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DESERTEC: EUROPE—MIDDLE EAST—NORTH AFRICA COOPERATION FOR SUSTAINABLE ENERGY

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Abstract

The DESERTEC concept for energy, water, and climate security was published by the Trans-Mediterranean Renewable Energy Cooperation (TREC) a decade ago in late 2007 in form of a whitebook presented at the European Parliament. Being as fascinating as resilient, it created big expectations and a considerable hype that was tangible in many international public and political discussions. Nevertheless, the original concept was lost on the way, when a multitude of experts and consultants started to speculate about a futuristic infrastructure called supergrid instead of concentrating on a concrete first point-to-point power line interconnecting a flexible solar power plant in the desert (provider) with a demand center in Europe (offtaker). The article at hand explains the original concept, diversions that lead to failure, and options to restart a concrete business case for a solar energy partnership in the EUMENA region.

1. *Introduction*

About 2,000 years ago, the Roman Empire, by then ranging all around the Mediterranean Sea and north up to the British Islands, tried to build a wall across Europe—the Limes—in order to keep the Barbarians out that were trying to enter from Eastern-Central Europe. History tells us that this venture failed, and little later, the Roman Empire vanished due to increasing social unrest caused by the greediness and decadence of its leading class.

Although it is theoretically possible to learn from history, it is practically difficult, especially if actors change roles: today, the former ‘Barbarians’ are trying to build walls across Europe in order to keep out the former ‘Romans’ from all around the Mediterranean that are now coming to the heart of Europe in the frame of the present refugee crisis.

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In the meantime, the leading class may also have changed, although perhaps not as much as would be desirable.

In this context, the title of this paper looks extremely ambitious in several senses: firstly it treats Europe, Middle East, and North Africa (EUMENA) as if it was one region, secondly, it re-starts thinking about the venture of energy cooperation within this region and thirdly, it aims at sustainable energy supply. In times of blooming populism, separatism, and nationalism each one of these innovations alone looks like unreachable fiction, and much more altogether.

Furthermore, the title above is very similar to that of a Whitebook that was published a decade ago by the Trans-Mediterranean Renewable Energy Cooperation in 2007[1] and a paper published by the German Aerospace Center DLR[2]. After being presented at the European Parliament, this paper started an unequaled hype about the so-called DESERTEC Initiative that had in mind to reach the abovementioned goals, but came to a sudden end in late 2014. So, recent history even tells us that our title story already had its chance, but failed to become reality.

Why then should we write (or read) another paper about this issue? Perhaps, in order to try to learn from history?

2. *The Vision of Cooperation for Sustainable Energy*

A major lesson we can learn from the DESERTEC history is to not mix up first steps with long-term visions. Figure 1[3] illustrates the concept of EUMENA solar energy cooperation developed by the German Aerospace Center (DLR) and the Trans-Mediterranean Renewable Energy Cooperation (TREC) and later followed up by the DESERTEC Foundation that is based on producing flexible power on demand in

[1] DESERTEC Foundation, White Book presented to the European Parliament, November 2007, 4th Edition from February 2009, accessed March 23, 2018. http://www.dun-eumena.com/sites/default/files/files/doc/trec_white_paper.pdf /.

[2] Trieb, Franz, and Hans Müller-Steinhagen, "Europe—Middle East—North Africa Cooperation for Sustainable Electricity and Water," *Sustainability Science* 2.2 (2007): 205–219. http://link.springer.com/article/10.1007%2Fs11625-007-0025-x#/page-1.

[3] Trieb, Franz et al., *Bringing Europe and Third Countries Closer Together through Renewable Energies—WP3 North Africa Case Study*. (Project Report 2015. Intelligent Energy Europe Contract No.: IEE/11/845/SI2.616378), accessed May 15, 2017. http://better-project.net/sites/default/files/D3.5.%20Final%20Report%20on%20the%20EU-North%20Africa%20case%20study_0.pdf.

concentrating solar thermal power stations (CSP) in the desert regions of MENA and sending it to European demand centers via High Voltage Direct Current (HVDC) links. A study published in 2006 showed the concept and potential impact of such venture.[4]

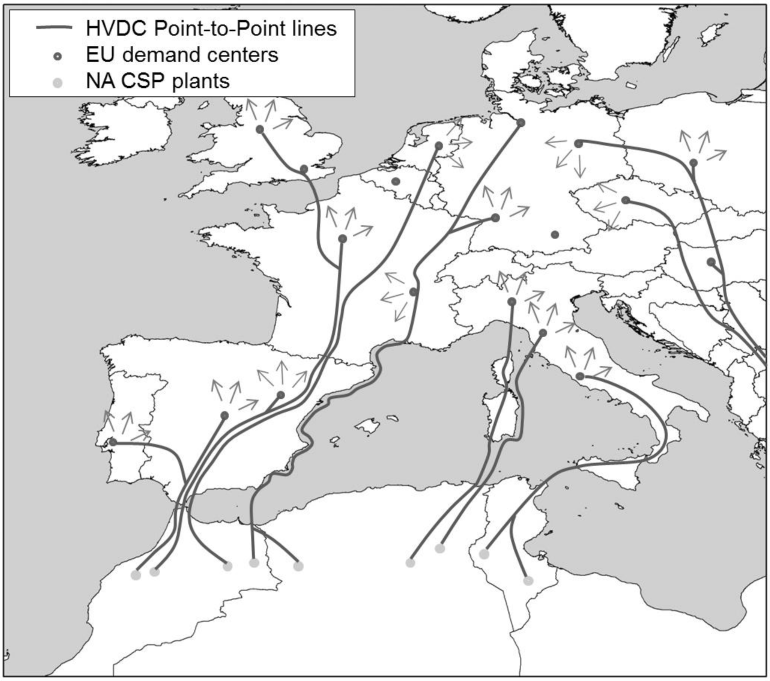

Figure 1. Sketch of point-to-point HVDC power lines interconnecting potential CSP plants in North Africa with demand centers in Europe

A point-to-point infrastructure of this type can be quantified precisely in technical and economic terms, with a specific site and size of the CSP plant in MENA, a specific center of demand where the power is fed into and distributed within the European electricity grid, and a specific HVDC power line connecting both points. The original task was to find a business case for such an infrastructure including provider region, off-

[4] Trieb, Franz et al., *Trans-Mediterranean Interconnection for Concentrating Solar Power (TRANS-CSP). German Aerospace Center (DLR)* (Stuttgart, 2006), accessed May 15, 2017. www.dlr.de/tt/trans-csp.

taker region and transit corridors for solar electricity from CSP with solar thermal energy storage that would have a high added value, as it can be produced and delivered just as required by the European demand centers.

Unfortunately, except for a first sketch in Chapter 5 of the TRANS-CSP study report [5], the illustration of the original point-to-point interconnection concept was not published in the early years, because the long-term vision of interconnecting all such power lines and all kinds of renewable energies in EUMENA was considered to be much more appealing to policy and the public. In fact, that vision lead to the creation of the DESERTEC Foundation and the DESERTEC Industrial Initiative in 2009, but at the same time it also put that initiative on a wrong track, as a potential, concrete, and quantifiable business case of a first point-to-point interconnection was then concealed by a sexier but less tangible vision of a futuristic infrastructure called “Supergrid”. Due to that change of wording and point of view, solar electricity imports were suddenly (mis)understood as long-term issue rather than short-term business opportunities.[6]

While the general idea of importing solar electricity from MENA to Europe was generally received well, the long-term supergrid vision and the idea of first concrete point-to-point interconnections for dispatchable solar power were increasingly mixed up and confused. The confusion became even greater when a third option, the interconnection of national electricity grids of neighboring countries, was also mixed up with the other two concepts.

