ASSESSMENT OF INTEGRATIG RENEWABLE ENERGY SYSTEMS TO THE ELECTRICITY GRID IN JORDAN

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ABSTRACT

This paper aims at studying the technical and economic impacts of integrating large scale renewable energy projects of wind and PV systems to the transmission grid in Jordan up to the year 2025. The existing transmission infrastructure is modelled using Digital Simulation and Electrical Network Calculation Program, DIgSILENT PowerFactory. Modelling of the grid is conducted for the alternating current (AC) transmission grid of 132 kV and above. The grid ability to integrate the Renewable Energy Systems (RES) projects according to Jordan's strategy goals and targets is evaluated. Grid expansions up to the year 2025 are identified based on the electricity demand resulting from three generation scenarios. All studied scenarios include RES. The main difference among the studied scenarios is the generation needed from non RES (i.e., Oils shale, Conventional and Nuclear). The proposed nuclear power plant projects are evaluated as part of the electricity generation and transmission system in Jordan in scenario C. The economic assessment of the studied scenarios are evaluated using Wien Automatic System Planning Model (WASP). It is found for all generation scenarios the grid will face minor overloads by 2018, while, most of transmission lines will be overloaded by 2020. It is found that for all generation scenarios the existence of a special transmission line from the RES generation sites in the south to the demand locations in the center (Green Corridor) is needed and it solves most overloads problems. The "Green Corridor" is included in all studied scenarios. It is found that in-spite-of the additional cost of the "Green Corridor" of 145 M$ for grid reinforcement, the LCOE by 2025 will vary only 25 % (between 100 to 125 USD/MWh) when the price of NG increases 50% (from 8 to 12 $/MMBTU). This mainly because of the dependence on RES.

INTRODUCTION

Jordan is one of the highest countries in the world in terms of its dependency on foreign energy sources where is around 97% of the energy needs are imported [1]. Also energy demand in Jordan is growing rapidly due to different reasons such as high growth in population, in addition to hosting high number of refugees from neighboring countries [2].The primary energy needs as of 2014 are around 8,157,000 tons oil equivalent (toe). Eighty-two percent of the primary energy is crude oil and products, 3% is coal, 1% is coke, 2% is renewable energy, 11% is natural gas, and 1% is imported electricity. The cost of energy bell exceeds 18% of Jordan's GDP and it comprises more than 80% of the country's exports. Thus, Jordan's energy bell is a burden on Jordan's economy. The national strategy [1] is designed to reduce imported crude oil and products from 82% to around 52-55% by 2020, keep the use of coal at around 3-5%, increase the renewable energy share in the energy mix to 10%, increase natural gas to 20%, reduce imported electricity, and start using the oil shale reserves for up to 10%. The household sector in Jordan consumes 43% of the generated electricity, 24% is consumed by the industrial sector, 17% commercially, 14% for water pumping, and 2% for street lighting. The exact numbers for the consumption of electricity can be taken from the electricity company's annual report [2].

Jordan's National efforts started in 2007 to meet challenges of increasing oil prices and dependency on imported energy resources. The national strategy developed in 2007 called for 7% of primary energy mix to be RE by 2015 and 15% by 2025.

In order to meet the high demand on electricity and to increase the local resources shares in the energy mix, the government has directed its efforts recently towards encouraging the investment in the renewable energy sector on both large and small scales. The electricity model in Jordan is based on single buyer model where all electricity from all resources is bought by National Electric Power Company (NEPCO) and then it is sold again to the distribution companies and bulk consumers directly through transmission network. The installed generation capacity in Jordan as of 2015 is 3.8 GW, around 2.6 GW through private projects and around 1.2 GW from governmental sector. The highest registered peak load is in 2015 is 3200 MW. The transmission voltages are 400 KV and 132 KV where distribution voltages are 33, 11, and 0.4 KV, the transmission lines length is around 4600

Km circuit and main substation capacity is around 12000 MVA. Furthermore, the Jordanian grid is connected to both Syrian and Egyptian networks through high voltage AC connection on 400 kV level. Furthermore, it is forecasted that the generation capacity will reach 5.8 GW by 2020. Therefore, it is anticipated that almost 300 MW of power plant is needed every year in order to meet the electricity demand by 2020. The recent RE targets reported by the MEMR are 1000 MW from wind, 600 MW from solar and 50 MW from biomass by 2020 and total of 2600 MW by 2025. In order to increase the local energy resources, and since Jordan has enormous reserve of oil shale and Uranium, the government targets building two power plants of 470 MW generation capacity for each using direct burning of oil shale and 2 GW nuclear power plants by 2025.

The expected renewable energy projects in Jordan come from three main paths: (1) direct proposal (2) bidding process, and (3) governmental projects, Jordan has set a target of 10% of the energy mix in 2020 to be produced from renewable energy resources [3]. For this purpose and to secure the supply and to diversify the energy resources in Jordan, several electricity generation projects are committed to be connected to the grid. Table 1 shows the renewable energy projects while Table 2 shows the conventional natural gas fired projects. It should be mentioned that around 70% of these Renewable Energy Systems (RES) are to be erected in the south of Jordan. This will add difficulties to evacuate the produced power to the load center in the middle of Jordan. These difficulties include overloading of transmission line, high short circuit current and other challenges that will be discussed and mentioned in the paper. Furthermore, the development of RES includes small power plants to be connected to the distribution network, the so called "dispersed generation". The effect of this generation is considered negligible for the purpose of this study.

Many researchers have worked in the field of evaluating the impact of renewable energy integration to the electrical systems in Europe [4], in Korea [4] and in North Africa and Europe [6-8].

Of interest the work of Kost et al. [8]. They studied the opportunities and challenges of high renewable energy deployment and electricity exchange for North Africa and Europe. They used the DIgSILENT software [9]. Their results indicated that, by 2050, high RES shares close to 100% are possible in North Africa countries. Wind energy is the dominant technology. Concentrated Solar Power (CSP) plants with thermal storage will have important role with rising RES shares. The work of Abu Dyak et al. [10] (the authors of this paper) can be considered as the first work that addresses the impact of introducing the RES on Jordan transmission grid. Their work addressed only one scenario toward 2025, while, this paper addresses three scenarios including the nuclear scenario. They presented the simple approach for comparing the economic value of the integration of the intermittent renewable energy resources by comparing the levelized cost of energy supplied by different resources proposed by [11].

The main purpose of this work is to asset technically and economically three scenarios to meet Jordan's need of electrical energy by 2025 via including renewable energy projects of WECS and PV systems connected to the transmission grid in Jordan.

MODELS AND METHODS

Within the framework of this paper, two different models are used. Each model covers certain aspect of the study.

