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Electricity Generation Mix Scenarios Simulation and Optimization in Jordan up to 2050 Using LEAP Software

Atef Gresat*, Sukruedee Sukchai and Prapita Thanarak

School of Renewable Energy Technology Naresuan University, Phitsanulok 65000, Thailand
***Corresponding author's email**: atef.gresat@yahoo.com
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Abstract

This paper presents simulation and optimization model for Six electricity generation mix scenarios for Jordan up to 2050 depending on Jordan new energy strategy in the period 2015-2025 according to the ministry of energy and mineral resources in Jordan. The Long-Range Energy Alternatives Planning system (LEAP) software was applied in scenarios simulation and optimization model application on six suggested electric generation mix scenarios in order to help the decision makers in electricity strategic generation planning to meet future electricity demand in the country. The results help in planning for optimal electricity generation mix. The sensitivity analysis to be carried on model results. LEAP software analysis results that the 13,355.2 Megawatt-Years electricity generation mix by the year 2050 in Jordan will be mainly to be generated from conventional power plants 53% followed by solar and wind technologies generation 28.3% followed by nuclear power generation 13.5% then oil shale direct fired generation 3.18% and finally from coal fired generation 1.9%.

Keywords:

Multi Criteria Decision Making, Long-Range Energy Alternatives Planning system, Renewable Energy, Electricity generation technologies, Electricity generation mix

1. Introduction

Jordan imports around 96% from its energy consumption from neighboring countries in the form of natural gas or crude oil or different types of refined fuels [1]. The Jordanian government represented by Ministry of Energy and Mineral Resources aims to achieve 10% of the country energy consumption from local renewable energy resources by the year 2020. [1,2]. The continuous flow of huge numbers of refugees in the previous few years and the population growth resulted in an overburden on the Jordanian economy due to high depletion of local resources such as water in addition to the increase of energy consumption and electricity demand. What increased the economic problems was the decrease then stoppage of Egyptian natural gas flow to Jordan, this forced the Jordanian government to find alternative sources of higher cost fuel and to take fast actions to the deployment of the country's local resources such as natural gas, oil shale, nuclear and renewable energy to help the country faces these numerous economic and fiscal challenges [2]. Because Jordan has a potential for renewable energy resources exploitation in addition to the discovery of good oil shale reserves that will be exploited in near future and the government plans to construct nuclear power plants for electricity generation in addition to current fossil fuel generation plants. It is necessary to search for an optimal energy mix to meet future electricity demand up to 2050. However, choosing the optimal energy mix for electricity generation is not an easy task and the very important question is: *Which energy mix is the optimal choice for future electricity generation demand?* The answer could be obtained by using Multi-Criteria Decision-Making (MCDM) methods. This paper presents the procedure of electricity generation mix simulation and optimization up to 2050 by using Long-Range Energy Alternatives Planning system (LEAP) software. The paper is organized as follows: in section 2 the MCDM are reviewed in general followed by optimization and simulation in general and LEAP features. Section 3 contains LEAP software applications on electric generation mix scenarios up to 2050 then discussion; the conclusion is presented in section 4.

2. Multi-criteria decision-making methods (MCDM)

This method was initially introduced by Saaty for the purpose of prioritization. These methods are helpful in decision making problems that compromise conflicting technical, economic, social, environmental Multiple-criteria that may be quantitative or qualitative criteria's to reach an acceptable solution, these methods can be used in many industries as well as energy and Renewable Energy (RE) planning processes. There are many types of such methods such as weighted product method (WPM) and the weighted sum method (WSM), analytical hierarchy process and its development the analytical network process (AHP/ANP), the preference ranking organization method for enrichment evaluation (PROMETHEE), the technique for the order of preference by similarity to the ideal solution (TOPSIS) and Elimination and choice expressing the reality (ELECTRE) and many other methods. The inputs for such methods may be deterministic or these methods may be extended to deal with stochastic inputs [3]. These methods can be used to evaluate sustainable performance due to its flexible nature and due to its allowance for interactions among all decision process parties**,** in addition to AHP, ELECTRE and PROMETHEE another method such as multi-attribute utility theory (MAUT) performance was presented with ten criteria to be satisfied with assessment tools for sustainability evaluation [4]**.** These methods can be identified by (8) steps: problem definition, and requirements determinations, then goals establishment, alternatives identification, criteria definition then decision tool selection, alternatives evaluation against criteria, and solutions validation against problem under consideration [5]. For a revision of MCDA in renewable energy field and its applications in energy storage techniques [6]. The main methods can be found in Alessio Ishizaka and Philippe Nemery book which provides an introduction to the available methods [7]. A revision for (90) articles about different methods applicability in addition to classification and applications fields, the most used method was AHP then outranking techniques PROMETHEE and ELECTRE [8]. An extensive review of MCDA methods applications and future prospects in RE field and sustainability has been performed by using MCDM technique [9-10]**.** For a systematic review of MCDM techniques and approaches in sustainable and renewable energy systems by a revision of more than 54 papers published from 2003–2015 in more than 20 high-ranking journals related to renewable energies and to sustainable field [10-11]**.**

2.1 Multi-objective optimization and simulation and why LEAP

Ioannis Chatzipoulidis in her study for Sustainable Energy Planning and Management, at Aalborg University using a computer tool to address the energy issues to design polices with well targeted social measures in the provincial government of West Java in Bandung, Indonesia. She summarized (12) studies that used three energy computer modeling tools MARKAL, LEAP and EnergyPLAN and the usefulness of these modeling tools. Then she used the LEAP software and its MILP optimization model OSeMOSYS in a case study to devise an optimal expansion pathway and dispatch scheduling of selected power generation technologies for the electricity generation system of West Java, Indonesia. Then she presents the results of two methodological approaches followed through the modeling tool's application which are deterministic scenario simulation and optimization simulation over a planning horizon of 20 years. She presents the main reasons for using LEAP software such as the software is user friendly and only requires a week of training to conduct the analysis also the software can account for energy consumption, production and resource extraction calculations at all sectors of an economy and can be used to track both energy and non-energy sector GHG emission sources and sinks at a regional, national or global scale, it can conduct long-range scenario analysis and it offers flexibility to users in respect to the wide range of different modeling methodologies that supports for both a demand and/or supply side analysis. Also it has an internal environmental Database and it is free to download and a large numbers of users over the world and it can support optimization modeling with a tight coupling of the software with the OSeMOSYS optimization model [12]**.** Albert K. Awopone in his article assessment of optimal pathways for power generation system in Ghana. In this study he found the optimum generation pathway using Energy Modelling System (OSeMOSYS), an optimisation model for long term energy planning, which is integrated in long range Energy Alternatives Planning (LEAP), simulating conventional and non-conventional energy technologies and to examine the technological, economic and environmental implications of renewable energy policies from 2010 to 2040[13].

