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Optimization of the technology mix for the Shagaya 2 GW renewable energy park in Kuwait

S. Lude[a]*, T.P. Fluri[a], S. Alhajraf[b], V. Jülch[a], P. Kühn[c], A. Marful[d] and J.R. Sanchez Contreras[d]

[a]*Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstrasse 2, 79110 Freiburg, Germany*
[b]*Kuwait Institute for Scientific Research, P.O Box 24885, 13109 Safat, Kuwait*
[c]*Fraunhofer Institute for Wind Energy and Energy System Technology, Königstor 59, 34119 Kassel, Germany*
[d]*Fichtner GmbH&Co.KG, Sarweystrasse 3, 70191 Stuttgart, Germany*

Abstract

As part of the Shagaya Renewable Energy Master Plan in Kuwait, the presented study describes the methodology developed and applied for the optimization of the technology mix for a 2 GW, 100 km² renewable energy park. Scenarios with different focuses for the technology mix were developed, selecting from 14 technology options (three wind, five PV and six CSP) and emphasizing either high peak load supply, high overall annual electricity production or low levelized cost of electricity. An optimization procedure that uses a general pattern search algorithm implemented in the software GenOpt was used to maximize a score calculated from eight criteria. These were determined in a social-techno-economic evaluation, which included performance simulations of every technology option for the allocated site in Kuwait. Besides the available land area, the capacity credit of the installed technology mix was included as an additional boundary condition. 2010 was selected as base year since it was the most recent year for which both high quality meteorological and electricity demand data was available. The results for all considered scenarios are presented in this paper, with the one that was chosen as final result of the master plan comprising 136 MW wind power, 614 MW of PV and 1250 MW of CSP. Furthermore, the study showed that thermal storage is indispensable to serve peak demand hours and a diverse technology mix is important to achieve a high capacity credit.

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Keywords: renewable energy mix, concentrating solar power, techno-economic evaluation, performance simulation, yield simulation

* Corresponding author. Tel.: +49 761 4588 5980; fax: +49 761 4588 9981.
E-mail address: simon.lude@ise.fraunhofer.de

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Nomenclature

Text abbreviations

CAPEX	capital expenditure
CC	capacity credit
CdTe	Cadmium Telluride
CPV	concentrating photovoltaics
CSP	concentrating solar thermal power
FLH	full load hours
GPS	generalized pattern search
HTF	heat transfer fluid
ISE	Fraunhofer Institute for Solar Energy Systems
IWES	Fraunhofer Institute for Wind Energy and Energy System Technology
KISR	Kuwait Institute for Scientific Research
LCOE	levelized cost of electricity
MS	molten salt
O&M	operation and maintenance
OPEX	operational expenditure
PV	photovoltaics
PLSC	peak load shaving capability
RE	renewable energy
SREMP	Shagaya renewable energy master plan
TMY	typical meteorological year
TES	thermal energy storage

Formula symbols

crit	critical hours
E	electricity
el	electric
inst	installed
max	maximum
min	minimum
n	plant lifetime
r	discount rate
res	residual
t	counting variable for year
th	thermal

1. Introduction

The Kuwait Institute for Scientific Research (KISR) has initiated and developed the master plan of a 2,000 MW multi-technology renewable energy park over 100 km^2 that has been allocated for the initiative. Based on a preliminary resources assessment study conducted by KISR in 2010 [1], CSP and PV technologies were selected as the most promising renewable technologies with high potential of utilization. Wind energy technology came then with high potential of utilization during peak power demand. The work presented in this paper was carried out as part of the development of the initial master plan of the park in close collaboration with leading partners in the field of renewable energy technologies including Fichtner, the project technical consultant and the Fraunhofer Institutes ISE and IWES. The aim of this study was to develop a methodology to optimize the technology mix in the Shagaya RE park to be implemented in several stages until 2030 and to present the project owner with three different options as to how the available land area can best be utilized under differing assumptions. The overall scope of SREMP also included infrastructure, planning policies and principles as well as an implementation and phasing plan, but these topics are not within the scope of this paper. It instead focuses on the optimization approach and the results under different assumptions. A description of the overall methodology is presented in chapter 2, the input data used for the simulation of the technology options and their evaluation is the topic of chapter 3, followed by the selection, energetic simulation and evaluation of the technology options in chapter 4. The optimization procedure is described in detail in chapter 5 and finally, the resulting technology mixes from the optimizations are presented, discussed and summarized in chapters 6 and 7. In general, this paper focuses on describing the developed and applied methodology. Input and result data are presented where possible but, due to reasons of confidentiality, are also often omitted (cost and financing parameters, project lifetime, detailed performance figures etc).

