Potential for the penetration of renewable energy sources in Jordan's energy system

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Abstract

Jordan's high dependence on imported energy is a serious ecological and economic problem. It is currently importing almost all of its primary energy, mostly in the form of oil and natural gas. These figures are not sustainable in the long run and such a high level of dependence on imported energy is unnecessary for a country as rich in renewable energy sources such as Jordan.

This paper will present the possibilities for the integration of renewable energy, namely wind and solar, in Jordan's current energy system using the EnergyPLAN model. It will show the impact of higher penetrations of renewables on the production of critical excess electricity, CO_2 emissions and cost of the system, both with and without energy storage.

Keywords

Jordan, renewable energy, PV, wind, energy storage, EnergyPLAN

Background

Almost all of the produced electricity in Jordan comes from imported fossil fuels. Almost 90% comes from natural gas while the rest comes mostly from oil and a negligible amount from renewables [1]. This is getting quite expensive. The Jordanian annual fuel bill exceeds 3 billion US$, which is approximately 20% of its GDP for the year 2011 [2]. This could become an even bigger problem since their official energy strategy predicts an annual increase in the consumption of electricity by 7.4% annually until 2020 [3] and the latest predictions say that the population in Jordan is likely to increase by 50% until the year 2030 [4]. The production of electricity from fossil fuels also has a profoundly negative impact on the environment.

This doesn't have to be so. Jordan is a country rich in renewable energy sources (RES), namely wind and solar. Several studies have shown a high potential for economically viable utilization of both wind [5], [6] and [7] and solar power [5], [8] and [9]. In some cases the payback period for wind power was as low as 6 [10] and for solar power as low as 2.3 years [11]. The problem with a high level of penetration of these technologies is the intermittent nature of their operation. Since their production is dependent on atmospheric conditions it cannot be fully controlled. Because of this, critical excess of electricity production (CEEP) can become a problem, especially during times of high productivity and low consumption. This issue can be addressed with the use of energy storage, but these technologies are still very expensive.

Energy planning is needed to properly evaluate and optimize a system. One tool used for this purpose is EnergyPLAN developed by the Sustainable Energy Planning Research Group at Aalborg University in Denmark [12]. It has already been used to recreate many different energy systems and devise numerous energy scenarios. For example, authors of [13] and [14] used the model to simulate different scenarios for the Macedonian energy system. In [15], [16], [17] and [18] EnergyPLAN has been used to model the Danish energy system and to analyze the potential for the integration of RES. The authors of [19] used both the EnergyPLAN and the H2RES [20] models to recreate the Croatian energy system and plan a 100% energy independent scenario. This paper is on the track of their work with a goal to estimate the potential for the penetration of solar and wind power in the Jordanian energy system. The impact of higher penetration on the production of CEEP, CO_2 emissions and the total cost of the system is presented here.

Methods

The Jordanian energy system has been recreated with the EnergyPLAN computer model for the purpose of this paper. EnergyPLAN is an input output computer model that creates an annual analysis of an energy system with a time step of one hour. The required inputs include total demands and demand curves, installed capacities, fuel mix and different regulation strategies. The results of the model, the outputs, are the energy balances, annual and hourly productions of energy and CEEP, fuel consumptions, total cost of the system and CO_2 emissions.

EnergyPLAN has already been successfully used to model different systems with a high share of RES and to create different energy scenarios in the past [21], [22] and [23]. This has already been demonstrated in the previous chapter.

Scenarios

A total of twelve different scenarios were created for the purpose of this analysis. Half of the scenarios are for different penetrations of wind power with a production ranging from 0 to 8.5 TWh, and half for different penetrations of PV power with a production ranging from 0 to 6.7 TWh. The six scenarios created for both cases are one with no storage and five with different capacities of pumped hydro storage (PHS). The different capacities range from an installed power of 200 to 1000 MW and a storage capacity of 1.2 to 6 GWh. This represents a storage capacity of six hours.