3. Analysis methodology

Using LEAP's two levels of simulation and optimization features to investigate a range of different technologies for generating electricity by suggesting many electricity generation mix scenarios. Then by the first level to compare LEAP simulation costs and benefit results of these scenarios where the base year for all scenarios is 2016, using the capital, operating and maintenance and fuel costs parameters of those technologies and many other input data that will be described later and then to perform sensitivity analyses to examine the effects of changing some input parameters on the result then in the second optimization level to find the least costs scenario when the externality costs of local air pollution are either excluded or included by exploring the implications of a cap on CO_2 emissions – how it alters the set of technologies chosen and how it affects the overall cost of the least costs scenario.

3.1 Scenario description

Scenario1 -Business as usual scenario (BAU)

This scenario to meet the 5653MW for year 2025 electricity demand using the current base line conventional electricity production which accounted for 3915 MW and the new 485 MW Hussien thermal power plant which will be under operation within the year 2018 plus the installation of the 2675 MW planed renewable energy projects up to 2025 and the construction of around 282 MW of coal fired plants up to 2025 starting from the 30MW that the government signed as a contract according to National electric power company(NEPCO) 2016 annual report. In addition, to that the construction of 470MW oil shale fired plant in Atarat Um Al-Ghodran region that will be under full operation within 2020 according to NEPCO 2016 annual report. New conventional gas fired power plant to be constructed to compensate for retired plants after the based year 2016 and to meet the electricity increasing demand up to 2050 the end of horizon years under this study.

Scenario 2 -The second scenario (BAU+RE) which is Business as usual scenario (BAU) up to 2025 plus the construction of renewable energy plants after 2025 to meet the increasing demand up to 2050 without construction of new conventional power plants instead of the retired plants.

Scenario 3 - The third scenario (BAU+Nuclear) which is Business as usual scenario (BAU) up to 2025 plus the construction of two nuclear power plants one to be under operation within 2025 according to NEPCO

2016 annual report and the other one after 2025 up to 2050 in addition to the construction of new gas fired conventional power plants instead of the retired plants also to meet the remaining increasing demand.

Scenario 4 -The fourth scenario is (BAU+RE+Nuclear) which is the BAU scenario in addition to both RE (solar& wind) according to the second scenario and the construction of the two nuclear power plants 1000MW each to meet the increasing demand up 2050.

Scenario 5 -The fifth scenario is optimization scenario (OPT) to find the optimum mix and the least costs after optimization but without any restrictions or constrains on CO_2 emissions.

Scenario 6 -The sixth scenario is CO_2 limit scenario which is the same as the previous scenario but with the application of CO_2 emissions restrictions or constrains up to 2050 and then to make a results comparison with the previous scenario.

3.2 Analysis Input data

3.2.1 Demand side input data

From National electric power company (NEPCO) 2016 annual report the generated electricity was 19730 GWh, and from the same report the electricity generation growth rate up to 2050 was calculated to be 5% from the forecast data shown in table 1

Table 1 Electricity demand forecast.

Year	Max Demand		Electrical Energy Generated	
	MW	Growth(%)	GWh	Growth(%)
2017	3282	3.7	19957	4.1
2018	3423	4.3	20915	4.8
2019	3570	4.3	21940	4.9
2020	3724	4.3	23037	5.0
2025	4667	4.5	29542	5.1
2030	5816	4.5	37883	5.1

where Growth rate from 2030-2050 is assumed to be 5.1% same as the 2030 value. In this study the aim is to evaluate the technical and financial potential of the supply side in order to meet this electricity growing demand up to the end year 2050.

3.2.2 Transformation side input data

The transformation process contains two stages the transmission and distribution and the electricity generation where according to the national electric power company (NEPCO) 2016 annual report the transmission and distribution losses of electricity was accounted to 13.77% in the base year 2016 and it is assumed that these losses will be reduced to 12% by the year 2050 due to electrical transmission network development and technical enhancement.

For the electricity generation stage and according to Jordan new energy strategy between 2015-2025 the generation plans and their data where entered including the current conventional generation capacities, PV solar and wind plants which accounted for 3915,285.5,198.4 MW in the base year 2016 respectively according to the NEPCO 2016 annual report in addition to plants capacities both exogenous and indo endogenous , produced energy in year 2016, plants efficiencies and the maximum availability, capacity credit in addition to plants capital costs, fixed OM costs and variable OM costs and the planning reserve margin which is assumed to be 25% and electricity to be as a single output fuel. In this study seven electric energy production technologies or process where considered and two types of fuels to be imported which are natural gas and coal bituminous where the local energy fuel production to be in the form of solar, wind, oil shale, Nuclear fuel. The technical and economic data for these seven technologies or process are show in table 2 and appendix 1.

Table 2 Technical and economical data for these seven technologies.

Process	Feedstock	Effic-iency (%)	Max Availab-ility (%)	Capacity Credit (%)	Capital Cost (Thousand $/MW)	Fixed O&M (Thousand $/MW)	Variable O&M ($/MWh)	Fuel Costs ($ /MMBTU)	Lifetime (yrs)
Conventional	Natual Gas+FO	41.9[*]	90[*]	84.6[**]	917[e]	12.48[e]	2.07[e]	1[f]	37[*]
Wind	Wind	46[a]	20	36.4[**]	1541[c]	30.3[e]	0.0[e]	0.0	25[d]
Coal	Coal Bituminous	36[a]	90	84.6[**]	1923[e]	27.53[e]	4.59[e]	4.3[a]	60[d]
Solar PV	Solar	20	18	19[**]	1708[c]	11.68[a]	0.63[a]	0.0	30[d]
Solar CSP	Solar	18	30	42	5365	30	9.0	0.0	30
Nuclear	Uranium	36	90	90.2[**]	4400[a]	2.27[a]	2.4[a]	2.54[a]	60[a]
Oil shale	Oil shale	43[a]	90	90[a]	3191[b] (1.5B/470MW)	0.0[a]	1.4[a]	3.74[a]	40[a]

After year 2025 for solar, wind, conventional power plants the new capacities addition will be in the form of new solar, new wind, new conventional plants, nuclear, respectively. The capital costs of solar PV, solar CSP, wind technologies are assumed to decrease to USD 600,825,895 respectively by the year 2050. For transformation system load curve the annual load curve is divided by 12 months with 8784hours, it consists from (80 periods of 1000 hours each and the last period 784 hours. The shape of the system energy load curve is defined in terms of the fraction of the annual energy load in each time-slice, with values sorted from high to low as shown in Fig. 1.