2. Methodology

The optimization of the technology mix was carried out in two phases as presented in Figure 1: A first phase aimed at the selection and techno-economic characterization of viable technology. This phase also included the collection and definition of meteorologic data and electricity demand data, software to be used for the performance simulation and criteria to evaluate the technology options.

Within the second phase, the goal was to find optimal technology mixes in a cost-benefit analysis.

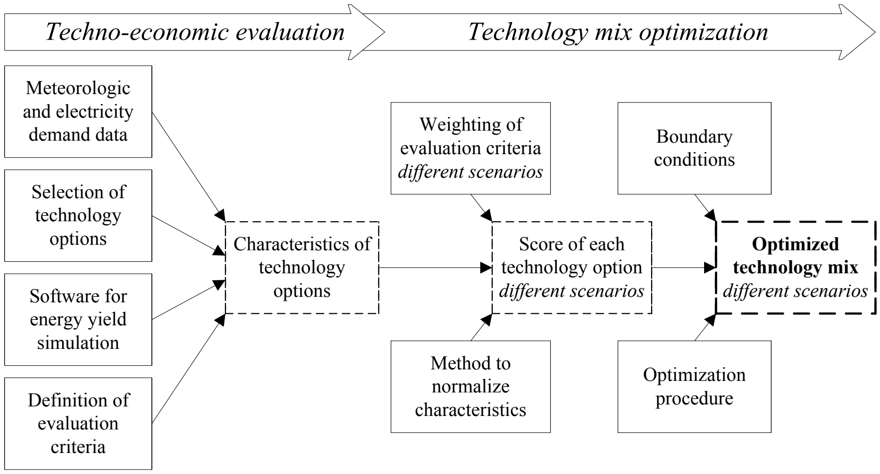

Fig. 1: Methodological structure for the technology mix optimization

3. Meteorological data and electrical demand data

High quality solar resource data for the project site was acquired from the SolarGIS data base both for a 13 year period up to 2011 as well as a typical meteorological year. Electrical demand data for Kuwait up to the year 2011 and wind resource data for the project site was made available through KISR. Since the optimization of the technology mix should include linking the produced electrical energy from the park to the actual demand, TMY data cannot be used for the simulation of the RE technology options. Data from a specific year has to be used instead. In this study the year 2010 was chosen, since both resource and demand data is available as a complete set of hourly values and with high quality. Predictions on how the demand will change in future are not included in the scope of this study. Based on the acquired TMY, the project location has an annual long-term average DNI of 1,857 kWh/(m²a) and a GHI of 2,085 kWh/(m²a).

4. Technology options

4.1. Definition of technology options

As a first step, a number of technology options were defined to serve as a basis for the technology mix optimization. For that a technology screening was conducted for the three technology families (wind, PV, CSP) under consideration for the Shagaya RE park. Based on a set of evaluation criteria that included for example the technological maturity, general suitability for the site and availability of a commercial storage system, technology options in each family were selected with the basic goal of covering a wide spectrum of each family.

Table 1 shows the list of selected technology options. As wind technology is already relatively mature and technology selection is relatively straight-forward for a given site, three options were considered. Two of them represent the current state-of-the-art turbine sizes with capacities of 2 MW and 3 MW, respectively. The third option with a turbine capacity of 5 MW represents a technology, which was at the time of the project start the upper limit of available systems and only available at small quantities. However, it is predicted that such large-capacity systems will most likely be more prevalent in the near future. Therefore it was included in the selection.

The different available flat plate PV technologies are most importantly distinguished by their conversion efficiency and their temperature coefficient. Thin film modules are less sensitive to high temperatures than the ones using crystalline cell technology. Therefore one thin film technology was considered as a technology option. Furthermore, a concentrating photovoltaic (CPV) technology was considered. The other three PV technology options were defined to be mono-crystalline technologies, one with a typical standard efficiency and one with a high efficiency of >20 %. Additionally, a tracking technology was considered with a North-South aligned horizontal tracking axis in order to extend the energy production period both in the morning and the afternoon. The cell technology for this option was defined to be the same as in the previously described standard mono-crystalline case, in order to allow for a direct comparison between tracked and non-tracked technologies.