The technical aspects are covered by the current electricity system model developed by NEPCO. This model describes the transmission grid, existing power plant locations, national electricity demand and generation. The model of year 2016 is used as a reference model. The model includes the database of the Jordanian power system available from NEPCO. This database includes (1) data for network representation in both static and dynamic analysis of the Jordanian network, (2) representation of power systems of Egypt and Syria, (3) representation of the generation units and (4) the retirement plan for the generation units. This database is revised related to the latest load forecast, generation expansion plan, power exchanges with neighboring countries and new renewable power plants. The existing transmission infrastructure and its ability to integrate additional power generation systems is modeled and simulated using DIgSILENTPowerFactory [9]. Grid expansion needs are evaluated based on the strategic plans of MEMR and load forecast.

DIgSILENTPowerFactory is used in the national grid analysis due to the proven advantages of this software and its overall functional integration, its applicability to the modelling of generation-, transmission-, distribution- and industrial grids, and the analysis of these grids' interactions.

Electrical grids, planning processes and operation processes are becoming increasingly complex due to market unbundling, expansion of interconnections and distributed generation. This increases the demands on software tools in terms of data quality, flexibility and manageability.

Now, the economic analysis are modeled and simulated using Wien Automatic System Planning (WASP) Package [12]. WASP is a software designed to carry out power generation expansion planning taking into consideration fuel availability and environmental constraints. It has the capability of finding the economically optimal expansion policy for an electric utility system within user specified constraints. It utilizes probabilistic estimation of system production costs; un- served energy costs, and reliability, linear programming technique for determining optimal dispatched policy satisfying exogenous constraints on environmental emissions, fuel availability and electricity generation by some plants, and the dynamic programming method for optimizing the costs of alternative system expansion policies.

All future generation expansions are introduced according to three scenarios toward 2025. Each Scenario meets the electricity demand as forecasted toward 2025. These scenarios are put forward by the authors based on announced strategy of the government.

Scenario A

In this scenario, the required electricity generation up to 2025 will be met according to RES projects listed in Table 1 and the conventional power plants listed in Table 2. This scenario includes install a total of 1200 MW of wind energy conversion systems (WECS), 1475 MW of Solar PV power plants and 2000 MW of conventional power plants. In Table 1, there are two types of projects. Committed and uncommitted projects. The location of committed projects is known and defined, however, the locations of the uncommitted projects is set by the authors. The main criteria used in the selection of site of RES are the availability of solar irradiation and wind energy potential and the distance from transmission lines.

Scenario B

This scenario is same as scenario A for RES. But, two 470 MW power plants operating on oil shale replaces similar power of conventional power plants. The location of the proposed power plants are chosen within the area where oil shale is available and close to the transmission lines.

Scenario C

This scenario is similar to scenario B for RES and oil shale power plants. The nuclear power plant is introduced to this scenario. Jordan is planning to generate electricity using Nuclear energy. It is proposed to build a one Gega Watt power plant in the central region of Jordan. This choice is introduced to this scenario. The location of the plant is predetermined. It should be noted that introducing Nuclear energy to the energy mix in Jordan is facing the difficulties of public acceptance and financing.

The following points summarized the main assumptions for the study:

1. Two stage calculations: stage (a) power flow calculation in sound N-network condition and stage (b) network condition in case of contingency (N-1 condition). The basic assumptions in N-network condition approach are related with N-criterion of transmission network. They are: the rating limits of transmission lines should be intended as maximum permanent currents; no overload of the transmission network is allowed; no generator will be above its continuous reactive capability. According to the Grid Code the performance requirement for operating voltages under Normal conditions are: 400 kV network, the admissible voltage range is between 380 kV and 420 kV (±5%); 132 kV network, the admissible voltage range is between 118.8 kV and 145.2 kV (±10%). In the Contingency (N-1) Conditions, (N-1) primary criterion is

applied to all credible scenarios. The (N-1) criterion is considered to be fulfilled, when following the first loss of a circuit or a generation unit with no violation of operation limits, overloads, loss of stability and uneconomic operation of generation units or load shedding [13]. In (N-1) steady-state conditions the voltages can be expected to deviate outside the above limits by a further +/- 5%.

2. The demand on the generation of the PV is assumed to be 70% of the total installed capacity of the PV projects, and for the wind projects is 80%.
3. The study is based on the assumption not to import power from the neighboring countries in the future. Transfer of power along the interconnections with Egypt and Syria are expected due to power wheeling. The representation of the neighboring countries is necessary for short circuit calculations. Even though it is assumed not to utilize the electrical interconnections but they have a lot of benefits to the Jordanian system like helping in balancing the frequency of the interconnected system and reduce the RE forecast error and share flexibility resources [14-16].
4. The cost of natural gas is based on three different scenarios of 8 \$/MMBTU,10 \$/MMBTU, and 12 \$/MMBTU [11] in addition to the transportation fees.
5. New generation using conventional system with total efficiency of 49%.
6. Yearly growth of peak load and energy of 5% [3].
7. The tariff of both nuclear and oil shale projects as the latest announced tariffs, 0.10 \$/Kwh for nuclear and 0.13 \$/Kwh for oil shale.
8. The tariff for the PV projects is 0.148 \$/Kwh for 2016 and 2017, 0.0705 \$/Kwh thereafter. For the wind projects is 0.117 \$/Kwh for 2016 and 2017, 0.1125 \$/Kwh thereafter.

9. Discount rate of 7% and 2016 as the base year.

RESULTS AND DISCUSSION

Scenario A

Loading of several key points in the grid was calculated based on both renewable energy projects and the expansions of the conventional power plants listed in Tables 1 and 2 and their connection on the grid are shown in Fig.1 and Fig. 2. Figure 1 shows the integration of the RES in the southern part while Fig. 2 shows the situation in the northern part of Jordan. From the analysis of the grid with the connection of the renewable projects, several overloading occur in the 132KV line especially in the southern area. Figure 3 shows the loading results up to 2025 in the southern part where most of the expansions and integration of renewable projects will be allocated. It is clear that several overloading in the lines exist due to high penetration of renewable energy beside that they are not in compliance with the N-1 security criterion.

To overcome this overloading problems and the presence of bottleneck in the lines from south area to load center, transmission reinforcement is highly needed. This reinforcement, according to NEPCO, will consist of 400/132/33kV New Ma'an substation with three 400MVA transformers, and two circuits 400kV overhead line from New Ma'an to Qatrana with length of 150Km as shown in Fig. 4. The table attached to Fig. 4 shows 14 lines highlighted in that region with names and numbers to be referred to during this work. This reinforcement "Green Corridor" is planned to be constructed starting in 2017. The reinforcements in several 132kV lines should be also considered as part of the green corridor project. It includes replacing the conductors of the lines by superheated conductors which increase the loading limit of the 132 KV Lines to almost double (200%) with current rating of 1500KA compared to the normal existing OHL conductors

The loading of the 14 selected 132kV lines is studied using DIgSILENT in four target years 2016, 2018, 2020 to 2025, with the presence of the green corridor taking year 2016 to present the current situation. The results shown in Fig. 5 shows the 132 kV grid loading after constructing the Green Corridor. The loading results of all 132kV lines in southern area show that these lines do no experience overloading conditions and, thus, they will be within the thermal rating limits for the next 10 Years.