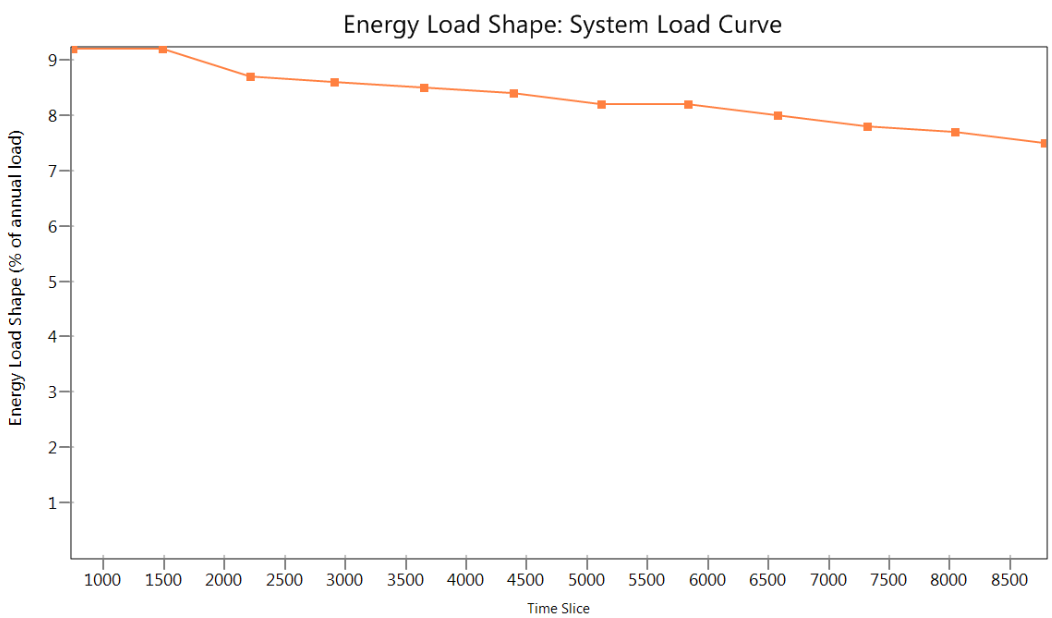

Fig 1. Energy load shape for entire electricity system (entered as % of the annual generation) from LEAP Software results.

3.2.3 Resources side input data

For fuel imported prices in 2016 it is assumed for both natural gas and coal bituminous for the current 2016 imported prices is assumed to be USD 12 /MMBTU and 20/Metric Tonne respectively and these prices to be increased by year 2050 to USD 15 /MMBTU and 35/Metric Tonne respectively.

For imported quantities of natural gas in the base year 2016 it was 1363 Gigajoule and this imported quantity will be increased or decreased for different scenarios BAU, BAU plus RE, BAU plus Nuclear, BAU plus RE and Nuclear, OPT, CO2 limit by the year 2050 to 2195, 387, 1493, 387, 2344, 2344 Gigajoule respectively. By LEAP simulation on the first four scenarios all plants energy output must be dispatched up to their full available capacity in order to meet the energy requirements with out producing excess electricity, for RE source availability the level of yield is assumed to be unlimited.

For the last two scenarios by LEAP optimization on OPT scenario it is to find the least costs production technologies mix but without CO_2 emissions constraints or without emissions cap, but for CO_2 limit scenarios the LEAP optimization is the same as in OPT scenario but with constraints on CO_2 emissions or emissions cap where CO_2 emissions are to be fixed to 8666.190 Thousands Metric Tonne from year 2016 up to year 2050.

4. Results and discussion

4.1 Simulation stage electric generation results

To meet the electricity increase demand over the study time horizon LEAP software simulation features gives the electricity generation mix for each of the first four scenarios which are BAU, BAU plus RE, BAU plus Nuclear, BAU plus Nuclear and RE respectively.

In simulation stage the LEAP software added capacities both exogenously first according to capacities entered in exogenous capacity for all technologies which are conventional plants, solar PV, wind, oil shale, coal plants that entered in the software exogenously in accordance to planned capacities in the new Jordan energy strategy up to 2025 then the software started to add additional capacities endogenously from the technologies named for new conventional plants, Nuclear plants, new solar PV, new wind and solar CSP in order to meet the planning reserve margin which is assumed to be 25% in order to meet the demand for all times during the study time horizon. The electricity generation mix (TWh) for the four scenarios is shown in Fig. 2.

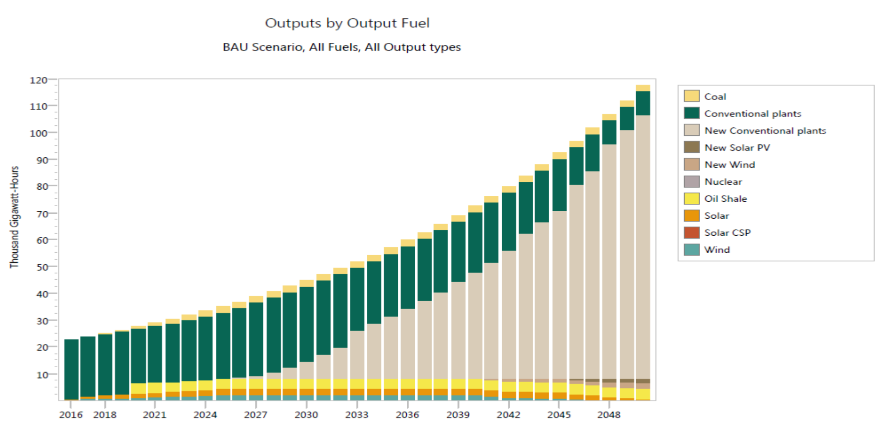

Fig.2 Electric generation mix (TWh) for BAU scenario for 2016-2050.

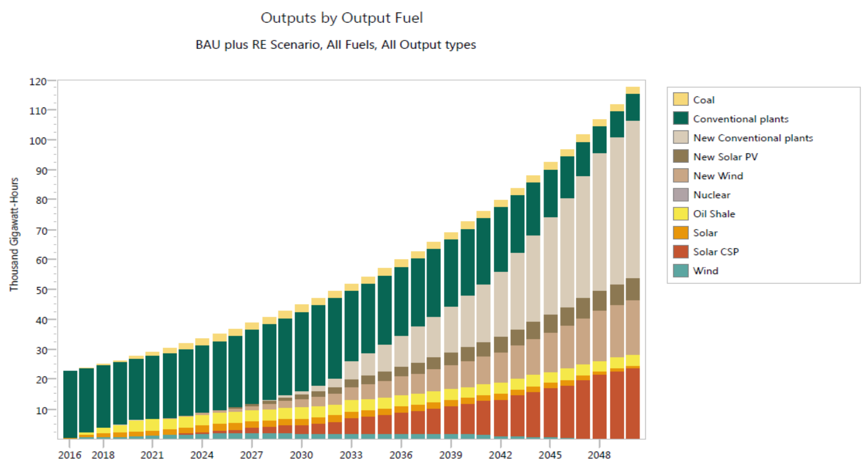

Fig3. Electric generation mix (TWh) for BAU plus RE scenario for 2016-2050.