For CSP, the selection of technology options is the most complex due to the large number of different collector technologies, heat transfer media alternatives, field layouts, storage options and the possible combinations thereof. Due to this large number of possible options, an evaluation matrix was employed to assess the different CSP and storage technologies in order to select a number of CSP technology options. A two-step approach was implemented, in the first of which all CSP technologies were evaluated according to appropriateness for summer afternoon peak supply, general appropriateness for the site conditions, potential for future cost reduction, state of commercial implementation and availability and efficiency of a thermal storage option.

The highest rated technologies from step one were again assessed in a second step with respect to their appropriate storage size, i.e. which technology is suitable for the application of a large thermal storage capacity. As a result of the described selection process the six CSP options shown in Table 1 were defined to be further used in the optimization process. Parabolic trough with thermal oil as heat transfer fluid is the most mature and most widely built technology. However, direct molten salt central receiver technology has recently been demonstrated on a commercial scale and promises higher power block efficiency due to an increased live steam temperature and more efficient storage integration due to the reduced number of heat exchangers and increased energy density in the storage tank. Therefore, parabolic trough was considered with small and medium size storage, whereas central receiver was selected with medium and large storage capacity. Additionally, two direct steam generating CSP technology options were selected, one also with central receiver technology and one with linear Fresnel technology. Since no commercially proven large scale and high capacity thermal storage is yet on the market for direct steam generating CSP technology, these technology options were considered without thermal storage, i.e. only having small buffer storages with a capacity of less than 30 min. Major technological advances that may occur in future, for example the availability of direct steam generation technology with large and cost-effective storage, were not considered within this study.

Table 1: List of selected technology options to be considered for the Shagaya renewable energy park

Technology family	Technology	Description
Wind	2 MW turbine	80 m hub height / 90 m rotor diameter
	3 MW turbine	100 m hub height / 112 m rotor diameter
	5 MW turbine	100 m hub height / 128 m rotor diameter
PV	CdTe thin film	typ. efficiency 9 - 10%, fix installation
	Mono crystalline standard	typ. efficiency 15 - 17%, fix installation
	Mono crystalline high	typ. efficiency 20 - 22%, fix installation
	Mono crystalline standard, tracked	typ. efficiency 15 - 17%, 1-axis (N-S) tracking
	CPV	typ. efficiency 40 - 42%, 2-axis tracking
CSP	Parabolic trough, oil, small TES[1]	thermal oil as collector HTF, indirect molten salt storage with approx. 5 h storage
	Parabolic trough, oil, medium TES[1]	thermal oil as collector HTF, indirect molten salt storage with approx. 10 h capacity
	Central receiver, MS, medium TES[1]	direct molten salt with approx. 10 h storage capacity
	Central receiver, MS, large TES[1]	direct molten salt with approx. 15 h storage capacity
	Central receiver, steam, no TES[1]	direct steam generation with only small buffer storage
	Linear Fresnel, steam, no TES[1]	direct steam generation with only small buffer storage

[1]TES: thermal energy storage

4.2. Performance simulation

Performance simulations were done for each of the 14 selected technology options giving hourly production profiles for the defined base year 2010. Performance models for the PV and CSP technologies were implemented in the software SAM (System Advisor Model) by NREL and the plausibility of the simulation results were checked internally at Fraunhofer ISE using in-house tools.

Since the production profiles for all fixed PV technologies (thin film, mono crystalline standard and high efficiency) are similar, they are combined to a single graph in Figure 2. This graph shows the differences between the considered PV technologies on an exemplary day with high available solar resource as well as on annual average. Power produced by CPV is generally lower compared to the other PV technologies as it can only harvest direct irradiance (DNI is shown in Figure 3). The tracked flat plate PV system shows extended production periods in the morning and afternoon due to its ability to track the sun and thus have a more favorable incidence angle on the collector surface which reduces cosine losses. Peak production around midday on the other hand is on average higher from fixed PV systems due to their tilt towards the equator.