The reinforcements by Green corridor in the 400kV network are shown in the Fig. 6. The enforcement is needed to accommodate the connection of renewable projects especially in southern area. It includes the New Ma’an 400kV/132Kv substation with three transformers each has capacity of 400MVA and the enforcement in the line (Qatrana- New Maan) 400kV with new double circuit also replacing the conductors in 132Kv line.

The lines loading results obtained in DIgSILENT simulation for the 400kV lines with and without the green corridor in the southern part are listed in Table 3. It is clear that this enforcement is needed after 2018.

The sound network condition analysis detected overloading problems in the loading of the following grid components (lines and transformers):

1- 132KV Line ABDOON-AMS.
2- Abdali-HTPS 132KV line
3- Amman South 400/132KV transformers.

4- Amman East 400/132 kV transformer (the third one). These overloading are strictly related to the increase of the demand in the area of Amman.

In addition to that; the presence of overloading in load center substations also should be solved either by expansion, construction of new substation or by transferring load between substations in order to accommodate the huge load growth in that areas for example (Marqa, Ashrafia, Abdoon, Sahab…. etc.).

The overloading elements detected after the contingency grid analysis (i.e., N-1 analysis) are highlighted and listed in Table 4. To overcome these overloading problems in the lines and transformers of the grid, recommended transmission network reinforcements and their costs are also given in Table 3. The summation of both transmission reinforcements and generation costs (i.e., total cost) for three scenarios of natural gas prices are calculated and listed in Table 5. For the purpose of better comparison among different technologies the LCOE is calculated for three scenarios of natural gas prices; 8 $/MMBTU, 10 $/MMBTU and 12 $/MMBTU. It is found that in-spite-of the additional cost of the “Green Corridor” of 145 M$, the LCOE by 2025 will vary only 25 % (between 100 to 125 USD/MWh) when the price of NG increases 50% (from 8 to 12 $/MMBTU). This mainly because of the dependence on RES. It is worth mentioning that the cost (or selling price to the government) of generating electricity in Jordan in 2014 is 223 $/MWh [2]. Thus, with the renewable energy systems and new conventional power plants the LCOE in 2025 will be 43 % less than that in 2014.

Scenario B

As indicated before, in this scenario 940 MW conventional power plants are replaced by two 470 MW oil shale fired power plants. The RES systems are as in scenario A. Table 6 shows a summary of the needed power plants (including the oil shale plants) and their year of operation to be connected until 2025 to meet energy demand and peak load demand requirements. It should be noted that the first oil shale power plant is expected to operate in 2019 (i.e., one year after Green Corridor construction). Table 6 also shows the suggested connection points. The location of the oil shale plants is chosen to be close to oil shale mines and to the transmission grid. Moreover, it is suggested to evacuate the produced power via 400 kV lines into the 400 kV corridor and then to the load center (in Amman). Thus, the first 470 MW project is connected via the 400 kV double circuit line to the existing line (Amman east-Amman south). The second 470 MW project is connected to the nearest Qatrana 400/132 kV substation.

Sound network condition analysis detects overloading problems in the loading of the following components (lines and transformers) in the network:

- 132KV Line ABDOON-AMS.
- Abdali-HTPS 132KV line
- Amman South 400/132KV transformers.
- Amman East 400/132 kV transformer (the third one). These reinforcements are strictly related to the increase of the demand in Amman area.

Due to the connection of oil shale project to the 400kV directly as suggested, no significant overload in the Network is detected. Moreover, the injected power flows to serve the load without large impact on the lines loading. No problem in the voltage profiles is detected.

Since the first oil shale power plant is planned to be in operation after constructing the green corridor lines, no overloading is observed in this scenario when integrating RES to the power system.

The overloading elements during the N-1 conditions analysis for this scenario are highlighted as in Table 7. This table includes the cost of transmission reinforcements (planned to get rid of contingencies and overloading in the network and to accommodate the increased internal load) the cost for the connection of generation projects and the cost of the suggested Green Corridor reinforcements in the 400KV &132KV lines in southern area. The summation of both transmission reinforcements and generation costs (i.e., total cost) for three natural-gas-prices scenarios of are calculated and listed in Table 8.

Close inspection of Table 8 reveals that the LCOE for this scenario will vary only 18 % (between 115 to 126 USD/MWh) when the price of NG increases 50% (from 8 to 12 $/MMBTU). This mainly because of the dependence on RES and Oil shale (local energy supply). However, the value of LCOE for this scenario is higher than that for scenario A because the initial cost of the oil shale power plant is high. The share of the grid reinforcement in the LCOE for this scenario is the minimum among all other scenarios because the oil shale power plant locations are close the existing grid.

Scenario C

This scenario contains introducing electricity generated using the first Jordanian nuclear power plant (see Table 8). The scenario can be considered as the most challenging one because there is still debates about the feasibility of the project and its public acceptance. The economic assessment of this scenario will shed light on this project "as being part of the National Electricity system not as a single isolated project”. Building the nuclear project in the designated location (SAMRA, as announced by the government) will introduce some complications to the grid: (1) Any sudden loss of generation due to any reason will get 1000MW power out of service and this imposes a huge stress on the network (may lead to partial blackout). One solution to this anticipated problem is to have several injection points in that area. This requires having at least two injection points at 400kV (one in Rehab and one in Azraq) and connect them to the 400kV grid. Moreover, this solution requires enhancing the 132KV system at certain locations (Azraq area). The main disadvantage of this solution is that the load in the area of this enhancement has low loads. Another solution is to connect the nuclear power plant lines to Samra 400kV and Rehab New 400/132kV substation; this requires limiting Samra generation plants to 300MW. (2) The presence of several power plants in the north east area (nuclear plant, 300 MW RES and the 470MW oil shale power plant) will lead to more power to flow through the south area grid (Aqaba-New Maan Path to Egypt tie). This results in an increase in the loading of these lines. It is found through this analysis that these loadings are still within the limit of N-1 criteria.

As regard the analysis in sound network condition, overloading problems have been detected in the loading of components the following lines and transformers:

1- 132KV Line ABDOON-AMS.

2- Abdali-HTPS 132KV line

3- Amman South 400/132KV transformers.

4- 132KV Samra- HTPS Line.

5- Samra- Amman North 400KV

6- Amman north 400/132KV transformers.

Due to the connection of Nuclear to the 400Kv directly; and the existence of generation in north area the 400Kv lines will be stressed and construction of new lines and injection points will be urgent.

