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The value of a dispatchable concentrating solar power transfer from Middle East and North Africa to Europe via point-to-point high voltage direct current lines

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HIGHLIGHTS

- Systemic evaluation of CSP in EUMENA with an energy system model.
- Multi-criteria analysis considering overlay grid and point-to-point interconnections.
- Application of a novel node-internal grid method for EUMENA.

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ABSTRACT

Dispatchable solar power from concentrating solar thermal power plants (CSP) combined with thermal energy storage and co-firing option can provide energy according to demand. A transfer of such electricity from CSP in desert regions to distant consumer centres may therefore complement domestic energies. A detailed energy system modelling showing the benefit and drawback of CSP from Middle East and North Africa for Europe was not yet done. This paper closes the scientific knowledge gap applying an energy system model with a least-cost approach and detailed scenario analysis for the year 2050. Energy system analyses describe the effects of including and excluding a transfer of CSP from MENA to EU via a grid or via point-to-point high voltage direct current (HVDC) transmission lines. A multi-criteria assessment reveals the impact of such CSP-HVDC power plants on energy infrastructure, operational behaviour, cost and emission of the energy system. To evaluate national grid expansion, a new grid methodology is used as composed of transmission and distribution grid. The evaluation shows that power plant capacity, electrical storage and grid expansion as well as electrical curtailment can cause a beneficial impact when CSP-HVDC is used to supplement the energy portfolio in Europe.

1. Introduction

Concentrating solar power (CSP) combined with thermal storage and co-firing option is one promising dispatchable and low carbon energy technology [1]. Especially in the MENA region, this solar technology is favourable to be implemented in countries with a rising electricity demand in addition to photovoltaics and wind energy. High renewable energy potentials, sparsely populated desert areas are one major advantage for implementing CSP efficiently. In Europe CSP is built in southern Spain, however with limited potential and seasonal unsteady supply. Thus, Europe could supplement its energy portfolio with CSP from MENA due to its limited domestic renewable dispatchable potentials [2] and MENA could profit from income, labour and new living area such as oasis near the power plants. Consequently, Europe as well as MENA could profit from a transfer of dispatchable renewable energy.

1.1. Transfer options, literature review and novelty

For the electricity transfer of CSP from MENA to EU three transmission topologies can be outlined. These are the existing transmission grid, a meshed overlay grid and point-to-point transmission lines. Such infrastructures differ in their capacity, topology, financing and operational behaviour. A point-to-point interconnection is an infrastructure which connects two precise points of a system. In the present case a point-to-point interconnection is defined as a high voltage direct current (HVDC) transmission line between a CSP hotspot in MENA and a demand centre in EU. Point-to-point HVDC and CSP build one power plant and are defined as CSP-HVDC in the following. A meshed overlay grid can be compared to the existing transmission grid with a higher

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Nomenclature

Abbreviations

AC Alternating current
AUE Arab Union of Electricity
CCS carbon capture and storage
CSP concentrated solar power
CSP-HVDC concentrated solar power plant combined with a point-to-point high voltage direct current transmission line
DLR Deutsches Zentrum für Luft- und Raumfahrt – German Aerospace Centre
DNI direct normal irradiance
ENTSO-e European Network of Transmission System Operators for Electricity
EU geographical Europe
EUMENA Europe, Middle East and North Africa
GDP gross domestic product
GHI global horizontal irradiance
HVDC high voltage direct current
MENA Middle East and North Africa
NPP net primary production
O&M operation and maintenance
OECD organisation for economic co-operation and development
OHL overhead line
P2G2P power-to-gas-to-power
P2P point-to-point
PEMFC proton exchange membrane fuel cell
PV photovoltaic
REMix-EnDAT renewable energy mix – energy data analysis tool
REMix-OptiMo renewable energy mix – energy system optimization
UGC underground cable
UN United Nation
USA United States of America
UTC universal time, coordinated