The third option, interconnecting neighboring national electricity grids, has several advantages for both sides, like sharing load and power plant capacity that may lead to compensation effects and cost savings. This measure can be considered as business as usual, but it does not necessarily lead to a business case for solar electricity exports from MENA to Europe. In fact the Maghreb Region in North Africa has in the meantime been connected to and synchronised with the European

[5] Trieb et al., Trans-Mediterranean Interconnection for Concentrating Solar Power (TRANS-CSP), 129–136.

[6] Zickfeld, Florian et al., *DESERT Power 2050—Perspectives on a Sustainable Power System for EUMENA* (Munich: Dii, 2012), 71–72, accessed May 15, 2017. http://dii-desertenergy.org/publications/.

electricity grid via Spain and Morocco[7], but due to strongly growing power demand in North Africa and persistent overcapacity in Spain, electricity flows from North to South rather than in the opposite direction. The theory of increasing renewable power production in North Africa until surpluses would flow northwards is not resilient and does not provide a business case. Occasional electricity surplus arriving in Europe would have a rather low value or even would be considered as disturbance and would not generate significant income for North Africa.

Regarding the supergrid, an open question was related to who would be in charge of building and operating supergrid interconnections to facilitate long-distance solar electricity trade between MENA and EU. In 2012 the DESERTEC Industrial Initiative (later called Dii GmbH) published its vision of an interconnected electricity grid in EUMENA in a comprehensive report, proposing a scenario for EUMENA with about ninety percent renewable electricity shares by 2050. The scenario was mainly based on variable generation from wind power and photovoltaics, and a supergrid was needed to distribute this large fluctuating power capacity anywhere in EUMENA. This virtual grid infrastructure was supposed to balance out fluctuations of supply and demand.[8]

The supergrid was modelled assuming a node in the middle of each country that was interconnected to other nodes by virtual HVDC power lines with sufficient transfer capacity. It was assumed that all electricity would freely flow through that supergrid in order to be produced and consumed anywhere in all connected countries.

As an example of the tremendous effort of such enterprise, the study revealed a necessary net transfer capacity (NTC) of the Spanish electricity grid of 170 gigawatt that would be about 55 times higher than the NTC of the presently existing grid infrastructure in Spain of about three gigawatt. Similar expansions of grid infrastructure would also be required in other countries. It was particularly interesting to see the evolution of the supergrid vision in the minds of its propagators: in the

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[7] ENTSO-E—European Network of Transfer System Operators for Electricity, *Regional Investment Plan 2015—Continental South West Region* (Brussels: ENTSO-E, 2015), 18–19, accessed May 15, 2017. https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202016/rgips/Regional%20Investment%20Plan%202015%20-%20RG%20CSW%20-%20Final.pdf.

[8] Zickfeld, Florian et al., *DESERT Power 2050—Perspectives on a Sustainable Power System for EUMENA* (Munich: Dii, 2012), 71–72, accessed May 15, 2017. http://dii-desertenergy.org/publications/.

course of the Dii analysis, the supergrid had become a simplistic, completely virtual infrastructure, with one virtual node at the geographic center of each country, and single lines with extremely high transmission capacity interconnecting each node to its neighbors, which represents not only a much higher degree of abstraction, but also a severe change of paradigm when compared to the original concept illustrated in Figure 1.

In 2012, a doctoral thesis by Stetter revealed that introducing point-to-point CSP-HVDC interconnections according to the original TRANS-CSP study would leave existing EUMENA grid infrastructure undisturbed in spite of achieving similarly high renewable energy shares.[9] Providing only fifteen to twenty percent dispatchable power from North African CSP plants to complement and compensate variable input from wind power and PV in Europe, and making use of flexible renewable sources in Europe like biomass, hydro-, and geothermal power, the necessary effort for installing grid extensions, and electricity storage facilities was reduced significantly. Unfortunately the publication of the Dii supergrid vision in 2012 started a relatively destructive public and political discussion on solar electricity imports. As a consequence Dii GmbH abandoned this idea officially by the end of 2014. While this again created a lot of attention, the work of Stetter that shows the positive impact of potential CSP-HVDC point-to-point interconnections was only published within the scientific community and widely ignored by policy and the public.

In 2012 the European Agency for Competitiveness and Innovation (EACI) commissioned a study with the title “Bringing Europe and Third Countries Closer Together through Renewable Energies—BETTER” in order to find out major barriers for renewable energy cooperation with neighbor regions and how they could be overcome. In the case of North Africa the answer was quite simple: the study recommends to turn back from the abstraction of a virtual supergrid infrastructure and instead concentrate on a concrete business case of a first point-to-point HVDC line interconnecting a flexible concentrating solar power plant in North

[9] Stetter, Daniel, “Enhancement of the REMix Energy Model—Global Renewable Energy Potentials Optimized Power Plant Siting and Scenario Validation”. PhD diss., University Stuttgart and DLR, 2012), xx, accessed May 15, 2017. https://elib.uni-stuttgart.de/handle/11682/6872?locale=en.

Africa with a European center of demand, as described in the TRANS-CSP study from 2006.[10]

The role of such infrastructure of providing access to remote sources of energy, the challenge related to its intercontinental size, and the required strategies for its realisation are analogous to the role, challenges, and success strategies related to conventional oil- and gas pipelines. Therefore, we call this infrastructure 'Solar Electricity Pipeline (SEP)'.

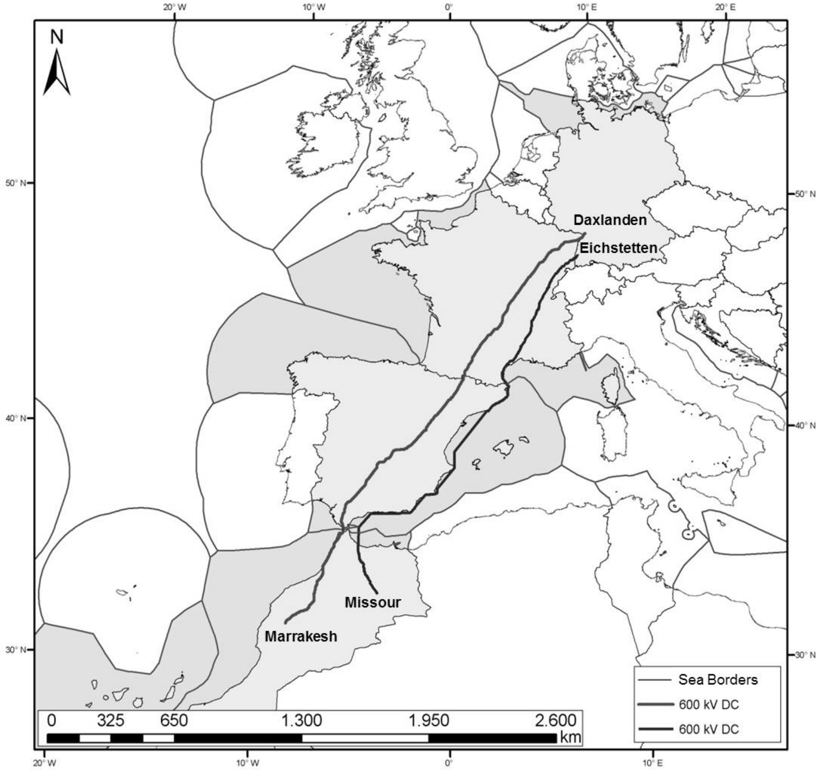

Figure 2. Example of two potential alternative HVDC transfer corridors from Marrakesh and Missour in Morocco to Daxlanden and Eichstetten in Germany identified by demand and supply side assessment and geographical analysis of the region.