The first step in order to analyze the potential for the penetration of RES in the Jordanian energy system is the creation of a reference model. The hourly electrical load curve was obtained from the Jordanian National Electric Power Company (NEPCO) [24] and the installed capacities for the year 2009 were taken from NEPCOs annual report [25]. The fuel mix for the installed thermoelectric power plants and the energy consumption in the residential, industrial, commercial and transport sectors were all taken from the International Energy Agency (IEA) [1].

The cost of the different technologies was taken from the SETIS calculator [26], Technological Data for Energy Plants published by the Danish Energy Agency [27], SET-Plan [28] and from [29]. The fuel prices were taken from the SETIS calculator [26] and from [14] while the CO_2 content of those fuels was taken from [14]. The meteorological data was obtained with the use of the computer program METEONORM [30].

Results and discussion

As it is already stated, several scenarios were created with different installed capacities of wind, PV and pumped hydro storage plants with different storage capacities. The production of CEEP, emissions of CO_2 and the total annual cost of the system were analyzed and compared. The results of the scenarios are presented in this chapter.

The reference model has been compared with the data obtained from the IEA website. Table 1 presents this comparison. There is a slight difference in the fuel consumption of the power plants (PP). The reason behind this is that the created model was done as a closed system and Jordan did import 0.383 TWh and export 0.139 TWh of electricity in 2009 [1]. The energy consumption of the transport, residential and industry sectors is virtually identical in both cases. Since EnergyPLAN doesn't support the distinction between the household and commercial sectors, they were both summed up and input into the "Individual" tab in the model. The consumption of energy for the agricultural, fishing and industry sectors has also been summed up and input in the industry tab.

Table 1 Comparison of the reference model and the data from the IEA

Energy consumption (TWh annually)	IEA [1]	EnergyPLAN
PP N. gas	35.88	36.49
PP Oil	3.9	3.97
PP Biomass	0.02	0.02
Transport	20.08	20.09
Residential	8.63	8.63
Industry	9.83	9.83

Figures 1 and 2 represent the amount of CEEP depending on the production of electricity from wind and PV power respectively for different capacities of PHS. According to the results presented in Figure 1, the Jordanian current energy system, without storage, could utilize approximately 2.02 TWh of wind power annually and still have CEEP equal less than 5% of the annual load. A PHS system with an installed power of 1000 MW and storage of 6 GWh could increase the potential for the utilization of wind to a little over 3.23 TWh annually.

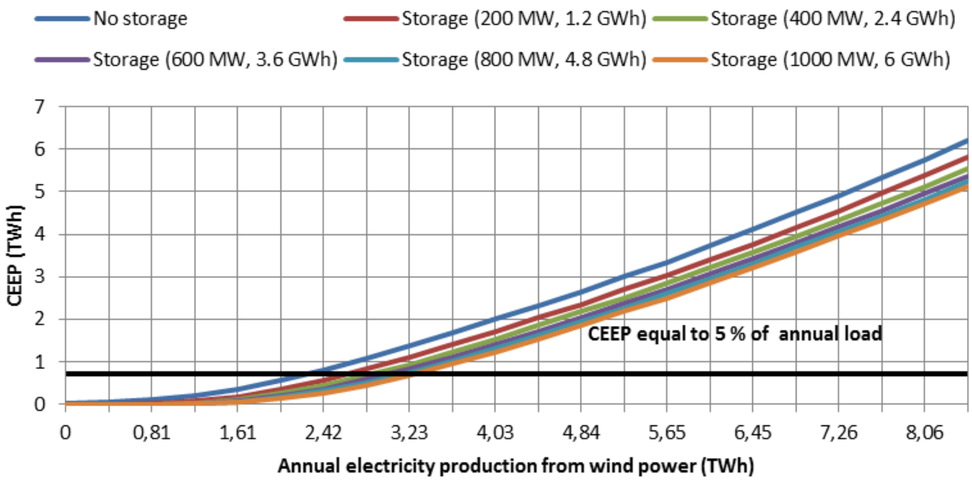

Figure 1 CEEP in relation to electricity production from wind power

The results are similar for PV as well. As Figure 2 shows, the described system could safely utilize a little over 2.25 TWh of PV power annually without storage and almost 4.49 TWh annually with a PHS system with a power of 1000 MW and storage of 6 GWh.

