billion. To reach price parity with gas with central tower plants, €1.7–2.4 billion of subsidies were necessary; with parabolic trough this amount would increase to €4.1–5.5 billion. Comparing local with imported wet cooling, required subsidies differ up to €2–24 million, depending on site characteristics, CSP technology and capacity goal.

5. Discussion

Concentrating solar power has the potential to become an important source for the future energy mix of Europe and North Africa. All types of CSP plants require a certain amount of water, while PT plants still require about 40% more water than CT technologies. Our study investigated regional environmental and economical drawbacks of CSP technologies that could hinder a large-scale development in North Africa. For CSP in desert regions, the energy-water nexus is a key issue when targeting a sustainable electricity generation. Eventually, the improvement of resource management together with enhanced efficiency of power generation will be needed for meeting future challenges in North Africa (Bakir, 2001; The World Bank, 2007). Otherwise serious (water) conflicts may become inevitable (Tropp and Jägerskog 2006; Maas and Tänzler, 2009).

But there are already technical solutions for reducing a high water demand and supplying plants with sustainable water sources. Wet cooling does require large amounts of water, especially in hot regions like the central Sahara, on average about 2240 (CT)/3180 (PT) m^3/GWh. Applying hybrid or dry cooling systems reduces this demand significantly. It leads to considerable output losses, in comparison to wet cooling up to 6% (hybrid) or 9% (dry cooling) annual efficiency loss at our hottest site in Aswan. In estimating cost penalties, three sets of factors currently appear important.

First, the hotter the climate in which CSP is located, the lower its output and the higher the cooling water demand for wet and hybrid cooling systems. There are noticeable differences in water demand contingent on location. Time will also play a role. Climate change will likely lead to increase in mean temperatures and thus declining water availability in North Africa as soon as during the next four decades. However, other uncertainties like variance in solar irradiation might disguise this effect to some extent. Despite this uncertainty, our study shows that climate change in North Africa would increase the cooling demand of CSP plants additionally, while their efficiencies would drop further. In our A1B scenario this means an increase in the cooling water demand of 2% for wet-cooled systems by 2050, for hybrid cooling systems between 1.5% and 3%, depending on technology.

Second, options for supplying the plant with sustainable water resources are highly site-dependent. In few parts of North Africa renewable freshwater resources may supply a plant's demand without competing with other water uses, but for most areas alternative water resources are required. For population centers Aswan and Tan Tan, wastewater treatment for plant cooling appears as the most sustainable option. For sites like Ghadames or Tataouine desalinated seawater seems more suitable, assuming the responsible brine disposal suggested by Trieb (2007).

Third, a review of cooling systems revealed that technological progress is to be expected. At the moment, a large water demand or significant output loss makes certain technologies appear environmentally or economically less attractive, but this is likely to change during the coming years. One set of potentially important technological research, of consequence for cooling, are improvements which allow higher working temperatures of the power cycle. The performance of dry-cooled plants may be enhanced by pre-cooling the inflow air to the air-cooled condenser (Gadhamsghetty et al., 2006). PV systems could be used to run cooling fans (Carter and Campbell, 2009), and in northern areas with lower DNI rates but sufficient organic material, a combination of CSP plants with biogas turbines is another possibility to reach better efficiencies in a sustainable way. Advanced CSP plants may also employ pressurized gas receivers that heat the air up to 1000 °C and do not require condenser cooling.

With technological progress, these alternatives can become more efficient, and economically as attractive as conventionally cooled plants. Even without such developments, however, the cost penalties associated with reducing water consumption appear to be relatively minor. Examining future scenarios, we have shown that the penalty costs of alternative cooling systems have little effect on the total subsidies required to establish CSP technology, or the time it will take for it to become cost-competitive. Thus, the sustainability of CSP does not depend on technical limitations or major economic penalties. Instead, it will likely depend on political regulation and governance to ensure an ecologically sound development that matches the appropriate technologies with different locations' precise needs.

Q1 Uncited references

Balogh and Szabó (2009), Central Intelligence Agency (CIA) (2010), Sargent and Lundy LLC Consulting Group (2003) and Worley Parsons (2008).

