Optimized Integration of Renewable Energy Technologies in MENA: Jordan Case Study

Introduction

Jordan has experienced a significant increase of peak load and annual electricity demand within the last years due to economic development and population growth as it is the case for most countries in the MENA region. The experienced growth rates are expected to continue during the next decades, making large investments in new power generation capacity necessary. Additionally, when gas supply from Egypt was interrupted several times and crude oil world market prices increased, recent years have shown painfully that a power supply exclusively based on fossil fuel imports is subject to a very high risk and can have a strong negative impact on the national budget. Electricity sector authorities are looking therefore for suitable solutions to keep up with the increasing electricity demand, to make Jordan more independent from fossil fuel imports and to provide electricity at reasonable prices in the future. The paper at hand presents a methodology for the optimized integration of renewable energy (RE) technologies into Jordan's existing power plant portfolio. The core of the methodology is the mixed integer linear optimization program ReMix-MENA (Renewable Energy Mix for the Middle East and North Africa) developed at DLR which optimizes capacity expansion and replacement as well as unit commitment of RE and conventional power generation technologies simultaneously.

Methodology

The methodology for an optimized integration of RE technologies into Jordan's power plant portfolio is shown at Figure 1.

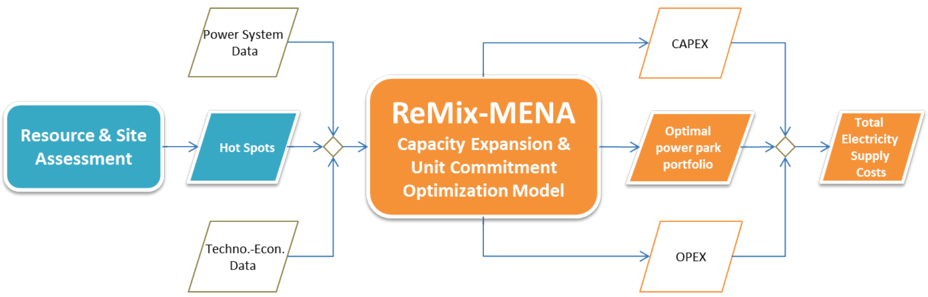

Figure 1: Methodology for an optimized integration of RE technologies into power plant portfolios

In a first step, within a resource and site assessment for utility-scale PV, onshore wind power and Concentrating Solar Power (CSP), technology specific hot spots for the most promising RE technologies in Jordan are identified using a Geographic Information System (GIS). Thereby, the technology specific hot spots are identified by applying a site-ranking process with respect to the availability of the primary energy source (wind speed, solar radiation) as well as to the distance to demand centers and infrastructure (substations, transmission lines, major streets, etc.). At each site, information about the hourly availability of the respective resource, the hourly ambient temperature and the maximal installable capacity are assessed. With this information representative hourly generation profiles of each technology at the respective sites are calculated. This information serves, together with detailed information about power demand and supply in Jordan and related techno-economic data, as input for the capacity expansion and replacement optimization model ReMix-MENA.

The emphasis of the ReMix-MENA optimization tool lies on the cost efficient short-term integration of RE technologies into existing power plant portfolios, while conserving the security of electricity supply of strongly increasing electricity sectors. Therefore, the tool optimizes the capacity expansion and replacement of conventional and renewable power generation technologies as well as the hourly interaction of the different conventional and renewable units of the power plant portfolio (unit commitment) taking into account all relevant restrictions on system level (e.g. reserve capacities, etc.) and unit level (e.g. start-up costs, part load efficiency, minimum up- and down-times, influence of ambient temperature, etc.). The optimization tool is formulated as a mixed integer linear optimization programming (MILP) problem written in GAMS (General Algebraic Modeling System) and solved by the commercial MILP solver CPLEX which is accessed via the GAMS/CPLEX interface. Contrary to traditional capacity expansion models which generally use load duration curves the ReMix-MENA optimization tool uses annual hourly load time series for optimizing the capacity expansion and replacement. Thereby, load chronology and information about the temporal availability of RE technologies as well as operating constraints and dynamics of thermal power generation units can be taken into account since the importance of these constraints increase significantly when RE technologies are part of the capacity optimization.