The utilization of PHS can greatly increase the potential penetration of both wind power and PV in the system. As both figures show a saturation point is reached with the final increase of the capacity of the PHS system. The potential penetration increased only slightly in both cases, if we compare the case of a system with 800 MW power and 4.8 GWh of storage and the one with 1000 MW power and 6 GWh of storage.

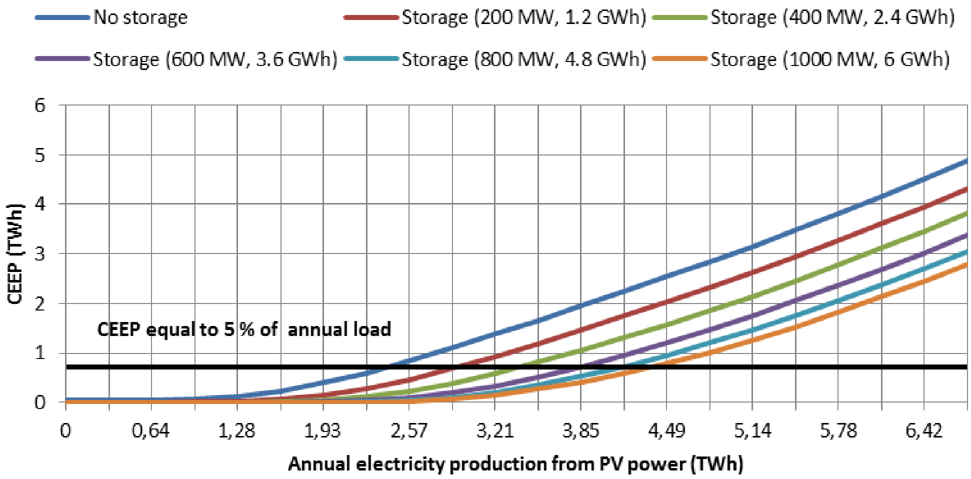

Figure 2 CEEP in relation to electricity production from PV power

Figures 3 and 4 represent the relation of CO_2 emissions and the production of electricity from wind and PV power respectively for different capacities of PHS. As expected, the increase of the installed capacities of any of the two RES will reduce the amount of CO_2 emissions, while PV does have a higher potential according to the model.