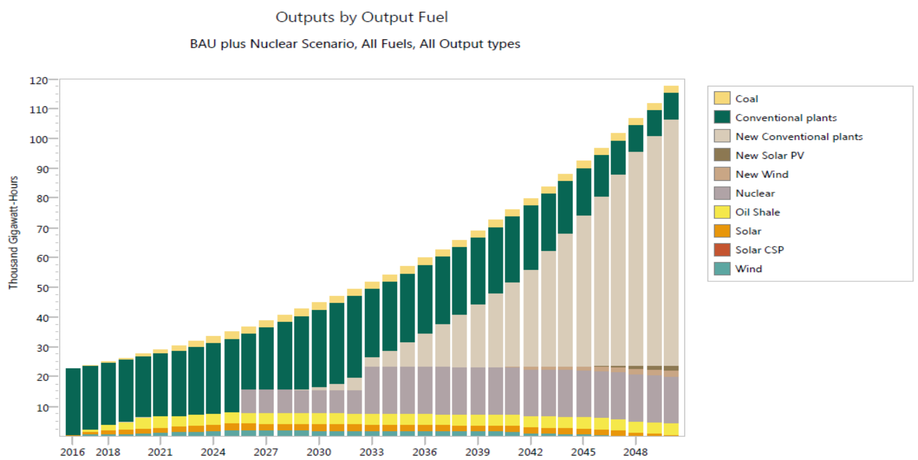

Fig 4. Electric generation mix (TWh) for BAU plus Nuclear scenario for 2016-2050.

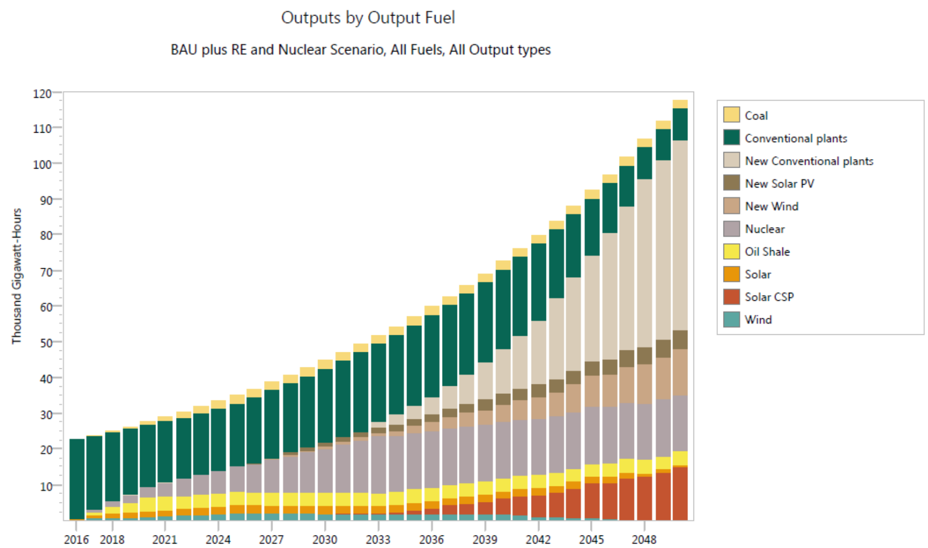

Fig 5. Electric generation mix (TWh) for BAU plus RE plus Nuclear scenario for 2016-2050.

4.2 Optimization stage electric generation results

For the fifth and the sixth scenarios which are OPT and CO_2 limit the optimization features of the software were enabled to give the least NPV for electric generation mix for OPT scenario and the results for this scenario optimization is shown in Fig. 6.

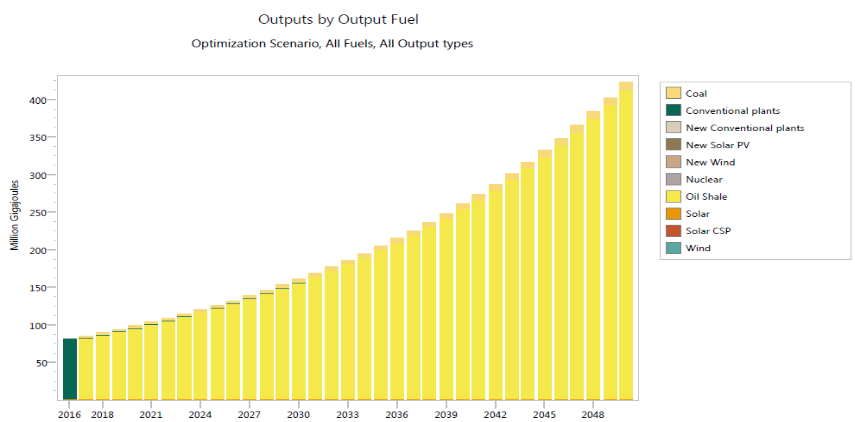

Fig 6. Electric generation mix (TWh) for OPT scenario for 2016-2050.

From the above Fig. 6 it is obvious that most of the electric generation mix in order to give the least NPV option must be from oil shale because oil shale fuel reserves in Jordan account for 40 billion metric ton without any imports from outside the country.

For the CO_2 limit scenario after the application of CO_2 emissions cap by assuming that the base year CO_2 emissions which accounted for 8666191 metric tons to remain stable over all the periods from 2016 up to 2050. The results for this scenario is show in Fig. 7.

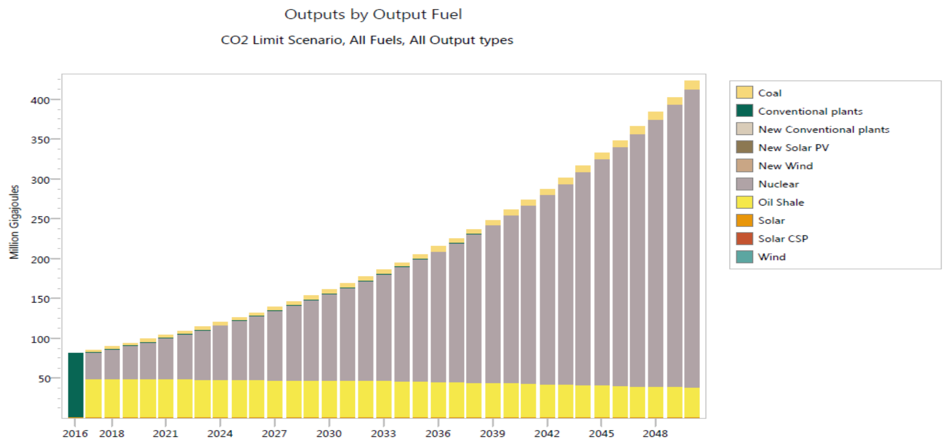

Fig 7. Electric generation mix (TWh) for CO_2 Limit scenario between 2016-2050.

Where from the above Fig. 7 it is shown that a large fraction of oil shale in the OPT scenario was replaced by Nuclear due to lower CO_2 emissions results from nuclear in comparison with oil shale direct fire generation plants due to the addition of CO_2 emission cap in the CO_2 Limit scenario.

4.3 All scenarios economical evaluation results

Social costs for all scenarios in the base and end year are shown in Fig (13). The Social costs values in year 2050 by scenarios BAU, BAU plus Nuclear, BAU plus RE and Nuclear, OPT, BAU plus RE, CO_2 Limit was 1911, 2236, 3313, 3469, 3823, 3964 million USD respectively, while in year 2016 the social costs values are fixed at 146million USD for all scenarios.