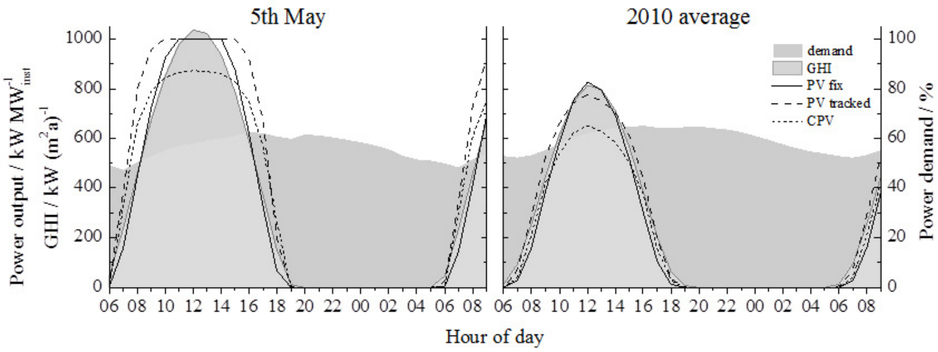

Fig. 2: Solar resource, electricity demand and PV power production profiles for an exemplary day in 2010 with high solar resource (left) and annual average hourly values in 2010 (right). Power output is shown per installed MW of capacity and power demand relative to the maximum demand in 2010.

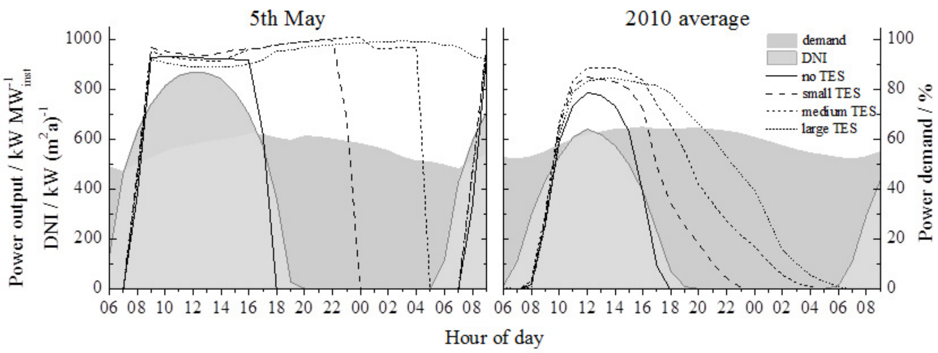

Fig. 3: Solar resource, electricity demand and CSP power production profiles for an exemplary day in 2010 with high solar resource (left) and annual average hourly values in 2010 (right). Power output is shown per installed MW of capacity and power demand relative to the maximum demand in 2010.

Due to their similarity, also the two CSP technologies with medium storage capacity are combined and represented as a single graph in the CSP production profiles shown in Figure 3. The effect of storage integration can be very well seen for the presented day of high available DNI resource (5th May). While CSP with no storage also only produces energy during times of sunshine, thermal energy storage (TES) extends the production of electricity according to its capacity until long after the sun has already set, and even an uninterrupted production is possible as demonstrated by the large TES capacity shown in the chart. Also on annual average the effect of storage is apparent. The performance simulation of CSP in this study only considered a very simple operational strategy for the CSP plants: When solar input is available, the power block is operated as a priority. If excess energy is available, the storage is filled simultaneously. Once the solar resource is not sufficient anymore, the storage is discharged to continue operating the power block until it is empty.

When comparing the production profiles of CSP and PV as presented in Figure 2 and Figure 3, it becomes clear that, at the same installed nominal capacity, CSP has the potential to provide electricity for longer periods of time. Especially when looking at the demand profile, CSP can provide power during a longer period of peak demand. How different operational strategies of CSP plants could enhance the overall performance of an RE park, particularly in combination with wind and PV, will be further discussed in chapter 6.

The performance simulation of the wind technology options including the calculation of several types of losses (temperature, wind farm array losses) were done using MATLAB and WindPRO models or were estimated (electrical losses, technical non-availability). Figure 4 shows an exemplary three days in 2010 and the simulated electricity production profiles from the three considered wind technology options. It can be seen that on some days, almost no electricity is produced from wind (5th May). Other days show very high production throughout the day (28th June) and some also show a typical calm period in the afternoon (14th June). Considering that the high demand period is usually in the afternoon, this of course is not advantageous for the integration of wind power.