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ANNEX IV

Paper submitted to Energy Policy

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Manuscript Number:

Title: Employment creation under vertical and horizontal transfer of concentrated solar power technology to North African countries

Article Type: Full Length Article

Keywords: Technology transfer, concentrated solar power, employment creation processes

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Abstract: The process of renewable energy technology transfer to developing countries can influence for the industrialization of their economies and the reduction of their greenhouse gas emissions. There are current plans to deploy large-scale solar and wind capacities in the North Africa countries, including the Mediterranean Solar Plan on the public side and the Desertec Industrial Initiative on the private side. We analyze both plans from a technology transfer perspective, drawing a distinction between vertical transfer—in which intellectual property and manufacturing capacity remains in industrialized countries—and horizontal transfer, in which manufacturing and development skills shift to the developing countries. We find that horizontal technology transfer, when more than a half of all components are manufactured locally, would bring three times more job-years to North Africans than vertical technology transfer, and that the greatest number of jobs are induced in the service industries. Total job creation would remain small compared to unemployment in the entire region. A case study of Morocco suggests, however, that employment effects could be important for any country that gains a disproportionate share of new investment.

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1 Introduction

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate (IPCC) the level of CO_2 emissions need to decline globally by 50% by 2050 in order to avoid dangerous climate impacts, with reductions of 80% in industrialized countries and regions, such as Europe (Metz et al., 2007). The development of large solar potentials in North Africa for generation of electricity for domestic use, and its export to Europe via high voltage direct current (HVDC) transmission lines, can be one of the options to reach such ambitious targets (DLR, 2009).

According to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, industrialized countries should transfer renewable energy technologies to developing countries, in order to help them to limit and decrease their CO_2 emissions. At the same time, analysts view the transfer of renewable energy technologies as an important element of socio-economic development, helping developing countries to modernize (Romer, 1990). The current rate of technology transfer appears too slow to meet either objective, and hence would need to increase (IEA, 2010).

But several questions remain open regarding actual benefits of technology transfer programs, which specific case studies can address. In this paper, we examine the case of CSP development in North Africa to identify how sensitive the benefits of technology transfer are the degree to CSP project development stimulate local supply chains, rather than he importing of key component. We analyze this in the context of recently proposed CSP growth scenarios for the region (ENPI, 2010; DESERTEC, 2008).

2 Background

2.1. Technology transfer

Until the second half of the 20^{th} century countries closely guarded their technology, seeing it as a source of military and economic power (Karakosta et al., 2010). However, the process of transferring renewable energy technologies (RET) from industrialized to developing countries became seen as an essential step in the global reduction of greenhouse gas emissions (TERI, 1997; IEA, 2010). Policy-makers included RET technology transfer as an essential element of the UNFCCC and the Kyoto Protocol.

Classically technology transfer is regarded as a large-scale public investment based on foreign technology and loans from multilateral organizations. These loans have lower interest rates and longer repayment period than commercial loans. In this context, technology transfer takes two forms (Leonard-Barton, 1990). The first involves the manufacturing and sale of technology in host countries, while the ownership remains in foreign hands. This is known as *vertical technology transfer*. In this case, new technologies are given via investment to a target group, but there is no transfer of knowledge or skills to local manufacturers. Most often a large multi-national corporation sets its factory in a developing country, with the goal of decreasing costs of operation. In order to minimize the risk of losing intellectual property, management and technical staff are nationals of developed countries, the general workforce is cheap local labour, and the whole enterprise is owned and operated by the multinational company.

Since vertical technology transfer includes only minimal knowledge transfer and domestic capacity building, some scholars claim that it is of little value, and suggest that there needs to be *horizontal technology transfer* (Schnepp et al., 1990). Under horizontal technology transfer a joint venture between a foreign and a local company is established, including technical and business training. This is a more lengthy process but it allows embedding of technology within local population and economy, which can eventually allow local partners to fund, manufacture, operate and maintain new the technologies themselves (Gallagher, 2006). Horizontal technology transfer is more preferable to local economies as skills and knowledge are built up in developing countries but makes it more difficult for foreign companies to protect their design and to control the quality of products manufactured by local partners.

The IPCC definition labels technology transfer as a process "covering the flows of know-how, experience and equipment, for mitigating and adapting to climate change among different stakeholders such as governments, private-sector entities, financial institutions, non-governmental organizations and research/educational institutions", and this favors the horizontal approach (Metz et al., 2000). The process can happen through joint ventures, foreign direct investment (FDI), government assistance programs, direct purchases, joint research and development programs, franchising and sale of turnkey plants (Metz at al., 2000).