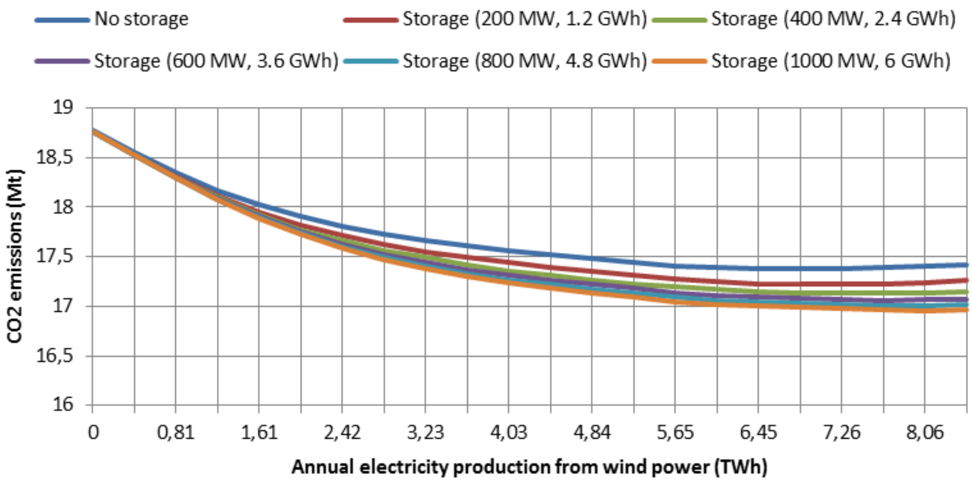

Figure 3 CO_2 emissions in relation to electricity production from wind power

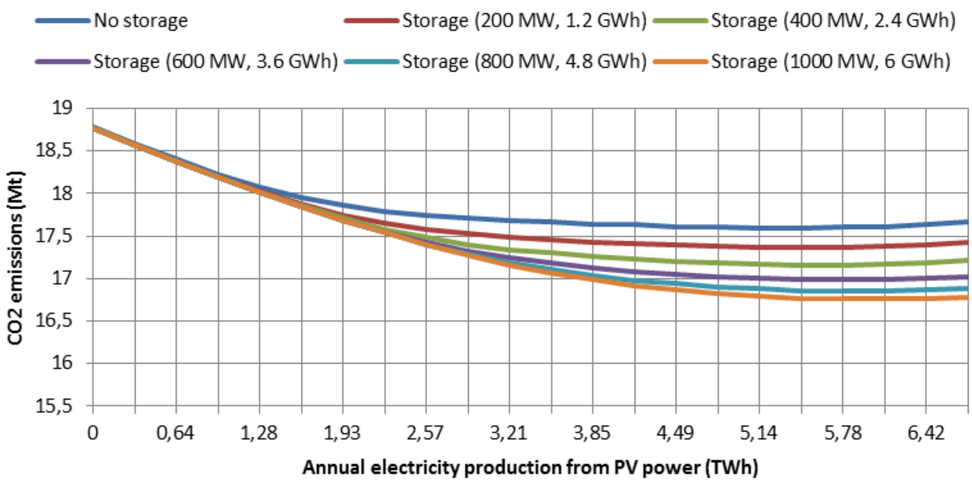

Figure 4 CO_2 emissions in relation to electricity production from PV power

As Figure 3 shows, the implementation of wind power has the potential to reduce the emissions of CO_2 from the base value of 18.78 to 17.42 Mt annually, without storage. If a PHS system with an installed power of 1000 MW and a storage capacity of 6 GWh is utilized the emissions could be reduced to 16.97 Mt annually.

PV, as it is already mentioned, has more potential for the reduction of CO_2 emissions than wind in this model. Without storage, the total annual CO_2 emissions could be reduced to 17.66 Mt annually, which is somewhat less than with wind. The case is different if a PHS system with an installed power of 1000 MW and a storage capacity of 6 GWh is introduced. The emissions could be reduced to as low as 16.78 Mt annually. This is a bigger reduction compared to the case with wind power and the same storage system.

Both technologies hold the potential to reduce the CO_2 emissions in Jordan's energy system especially with the implementation of PHS. In a system with little or no PHS capacity wind has a higher potential to reduce emissions, and PV has the advantage in a system with a sizable PHS system.

Figures 5 and 6 present the relation between the total annual cost of the system and the production of electricity from wind and PV power respectively with different PHS systems. As Figure 5 shows, the integration of wind power can actually reduce the total annual cost of the system up to a certain level of penetration. The minimum cost of the system of 4343 million EUR is achieved with an electricity production of 2.82 TWh from wind power and a PHS system with an installed power of 400 MW and a storage capacity of 2.4 GWh. CEEP is 0.68 TWh annually in that scenario which is less than 5% of total annual load.