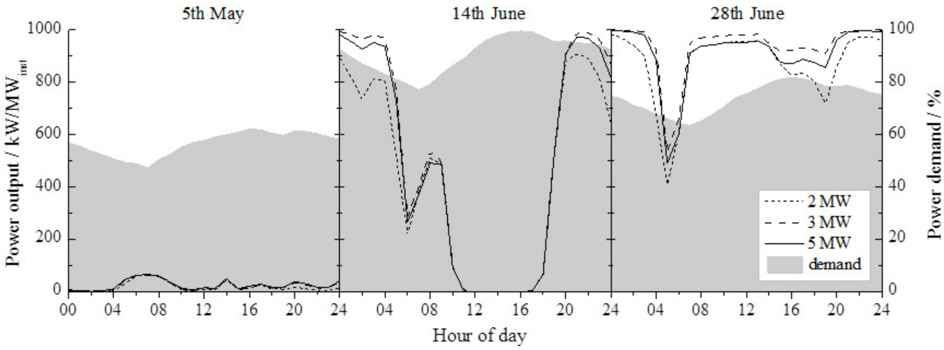

Fig. 4: Electricity demand and wind power production profiles of the three considered turbine sizes on three selected days in 2010. Power output is shown per installed MW of capacity and power demand relative to the maximum demand in 2010.

4.3. Socio-economic assumptions

CAPEX and OPEX values for each of the 14 technology options were assumed based on project experience by Fichtner. Cost decrease functions were included for predictions until 2030 according to the development potential of each technology. The job creation potential, water consumption and fuel consumption were determined for each technology option based on available data and internal experience from the involved project parties.

4.4. Evaluation criteria

Based on the performance simulation and the socio-economic figures, a set of criteria as shown in Table 2 was defined to assess the technology options.

Table 2: List of defined criteria used to evaluate the technology options

Criterion	Unit
Yield per area	$kWh_{el} (m^2a)^{-1}$
Full load hours	$h\ a^{-1}$
Peak load shaving capability	$MWh_{el} (MW_{inst}\ h)^{-1}$
Levelized cost of electricity	$\$\ MWh_{el}^{-1}$
O&M jobs	MW_{inst}^{-1}
Construction jobs	(person years) MW_{inst}^{-1}
Water consumption	$m^3 (MWh_{el}\ a)^{-1}$
Plant availability	%

The land use efficiency and the electrical yield of a technology are taken into account in the criterion yield per area. Equivalent full load hours (FLH) can be at maximum 8,760 h/a, which would be achieved if the plant were run at nominal capacity around the clock the whole year long. FLH is used alternatively to capacity factor and is a measure for how well the nominal capacity of a plant is utilized.

The load peak in Kuwait occurs mainly on summer afternoons, when temperatures are highest and air conditioners are in operation. In order to replace conventional fossil power plants, the renewable energy park should reduce this peak load as much as possible. For this reason, a criterion called PLSC was introduced and is defined as in eq. 1. Hours in which the load is above a certain threshold are defined as critical hours. The amount of electricity *E(crit)* produced by a technology during these critical hours divided by the number of critical hours *crit* is defined as the peak load shaving capability. The peak load shaving capability therefore describes the average hourly amount of electricity produced by a technology in critical hours.

$$PLSC = \frac{\sum_{t=1}^{n} E(crit)}{crit} \tag{1}$$

As a cost evaluation figure, the levelized cost of electricity (LCOE) is chosen which is calculated for each asset individually, taking into account the aforementioned cost decrease functions based on the year of installation. LCOE calculation is defined as stated in eq. 2: the upper term describes the CAPEX and OPEX in each year *t*. In all technologies CAPEX values are highest during construction and are only minor later on. The lower term is the amount of electricity *E* generated in each year. Both expenditures and electricity generation are discounted by the discount rate *r* to the first year of electricity production. Due to increasing O&M effort over the years, an annual increase in OPEX of 2 % was considered for the LCOE calculation. Based on the CAPEX and OPEX assumptions, which considered also different plant sizes, a polynomial fit was done to describe the LCOE of plants of varying size. This fit was implemented later in the optimization procedure, so that the LCOE in every optimization step accounted for the year in which the plant is built and the size of the plant.

$$LCOE = \frac{\sum_{t=0}^{n} \frac{CAPEX_t + OPEX_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}} \tag{2}$$

Additional evaluation criteria were the number of jobs created both during the construction and the operation phase of a plant. As it is especially important in desert areas, water consumption was also considered as a criterion. Finally, plant availability was also considered.