Both vertical and horizontal technology transfer involve both private and public partners. The participation of private companies is essential, since they own the rights to most of the renewable energy technologies. Hence, private companies need to want to invest in projects, even though the risks are often high in developing countries (Komendantova et al, 2009). The public sector plays a key role through the creation of an adequate institutional framework and industrial market, as well as a favourable investment climate, all of which can reduce the perceived risks (Komendantova et al, in review). To signal their reliability, national governments often state targets for deployment of different technologies.

2.2. Scenarios for scaling up CSP in North Africa

Today the worldwide installed capacity of CSP plants in operation reaches 540 MW, and about 1 GW is currently under construction. The biggest share of the installed capacity is in the United States (85%), followed by Spain (15%). During the last year the European and American solar energy companies started to expand significantly their business to key developing countries, such as the Middle East and North Africa (MENA) region, China, and India.

Currently there are three CSP power plants in construction or operation in Algeria (Hassi R´mel), Morocco (Ain Beni Mathar) and Egypt (Kuraymat). Each of these plants has 20 MW of solar capacity. They all are hybrid projects, generating energy from both gas and solar heat sources. All three CSP plants were developed using the financing from the World Bank and almost all components and equipments for these plants were imported. Projects in the planning stage are much more ambitious. The largest volumes of projects are currently at the planning stage in Morocco (250 MW), followed by Algeria (240 MW), Egypt (110 MW) and Tunisia (50 MW) (Figure 1).

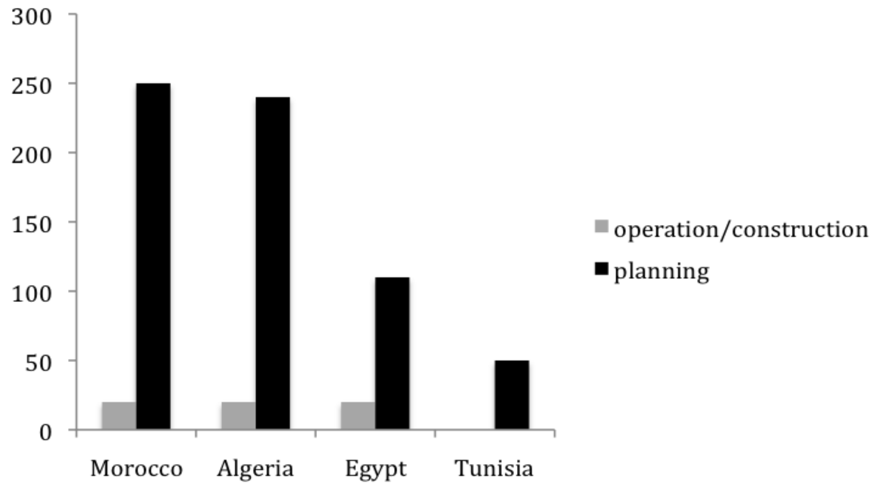

Figure 1: CSP capacities in MENA region in planning or operation. Source: Sun and Wind Energy, 2010

There have been several studies demonstrating the feasibility and costs of scaling up of CSP technology in the North African region, coupled with high voltage direct current (HVDC) lines to Europe, entailing transmission losses of only 10 – 15% (Czisch, 2005, Trieb, 2005, 2006 and 2009). The economic potentials for solar energy in the Sahara deserts are much higher than all estimates for local and European energy demand (Sims, 2007). Solar electricity imports have potential to be scaled up to 700 TWh/y by 2050. Furthermore, there are large opportunities for cost reductions of CSP electricity (Trieb, 2006). In the North African region, where solar irradiance is most favorable, this can result in solar electricity costs falling to 0.05 € / kWh before 2025, at which point they will be competitive with coal and gas, even in the absence of a carbon price or a direct subsidy (Ummel and Wheeler, 2008; Williges et al., 2010).

This research has supported the development of several scenarios and plans for developing CSP capacities in North Africa over the coming decades. In 2008, the European Union launched the Mediterranean Solar Plan (MSP). This plan foresees deployment of 20 GW of renewable energy capacities in the Mediterranean region, mainly solar and wind, by 2020 (ENPI, 2010). Built on the experience of the Barcelona process and integrates its institutions and policies, it includes reinforcement of power grid interconnections and technology transfer in the Mediterranean region. The plan foresees implementation of large-scale CSP plants with capacities up to 200 MW as well as small commercial CSP plants with capacities below 50 MW (RAL, 2010).