The N-1 analysis of this scenario reveals several overloading elements as shown in Table 9. This table also shows the cost of transmission reinforcements needed to get rid of contingencies and overloading in the network and to accommodate the increased internal loads for this scenario. Table 10 shows the LCOE of this scenario. It shows that the LCOE with the highest NG price reaches 132.77 $/MWh. This cost is 5.6 % higher than that in Scenario A. One reason is that the grid reinforcement needed for this scenario is higher than that for the other two scenarios because of the nuclear power plant. It needs more grid enforcement.

Conclusions

In this paper the Jordanian electrical transmission grid was simulated in power system analysis program DIgSILENT. The grid is modified to reflect the grid situation in each target year for three Scenarios for electricity generation to meet the electricity demands up to 2025. These scenarios included different generation systems; RES, oils shale, nuclear and conventional power plants. All scenarios showed that there is a need for grid reinforcements between the southern part of the country (where most RES are allocated) and the center of the country where most of load is demanded. The analysis showed that with the enforcement of the “Green Corridor” the overloading problems are solved.

In all three scenarios the Jordanian national grid is studied with different generation schemes considered, renewable integration is common for all cases, now for first case conventional generation projects are analyzed, for the second case oil shale projects integrated with total capacity of around 900MW and for the last case nuclear and oil shale integration both are considered with total capacity of around 1900MW for nuclear and oil scale power projects, these cases are studied and compared from technical and economical point of view then the reinforcements needed and LCOE are calculated for three scenarios of Gas prices.

The second case that related to oil shale integration was better in term of transmission reinforcements needed for the grid and based on current electricity prices case 2 shows a good economic indicators, the first case give better LCOE but on the other hand this will not serve the national strategy for secure of supply of electricity and the need for diversity of energy resources in the system. So at the end from overall cost values of total needed transmission reinforcements needed plus the cost of Generation based on three NG prices and Levelized cost of energy, the last case gives the best economic indicator and in addition it will serve the purpose of energy diversity.   .

References:

[1] Ministry of Energy and Mineral Resources in Jordan: Annual report 2013. http://memr1.test.jo/echobusv3.0/SystemAssets/fc96a03e-19a4-4626-abb3-7a0b775feb26.pdf.

[2] National Electric Power Company (NEPCO): Annual reports. http://www.nepco.com.jo/annual_report_ar.aspx.

[3] National Energy Research Center (NERC), Strategic plan for the energy sector in Jordan. http://www.nerc.gov.jo/Download/arabic-energy%20strategy.pdf. 2007-2020

[4] Working Group on European Electricity Infrastructure integrating renewable energy sources into European grids European Commission Directorate-General for Research Information and Communication Unit BE-1049 Brussels, ISBN 92-79-03725-0 European Communities, 2007.

[5] S. Cho and J. Kim. "Feasibility and impact analysis of a renewable energy source (RES)- based energy system in Korea", Energy, 85 (2015), pp.317-328.

[6] Q. Zhou, J.W. Bialek, Approximate model of European interconnected system as a benchmark system to study effects of cross-border trades, IEEE Trans.Power Syst. Vol.20 (2) (2005), pp.782-789.

[7] C. Kost, T. Schlegl, D. Most, Integration of renewable energies in North Africa to supply European electricity markets, in: 13th European IAEE Conference 2013, 2013.

[8] I. Boie, C. Kost, S. Bohn, M. Agsten, P. Bretschneider, O. Snigovyi, M. Pudlik, M. Ragwitz, T. Schlegl and D. Westermann "Opportunities and challenges of high renewable energy deployment and electricity exchange for North Africa and Europe e Scenarios for power sector and transmission infrastructure in 2030 and 2050" Renewable Energy 87 (2016) 130-144

[9] DIgSILENT GmbH, DIgSILENT PowerFactory (Company Webpage), http://www.digsilent.de/.User Manual PowerFactory 15.2 (including Technical References) Visited July, 2015

[10] A. T. Abu Dyak, E. O. Abu-Lehyeh and S. Kiwan, "Techno-economic assessment of integrating renewable energy on the electricity grid in Jordan", GCREEDER 2016 conference, Amman-Jordan, April 4th – 6th 2016.

[11] Erika de Visser, Anne Held. Methodologies for estimating Levelised Cost of Electricity (LCOE) July 2014, European Commission, DG Energy3526 KL Utrecht.

[12] International Atomic Energy Agency (IAEA), Wien Automatic System Planning (WASP) Package: A Computer Code for Power Generating System Expansion Planning, Version WASP-IV, Vienna 2011: http://www-pub.iaea.org/books/ IAEABooks/6327/Wien-Automatic-System-Planning-WASP-Package-A-Computer-Code-for-Power-Generating-System-Expansion-Planning-Version-WASP-IV; visited Jan. 2016.

[13] Transmission Grid Code in Jordan. http://www.ideco.com.jo/portal/otherfiles/library/gcmcjune2009.pdf. June 2009 Second Version (First Approved Version – September2004).

[14] European Commission, Energy Union Package. Brussels, 2-2015, COM (2015) 82 final.

[15] IEC. Grid integration of large-capacity Renewable Energy sources and use of large-capacity Electrical Energy Storage. Switzerland CH-1211 Geneva 2012 20
[16] M. Abderrazzaq and B. A. Al Zahawi, Transmission and distribution world. Magazine, 1997.2

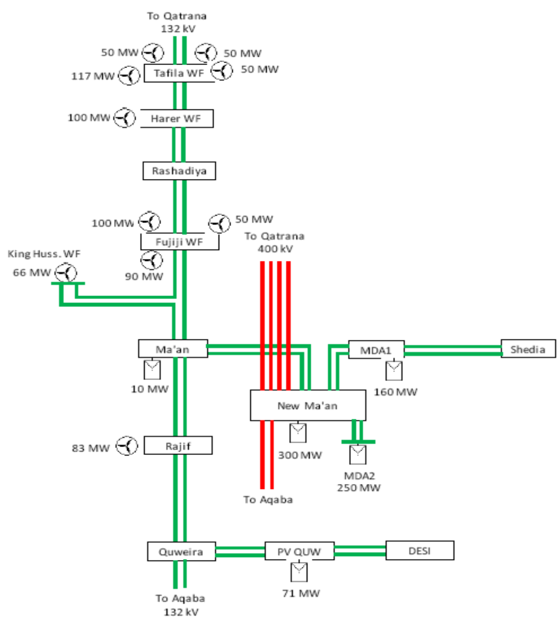


Fig. 1. The connection of renewable projects in the southern area in year 2025 (red line is the Green Corridor)