[10] Trieb et al, *Bringing Europe and Third Countries Closer Together through Renewable Energies*, 160–172.

The North Africa Case Study of the BETTER Project concluded that the original concept of point-to-point interconnections has not yet been but should be assessed in the frame of detailed feasibility studies. Also, as an example, a first rough picture of such an infrastructure, interconnecting potential CSP plants in Morocco with points of high demand in Germany was presented (Figure 2)[11], the layout of the CSP plants being such that they could actually substitute the last nuclear power stations scheduled to be shut down in Germany in 2022. However, the study also concludes that the years lost by the supergrid diversion will make it difficult if not impossible to finalise such infrastructure in due time before that date.

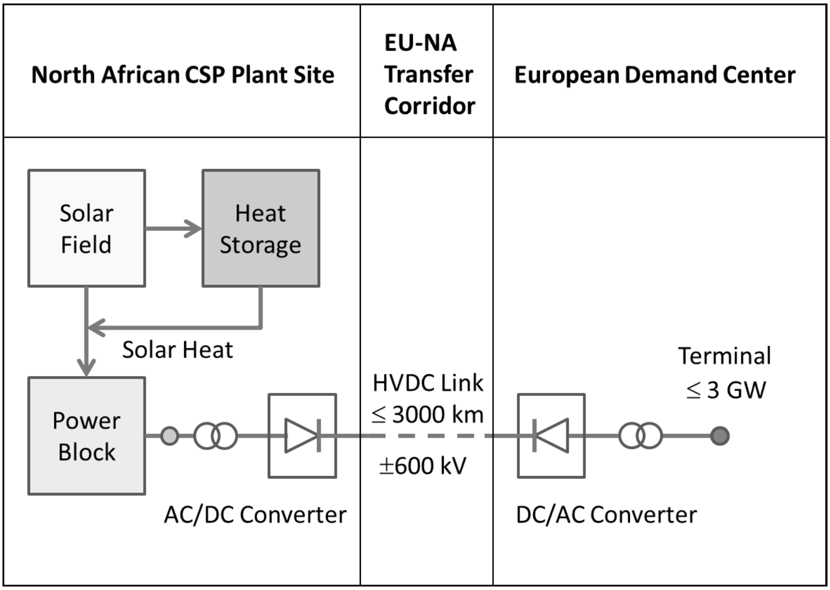

Figure 3. Components of a CSP-HVDC Solar Electricity Pipeline (SEP).

[11] Hess, Denis, "Fernübertragung regelbarer Solarenergie von Nordafrika nach Mitteleuropa," (Diploma Thesis, University of Stuttgart, 2013), 84, accessed May 15, 2017. http://elib.dlr.de/83385/.

3. *Technical Background of Solar Electricity Transfers*

The technical background of potential CSP-HVDC Solar Electricity Pipelines is illustrated in Figure 3. The elements required for such infrastructure are all commercially proven technologies: a solar power station including concentrating solar thermal collector field, high-temperature heat storage and steam cycle power block, transformers and rectifiers that allow for a conversion from low voltage to high voltage and from Alternating Current (AC) to Direct Current (DC) and vice-versa, and High-Voltage-Direct-Current (HVDC) overhead-, underground- or sea cables for efficient long-distance electricity transfer .[12] For security reasons the maximum allowed outage capacity of single production units in Europe is restricted to three gigawatt[13], which also accounts for such interconnections.

The added value of solar electricity imports at the terminal stems from the flexibility of a CSP power plant that is capable of providing firm and flexible capacity just as needed by the load, no mater if the sun shines or not. The heat needed for steam- and power production comes either directly from the solar field, from the heat storage, or—as last resort—from a secondary fuel used for steam generation, which may be natural gas, fuel oil, coal or—preferably—biomass. In this way, a solar electricity pipeline will provide firm capacity and power on demand just like a conventional power plant, independent from sunshine, but will consume much less or even no fossil fuel to do so.[14]

3.1. *Concentrating Solar Thermal Power Plants*

In contrast to wind- and photovoltaic power plants, a CSP plant is capable of producing electricity on demand, not only when the wind blows or when the sun shines. This is due to the fact that a CSP plant uses a conventional steam cycle for power generation. A conventional power plant uses coal or natural gas to generate pressurised high

[12] ABB, “HVDC”, web page on HVDC applications, accessed May 15, 2017. http://new.abb.com/systems/hvdc.

[13] ENTSO-E—European Network of Transmission System Operators for Electricity, “Continental Europe Operation Handbook,” accessed May 15, 2017. https://www.entsoe.eu/publications/system-operations-reports/operation-handbook/.

[14] Trieb, Franz, Tobias Fichter, and Massimo Moser, “Concentrating Solar Power in a Sustainable Future Electricity Mix,” *Sustainability Science* 9.1 (2014): 47—60. DOI 10.1007/s11625-013-0229-1.

temperature steam that drives a turbine to generate electricity. Instead of coal or gas, a CSP plant uses heat from a solar collector field for the same purpose. The size of the solar field can be extended to produce extra heat that can be stored for night-time operation or for times with little sunshine, thus allowing for steam generation and power production at any time, not only during the sunny hours of a day. In principle, a CSP plant can be operated just like a conventional power plant, but if correctly designed and placed on a good sunny site, it will not consume any or very little fossil fuel.[15]

This explains the high value of this type of power plant: it provides dispatchable power and firm capacity that can be freely adapted to the need of consumers, and at the same time it makes use of a very large and renewable source of energy. This makes CSP comparable to hydropower, biomass or geothermal power with however much larger technical and economic potential than those resources.[16] The availability of CSP depends very much on the specific site where such plants are installed: solar energy can only be concentrated on clear days to produce high temperature heat, and the heat storage capacity is limited for technical and economic reasons to about 24 hours of full load operation. This means that the number of clear days per year directly defines the availability of solar power from a CSP plant.

Another impact on availability is related to the position of the sun in the sky: at high latitudes like in Europe, the sun is very low on the sky in winter, which leads to rather unfavorable angles of incidence and low efficiency of the concentrating solar collectors, while in lower latitudes like in MENA, the geometrical relations between sun and collector are more favorable all over the year. This and the higher number of sunny

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[15] Trieb, Franz, Tobias Fichter, and Massimo Moser, "Concentrating Solar Power in a Sustainable Future Electricity Mix," *Sustainability Science* 9.1 (2014): 47—60. DOI 10.1007/s11625-013-0229-1.