The objective function of the model is shown at Equation (1). The total system costs are minimized by optimizing the unit commitment of the already existing and the possible new conventional and renewable power generation units over one year on an hourly basis taking into account annual capital costs of the potentially new and the existing but still not depreciated generation units u ($CAPEX_u$), the annual fix and variable operation costs of all existing and potentially new units g ($OPEX_g$) and costs for power imports and exports ($IMPORT * c_i$, $EXPORT * c_e$).

$$Minimize \sum_{u \in U} CAPEX_u(y) + \sum_{g \in G} OPEX_g(y) + \sum_{t \in T} IMPORT * c_i - \sum_{t \in T} EXPORT * c_e , \qquad \forall y \in Y \qquad (1)$$

This optimization is carried out for planning steps of 1 – 5 years, e.g. for the years 2012, 2015, 2017, 2020, 2022, whereas the results of the previous planning step serves as input for the next planning step. In terms of integration of RE technologies into the power plant portfolio the approach is very conservative since RE technologies are only integrated if their utilization associated with their total annual costs (CAPEX + OPEX) contributes to reduce total system costs in the investigated year.

Results

The results of the capacity expansion optimization ("base case" scenario) are shown in Figure 2. As can be observed, RE technologies are already competitive in the short term in Jordan. Until the end of the optimization time-frame in the year 2022 about 2200 MW of CSP, 2100 MW of utility-scale PV, 1000 MW of onshore wind power and 1800 MW of conventional capacity is installed. The share of power generation by RE technologies is increased from about 0.3 % in 2012 to more than 47 % in 2022, whereby Jordan becomes significantly more independent from fossil fuels and the related risk of cost escalation.

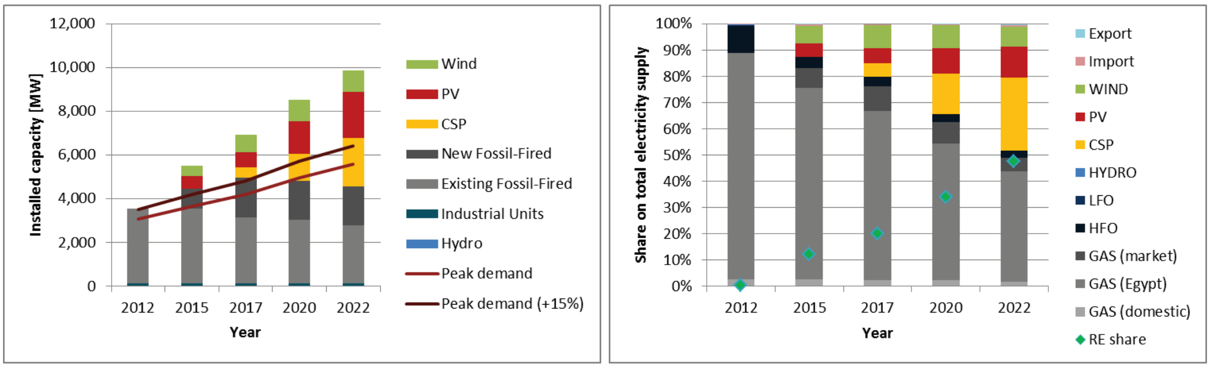

Figure 2: Development of generation capacity and power generation until 2022 („base case")

Figure 3 shows the development of the unit dispatch over the optimization time-frame in Jordan exemplarily for a summer week of the years 2012, 2017 and 2022 for the "base case" scenario. As can be observed, peak load power which is served by expensive fuel oil in the year 2012 is replaced in a first place. Utility-scale PV plants and onshore wind power plants are used as inexpensive "fuel savers" due to their comparably low generation costs. On the other hand, CSP plants are operated as peak/ upper-mid merit power plants providing strongly required firm and flexible power generation capacity. Until 2022, the share of power generation by RE technologies is increased continuously, especially due to CSP units with increased solar field and thermal energy storage operated as mid-merit power plants.