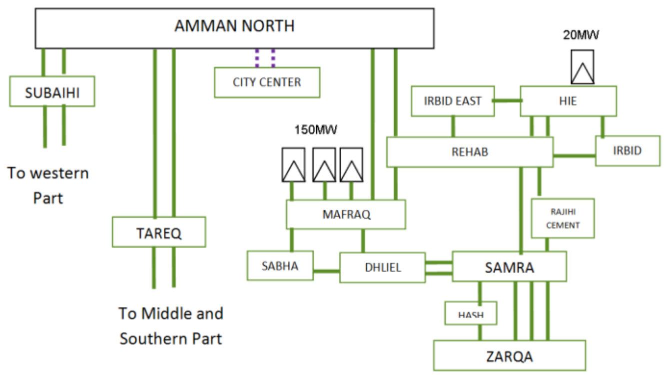
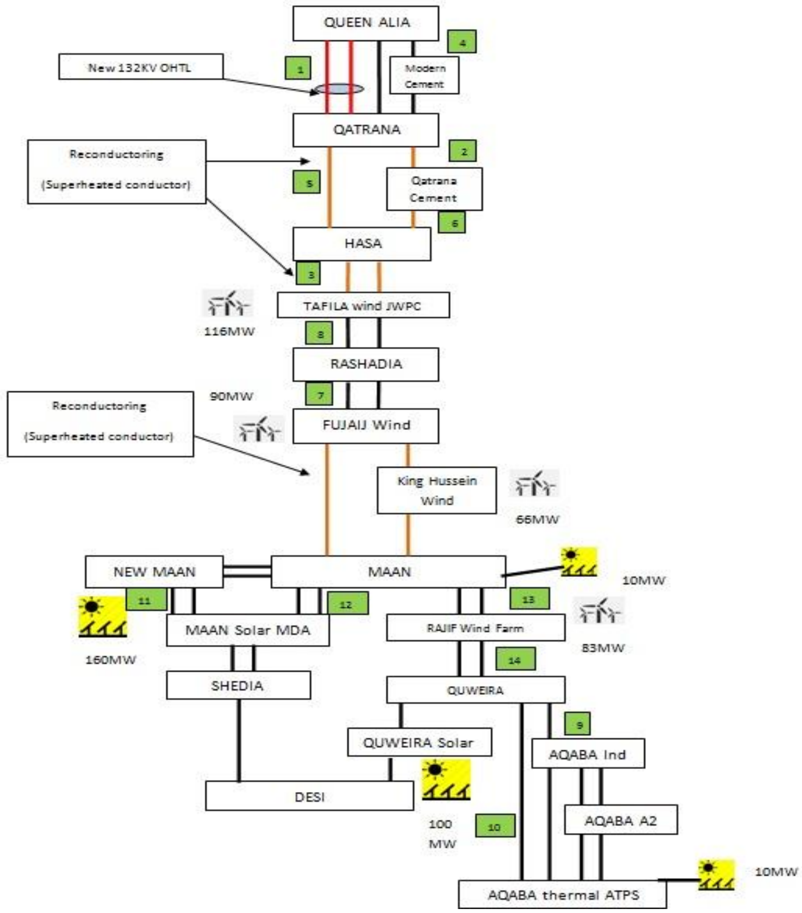


Fig. 2. The connection of committed renewable projects in the northern area in year 2025



No	132KV Lines
1	QAIA-QAT X1
2	CMNT-QAT
3	HASA-TAF(1)
4	QAIA-CEMENT
5	QAT-HASA(3)
6	CEMENT -HASA(1)
7	RAS-FUJ
8	RAS-TAF(1)
9	AQI-QUW(1)
10	ATPS-QUW(1)
11	NWMAAN-MDA
12	MDA-MAAN
13	MAAN-RAJIF
14	QWERA-RAJIF

Fig. 3 The connection of renewable projects in southern area in 2018 with reinforcement in the 132KV grid

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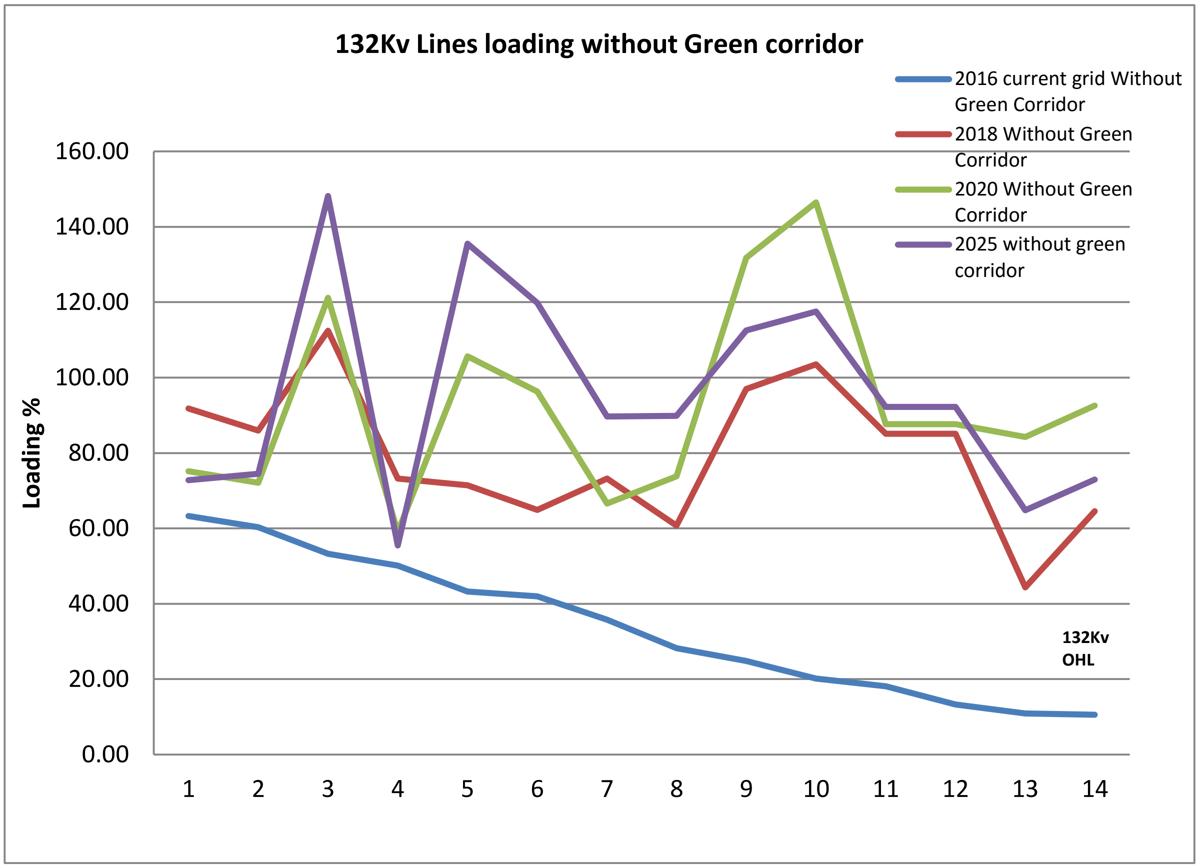

Fig. 4.Loading of the 132KV lines in the southern part of Jordan using current grid.