[16] Trieb, Franz et al., *Characterization of Solar Electricity Import Corridors from MENA to Europe—Export Potentials, Infrastructures and Costs* (Stuttgart: DLR, 2009), 79-80. http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/publications/Trieb_Presentation_SolarPaces_Berlin_09-2009-02.pdf; and Technical Note TN2.3 for REACCESS project, funded by European Commission 7th Framework Programme. www.dlr.de/tt/csp-resources.

days leads to a much better availability of power from CSP plants in MENA than in Europe (Figure 4)[17].

In principle it is possible to extend the technical components of such a plant, e.g. in order to avoid fossil fuel for co-firing by using biomass for additional steam generation, or using PV during the day to cover the internal parasitic electricity demand for collector tracking, pumping, and control. It is also possible to form virtual power stations that operate like one single unit including other renewable sources.

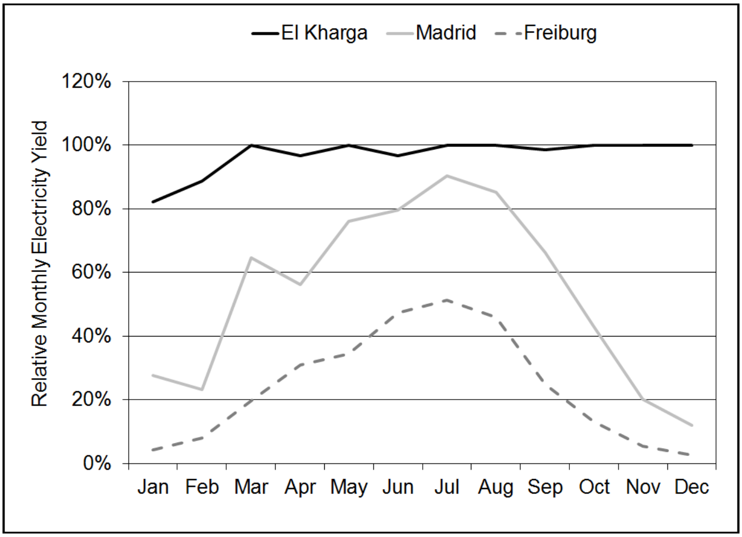

Figure 4. Modelled solar power availability of identical CSP plants with large solar field and heat storage at different sites in Egypt (El Kharga), Spain (Madrid) or Germany (Freiburg)..The availability of the plant in El Kharga, Egypt is equivalent to over 7,500 full load operating hours per year, similar to the typical utilisation of nuclear plants, but at lower cost than those.

Concentrating Solar Power plants are in operation world wide since the 1980ies. Recently, a large plant of this type with 160 megawatt rated

[17] Trieb et al., *Trans-Mediterranean Interconnection for Concentrating Solar Power (TRANS-CSP)*, 55–56; and Trieb, Franz., Tobias Fichter, and Massimo Moser. “Concentrating Solar Power in a Sustainable Future Electricity Mix.”

power capacity has been commissioned in Morocco (Figure 5).[18] World wide existing cumulated CSP capacity was about five gigawatt (5,000 megawatt) in the year 2015, which still is little compared to 230 gigawatt photovoltaic and 430 gigawatt wind power.[19] Different CSP technologies are available like Parabolic Trough, Linear Fresnel or Central Receiver collectors. Molten salt, concrete or rocks are used for heat storage, and Steam Turbine (Rankine) or Gas Turbine (Brayton) Power Cycles are used for power generation.[20] Up to now most CSP capacity has been installed in the US and Spain. Lately, China has set up an ambitious plan to install five gigawatt additional CSP power capacity until 2020.[21]

Figure 5. Steam cycle power station and solar heat storage in the center of the concentrating solar thermal collector field of NOOR 1, a CSP plant with 160 megawatt power capacity at Ouarzazate, Morocco commissioned in early 2016.

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[18] © MASEN

[19] REN21—Renewable Energy Policy Network of the 21st Century, "Renewables 2016 Global Status Report" (Paris: REN21, 2016), 19, accessed May 15, 2017. http://www.ren21.net/REN21Activities/GlobalStatusReport.aspx.

[20] ESTELA—European Solar Thermal Electricity Association, accessed May 15, 2017. http://www.estelasolar.org/ste-means-eu-energy-security/the-ste-technologies/.

[21] CSP Focus, "China Officially Targets 5GW of CSP Allocation by 2020," accessed May 15, 2017. http://www.cspfocus.cn/en/market/detail_193.htm.

3.2. *High Voltage Direct Current Transmission Links*

In technical terms, the installation of HVDC power lines over thousands of kilometres is challenging, but it also is state of the art. The option of including a dispatchable, but remote source of renewable energy in the national power plant portfolio by transferring electricity over long distances from a remote power plant to a local centre of demand has a fifty year long history on all continents, except in Europe. Examples are the HVDC interconnections of the Inga and Itaipu hydropower plants in Central Africa and Brazil respectively, the HVDC lines interconnecting geothermal power stations on one island with centers of demand on other islands in the Philippines or the HVDC links from hydropower dams to centers of demand with a total capacity of almost forty gigawatt in China.[22]

While HVDC links in China have up to seven gigawatt capacity each, an HVDC interconnection in Europe would be limited by the maximum outage capacity a single unit is allowed to have. This capacity is limited to about three gigawatt, because this is the maximum capacity that can be compensated by the European interconnected system in case of failure.[23]

In order to provide high flexibility for power supply, HVDC interconnections in Europe would be based on Voltage Source Converter (HVDC-VSC) technology that allows for black start and for generation of reactive power and is highly flexible for part load operation or stand-by. While maximum voltage in some HVDC links in China reaches up to ± 1,000 kilovolt, European HVDC-VSC links would be limited to about ± 600 kilovolt operating voltage.[24] Moreover, the HVDC links would use bipolar interconnections with a positive and a negative pole and a third, redundant line that helps to keep up fifty percent of capacity in case one of the main lines breaks. HVDC links can be composed of different sections of overhead lines, underground cables or sea cables depending

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[22] ABB, "HVDC", web page on HVDC applications, accessed May 15, 2017. http://new.abb.com/systems/hvdc.

[23] ENTSO-E—European Network of Transmission System Operators for Electricity, "Continental Europe Operation Handbook."

[24] Hess, Denis, "Fernübertragung regelbarer Solarenergie von Nordafrika nach Mitteleuropa," (Diploma Thesis, University of Stuttgart, 2013), accessed May 15, 2017. http://elib.dlr.de/83385/.

on local demands, like e.g. bridging large water bodies or environmentally sensitive areas like bird migration routes.

3.3 *CSP-HVDC Overall System Performance*

On average over the year, 15–17 percent of solar energy reaching a concentrating solar collector field can be transformed into net electricity output of a CSP plant. While typical AC/DC or DC/AC converter stations lose about one percent of power input each, typical losses of the HVDC overhead lines with an operative voltage of ± 600 kilovolt are in the order of three to four percent per 1,000 kilometre transfer distance. Including all losses, the overall annual efficiency of CSP-HVDC imports from Morocco to Germany over 2,600 kilometre distance referring to net electricity at the European center of demand versus solar energy input to the North African plant would typically be in the order of 14 ± 1 percent. This value is comparable to the overall efficiency of present grid-connected PV systems. However, the electricity output of CSP-HVDC links can be adapted to demand and provide dispatchable power just as required by consumers and for grid stabilisation, which is a strong added value of this type of power generation. A techno-economic analysis of potential CSP-HVDC interconnections from MENA to Europe has been published by Trieb et al in 2012.[25]

Typical technical and economic characteristics have been obtained from modelling of a potential solar electricity pipeline reaching from Morocco to Germany. The model results shown in Table 1 are based on first estimates of the technical and economic performance of such an infrastructure.[26]

[25] Trieb, Franz et al., "Solar Electricity Imports from the Middle East and North Africa to Europe," *Energy Policy* 42 (2012): 341–353.