5. Optimization methodology

Using the evaluation criteria defined in the previous chapter, cost-benefit analysis was performed in order to evaluate a given technology mix under different scenarios.

5.1. Scenario definition

Based on the evaluation criteria described in chapter 4.4 the technology mix in the Shagaya RE park was to be optimized. During discussions in the project team, it became clear that not all evaluation criteria are equally important but that a weighting should be applied for the criteria set. An additional goal was to develop several so-called scenarios which differ by the weighting of criteria, thus putting an emphasis on different aspects and elaborating the influence of the criteria on the optimal technology mix. Consequently, three scenarios were defined, each one emphasizing one of the three evaluation criteria considered most important for the Shagaya project by the project team: The scenario S1 *peak load shaving* emphasizes electricity production during peak demand periods as defined in the PLSC criterion. The scenario S2 *high annual yield* aims at a high overall annual electricity production and therefore has an increased weighting of the FLH criterion. Lastly, the scenario S3 *low LCOE* focuses on decreasing the overall levelized cost of electricity generated by the Shagaya park. Apart from the three criteria that are emphasized in the scenarios, the other five criteria are assigned the same weight in all three scenarios.

After the results for the optimal technology mix for the three scenarios were obtained (results see chapter 6), it was decided to introduce an additional scenario which was a variation of the peak load shaving (S1) scenario but included a fixed minimum share of 136 MW installed wind power capacity. This amount of wind power corresponds to a single line of wind turbines along the Shagaya park border that faces the prevailing wind direction. By this measure the downwind spacing of the wind turbines can be neglected, leading to an increased land use efficiency of wind power. Compared to the other technologies, wind has rather low land use efficiency and given the confined area that was available for the Shagaya RE park, this was the main reason that led to the non-selection of wind power during the technology mix optimization of scenarios S1 and S2. The reasons for this measure are again discussed in more detail in chapter 6. The scenario with the fix wind capacity as described is referred to as *S1_fixwind* and the same criteria weighting scheme as for S1 is applied for the technology mix optimization.

5.2. Boundary conditions

Four boundary conditions were implemented in the optimization procedure: (i) the land area available to the park as a maximum condition, (ii) the installed capacity of the park as being exactly 2,000 MW and a minimum capacity credit (CC) for the technology mix both after phase 2 and phase 3 (iii and iv, respectively).

For the maximum capacity boundary condition (ii), the nominal turbine capacity was considered for wind technologies, the net nominal turbine capacity for CSP, and the nominal kWp rating for PV systems. As it describes the ability of the newly installed renewable energy capacity to replace conventional production capacity, the capacity credit is an adequate indicator to ensure a certain penetration level of renewable energy in the grid. It is calculated as shown in eq. 3 by relating the difference between the maximum load and the maximum residual load that occur in the considered period to the installed renewable energy capacity [2].

$$CC = \frac{max(load(t)) - max(res\_load(t))}{installed\_capacity} \tag{3}$$

In order to evaluate the influence of the CC boundary on the technology mix, a sensitivity study was conducted with CC boundaries of ±2 %p, the results of which are also presented for the S1_fixwind scenario in chapter 6.

5.3. Optimization

Due to the discontinuous element introduced by the inclusion of the capacity credit into the optimization and the multiple parameters, a multitude of local minima is to be expected for the objective function. Since the number of candidates is prohibitively large to check all possible combinations of technology mixes in a brute force method, a two-step approach to finding the global minimum with a high probability was therefore adapted for the optimization procedure. Firstly, a generalized pattern search (GPS) with multiple starting points was implemented in order to identify a technology mix with minimal score under the respective scenario. Secondly, a brute force method was applied to check the validity of the optimal technology mix determined by GPS, leaving out the technology options that were not selected by the GPS.