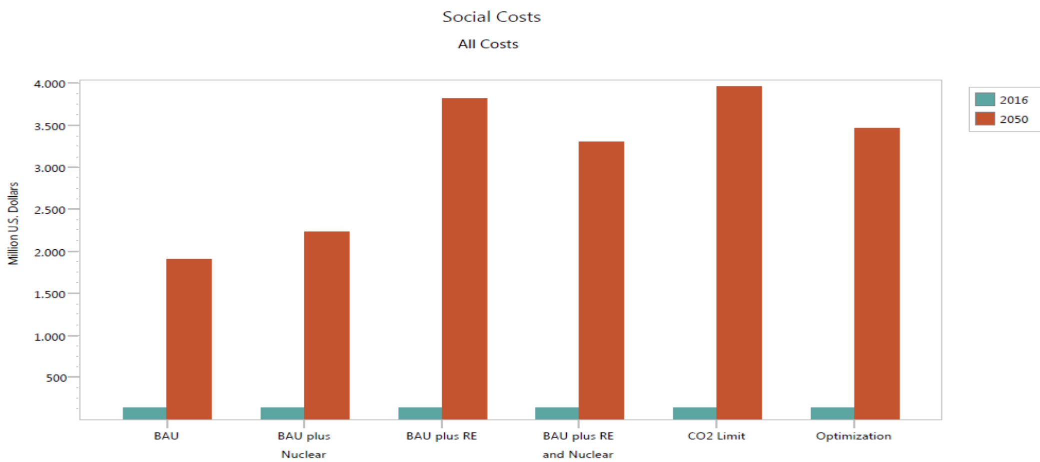

Fig.8 Social costs for all scenarios in years 2016 and 2050 in million USD.

Investment costs for all scenarios in 2016 and 2050 is shown in Fig. 9.

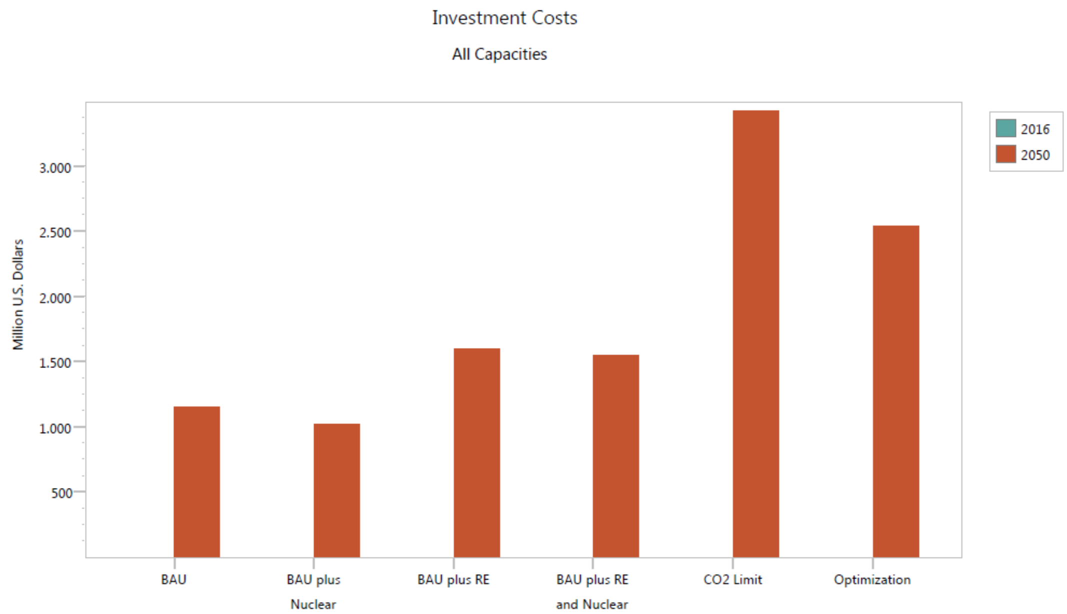

Fig 9. Investment costs for all scenarios in 2016 and 2050.

Investments costs values in year 2050 by scenarios BAU plus Nuclear, BAU, BAU plus RE and Nuclear, BAU plus RE, OPT, CO_2 Limit was 1022, 1158, 1555, 1600, 2545, 3424 million USD respectively, while in year 2016 there is no investments costs.

Table 3 Cumulative costs and benefits for all scenarios 2016-2050.

Cumulative Costs && Benefits: 2016-2050. :Discounted at 5,0% to year 2016. Units: Billion 2016 U.S. Dollar

	BAU	Optimization	BAU plus RE	BAU plus Nuclear	BAU plus RE and Nuclear	CO2 Limit
Demand	-	-	-	-	-	-
All Electricity	-	-	-	-	-	-
Transformation	11,8	20,1	19,8	14,3	18,2	23,8
Transmission and Distribution	-	-	-	-	-	-
Electricity Generation	11,8	20,1	19,8	14,3	18,2	23,8
Resources	70,1	2,3	52,2	57,4	45,0	2,3
Production	-	-	-	-	-	-
Imports	70,1	2,3	52,2	57,4	45,0	2,3
Exports	-	-	-	-	-	-
Unmet Requirements	-	-	-	-	-	-
Environmental Externalities	1,0	1,9	0,9	0,9	0,8	0,6
Non Energy Sector Costs	-	-	-	-	-	-
Net Present Value	82,8	24,3	73,0	72,6	64,1	26,7
GHG Emissions (Mill Tonnes CO2e)	495,7	1.240,5	483,5	478,7	448,2	306,3

From the table above it is noticed that among the four simulation scenarios BAU plus RE and Nuclear scenario have the lowest NPV which accounted for 64.1Billion USD discount to year 2016.
While for the two optimization scenarios the NPV for OPT, CO_2 Limit scenarios accounted for 24.3, 26.7 Billion USD respectively.

4.4 Resource imports and indigenous production results

Fig. 10 shows the indigenous resource production for years 2016 and 2050 while fig. 11 shows the resource imports for the same years.

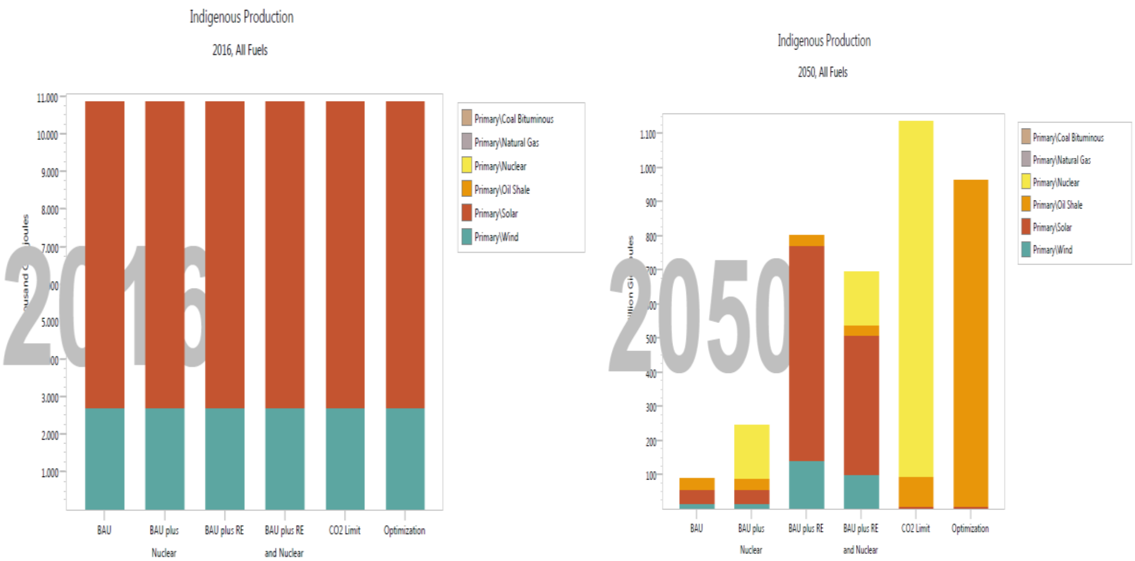

Fig. 10 Indigenous resource production in years 2016, 2050.