[26] Hess, "Fernübertragung regelbarer Solarenergie von Nordafrika nach Mitteleuropa"; Trieb et al, *Bringing Europe and Third Countries Closer Together through Renewable Energies*, 192–218.

Power capacity:	ca. 3 GW (30 CSP plants á 100 MW)
Electricity produced:	ca. 800 TWh (20,000 GWh/year x 40 years)
Solar collector field area:	ca. 300 km²
Area of oasis incl. solar collector field	ca. 600 - 900 km²
Length of HVDC link:	ca. 2,600 km
Transmission losses of HVDC link:	ca. 10%
Planning and construction time:	ca. 10 years
Water consumption of the CSP plant:	ca. 10 million m³/year
Production of sea water desalination plant:	ca. 150 million m³/year
Electricity consumption of desalination plant:	ca. 100 MW, 600 GWh/year
Length of water pipeline from sea shore:	ca. 300 km
Direct employment:	ca. 5,000 persons
Operation time:	ca. 40 years
Electricity cost CIF Germany:	ca. 0.12 €/kWh (excl. taxes)
Investment incl. HVDC transfer and water:	ca. 30 billion €
Investment Desalination plant:	ca. 2 billion €
Annual turnover:	ca. 2.4 billion €/year
Compensation payment for land use:	ca. 50 million €/year

Table 1. Estimates of some techno-economic performance indicators of a solar electricity pipeline project.

4. *Economic Performance and Market Perspectives*

The BETTER project provides a first rough estimate of the economic performance of such an infrastructure with 1.5 gigawatt net capacity and roughly ten billion kWh annual electricity production equivalent to about 6,500 full load operating hours—including a CSP plant with thermal energy storage, an HVDC link across 2,600 kilometre from Morocco to Germany according to Figure 3 and the necessary infrastructure for seawater desalination and transport to cover the plant's freshwater demand, revealing a CAPEX of about 15 billion Euro.[27] The specific investment of such infrastructure of around 10,000€ per kilowatt would be lower than e.g. that of the nuclear power plant Hinkley Point C planned recently in the UK with equivalent capacity and power output.[28] With a weighted average cost of capital (WACC) of about five percent per year and an OPEX of 0.045€/kWh including compensation payments for the land used by the total infrastructure in all countries involved, a

[27] Ibid; Trieb, et al., "Solar Electricity Imports from the Middle East and North Africa to Europe".

[28] European Commission, "State Aid: Commission Concludes Modified UK Measures for Hinkley Point Nuclear Power Plant are Compatible with EU Rules" accessed May 15, 2017. http://europa.eu/rapid/press-release_IP-14-1093_en.htm.

total average electricity cost of around 0.12€/kWh for first projects around 2025 and 0.07 to 0.11€/kWh for later ones could be achieved.[29]

This cost level looks rather high compared e.g. to the cost of electricity from wind power or coal, but this is natural, as CSP-HVDC imports represent a higher quality, being at the same time dispatchable as power from a coal plant but also renewable and emission-free like wind power. As this quality is hard to find in Europe, we have here a promising business case for solar electricity imports (Table 2)[30].

From the European off-taker point of view, the question is not so much whether domestic or imported wind- or photovolataic power would be cheaper or more expensive than CSP imports. The question is whether there is an added value for CSP imports in Europe, just like there is obviously an added value for fuel oil and natural gas imports, because these are highly dispatchable, valuable forms of energy. On the other side from the MENA point of view, there is no other form of energy except oil and gas with such added value that may find an interested off-taker when exported to Europe.

Large scale international investments suffer from considerable risk perception, especially when talking about regions like North Africa and the Middle East. High risk always means high interest rates of banks and private equity investors, which translates to high capital cost of such projects. Especially renewable energy projects—that are primarily based on capital investment—risk becoming unprofitable if expected capital cost is high.

Mitigating the risk of such projects is therefore a very effective measure to reduce the cost for consumers without the need of providing subsidies like soft loans or grants. One of the best measures is a power purchase agreement between credible partners that might be backed by international guarantees.[31] Making solar electricity pipelines very good (AAA) investment opportunities will certainly trigger real world projects

29 Trieb et al., "Solar Electricity Imports from the Middle East and North Africa to Europe".

30 Trieb et al, *Bringing Europe and Third Countries Closer Together through Renewable Energies*, 160–172.

31 Waissbein, Oliver, Yannik Glemarec, Hande Bayractar and Tobias S. Schmidt, *De-risking Renewable Energy Investment—A Framework to Support Policymakers in Selecting Public Instruments to Promote Renewable Energy Investments in Developing Countries* (New York, United Nations Development Programme (UNDP), New York, 2013), accessed May 15, 2017. www.undp.org/drei.

in the short and medium term. Unfortunately due to the DESERTEC failure and the related misconceptions, political support for such enterprise is at the moment at its historical minimum, just as if all possible support was already spent by the DESERTEC initiative. A revival of support can only be expected if the original concept of concrete point-to-point solar electricity pipelines is finally understood and pursuit by serious entrepreneurs.

Source	**Type**	**Quality**	**North Africa**	**Europe**	**Business Case**
Biomass	renewable	dispatchable	scarce	available	no
Hydropower	renewable	limited dispatchable	scarce	available	no
Geothermal	renewable	limited dispatchable	scarce	scarce	no
CSP	**renewable**	**dispatchable**	**plentiful**	**scarce**	**yes**
PV	renewable	intermittent	plentiful	plentiful	no
Wind Power	renewable	intermittent	plentiful	plentiful	no
Coal / Lignite	fossil	limited dispatchable	not available	available	no
Natural Gas	**fossil**	**dispatchable**	**available**	**scarce**	**yes**
Oil Products	**fossil**	**dispatchable**	**available**	**scarce**	**yes**
Nuclear	fossil	limited dispatchable	not available	available	no

Table 2. Quality and availability of renewable energy and fossil fuel resources in Europe and North Africa and opportunities for a potential business case for exports from North Africa to Europe.