The GPS algorithm was implemented in the software GenOpt [3]. The brute force check with the reduced number of technology options was consecutively implemented in C to test all combinations for a solution with a better score. Here the increment for each technology option was constant, with 10 MW for wind and PV and 50 MW for CSP. These increments were necessary to reduce the number of candidates to a number which could be handled in a realistic processing time. This means that in consequence the optimal results found by GenOpt and the brute force method might differ slightly, but within this uncertainty the brute force method confirmed the GenOpt results.

6. Results and discussion

The results from the technology mix optimization of the three original scenarios *peak load shaving (S1), high annual yield (S2) and low LCOE (S3)* are presented in Figure 5 (left). It shows the technology mix after all three extension phases and also the result of the technology mix optimization for the adjusted S1 scenario with the fixed minimum wind capacity of 136 MW is included. Looking at the results for the three original scenarios, it is apparent that the technology mix is rather similar for both the peak load shaving scenario and the high annual yield scenario. The fact that CSP is dominating the technology mix under both scenarios is plausible since the critical hours as defined in the PLSC criterion often occur in late in the afternoon or even in the first half of the night and the thermal storage available to CSP can be used to serve these hours. Additionally, CSP with storage is able to produce more electricity from the same nominal capacity compared to wind and PV technologies. In combination with the upper park capacity limit of 2 GW and sufficient land available, CSP is favored. However, CSP is still a quite expensive technology, at least from a LCOE point of view, which is reflected in the results of the technology mix for the low LCOE scenario, where CSP is completely missing and the mix consists only of PV and wind. The reason why the share of wind technology stays limited is its high land use per installed MW and its fluctuating nature.

The similar results for scenarios S1 and S2 present the opportunity to combine two major goals in one final technology mix. But keeping in mind the overall cost and the technological diversity in the park, which is, amongst others, beneficial regarding risk diversification, a fixed amount of wind capacity is installed in the technology mix as presented in Figure 5 (left). By this measure, which is also discussed in chapter 5.1, the amount of CSP is slightly reduced.

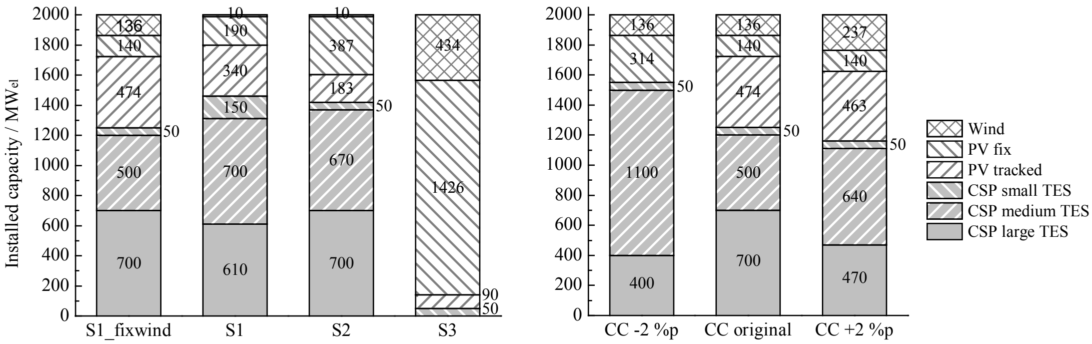

Fig. 5: Left: results for the optimized technology mix under the three original (S1, S2, S3) and the scenario with the fixed wind capacity (S1_windfix). Right: results of sensitivity for the capacity credit boundary condition based on the S1_windfix scenario.