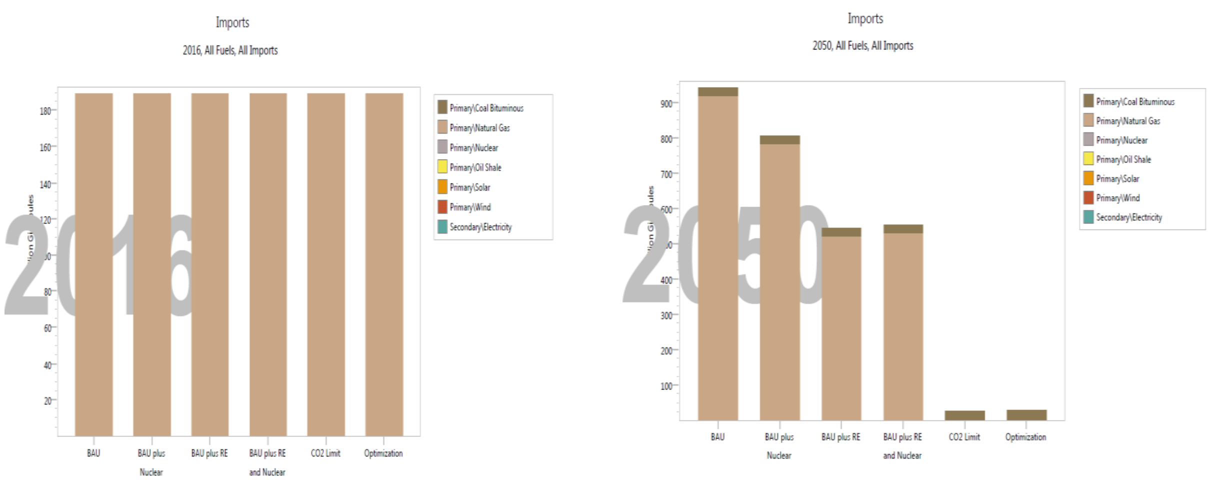

Fig. 11 Resource imports in years 2016, 2050.

4.5 Environmental effects results

For all scenarios and for the three types of fuels which are natural gas, coal and oil shale the GWP for the study period from 2016-2050 is shown in fig. 12 which shows that GWP from the three fuels is the lowest for the CO_2 limit scenario due to the emissions cap assumed followed by BAU plus RE and Nuclear then BAU plus Nuclear followed by BAU plus RE then OPT Scenario with GWP values accounting for 306.3, 448.2, 478.7, 483.5, 495,7, 1240.5 million Tones CO_2 eq.

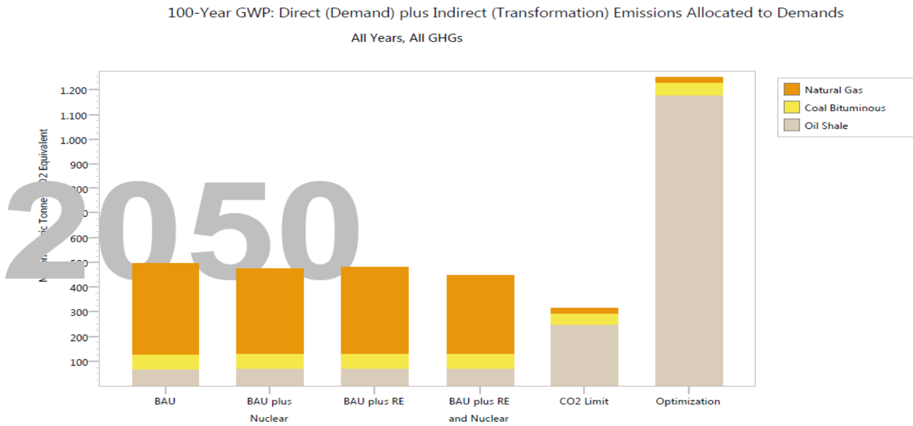

Fig. 12 Cumulative GWP during 2016-2050 for all fuel types.

4.6 Sensitivity analysis

4.6.1 CO_2 limit effects

In the previous calculations no CO_2 emission caps were introduced where the upper limited values in all scenarios were entered in the software as unlimited except the CO_2 limit scenario where CO_2 cap was assumed. To examine the effect of introducing CO_2 cap on the four simulation scenarios and the OPT scenario the upper CO_2 limit to be changed from Unlimited to 75% from the forecasted emission in 2050 which accounts for 19754000 metric tons of CO_2 eq. The new electric generation mix results are shown in Fig. 13.

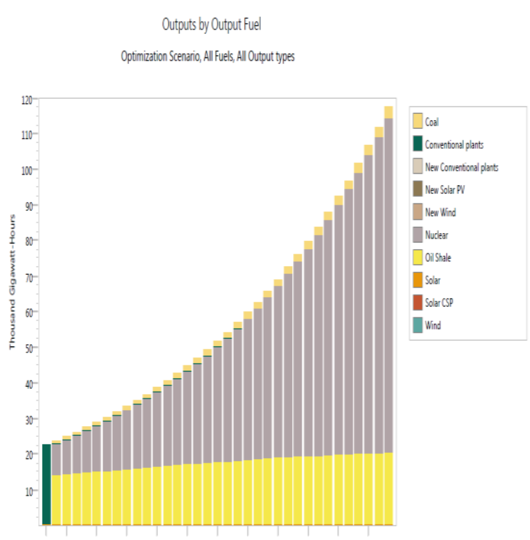

Fig. 13 New OPT scenario mix with CO_2 limit.

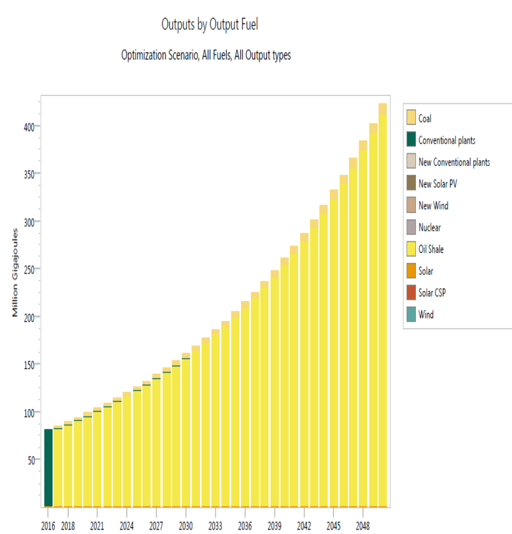

Fig. 14 Old OPT scenario mix without CO_2 limit.