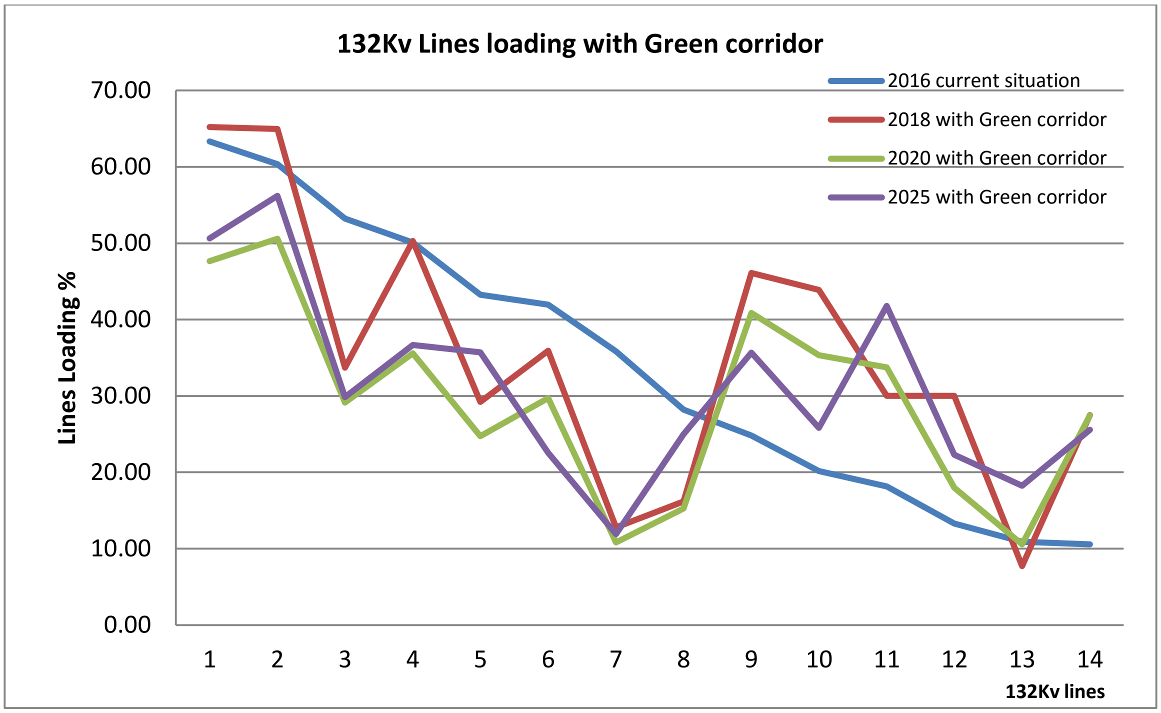

Fig. 5. Loading of the 132KV lines in the southern part of Jordan with "Green Corridor"

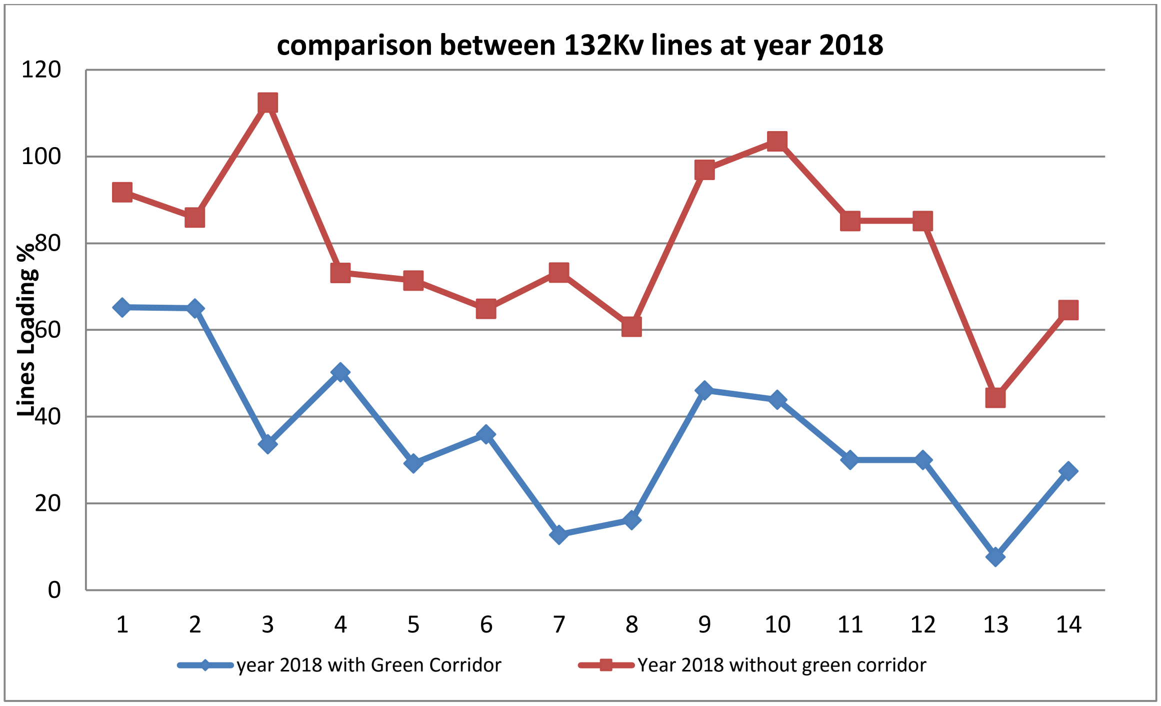

Fig. 6.Comparison of the Loading of the 132KV lines in the southern part of Jordan with/without green corridor in year 2018.

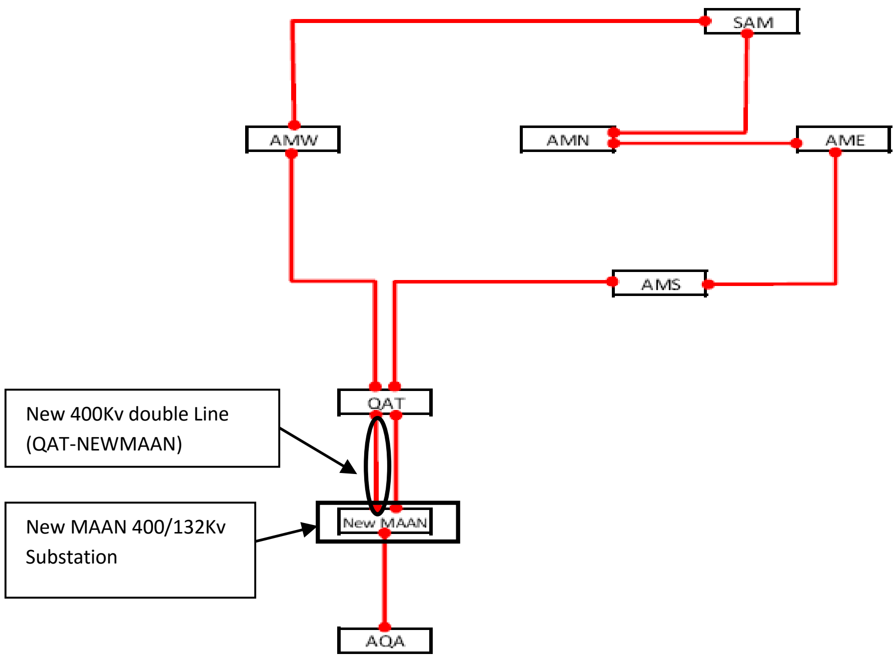

Fig.7. current Jordanian 400Kv grid structure with the Reinforcements in the southern part