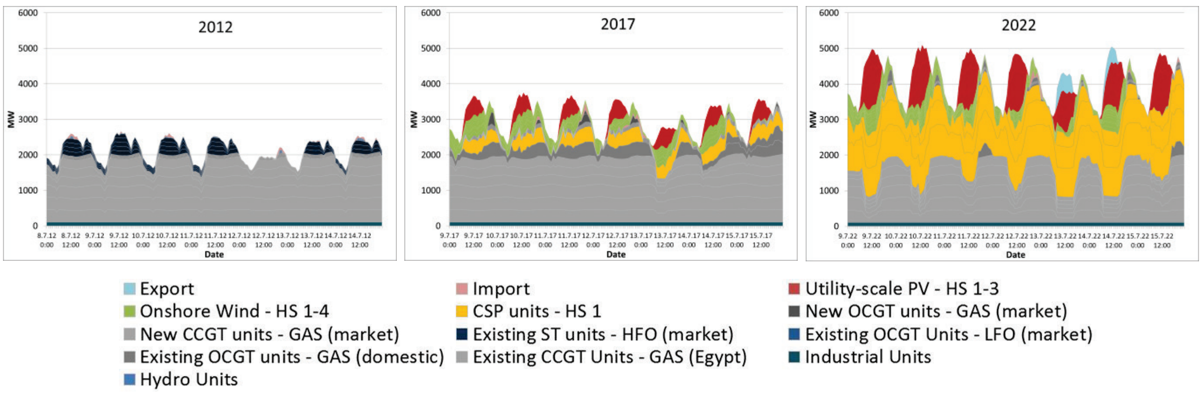

Figure 3: Power generation dispatch in selected summer weeks in 2012, 2017 and 2022 ("base case")

In Figure 4, the development of the average specific generation costs of the "base case" scenario is compared with a "fossil fuel" scenario (investments only in conventional technologies) and a “fluctuating RE” scenario (no investments in CSP units). As can be observed, the optimization shows that a well balanced mix of all available RE technologies and some conventional generation technologies according to the “base case” scenario is the least cost option for Jordan to meet future power demand.

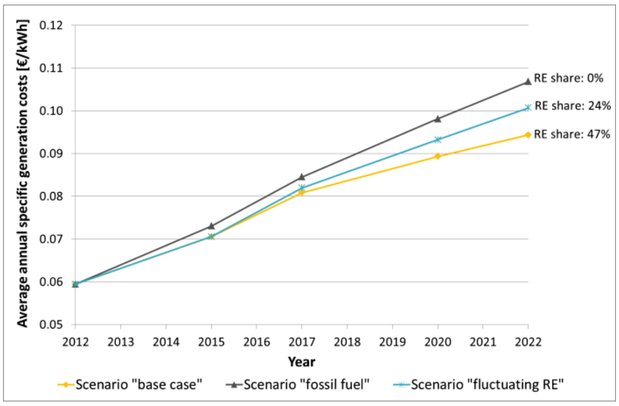

Figure 4: Comparison of average specific generation costs of the power plant portfolio for the capacity expansion according to the “base case”, the “fossil fuel” and the “fluctuating RE” scenario.

Conclusion

The future challenges for Jordan’s electricity authorities have become obvious in the last years. Reliable electricity supply at reasonable prices is a key factor for Jordan in order to ensure the future economic development. The paper at hand describes how a well balanced mix of renewable and conventional power generation technologies can ensure to keep up with Jordan’s strong increasing electricity demand and to get simultaneously more independent from fossil fuel imports whereby the escalation of future electricity generation costs can be significantly absorbed. It shows that CSP, utility-scale PV and onshore wind power, due to the excellent solar and wind resources, are already competitive today in certain load segments of Jordan’s electricity sector. Each of these technologies has characteristics which determine the application within the electricity system. PV and wind power can be used as cheap fossil “fuel saver”. The CSP technology, as a dispatchable and renewable power generation technology, can deliver strongly required firm and flexible power generation capacity and - due to its constant generation costs - has a significant advantage over fossil-fuel based technologies.

However, even though the analysis has shown that RE technologies are competitive in Jordan in the short-term and the large-scale introduction is favorable for economic reasons, suitable market conditions still have to be implemented in order to trigger investments in renewable power generation projects. Providing security about future revenues is the easiest way to attract private investors and to bring down generation costs of RE technologies. One possibility is the introduction of technology specific international insured long-term power purchased agreements whereby project risks can be brought down to an AAA level.