So from the above two figures the OPT scenario electric generation mix results was changed and a large fraction of oil shale was replaced by nuclear technology due to its lower emissions in comparison with oil shale technology. Regarding the other scenarios electric generation mix results remained the same without any changed due to CO_2 Limits applications. Also to examine the effects of CO_2 Limit application on economical evaluation results. It needs to compare the data in the following costs and benefits table.

Table 4 Cumulative costs and benefits for all scenarios 2016-2050.

Cumulative Costs && Benefits: 2016-2050.:Discounted at 5,0% to year 2016. Units: Billion 2016 U.S. Dollar

	BAU	Optimization	BAU plus RE	BAU plus Nuclear	BAU plus RE and Nuclear	CO2 Limit
Demand	-	-	-	-	-	-
All Electricity	-	-	-	-	-	-
Transformation	11,8	28,3	19,9	15,5	19,8	29,3
Transmission and Distribution	-	-	-	-	-	-
Electricity Generation	11,8	28,3	19,9	15,5	19,8	29,3
Resources	70,1	2,1	52,2	57,4	45,0	2,1
Production	-	-	-	-	-	-
Imports	70,1	2,1	52,2	57,4	45,0	2,1
Exports	-	-	-	-	-	-
Unmet Requirements	-	-	-	-	-	-
Environmental Externalities	1,0	0,7	0,9	0,9	0,8	0,6
Non Energy Sector Costs	-	-	-	-	-	-
Net Present Value	82,9	31,2	73,0	73,8	65,6	32,1
GHG Emissions (Mill Tonnes CO2e)	495,7	414,2	483,5	478,7	448,2	306,2

From the above table any one can noticed that the GHG emission was changed for OPT scenario from 1240.5 to 414.2 million tones CO_2 eq.

Regarding the net present value for all scenarios the changes is shown in table 5.

Table 5 changed NPV for all scenarios due to the application of CO_2 cap in Billion 2016 USD.

Scenario	BAU	OPT	BAU+RE	BAU+Nuclear	BAU+RE+Nuclear	CO_2 limit
Old NPV	82.8	24.3	73	72.6	64.1	26.7
New NPV	82.9	31.2	73	73.8	65.6	32.1

All NPV were increased to improve the generation plants to produce less quantities of CO_2 emissions without increase in NPV for RE Plants only because RE production plant don not need any improvements costs requirements to reduce CO_2 emissions.

4.6.2 Increasing of fuel prices effects

If the import price of natural gas to be increased from 15 USD per MMBTU in year 2050 as assumed in the previous calculations to 20 USD per MMBTU, and the import price for coal to be increased to 50 USD per metric ton instead of 35 USD. Also the indigenous costs for both local nuclear fuel and oil shale mining to be one USD/Gigajoule and 3 USD/metric tons respectively instead of zeros as in the previous calculations.

The new and old electric generation mix (TWh) for 2016-2050 are shown in fig. 15 & fig. 16.

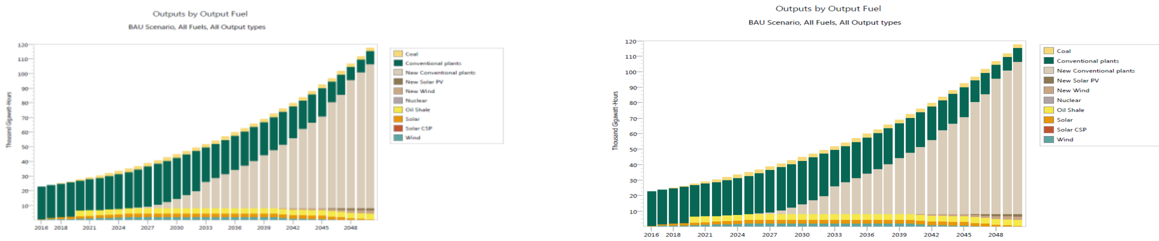

Fig. 15 BAU scenario new(left) and old electric generation mix (TWh) for 2016-2050.

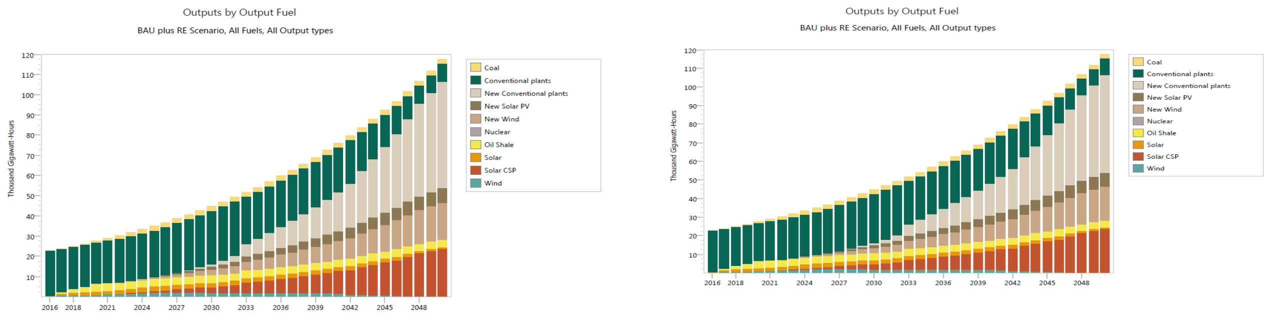

Fig. 16 BAU plus RE scenario new (left) and old electric generation mix (TWh) for 2016-2050.

No changed same as in figure 15&16 above on the other scenarios electric generation mix due to the suggested changed on fuel imports price. To examine the effects of fuel imports price on economical evaluation results. It needs to compare the data in the following costs and benefits table with the previous one.

Table 6 Cumulative costs and benefits for all scenarios 2016-2050.

Cumulative Costs && Benefits: 2016-2050.:Discounted at 5,0% to year 2016. Units: Billion 2016 U.S. Dollar

	BAU	Optimization	BAU plus RE	BAU plus Nuclear	BAU plus RE and Nuclear	CO2 Limit
Demand	-	-	-	-	-	-
All Electricity	-	-	-	-	-	-
Transformation	11,8	28,3	19,9	15,5	19,8	29,4
Transmission and Distribution	-	-	-	-	-	-
Electricity Generation	11,8	28,3	19,9	15,5	19,8	29,4
Resources	83,1	7,4	60,9	68,8	54,2	7,8
Production	0,1	5,3	0,1	1,3	1,6	5,7
Imports	83,0	2,1	60,8	67,5	52,6	2,1
Exports	-	-	-	-	-	-
Unmet Requirements	-	-	-	-	-	-
Environmental Externalities	1,0	0,7	0,9	0,9	0,8	0,6
Non Energy Sector Costs	-	-	-	-	-	-
Net Present Value	95,9	36,4	81,7	85,2	74,8	37,8
GHG Emissions (Mill Tonnes CO2e)	495,7	414,2	483,5	478,7	448,2	306,2

From the above table it can be noticed that there is no changes on GHG emission due to changes of fuel import price.