5. *Political Framework*

The possibility of producing renewable energy in the Middle East and North Africa region (MENA) and exporting it to the European Union (EU) has received a lot of interest among scientists, industry, and policy makers alike. However, despite the promising outcomes of such cooperation, numerous barriers of different nature remain that prevent this concept from becoming a reality. Among other pre-requisites such as having sufficient financial resources to undertake such power plant investments, designing a sustainable energy system for the Euro-Mediterranean region requires strong political will as well as international collaboration and coordination among various actors. To date, various initiatives, policies, and regulations have been implemented on both sides of the Mediterranean Sea to promote the large-scale deployment of renewable energy and also to allow a cross-border renewable electricity exchange between North Africa and Europe with, however, limited success.[32]

One of the instruments aimed at fostering such cooperation was introduced by the Directive 29/2009/EC of the European Commission, also known as the Renewable Energy Directive—RED.[33] The RED is part of the EU Climate and Energy package that came into force in June 2009 and sets mandatory national renewable energy targets for EU Member States (MS) to achieve a renewable energy target of a twenty percent share of the EU's gross final energy consumption by 2020. In order to grant member states more flexibility as well as to reach the overall EU target in a cost effective manner, the RED allows member states to partially fulfil their national targets in other countries with large renewable energy potential and low generation costs. Such cooperation can take place within Europe (Articles 6, 7 and 11) but also with third countries (Article 9), in that latter case called the 4th cooperation mechanism.

In order to implement Article 9, projects must meet various conditions. Among others, (i) the project must have been constructed after 2009, (ii) electricity must be physically transferred from plants installed in the origin non-EU countries and consumed in the destination EU countries, (iii) the amount of electricity exported must be tied to the allocated interconnection capacity by all responsible transmission system operators involved, (iv) electricity produced should not have received support from a third country other than investment aid granted to the power plant and, finally, (v) the amount of electricity nominated for export and the production of electricity from renewable energy sources are referring to the same period of time.

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[32] Lilliestam, Johann, et al., "Understanding the Absence of Renewable Electricity Imports to the European Union*," International Journal of Energy Sector Management* 10.3 (2016), 291–311, accessed May 15, 2017. DOI 10.1108/IJESM-10-2014-0002.

[31] European Commission. "Directive 2009/28/EC" of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, L 140/16 particularly Art.9 related to Joint projects between member states and third countries, accessed May 15, 2017. https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive.

The idea of solar electricity transfers found its way into the concept of the Mediterranean Solar Plan (MSP) of the Union for the Mediterranean and got a strong push forward with the foundation of the DESERTEC Foundation and the DESERTEC Industrial Initiative (later called Dii GmbH) in 2009.[34] Those were followed by several other initiatives like Transgreen and later MedGrid in 2010 (.[35]

On the regulatory side some North African countries undertook important steps in that direction such as the Moroccan Renewable Energy Law from 2009 that includes the option of renewable electricity exports to Europe, also considering the construction of the necessary transmission lines that should be physically separated and independent from the national electricity supply and grid infrastructure.[36] Similarly, in 2011, Algeria launched its Renewable Energy and Efficiency Program that includes ten gigawatt of renewable power capacity scheduled for export to Europe.[37]

Summarising, the great renewable potential in the North African region, potential business opportunities, favourable regulatory environment, as well as the interest of governments on both sides of the

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[34] Ruchser, Matthias, *Desertec or the Mediterranean Solar Plan—Whose Sun is Shining Brighter?* (Bonn: Deutsches Institut für Entwicklungspolitik (DIE), 2010), https://www.die-gdi.de/uploads/media/Column_Ruchser.02.08.2010.pdf; Union for the Mediterranean (UfM), Secretariat of the Union for the Mediterranean, "The UfM: An Action-Driven Organisation with a Common Ambition," accessed May 15, 2017. http://ufmsecretariat.org/wp-content/uploads/2017/10/UfM-Roadmap-for-action-2017.pdf; Desertec Foundation, "Archive of Press Releases Since 2008", accessed May 15, 2017. http://www.desertec.org/press; Dii 2017, "Great Idea: Power from the Desert," accessed May 15, 2017. http://dii-desertenergy.org/.

[35] Cole, Stijn et al., "A European Supergrid: Present State and Future Challenges" (17th Power Systems Computation Conference, Stockholm, August 22–26, 2011), accessed May 15, 2017. https://www.pscc-central.org/uploads/tx_ethpublications/sp2.pdf; Observatoire Mediterraneén de l'Energie (OME), "Mediterranean Energy Perspectives 2011," in: *L'Energie*, ed. O,M.d. (Paris: O.M.d., 2011), accessed May 15, 2017. http://www.ome.org/publications/mep-2011/; European Commission, "Commission Welcomes Desertec and Medgrid Cooperation on Solar Energy in North Africa and the Middle East," last modified February 19, 2018, accessed May 15, 2017. http://europa.eu/rapid/press-release_IP-11-1448_en.htm.

[36] Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement (MEMEE), *Loi 13–09 relative aux énergies renouvelables* (Rabat: MEMEE, 2010), accessed May 15. 2017.http://www.mem.gov.ma/SiteAssets/PdfDocumentation/LoiEnergiesRenouvelables.pdf.

[37] Ministère de l'Énergie et des Mines (MEM), "Renewable Energy and Energy Efficiency Program," accessed May 15, 2017. www.mem-algeria.org/francais/uploads/enr/Programme_ENR_et_efficacite_energetique_en.pdf.

Mediterranean led to great expectations around the attractiveness and feasibility to export renewable electricity to the European continent. However, despite great expectations that were created around Article 9 of the RED, not a single project has seen the light as of today and remains unlikely to happen in the short term. There are various factors that can partially explain this fact such as the current lack of demand within the EU for cross-border RES imports from third countries, the missing grid infrastructure including high voltage transmission lines across the Mediterranean Sea and the regulatory and legislative gaps related to the harmonisation of the EU and South Mediterranean energy markets.

While the above mentioned hurdles could in principle have been overcome, the long-term vision of a future EUMENA Supergrid, as explained before, avoided the finding of a concrete short term business case that would have tapped the added value of dispatchable solar power for the benefit of both sides of the Mediterranean Sea.

6. *Pilot Study Required for a First Solar Electricity Pipeline*

Since 2009, several initiatives proposed to establish 'pilot' projects to demonstrate the 4th cooperation mechanism on a smaller scale. However, just like in the case of natural gas pipeline projects, in the case of a solar electricity pipeline project a smaller scale demonstration prior to a real project is impossible, as the related effort would be almost the same as that of a full size project and would not be justified by smaller electricity output. This and the erroneous concept that formed the basis of those considerations up to now has avoided the realisation of concrete projects under the 4th cooperation mechanism, although, as has been shown in the BETTER report, flexible renewable energy imports will most probably be needed in Europe shortly after 2020, and planning should be started as soon as possible in order to enable such options.[38] Therefore, it might be considered by the European Commission to release a call for a CSP-HVDC Pilot Study that may contain, among

[38] Trieb et al, *Bringing Europe and Third Countries Closer Together through Renewable Energies*; Trieb, Franz et al.,"Rescuing the Concept of Solar Electricity Transfers from North Africa to Europe," *International Journal of Energy Sector Management* 10.3 (2016): 448–473, accessed May 15, 2017. www.emeraldinsight.com/1750-6220.htm.

others, the topics listed in Table 3 to be assessed in reasonable detail. Such a study could be commissioned directly by the European Commission or included in the HORIZON 2020 Call .[39] It would help the commission to evaluate the potential and assess the importance of such infrastructures for the EU's future energy infrastructure.

GEOGRAPHICAL ASSESSMENT

- Demand side analysis of potential off taker regions in EU for dispatchable solar electricity imports.
- CSP production site screening of potential supplier regions in NA.
- Geographic analysis of potential HVDC corridors in selected transit regions.