From the side of private investors, a consortium of private companies launched the Desertec Industrial Initiative (DII) in 2009. Located in Munich, the partners include several solar and wind companies, banks, insurers, and transmission operators. The long-term goal of DII is to satisfy about 15% of the Europe’s electricity demand by 2050 with power produced from sun and wind in the deserts of North Africa (DII, 2010).

The World Bank supports deployment of CSP in five North African and Middle East countries such as Morocco, Algeria, Tunisia and Egypt as well as in Jordan. The goal of the World Bank is to scale up the deployment of CSP technology to about 1 GW over a 3-5 year time frame. In December 2009 the Clean Technology Fund of the World Bank approved financing of $750 million to deployment of CSP technology in five above-mentioned countries. This investment is a part of an investment plan to mobilize an additional $4.85 billion from other sources (Climate Investment Funds, 2010).

2.3. Estimates of employment benefits

Between 1970 and 2001 the population of the MENA region grew up from 173 million to 386 million people. The fertility rate per woman declined from 7.0 births in 1960 to 3.6 births in 2001 (Roudi-Fahimi et al., 2002). Nevertheless, the MENA region has one of the fastest growing populations in the world, averaging 2% growth per year, or nearly 7 million new people, and partly because of its young age structure— more than 30% of population are below the age of 15—it is expected that the MENA region population will double again by 2050 (UNDESA, 2008).

Within the MENA region, North Africa in particular is characterized by one of the highest unemployment rates in the world. Only 45.3% of population of active age is employed, while 42% of all employed are working poor, earning less than US$2 a day; the total unemployment rate increased by 25% between 1997 and 2007 (ILO, 2009). The unemployment rate among young people is the highest in the world, and indeed 25% of the world's unemployed youth resides in the region (World Bank, 2007). Only 20% of all women in working age have employment, although many of them are not seeking employment: those officially registered as unemployed constituted 32.2% of the working age female population in 2008 (ILO, 2009).

Generally, the expectations regarding creation of employment opportunities under the renewable energy transfer are optimistic (European Photovoltaic Industry Association, 2006). The projections rest on the extrapolation of past job growth to future growth scenarios. Between 1990 and 2008, for example, the wind industry increased by a factor of almost 50, creating XXX jobs (IEA Scoreboard, 2009). Plausible future scenarios describe renewable energy accounting for 48% of power generation by 2050 (IEA, Blue Map Scenario, 2010). Typical of reports from lobbying and industrial organizations are sentences such as "we are currently at the beginning of the area of clean-technology jobs, which will be the greatest opportunity for wealth and global competitiveness since the advent of computer and Internet" (CleanEdge, 2009). There is one estimate that globally up to 2 million people will be employed in the CSP sector alone by 2050 (ESTELA Solar, 2009).

While there have been many estimates of green job creation in general, most have focused on Europe and North America, with a dearth of studies focusing on developing countries' employment benefits, and no robust studies at all looking at North Africa (UNEP, 2008). This reflects the fact that the bulk of documented growth of green jobs has taken place mostly in industrialized countries, and only recently in fast growing the developing countries like China, Brazil, and India.

While there have been studies of job creation from wind power in, only two have focused on employment from CSP, a newer and until now less important technology. First, the National Renewable Energy Laboratory (NREL) in the United States estimated employment impacts of CSP deployment in California. In 2002, NREL had developed the Job and Economic Development Impact Model (JEDI), using an input-output framework to evaluate the employment impacts of wind power deployment. In 2008, the adapted this to parabolic trough technology, calling it JEDI-CSP. The model evaluates employment effects of deployment of 100 MW of CSP power in California, and the results show that during the construction phase, 455 job-years of direct employment and 3,500 job-years of indirect employment will be created. The main assumption is that the balance of plants equipment as well as all construction, installation and engineering works are provided by domestic suppliers and manufactured in California (NREL, 2008). Indirect or induced emplyment is created from the spending of income of people employed directly by CSP industry. The European Solar Thermal Electricity Association (ESTELA) conducted the second employment study of CSP, evaluating employment impacts in the Mediterranean region. The estimates of ESTELA are based on interviews with industrial stakeholders, and does not include the more robust methods found in the NREL analysis. The results project that 20 GW of CSP capacity deployment in the Mediterranean region will create up to 200,000 direct job-years by 2020 in the construction of installations and the manufacturing of components. The ESTELA study assumed that 50% of components necessary for CSP installations will be manufactured in Europe and 50% in North Africa (ESTELA, 2009).