Regarding the net present value for all scenarios the changes is shown in table 7.

Table 7 changed of NPV for all scenarios due to the changes on fuel prices in Billion 2016 USD.

Scenario	BAU	OPT	BAU+RE	BAU+Nuclear	BAU+RE+Nuclear	CO_2 limit
Old NPV with CO_2 cap	82.9	31.2	73	73.8	65.6	32.1
New NPV With fuel price changes	95.9	36.4	81.7	85.2	74.8	37.8

The change that happened was in the resource branch if we compare cumulative costs and benefits for all scenarios 2016-2050 in tables 6 and table 7.

5. Conclusion

For the electric generation mix long term planning up to 2050 six generation mix scenarios were suggested based on Jordan's new energy strategy 2015-2025 that contain the current installation capacities in the base year 2016 in this study were 3915MW conventional plants, 285.5MW solar PV, 198.4 MW wind and 480MW new Hussein thermal power plant that will be under operation within the year 2018 and coal fired plants that will start from 30MW up to 282 MW by the end of 2025 in addition to the construction of 470MW oil shale direct fire plant that will be under operation by the year 2020 where all of these capacities are common among all suggested scenarios, also solar PV plant installation to be increased to 1475MW and wind installation to be increased to 1200MW by the end of year 2025.

In addition to that Jordan plans to construct two nuclear power plants 1000MW each with the first one to be under operation within the year 2025 according to National Power Company (NEPCO) annual report 2016 and the second one according to this study was suggested to be in 2033.

Depending on that the first scenario that has been suggested was BAU which include all the above capacities up to year 2025 and after year 2025 only new conventional plants fired by natural gas to be constructed to compensate for the retired old conventional plants and to meet the increasing demand where only new solar PV and wind installation will compensate for solar PV and wind retired plants only.

In addition to that Jordan plans to construct two nuclear power plants 1000MW each where the first one to be under operation within the year 2025 according to National power company (NEPCO) annual report 2016 and the second one according to this study was suggested to be year 2033, so the second scenario suggested was BAU plus Nuclear which is the same as BAU up to 2025 in addition to the two 1000MW nuclear plants to be added in 2025 and 2033 combined with new conventional plants fired by natural gas to be constructed to compensate for the retired old conventional plants and to meet the increasing demand where only new solar PV and wind installation to compensate for solar PV and wind retired plants only.

The third scenario suggested was BAU plus RE which is the same as BAU up to 2025 in addition to new RE plants to be added between 2025 and 2050 in the form of new solar PV and new wind and solar CSP to meet the increasing demand up to 2050 then the fourth scenario is same as the previous one but in combination with RE and the two 1000 MW each nuclear plants to meet the increasing demand up to 2050.

After application of LEAP software with its simulation features on the previous four scenarios and the optimization features on the fifth scenario OPT by which LEAP Suggested the least cost optimized electric generation mix followed by the sixth scenario which is the same as OPT scenario but with application of a Cap on CO_2 emissions and all six scenarios simulation and optimization results can be summarized as following:

1-Among the four simulation scenarios the scenario with least net present value without any constraints on CO_2 emissions was for BAU plus RE and nuclear with 64.1 Billion USD NPV discounted to year 2016 followed by BAU plus nuclear then BAU plus RE and finally BAU with the largest NPV.

2- Among the four simulation scenarios the scenario with least net present value with constraints on CO_2 emissions by reducing 25% of 2050 emissions was also for BAU plus RE and nuclear with 65.6 Billion USD NPV compared to 64.1 Billion USD NPV without constraints on CO_2 emissions because to reduce the emission it needs to spend 1.5 Billion USD to improve generation plants for the purpose of emissions reduction.

The following less NPV scenario after BAU plus RE and nuclear was BAU plus RE with NPV 73 Billion USD followed by BAU plus nuclear with NPV 73.8 Billion USD then finally BAU with the largest NPV.

3- For the least NPV scenario which is BAU plus RE and nuclear the total electricity generation by the year 2050 is 117 Thousand Gigawatt-Hour and 13355.2 Megawatt-Years distributed as in table 8.

Table 8 Electricity generation by the year 2050 in Gigawatt-Hour & Megawatt-Years.

Technology	**Coal**	**Conventional**	**New conventional**	**Solar PV**	**New wind**	**Solar CSP**	**Nuclear**	**Oil shale**
Generation Gigwatt-Hour	2.2	8.8	53.3	5.2	13	15	15.8	3.7
Generation Megawatt-Years	254.5	1003.5	6082.9	589.3	1481.2	1714.7	1804.9	424.2

4-For the optimization scenario OPT without CO_2 cap the 117 Thousand Gigawatt-Hour in 2050 to be met by oil shale according to software automatic selection due to the high oil shale local reserve and due to the reduction of high fuel import costs in comparison with natural gas while in case of CO_2 emissions constraints the 117 Thousand Gigawatt-Hour to be met as 24.4 Thousand Gigawatt-Hour from oil shale and 92.6 Thousand Gigawatt-Hour from nuclear plants due to it is lower emissions in comparison with oil shale plants.

The software selected oil shale and nuclear plant due to high local reserves from both fuels and due to the fact that their plants have higher efficiency and availability in comparison with RE plants.

The net present value for OPT scenario was Billion 2016 USD 24.3 and 31.2 without and with CO_2 cap respectively.

5-For the CO_2 limit scenario the 117 Thousand Gigawatt-Hour to be met by year 2050 will be 102.7 Thousand Gigawatt-Hour from nuclear and 14.3Thousand Gigawatt-Hour from oil shale.

The net present value for CO_2 limit scenario was in Billion 2016 USD 26.7 and 32.1 without and with CO_2 cap respectively.

6-The increased in fuel imports price increase the NPV but the orders of all scenarios remain the same.

7-It is recommended to shift toward optimization by increasing the installation of oil shale direct fired plants by 600MW according to recent government plans by adding the additional oil shale capacities to the electric generation mix and this needs to cancel the coal plant in table 8 which accounted for 254.5 MW and to reduce the new conventional plants to 5737.4 MW by the end 2050 instead of 6082.9MW.

Taking into consideration that shifting toward optimization using additional nuclear plans is not practical due to water resource shortage in Jordan and verification for this need further future studies for verification of water availability to add new nuclear power plants, table 9 shows the final optimum electric generation mix up to 2050.

Table 9 Optimal electricity generation mix by the year 2050 in Megawatt-Years.

Technology	Coal	Conventional	New conventional	Solar PV	New wind	Solar CSP	Nuclear	Oil shale
Generation Megawatt-Years	254.5	1003.5	6082.9	589.3	1481.2	1714.7	1804.9	424.2
Generation Megawatt-Years to shift toward optimization	-	1003.5	5737.4	589.3	1481.2	1714.7	1804.9	1024.2

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