TECHNICAL AND FINANCIAL ASSESSMENT

- Technical design and performance study related to the prior demand side analysis.
- Economic and financial engineering study including de-risking opportunities, compensation payments and citizen participation.
- Assessment of the necessary logistics and time schedule.

IMPACT ASSESSMENT

- Environmental impact study.
- Socio-economic impact study.
- Social acceptance and citizen involvement study including a concept for a prior public visualization of the infrastructure and for citizen dialogue and participation.
- Analysis of the replication potential of such projects.

POLITICAL AND REGULATORY FRAMEWORK ASSESSMENT

- Analysis of existing and missing political framework requirements including the role of authorities at different levels.
- Analysis of existing and missing regulatory framework requirements including the role and identification of permitting authorities.

Table 3. Topics of a tentative CSP-HVDC pilot study.

In addition to that, a recently published "Joint Declaration on the Establishment of a Roadmap for Sustainable Electricity Trade between Morocco and the European Internal Energy Market" between the Federal Republic of Germany, the French Republic, the Kingdom of Spain, the Portuguese Republic and the Kingdom of Morocco has in principle

[39] European Commission, "HORIZON 2020—The EU Framework Programme for Research and Innovation—Call for projects 2014—2020", accessed May 15, 2017. http://ec.europa.eu/programmes/horizon2020/en.

opened a possible gate for such activities after the COP 22 in Marrakech, Morocco.[40]

However, HORIZON 2020 and the "Roadmap for Sustainable Electricity Trade (SET)" do not include the concept of solar electricity pipelines in their portfolio of possible options.

7. *Social Context and Acceptance*

In the public and political discussion about DESERTEC after 2009, doubts were raised about the security of supply related to power from MENA, to the vulnerability of such infrastructures, to the environmental protection of desert areas, to water consumption in the desert and to the colonial-stile-like exploitation of natural resources of developing countries that eventually would not profit from such venture.[41] Although there are quite satisfying answers to that doubts, the populistic outspread of distrust against a solar electricity partnership of MENA and Europe was much more effective than that of the answers.

A very popular argument takes neo-colonialism as reference, stating that solar energy from the Sahara belongs to Africa but not to Europe. This is very true, but the quality and value of solar energy is very different to e.g. that of commodities like natural gas or mineral oil. Exploiting the latter for export will certainly deprive Africa from using them for its own development, as the resources simply will be gone after being exported. On the contrary, exploiting solar energy for export is certainly a way for Africa to tap that wealth. Or, saying it in another way: the only way to deprive (North) Africa from its wealth of solar energy is by not making use of it for export. This is a fundamental difference between solar energy and limited commodities like natural gas or crude oil. Using solar energy for export will leave more than enough

[40] European Commission, "Joint Declaration on the Establishment of a Roadmap for Sustainable Electricity Trade Between Morocco and the European Internal Energy Market between The Federal Republic of Germany, The French Republic, The Kingdom of Spain, The Portuguese Republic, and The Kingdom of Morocco", executed at Marrakech during COP22 on the 17th November 2016, accessed May 15, 2017. https://ec.europa.eu/energy/sites/ener/files/documents/2016_11_13_set_roadmap_joint_declaration-vf.pdf.

[41] Euractive, "First Steps to Bring Saharan Solar to Europe," last modified February 22, 2010, accessed May 15, 2017. http://www.euractiv.com/section/energy/news/first-steps-to-bring-saharan-solar-to-europe/.

potential for own solar power plants[42] that by the way are already being installed in many places.[43] Creating added value and selling dispatchable solar power to Europe will create additional income for the North African countries. This income can among others help to finance their own solar energy supply, by no means depriving them from doing so, but on the contrary providing finance and intensifying local solar industry, economy and know-how transfer.

Another very popular argument against EUMENA solar energy partnerships postulates a "dangerous" dependency of Europe on "insecure" North African states. This argument is particularly interesting in view of massive natural gas imports from Russia to Europe, a country with OECD country risk rating 4 and involved in armed conflicts in Ukraine and Syria, while Morocco, a major candidate for solar exports to Europe, has a rating of 3 and, needless to say, no armed conflict with European or Mediterranean countries.[44] Even if both countries (Morocco and Russia) would have the same risk rating, adding another energy supplier to the European portfolio of suppliers would, by simple logic, always reduce, but never increase European energy supply risk. Further answers to the risk myth have been given by Lilliestam and Ellenbeck .[45]

Regarding security of grid stability the European Network of Transfer System Operators for Electricity (ENTSO-E) has a rule called n-1 Criterion which states that no single unit can be larger than the maximum capacity that can be compensated within a TSO's control area in case of an emergency outage.[46] This rule is applied to power plants and all other equipment and also applies to potential future CSP-HVDC solar electricity pipelines. The approximate size of this maximum capacity

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[42] Trieb et al., *Characterization of Solar Electricity Import Corridors from MENA to Europe—Export Potentials, Infrastructures and Costs*.

[43] Moroccan Agency for Solar Energy (MASEN), *Endless Power for Progress* (Rabat, MASEN, 2016), accessed May 15, 2017. http://www.masen.ma/media/uploads/documents/MASEN_Brochure_instit_Anglais_finale_FPeQ8Wd.pdf.

[44] Organisation for Economic Co-Operation and Development (OECD), "OECD Country Risk Classification," last modified December 21, 2017, accessed May 21, 2018. http://www.oecd.org/tad/xcred/crc.htm.

[45] Lilliestam, Johann and Saskia Ellenbeck, "Energy Security and Renewable Electricity Trade—Will Desertec Make Europe Vulnerable to the 'Energy Weapon'?," *Energy Policy* 39.6 (2011): 3380–3391

[46] ENTSO-E—European Network of Transmission System Operators for Electricity, "Continental Europe Operation Handbook."

limit is about three gigawatt and depends on the respective position of the interconnection of the respective device within the grid. This limits the size of a single solar electricity pipeline to about three gigawatt net import capacity.

A common argument against operating steam turbines in desert regions is the lack of water for cooling the condenser of the power plants. This is a very good argument, as there is usually little water available in the desert, and if so, there are better and more important uses for it than evaporating it for cooling a power cycle.

However, many desert regions have actually steam cycle power plants running, so the question is, how can they do so? The answer again is very simple: they use air-cooled condensers.[47] Air cooled condensers use air to cool the engine, just like most automobiles do. Some plants use fans to move air through the condensing heat exchangers, some, like the Heller cooling towers, use natural convection in a large chimney. Both concepts work well in many arid regions and are applied world-wide since many years in places where water for evaporation is scarce.

It is finally criticised that air-cooling will reduce the efficiency of power plants compared to evaporation-cooling. This is true, but only critical for plants that burn fossil fuel for power generation, because in that case more fuel will be needed per kilowatt-hour of electricity produced. When using air-cooling in a concentrating solar power plant, its design efficiency will be certainly lowest on hot days—usually days with a lot of sunshine and excess heat from the solar collectors—but highest on cold days in winter (and at night), when solar energy is scarce. So, for solar steam cycle power plants, air-cooled condensers will reduce surplus and curtailment of solar heat rather than reduce overall efficiency, the impact of dry-cooling being just a question of proper design and operation.[48]

[47] Bracken, et al., *Concentrating Solar Power and Water Issues in the U.S. Southwest*, Technical Report, NREL/TP-6A50-61376 (Denver: The Joint Institute for Strategic Engergy Analysis, 2015), accessed May 15, 2017. http://www.nrel.gov/docs/fy15osti/61376.pdf.