Parameters

$c_{Emission}$ specific emission cost [k€/GWh]
c_{Fuel} specific fuel cost [k€/GWh]
$c_{O\&M\ Fix}$ specific operation and maintenance fix costs [%/y]
$c_{O\&M\ Variable}$ specific operation and maintenance variable costs [k€/MWh]
$c_{specInv}$ specific investment cost [k€/MW]
$f_{annuity}$ Annuity factor [–]
$\eta_{generator}$ efficiency of the generator [%]
η_{charge} charging efficiency of the storage [%]
$\eta_{discharge}$ discharging efficiency of the storage [%]
η_{self} self-discharging rate of the storage [%]
i interest and discount rate [%]
$P_{existCap}$ capacity of existing power plants [GW_{el}]
P_{HVDC} capacity of the HVDC transmission line [GW_{el}]
$P_{PB,\ CSP}$ capacity of the CSP power block [GW_{el}]
$P_{SF,\ CSP}$ capacity of the CSP solar field [GW_{th}]
$P_{TES,\ CSP}$ Thermal energy storage capacity of the CSP [GWh_{th}]
$s_{gen}(t)$ normalised generation time series of fluctuating energy [–]
SM solar multiple [–]
Δt calculation time interval [h]
t_y amortization time [y]
t time [h]

Variables

$\boldsymbol{C}_{capital}$ annual depreciation of capital expenditure [k€/y]
$\boldsymbol{C}_{operation}$ operation and maintenance costs [k€/y]
$\boldsymbol{P}_{addedCap}$ capacity of additional power plants [GW_{el}]
$\boldsymbol{P}_{gen}(t)$ power generation [GW_{el}]
$\boldsymbol{Q}_{addedCap}(t)$ capacity of model endogenous CSP solar field [GW_{el}]
$\boldsymbol{Q}_{BUS}(t)$ thermal output of the CSP co-firing system [GW_{el}]
$\boldsymbol{Q}_{charge}(t)$ thermal energy storage input [GW_{el}]
$\boldsymbol{Q}_{curtail}(t)$ thermal curtailment of the solar field [GW_{el}]
$\boldsymbol{Q}_{disharge}(t)$ thermal energy storage output [GW_{el}]
$\boldsymbol{Q}_{SF}(t)$ thermal output of the solar field [GW_{el}]
$\boldsymbol{U}_{level}(t)$ thermal energy storage level [GWh_{th}]

transmission capacity. It is often used in the context of transmitting a high energy amount over a large spatial distance without specific destination such as in Europe [3].

HVDC and CSP are state-of-the-art technologies which are applied worldwide. CSP is often used as dispatchable baseload technology due to its relative cheap thermal storage and almost seasonal constant day-to-day sun cycle in the sun belt area. HVDC is applied as a low-loss electricity transmission technology to transfer electricity over high distances and to interconnect asynchronous power grids [4]. A review of the technical performance of HVDC led to the result that an electricity transfer from North Africa to Europe can improve the dynamic performance of power system in Europe [5]. Public initiatives such as DESERTEC focus to exploit the energy potential of renewable energies in the world's sun belt area for domestic use and for a transfer to high energy consuming regions such as Europe. However, a transfer of a specific type of renewable energy which can be from high value for the destination region was not analysed in detail so far. In the paper at hand an analysis is performed which identifies the advantageous kind of renewable energy and the type of transfer topology with an optimization model at the first time.

Scientific test cases considering the economic comparison of CSP and PV have led to the result that in southern Italy and Egypt CSP is more cost efficient than PV due to its base load character [6]. However, the export of CSP via point-to-point HVDC to Europe with its local competitive renewable energy technologies has not been examined.

Transmission grid studies in Europe by [7,8] found out that a transmission grid expansion with the integration of fluctuating renewable energies is beneficial in the long term. However, the use of CSP in MENA for Europe wasn't analysed because the study was limited to Europe. In the case of the meshed overlay grid, former studies used a least-cost approach with an energy system model with high shares of renewable energies in EUMENA (Europe, Middle East and North Africa) with such an infrastructure. They found out that a meshed overlay grid is cost-efficient and therefore often integrated by the used energy optimization model [9,10]. In these studies, CSP was also integrated in the model. CSP is also analysed in a fully renewable energy system in Texas in the USA regarding the operational behaviour from the system operator viewpoint [11]. However, such optimisation considers predominantly cost and does not lead to the view of other energy system relevant criteria. Showing the impact of a meshed overlay grid on the energy system, a multi-criteria analysis is performed with and without meshed overlay. In the context of CSP, point-to-point transmission infrastructures have been only outlined and described quantitatively in Refs. [12,13]. Point-to-point transmission infrastructures from a CSP power plant to a distant centre of demand have not been analysed in detail in EUMENA with an energy system optimisation model. Showing the effects of point-to-point CSP-HVDC for the energy system, this combined technology is implemented in such a model in the present