Because ESTELA is an lobbying organization and its results were based on methods less transparent that the NREL study, there remains a need for robust and credible analysis of CSP job creation in North Africa. Such analysis, including the relative benefits of the vertical and horizontal technology transfer, could be an essential input into future negotiations on the terms of technology deployment between European and North African governments. To address this need, we adapted the JEDI-CSP model to the North African investment context, and applied it to the growth scenarios for CSP that have been developed for the region.

3 Methods

The goal of this research was to estimate direct and induced employment caused by both horizontal and vertical CSP transfer to the North African region. Therefore we used an input-output (I-O) model. The advantage of this model in comparison to analytical mixed qualitative and quantitative methods, on which the ESTELA study relied, is that it not only calculates the numbers of direct job-yeas, but also allows an estimation of induced job-years using a multiplier effect. A review of existing literature shows reliance on I-O models by policy-makers (Kammen et al., 2004).

First, we started with the JEDI-CSP model, which to our knowledge is the only existing model developed explicitly to capture employment effects from CSP (Stoddard, 2006). We base our modelling work on two assumptions, which we take from NREL studies of construction processes of CSP plants and logistic issues (NREL, 2008). First, we assumed that the share of materials for construction such as concrete rebar, equipment, roads and site preparation is constant, making up 95% of local production. Second, we assumed that labour for field erection is mainly done by local people, relying on 80% local labour for site-work and infrastructure, field erection, support structures, piping, and electrical works. Figure 2 shows the sets of investment parameters that we then adapted to North African conditions. We derive these data from several sources, most importantly fact-finding missions of Solarpaces to the North African countries, from databases and publications of the International Energy Agency and the World Bank (World Bank, 2009; IEA, 2009; Solarpaces, 2003).

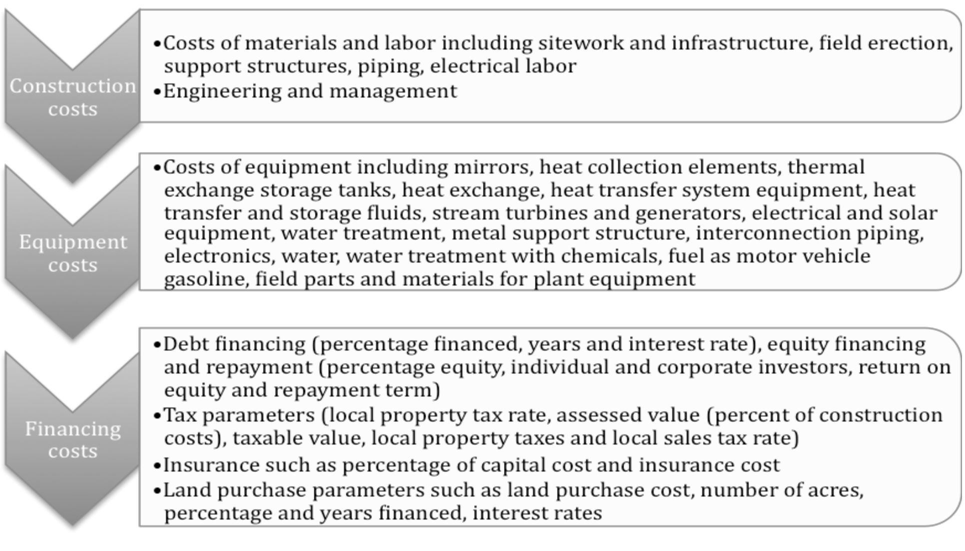

Figure 2: Groups of costs parameters.

Second, we examined the sensitivity of the number of direct and induced job-years generated by the CSP industry according to the share of components produced in the North African countries. We examine four scenarios:

- When all high and medium technology components are produced outside North Africa,
- When 40% of components are manufactured locally,
- When 60% of components are manufactured locally,
- When all 100% of components are manufactured in North African countries

One can describe horizontal technology transfer as taking place when the share of components and equipments manufactured locally is higher than 40%, a result of technology specific modelling conducted by the German government (Trieb et al., 2009). The preliminary assessment conducted by the World Bank shows that potentials of North African countries to manufacture components of the CSP plants are high. The basic infrastructure work, like installation of solar fields and construction of power blocks and storage systems will account roughly 17% of total CSP investment. This work as well as mounting structure in case when local companies can adapt manufacturing processes to produce steel and aluminium components with high quality, can be carries out by local people. The manufacturing of more complex components will require joint ventures with European companies or foreign direct investment to install new production facilities in the North African region (Climate Investment Funds, 2010).