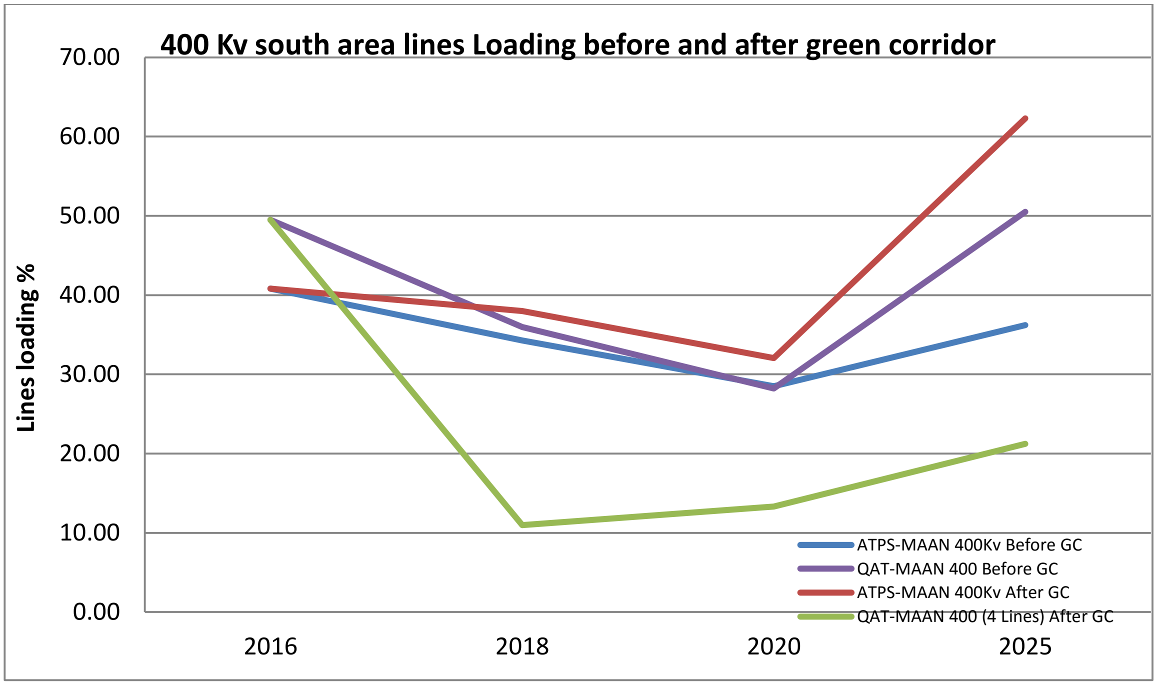

Fig.8. Comparison of the 400Kv lines loading in the southern part of Jordan with/without green corridor.

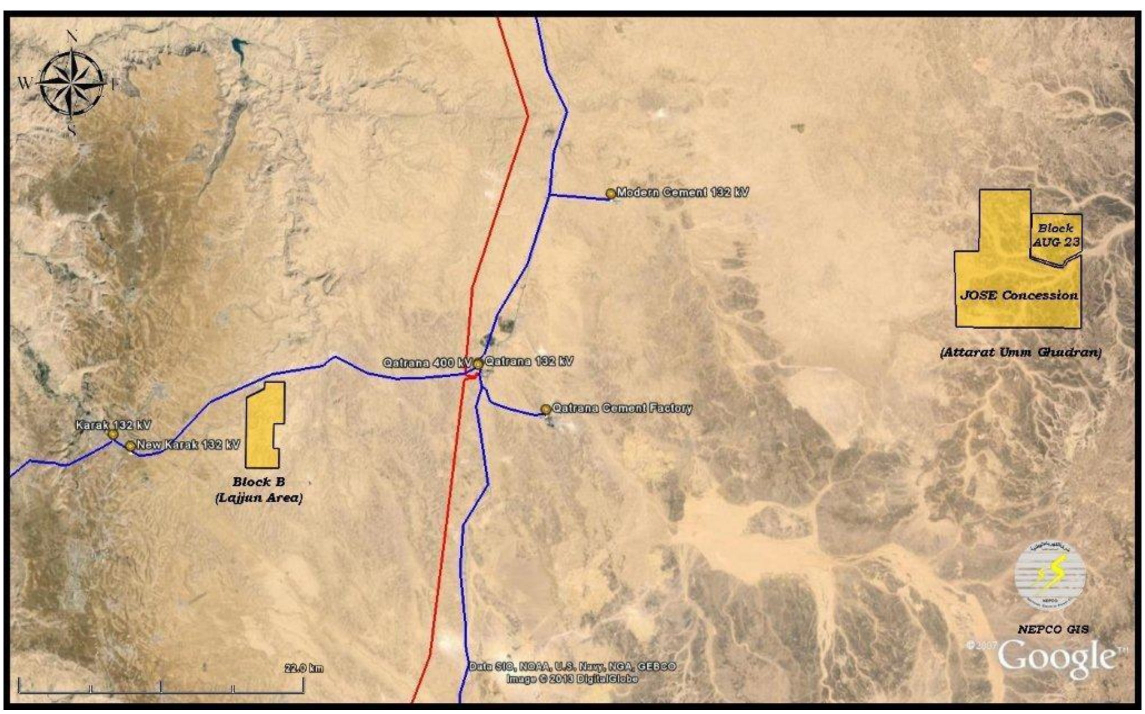

Fig.9. Proposed locations of oil shale project 1 and 2.