[48] Moser, Massimo, "Techno-economic Analysis of Enhanced Dry Cooling for CSP," *Energy Procedia* 49 (2014): 1177–1186, accessed May 15, 2017. http://www.sciencedirect.com/science/article/pii/S1876610214005815.

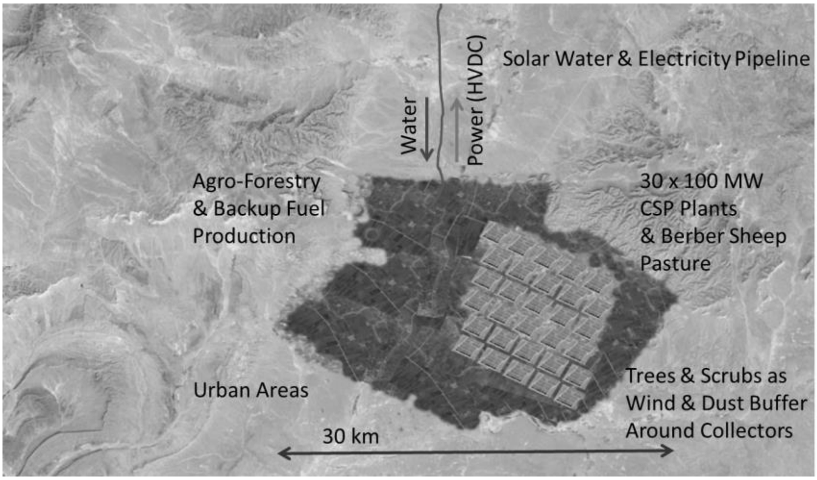

Figure 6. Potential oasis formed at the southern end of a three gigawatt solar electricity pipeline from MENA to Europe including agro-forestry and related communal services. Artist view created with Google Earth.

Nevertheless, it is true that large scale CSP plants in the middle of the desert will require a lot of water. As an example, a three gigawatt plant producing about 20,000 gigawatt-hours of electricity per year will consume about ten million cubic meters of fresh water per year, for operation and maintenance, cleaning of the concentrating solar collectors and drinking water for the staff. As this water should not be taken from local sources, each plant must reserve about one to two percent of its energy output for seawater desalination and for pumping about 100–150 million cubic meters per year from the sea shore to the plant site in the desert (Table 1). This way, each solar electricity pipeline will export solar energy from the desert to populated places in Europe, and at the same time import freshwater to the plant site in the desert, in order to feed the needs of the plant and surrounding communities. Seawater desalination cannot only be combined with concentrating solar power plants for export, but also with those for national electricity supply.[49]

[49] Moser, Massimo, Franz Trieb, and Tobias Fichter, "Potential of Concentrating Solar Power Plants for the Combined Production of Water and Electricity in MENA Countries," *Journal of Sustainable Development of Energy, Water and Environment Systems* 1.2 (2013): 122–140, accessed May 15, 2017. DOI: http://dx.doi.org/10.13044/j.sdewes.2013.01.0009

An important aspect of high quality of living and working in the desert—we are talking of about 5,000 direct employees of a three gigawatt CSP plant plus indirect services needed—is shade from trees and all kind of plants that will need water for irrigation. A side-effect of agro-forestry that can be started when importing sufficient additional amounts of freshwater is the availability of food, labour, and manifold opportunities for local income. As an example, drip water from cleaning the collectors, together with shade from the collectors, will enhance the growth of grass and small vegetation all over the solar collector field. That growth must be controlled because of fire hazard. A herd of sheep may effectively keep the grass and plants short enough and at the same time use the solar collector field as pasture in order to provide labour and income for locals.

Scrubs and trees separating the collector fields of each power plant unit will reduce wind and dust load on the collectors and provide additional biomass for backup steam generation for the few occasions when there is not enough solar energy available for some days over the year, at the same time creating additional local labour opportunities. Depending on the local annual rainfall levels that will complement freshwater from seawater desalination, an oasis with about six hundred to nine hundred square kilometres surface area can be created by each solar electricity pipeline project (Figure 6). This is particularly interesting for reactivating former agricultural areas that have been lost to desertification.

Host countries may (and should) participate in the finance of such infrastructures depending on their readiness to invest and their interest to share the investment. In addition to and independent from that, they will receive a regular compensation payment from each project that will be quantified in accordance to the amount of land used for the power plants and for the power transmission lines. For a three gigawatt unit, this payment would be in the order of magnitude of fifty million euro per year for the total lifetime of forty years scheduled for such plants.[50]

On such basis, agricultural, urban and eventually also touristic areas could be developed in the vicinity of such plants, and strong economic zones could be started in many desert regions throughout the Sahara. Another aspect is education and training, opening fascinating

[50] Hess, Denis, "Fernübertragung regelbarer Solarenergie von Nordafrika nach Mitteleuropa".

opportunities in very innovative but also rather traditional fields of education, ranging from energy and water engineering to desert agro-forestry and urban planning, that will provide useful knowledge for students not only from the host countries, but world wide.

Recently, the German Federal Ministry for Economic Cooperation and Development (BMZ) published the idea for an initiative called "Marshall Plan with Africa". Although the German Section of the Club of Rome and the Global Marshall Plan Initiative proposed to include the concept of solar electricity exports to that initiative[51] it was unfortunately not taken into consideration within the paper released by the ministry in January 2017 .[52]

8. *Conclusions*

In spite of the failure of DESERTEC, the concept of solar electricity exports from MENA to Europe has not lost any relevance for a sustainable development of both regions. On the contrary, affordable solar electricity that can be delivered just on demand is a key to the European "Energiewende", as it provides the same quality as conventional power plants but doesn't suffer from any emissions. This high added value for Europe is the basis for concrete business cases, power purchase agreements and real world projects in the short-, medium- and long-term future.

The added value of such infrastructures for MENA is not less, as it is not limited to the monetary value of such exports. The creation of new economic zones in the desert is crucial for a growing population in a severely limited natural environment. The availability of energy leads to the availability of water, food, labour, and income at the solar production sites, creating multiple opportunities for jobs, training, tourism, and living. Synergies of technical innovation and traditional agroforestry will

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[51] Beyers, Bert et al., *Migration, Nachhaltigkeit und ein Marshall Plan mit Afrika – Denkschrift für die Bundesregierung* (Ulm: Club of Rome and Senat der Wirtschaft, 2017), accessed May 2017. http://www.faw-neu-ulm.de/portfolio-item/denkschrift-bundesregierung.

[52] Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (BMZ), *Afrika und Europa – Neue Partnerschaft für Entwicklung, Frieden und Zukunft – Eckpunkte für einen Marshallplan mit Afrika* (Berlin: BMZ, 2017), accessed March 25, 2017.
http://www.bmz.de/de/laender_regionen/marshallplan_mit_afrika/einleitung/index.jsp.

create new and fascinating fields of work in an environment that otherwise would be lost to the desert and left unused.

The major challenge is to overcome the misconceptions related to the DESERTEC failure. As long as policy and the public do not recognise the role and benefits of point-to-point interconnections for dispatchable solar power, the idea of EUMENA solar electricity imports will remain on hold.