Third, we focused analysis of particular growth scenarios on the country of Morocco. We chose Morocco because of its ambitious plans to deploy CSP capacities, and its ideal location to serve European energy markets (Walters, 2010). In November 2009, Morocco launched a $9 billion solar plan, foreseeing deployment of five CSP plants between 2015 and 2020 with a total capacity of 2,000 MW (National Agency for the Development of Renewable Energy and Energy Efficiency, 2010). One of these, already planned to be cited in Ouarzazate, will have a capacity of 500 MW, and will be an important step towards energy security of the country, which is currently heavily reliant on imported fossil fuels. The Ouarzazate will be the first plant developed under the CSP investment plan of the World Bank, with the Climate Technology Fund and the African Development Bank being two other potential contributors. It is expected that this project will create employment opportunities in CSP related industries (Climate Investment Funds, 2010). Existing electrical connections between Morocco and Spain would allow as well exports of electricity to Europe. The interconnections exist since 1997 and connect the electricity grid in the north of Morocco to the grid in the south of Spain across the Strait of Gibraltar. The capacities of these grids are 1400 MW.

4 Results

4.1 Plant based estimates

According to the adjusted parameters we were able to calculate the number of job-years in direct and induced employment generated per 100 MW of CSP capacity deployed in the region, following the four different scenarios regarding the share of components manufactured locally. Table 1 shows the results.

Table 1: Number of job-years created per 100 MW of CSP capacities

Jobs years per 100 MW	0%	40%	60%	100%

Planning and Construction	74	83	146	151
Materials and Components	126	240	284	463
Total Direct Jobs	200	323	430	614
Induced Jobs	1,520	2,455	3,268	4,666

These results allow us to reach three important conclusions. First, the number of job-years created in case when all components are manufactured locally exceeds the number of job-years created when all components are manufactured abroad by more than a factor 3 (614 job-years comparatively to 200 job-years). Second, in the case when all components are manufactured locally 100 MW of CSP capacities in North Africa create more job-years than 100 MW of CSP capacities in California (614 job- years comparatively to 455 job-years). Third, the number of induced jobs is as well higher (4,666 job-years comparatively to 3,500 job-years), likely because of the lower level of wages in North Africa compared to California.

4.2 Scenarios

Next, we scale up the number of job-years generated per 100 MW up to 20 GW of CSP capacity. We assumed that all 20GW were just CSP capacities and that they were deployed in the North African countries, but we examined two scenarios for technology transfer. Vertical transfer is based on our 0% components scenario in the previous section, while horizontal transfer is based on our 100% scenario. We compare the results of our calculations of direct jobs-years with results of ESTELA and NREL, and the indirect employment estimates with those of NREL alone.

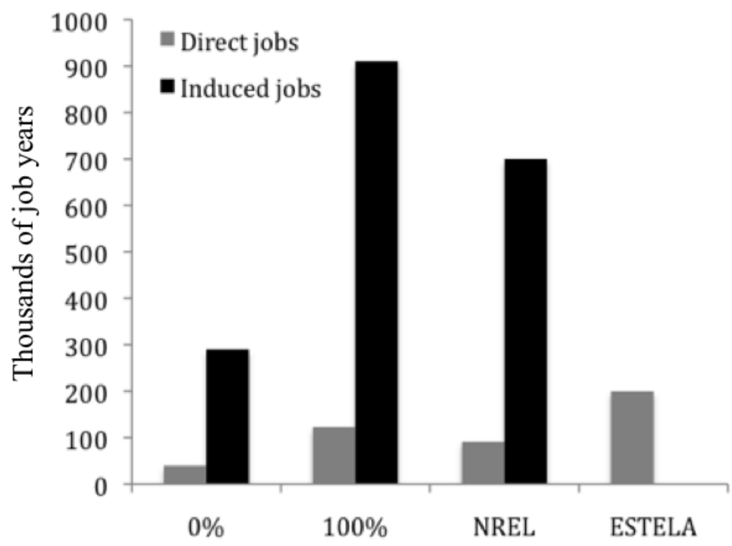

Figure 3: Scaled up comparison

In case of horizontal technology transfer, when all components are manufactured locally, the deployment of MSP, namely of 20 GW of CSP capacities, will create 122,600 direct job-years and more than 900,000 induced job-years. In case of vertical technology transfer, when all components are manufactured abroad, MSP will bring to North African only 40,000 direct job-years and less than 300,000 induced job-years. The estimations of NREL are between our 0% and 100% scenarios and assume that if all components are produced in California the deployment of 20GW of CSP capacities will bring 91,000 job-years in direct employment and 700,000 job-years in induced employment. The estimations of ESTELA are substantially higher, saying that MSP will create 200,000 direct job-years.