Table 1. Renewable Energy Projects until 2025 for all scenarios

Year	PV (MW)	Wind (MW)	Total (MW)
2016*	475	350	825
2017*	475	500	975
2018	775	500	1275
2019	875	600	1475
2020	975	700	1675
2021	1075	800	1875
2022	1175	900	2075
2023	1275	1000	2275
2024	1375	1100	2475
2025	1475	1200	2675

* Committed projects

Table 2. Proposed required conventional power plants generation for Scenario A

Proposed Name	Proposed new connection point	Capacity (MW)	YEAR
New Rehab	REHAB 400/132kv	500	2019
Al Hizam	Al Hizam 132/33	500	2021
New Aqaba	Aqaba 132/33	500	2024
Swaimah	Swaimah S/S	500	2025
Total	---	2000	---

Table 3. Results of (N-1) analysis loading and transmission reinforcements needed in Scenario A and their costs until 2025

Network Element	N-1 loading %	Reinforcement Description	Reinforcement cost (K$)
ABDOON-AMS 132KV line	173.8	6.9km/132KVUnderground Cable, double circuit. 2020	1400
Abdali-HTPS 132KV line	115	12.77Km- 132KV overhead, double circuit. 2018	3000
MADABAH-SUWMEH 132KV Line	135.5	20km-132KVoverhead, double circuit.2025	5000
QAIA-MADBA 132KV Line	128.5	19Km- 132KV Reconductering with Superheated conductor.2025	3000
NBAYADER-AMS 132KV Line	126.2	12Km- 132KV overhead, double circuit. 2017	3000
SALT-AMW 132KV Line	122.3	15Km- 132KV Reconductering with Superheated conductor.2017	2200
TAREQ-AMN132(1)	120	5.5Km- 132KV Reconductering with bundle conductor.2020	1000
HASANIND-IRBID 132KV Line	108.3	25Km- 132KV overhead, double circuit.2019	3500
Amman South Transformer	117	Amman South Expansion.2020	7000
Amman East Transformers	110	Amman east Expansion.2018	7000
New Rehab Gen	-	2019	35000
Al Hizam Gen	-	2021	3800
Swaimah Gen	-	2025	2800
HTPS repowering	-	2018	1000
New Aqaba repowering	-	2024	1500
Amman west substation and lines	-	2017	89000
Total cost	-	-	169200
Green corridor cost	-	2017	145000
Total Transmission cost	**-**	**-**	**314200**

Table 4. Costs of Scenario A for different gas prices

	Gas Price (8$/MMBTU)		Gas Price (10$/MMBTU)		Gas Price (12$/MMBTU)	
Item	Total discounted cost in M$	Average LCOE (USD/MWh)	Total discounted cost in M$	Average LCOE (USD/MWh)	Total discounted cost in M$	Average LCOE (USD/MWh)
Generation cost	16,669.5	98.59	18,793.7	111.15	20,909.4	123.66
Transmission cost	281.2	1.66	281.2	1.66	281.2	1.66
Total	16,950.8	100.25	19,074.9	112.81	21,190.6	125.32

Table 5. Proposed non renewable generation projects for Scenario B.

Project name	**Connection point**	**Capacity (MW)**	**YEAR**
Al Hizam	Al Hizam 132/33 kV	500	2024
NEW Aqaba	Aqaba 132/33 kV	500	2025
Oil shale project 2	Qatrana 400 kV s/s	470	2021
Oil shale project 1	400KV Line Amman-east Amman-south	470	2019
Total	---	1940	---

Table 6. Results of (N-1) analysis loading and transmission reinforcements needed in Scenario B and their costs until 2025

Element (lines)	**N-1 loading %**	**Reinforcement Description**	**Reinforcement Cost (k$)**
ABDOON-AMS 132KV line	173.8	6.9km/132KV Underground Cable, double circuit. 2020	1400
Abdali-HTPS 132KV line	115	12.77Km- 132KV overhead, double circuit.2018	3000
NBAYADER-AMS 132KV Line	126.2	12Km- 132KV overhead, double circuit.2025	3000
TAREQ-AMN132(1)	120	5.5Km- 132KV Reconducte ring with bundle conductor.2020	1000
HASANIND-IRBID 132KV Line	108.3	25Km- 132KV overhead, double circuit.2019	3500
Amman South Transformer	117	Amman South Expansion.2020	7000
Amman East Transformers	110	Amman east Expansion.2018	7000
Al Hizam	-	2024	3800
New Aqaba	-	2025	1500
Oilshale 1		2019	5000
Oilshale 2		2021	10000
HTPS replacement		2018	1000
Amman west substation and lines		2017	62000
Total elements cost	-		109200
Green Corridor cost	-	2017	145000
Total Transmission cost			254200

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Table 7. Costs of Scenario B for different gas prices

	Gas Price (8$/MMBTU)		**Gas Price (10$/MMBTU)**		**Gas Price (12$/MMBTU)**	
Item	Total discounted cost in M$	Average LCOE (USD/MWh)	Total discounted cost in M$	Average LCOE (USD/MWh)	Total discounted cost in M$	Average LCOE (USD/MWh)
Generation cost	19,255.0	113.88	21,005.6	124.23	22,748.4	134.54
Transmission cost	254.2	1.50	254.2	1.50	254.2	1.50
Total	19,509.2	115.38	21,259.8	125.73	23,002.6	136.04

Table 8. Proposed non renewable generation projects for Scenario C

Project name	**Connection point**	**Capacity (MW)**	**YEAR**
Oil shale project 1	Line Amman-east Amman south	470	2019
Oil shale project 2	Qatrana 400Kv s/s	470	2021
Nuclear Project	Azraq 400/132 and Rehab 400/132	1000	2024
Total		1940	

Table 9. Results of (N-1) analysis loading and transmission reinforcements needed in Scenario C and their costs until 2025

Element (lines)	N-1 loading %	Reinforcement Description	Cost
ABDOON-AMS 132KV line	178	6.9km/132KVUnderground Cable, double circuit. 2020	1400
Abdali-HTPS 132KV line	135	12.77Km- 132KV overhead, double circuit. 2018	3000
NBAYADER-AMS 132KV Line	130	12Km- 132KV overhead, double circuit. 2025	3000
TAREQ-AMN132(1)	125	5.5Km- 132KV Reconductering with bundle conductor. 2020	2000
Samra- Amman North	110	27Km 400Kv new OHTL double circuit. 2024	17000
HASANIND-IRBID 132KV Line	108.3	25Km- 132KV overhead, double circuit. 2019	3500
Samra – HTPS	150	6.9km Reconductering with bundle conductor. 2024	1500
Amman South Transformer	117	Amman South Expansion.2020	7000
Amman North Transformers	110	Amman north Expansion. 2024	7000
Oil shale project 1	-	2019	5000
Oil shale project 2	-	2021	10000
Nuclear Project	-	2024	45000
HTPS replacement	-	2018	1000
Amman west substation and lines	-	2017	62000
Total Elements cost for this case			106500
Green corridor cost	-	2017	145000
Total			313500

Table 10. Costs of Scenario C for different gas prices

	Gas Price (8$/MMBTU)		Gas Price (10$/MMBTU)		Gas Price (12$/MMBTU)	
Item	Total discounted cost in M$	Average LCOE (USD/MWh)	Total discounted cost in M$	Average LCOE (USD/MWh)	Total discounted cost in M$	Average LCOE (USD/MWh)
Generation cost	18,540.1	109.65	20,318.3	120.16	22,088.6	130.63
Transmission cost	313.5	2.14	312.5	2.14	313.5	2.14
Total	18,853.6	111.79	20,630.8	122.30	22,402.2	132.77