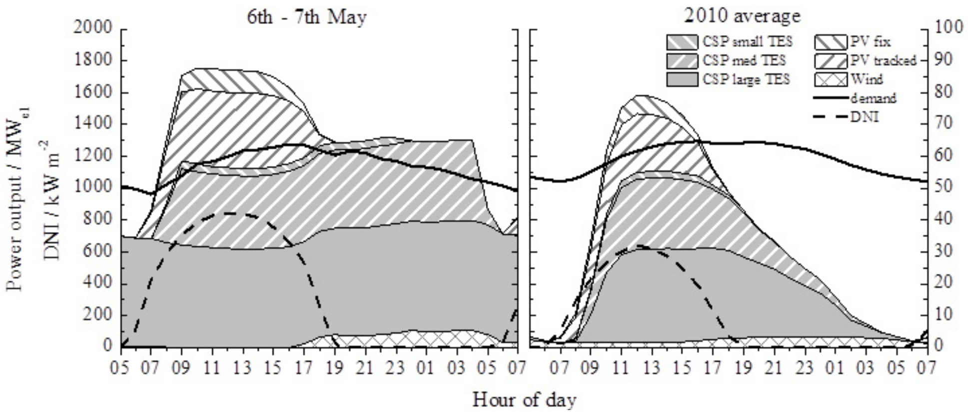

Fig. 6: Overall power output profiles from the Shagaya RE park with the technology mix as determined in the peak load shaving scenario with a fixed minimum wind capacity of 136 MW. Profiles are presented as stacked area charts for an exemplary day (left) and the annual average for 2010 (right).

As already discussed in a previous chapter, the modeled CSP operational strategy is not flexible in a sense that the storage is simply discharged until it is empty after the solar input is not sufficient anymore to run the power block by itself. This means that by a more flexible utilization of the storage of CSP, the fluctuations in PV and wind power could be better compensated, hence more PV and wind could perhaps be installed with the same security of supply and PLSC. However, the overall electricity yield would then again be lower.

For this adjusted S1 scenario - *peak load shaving* - with the fixed amount of wind, which was also recommended to the project owner, electricity production profiles for both an exemplary day and the annual average for 2010 are shown in Figure 6. On a day with good solar resource available as is the case on May 6th, the TES of CSP is fully charged and, in case of large storage capacity, a continuous operation throughout the night is possible. Also on annual average, CSP can produce until late into the night. An even more even electricity production profile might be achieved if, as already mentioned, CSP would be operated more flexibly. This could for example mean that during times that electricity is produced from PV, some CSP plants focus on charging their storage instead of operating the power block. Then, after production from PV drops in the late afternoon, CSP takes over production. Such a scheme would however require adequately rewarding the flexibility provided by CSP, as the plant would not be operated at the maximum electricity production possible and would therefore present a monetary disadvantage to the plant owner and operator under a constant feed-in tariff scheme.

The influence of the CC boundary condition was additionally examined by varying it by 2 %-points to either side from the originally set CC, the results of which are presented in Figure 5 (right) for the adjusted S1 scenario with the fixed minimum wind capacity. They show that the CC boundary directly influences the resulting technology mix from the optimization procedure: Increasing the CC boundary results in a diversification of the technology mix by reducing the CSP share and increasing the wind share at the expense of PLSC. On the other hand, allowing a lower CC increase the share of CSP as it is the technology which provides the highest PLSC, which is the criterion with the highest weight in this scenario.

7. Summary and conclusions

It is well known that optimum renewable technology mix is site specific and it depends on many controlling parameters such as resources, land topography, grid infrastructure, demand profile and many others. However, some general conclusions can be drawn from the results obtained in this study with respect to the technology mix for the Shagaya site: (i) thermal storage of CSP is important to serve the peak load and to achieve a high annual yield, (ii) despite having the lowest LCOE, wind is often neglected due to its low land use efficiency in case the main focus is on the amount of electricity produced, (iii) PV and wind power are preferred for a low LCOE, (iv) inclusion of PV increases the land use efficiency and (v) a diverse technology mix is important for a high capacity credit, no single technology can be definitely identified that is more or less important.

Main parameters influencing the results obtained from the presented technology mix optimization method include (i) the choice of the capacity credit boundary condition (ii) the overall installed capacity in the park, (iii) the selected base year as available wind and solar resource as well as the demand profile is different in each year and (iv) the operational strategies implemented for CSP technologies with respect to TES operation. It was previously discussed that some technology options defined in this study are rather similar, therefore future studies should reduce the number of technology options and only consider one from each technology class. The value added by considering additional technology options within on class (e.g. parabolic trough with medium TES and additionally power tower with medium TES) does not necessarily justify the increased complexity and computational time at the level of detailed required for a master plan study such as the one presented. As operational experience, ground measured meteorological data, performance and cost data will become available from the first phase of the Shagaya project, the study should be revisited and refined.

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