Next, we extrapolated these results to the plans of the Desertec Industrial Initiative (DII), namely to generate electricity from CSP that will be equal to 15% of the Europe's electricity demand by 2050, which translates to 700 TWh/y of electricity. In this case, vertical transfer would create 265,000 job-years in North Africa in case when all components are produced outside the region and 430,000 jobs-years if the share of components were 40%. This would result in between 2 and 3 million jobs-years respectively in induced employment, assuming that multiplier effects remain constant in the case of such large-scale development. Horizontal transfer would lead to 575,000 job-years in direct employment if more than a half of all components are produced in the region, and 820,000 job-years if North Africans produce all components. If the multiplier effects were still constant, this could lead to 6 million induced job-years.

4.3 Moroccan case study

We compared existing statistics for Morocco with our results on CSP employment, in order to estimate what CSP deployment consistent with the MSP would mean for the Moroccan labour market. In 2008 the Moroccan population reached 31 million people, of whom only 36.8% were economically active (World Bank, 2010). We base our analysis on four assumptions: that all 20 GW of CSP capacities will be deployed in Morocco; that all CSP installations will be constructed over the course of a five year period; that the rate of horizontal transfer will be the highest when all components are manufactured locally; and, that all newly employed directly by CSP industry people come from the number of unemployed people and not from other sectors of economy.

Four economic sectors can be affected directly by deployment of CSP capacities. These are mining and quarrying, manufacturing, electricity, gas and water supply and construction. Manufacturing is by far the largest employer among these sectors, employing 1.2 million people, while leaving 166 thousand trained workers unemployed. Construction employs another 0.8 million, leaving 108 thousand trained workers unemployed. Electricity, gas and water supply employs 45 thousand people, while mining and quarrying employ 42 thousand people, with less than 4,000 trained workers unemployed between the two sectors. (ILO, 2008). Our model suggests that deployment of 20 GW capacity would bring direct employment ranging between 40 and 125 thousand job-years, depending on whether vertical or horizontal technology transfer takes place. This could relieve, but not eliminate, unemployment on these four sectors.

The induced effects from CSP deployment, by contrast, would again be substantially greater. Looking to the structure of the Moroccan economy, it could take place in the following sectors: trade, hotels and restaurants, transport, telecommunications, financial services, and real estate. The increased government revenues from CSP could also influence employment in public administration, defence, and education. In 2008, the largest share of the population had employment in trade, hotels and restaurants (1.7 million), followed by the public sector, with 1.5 million, while transport and telecommunications employed 424 thousand, and the real estate and financial sectors employed 168 thousand people combined. The number of officially registered unemployed in these sectors in 2008 reached 270 thousand, with just over half of these in trade, restaurants and hotels (ILO, 2008).

Deployment of 20 GW of CSP capacity in Morocco would not only bring employment opportunities, but would also bring restructuring to the Moroccan economy of horizontal technology transfer were to take place. As Figure 5 shows, the indirect job-years generated by CSP deployment would meet or exceed the number of currently unemployed trained workers in the relevant economic sectors. Even scaling these down by a factor of five—given the five year construction schedule—means that indirect employment from CSP deployment could approach total unemployment in the service sector. This would likely lead to some of those listed as unemployed in sectors such as manufacturing to jump over into more service-oriented activities.

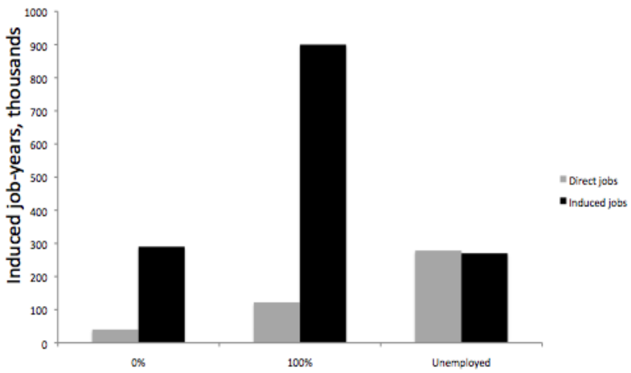

Figure 5: Employment created in case of horizontal and vertical technology transfer and the number of unemployed where creation of direct and induced job-years is possible