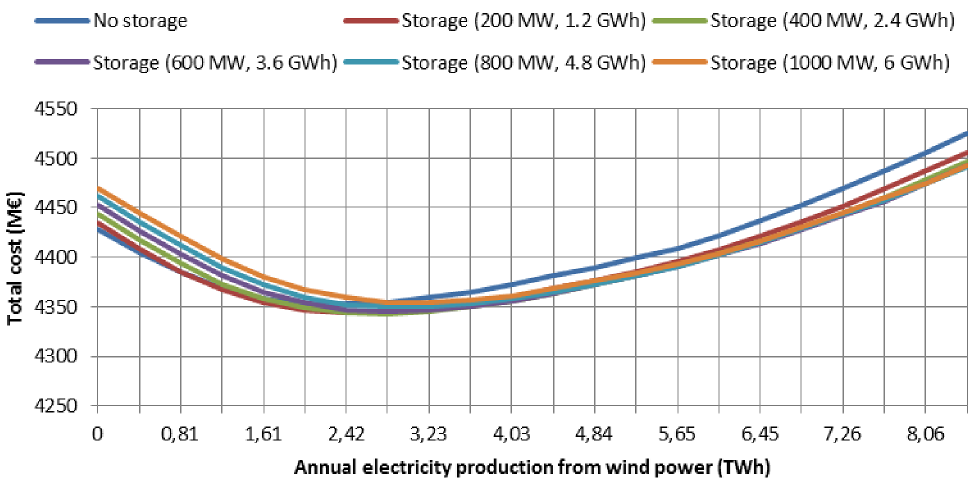

Figure 5 Total annual cost of the system in relation to electricity production from wind power

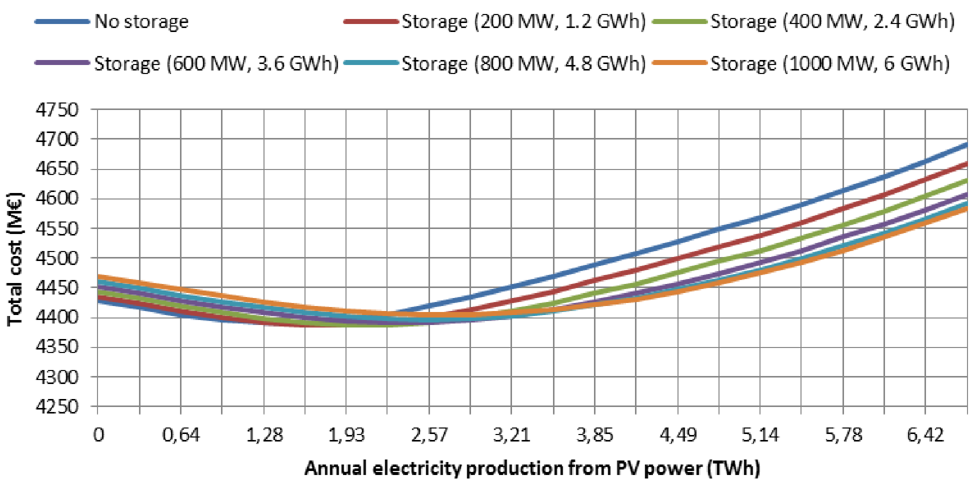

Figure 6 Total annual cost of the system in relation to electricity production from PV power

The increase of the installed PV power has a similar effect on the total cost of the system as does wind. As Figure 6 shows, the minimum cost of the system, of 4387 million EUR is for the scenario with an electricity production of 1.6 TWh from PV and a PHS system with an installed power of 200 MW and 1.2 GWh of storage. In this scenario CEEP is 0.07 TWh annually which is far below 5% of the annual electrical load.

Conclusions

There is a lot of potential for the utilization of renewables in Jordan. Not only could the implementation of RES reduce the CO_2 emissions in Jordan and increase its energy independence, but it could actually reduce the total cost of the energy system.

For the case of wind power the lowest cost of the system is for the scenario with an electricity production of 2.82 TWh annually and a PHS system with a power of 400 MW and a capacity of 2.4 GWh. The cost of that system is 4343 million EUR which is 85 million less than the reference scenario (no RES and no storage). The CO_2 emissions for that scenario are 17.56 Mt annually which is 1.22 Mt less than the reference model. CEEP is 0.68 TWh annually which is less than 5% of the total annual load in Jordan for the year 2009.

The scenario with the lowest cost for PV is the one with an electricity production of 1.6 TWh annually and a PHS system with an installed power of 200 MW and a storage capacity of 1.2 GWh. The total annual cost of that system is 4387 million EUR which is 41 million EUR less than the reference scenario. The CO_2 emissions are 17.88 Mt which is 0.9 Mt less than the reference model. CEEP is 0.07 TWh annually which is far below 5% of the annual electrical load.

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