5 Discussion

The results show the number of job-years that would be created in direct and induced employment in case of large-scale deployment of CSP capacities in North Africa. The first interesting conclusion to draw from them is that the results of the ESTELA study appear optimistic. Our results showed an increase in employment compared to the NREL study for California, not surprising because of difference in labour costs, but substantially less employment than the 200,000 direct job-years estimated by ESTELA. In the case of completely vertical technology transfer, we estimate only 40,000 direct job-years created, while the completely horizontal transfer, assuming 100% local production, would generate 125,000 direct job-years.

CSP deployment could begin to make difference for North African economies, but largely to the extent that local manufacturing of CSP components does take place, given horizontal technology transfer. The total, direct and indirect, job-years created by the DII scenario would be 2 million if 40% of component manufacturing were local, and rising to 6 million if it were eventually 100%. If this were spread over 20 years, it would lead to annual employment of between 100,000 and 300,000. Under vertical technology transfer, fewer than 100,000 jobs would be created. These numbers compare with total unemployment of 7 million in the North African region (ILO, 2009).

The results would be different if a disproportionate share of deployment were to take place in a single country, such as Morocco. We examined a case where the entire 20 GW of the MSP were located in Morocco, due to its comparative advantage in terms of proximity for transmission and a pro-active government. Our assumption that development would take place over 5 years, leading to 4 GW average annual deployment, is also not inconsistent with the longer terms growth scenarios of the DII. The resulting job creation under a horizontal technology transfer strategy could be substantially enough to push the country towards a more service-oriented economy, closer in structure to those of industrialized countries. On the one hand, this suggests that North African countries could have an incentive to compete against each other for CSP deployment. On the other hand, it suggests that any country that wins such a contest would also have to ensure that it was prepared for an eventual end to the CSP construction boom, once European import needs were met.

It is important to note that any assumption of 100% local production seems unrealistic in the short run. Currently the major manufacturers of components for CSP industries are located outside North Africa, but the probability exists that they will move to North Africa to be able to reduce transport and labour costs. A benchmark example could be the aerospace or auto industries in Europe that use components produced in North Africa. Several of these components have similar components to CSP industries. These include manufacturing of glass, mechanical engineering and electrical equipment. The opportunity exists that the auto and aero suppliers to Europe will be able to diversify their production to CSP components. Nevertheless, these processes take time.

The limitations of this study lay in the scope of our research work. The main scope was to analyze potential economic benefits of CSP component manufacturing industries in the North African region in terms of direct and induced employment. It was out of the scope of this study to conduct a more detail analysis of manufacturing processes of components. Therefore, we were able to give a general evaluation of the number of new job-years created to be able to compare employment effects under vertical and horizontal technology transfer scenarios. Other limitations are connected with our assumptions that in case of Morocco all 20 GW will be constructed in a five year period. But at the current stage of research the uncertainty is too high about the speed of construction of CSP installations and we needed these results for comparison of impacts from vertical and horizontal technology transfer under conditions of a concrete country.

This study could have implications for international, regional and national policies dealing with the issues of technology transfer. It shows that horizontal technology transfer could have significant impacts in terms of induced employment, especially if particular countries gain a disproportionate share of new projects. This will allow to provide employment to most of officially unemployed people as well as to empower women who are currently not officially registered as unemployed and do not participate actively in the income generating activities and to decide emigration problems.

Additional research is needed on the process of CSP transfer to the North African region itself. There is need for multidisciplinary study evaluating the perceptions of stakeholders regarding the horizontal and vertical technology transfer processes, and the feasibility of both options in the region. Behavioural and policy research needs to focus on the motivations of countries that are leaders in manufacturing of renewable energy components to participate in the technology transfer. It is also important to focus on motivation of private companies that are leaders in research and development of CSP, and whether they will participate in technology transfer without harming their balance sheets and returns to shareholders. Secondly, feasibility studies could evaluate local existing conditions for horizontal and vertical CSP technology transfer, including local capacities to produce high quality manufacturing components and existing scientific and industrial base. Such research would assess potentials for CSP manufacturing industry in the North African region, including cost reduction potentials for key CSP components and establishing of a roadmap for development of local CSP manufacturing.

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