RESTRUCTURING OF THE JORDANIAN UTILITY SECTOR AND ITS ASSOCIATED GHG EMISSIONS: A FUTURE PROJECTION

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Abstract

As a small, non-oil producing, Middle Eastern country of a young and growing population and rapid urbanization, Jordan, like many countries all over the world, was and is still facing the problem of meeting the rapidly increasing demand of electricity. The main objective of this study is to review many current aspects of the Jordanian electricity sector, including electricity generation, electricity consumption, energy related emissions, and future possibilities, based on time series forecasting, through the term of the **Clean Development Mechanism (CDM)** arrangement under the **Kyoto Protocol**, in which the Hashemite Kingdom of Jordan had signed lately, which allows industrialized countries with a greenhouse gas reduction commitment to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. Several scenarios are proposed in this study, based on projected electricity consumption data until year 2028. Without attempting to replace the currently existing fossil-fuel based power plant technologies in Jordan by clean ones, electricity consumption and associated GHG emissions are predicted to rise by 138% by year 2028; however, if new clean technologies are adopted gradually over the same period, electricity consumption as well as GHG emissions will ascend at a lower rate.

Keywords: Jordan; Electricity generation; Kyoto protocol; GHG emissions

1. Introduction

Jordan is a lower-middle income, Middle Eastern country, of about 5.7 million inhabitants (Department of Statistics (DoS), 2007). It suffers from a chronic lack of adequate supplies of natural resources including water, crude oil and natural gas. Jordan depends heavily on imports of oil and gas from neighbouring Arab countries as the main source of energy. Its current imports of around 100,000 barrels of crude oil per day are placing the country under extreme economic pressures. The annual energy bill has been rapidly increasing over the past few years due to high rates of population and economic growth combined with the consecutive increase in oil price. In Jordan, there has been a growing concern about energy consumption and its adverse impact on the economy and environment.

In 2006, electricity consumption reached nearly 8965 GWh. Heavy fuel oil (HFO) was the dominant fuel used because the two main power stations, i.e. Aqaba and Hussein, are conventional thermal plants employing Rankin steam cycle and fired by such an inexpensive fuel. However, since 2003, imported natural gas from Egypt replaced HFO in Aqaba power station and in early 2006 replaced diesel fuel at Rehab and Asamrah power plants. In 2007, about 83% total electricity generated was produced using natural gas. Electricity harnessed via renewable sources, such as hydropower and wind, accounted for only a negligible percentage of the total electricity generated (Central Electricity Generation Company (CEGCO), 2007).

In recent years, economic growth has been associated with the privatization of public enterprises. The macroeconomic performance was boosted by the growth in energy sector. The service and industry sectors became predominant while agriculture receded. As for electricity, it is produced by thermal power plants that use Natural Gas, Diesel, and Heavy Fuel in addition to wind and hydro power plants (recent and limited). Jordan's experience in renewable energy systems has been on the small and experimental scale, and though there are many proposals considering the utilization of these sectors, they are not greatly of benefit due to their low generation capacity. There is no nuclear power plant in Jordan yet; however, a decision has been made in regard of the need for a one and it is estimated that the first Jordanian nuclear power plant will be put into operation by year 2015.

Since its establishment, the Central Electricity Generation Company (CEGCO) took all available efforts to generate electricity with quality and performance indicators as well as can be found in developed countries. Since year 1999, the company managed to develop its performance year by year considering availability and overall efficiency, and not hesitating to install up-to-date technology, managerial, and maintenance measures that had a great effect in decreasing costs and projected losses due to accidents and breakdowns.

Although greenhouse gas (GHG), e.g. carbon dioxide (CO_2), emissions were not initially included in most emission legislations, this has started to change over the past few years. Currently, CO_2 is regulated in many parts of the world either directly as in the case of Japan or indirectly as in the case of the EU. This is due to the belief that CO_2 is responsible for around 80% of the anthropogenic climate change and global warming effects (Ritter, 1998). Since the 1960s, the tropospheric CO_2 concentration has been increasing at a rate of 0.45% every year (Lenz and Cozzarini, 1999). These concerns have been addressed in Rio and Kyoto summits leading to the adoption of the ''Kyoto Protocol'', which demanded a worldwide reduction of CO_2 emissions by at least 5%, compared with the 1990 level, by year 2010 (UNFCCC, 1997). As most developing countries are not currently in the position to make absolute emission reductions, the most immediate and realistic challenge is lowering the CO_2 intensity of these countries.

Jordan's annual CO_2 emissions were estimated in 2004 to be $1.67x10^6$ ton. Although this constitutes less than 0.1% of the world's annual CO_2 emissions, its intensity is considerably high: about 4 times that of most Western European countries, and almost similar to those of oil-producing Arab countries as indicated in figure. I. This implies that there is room for energy-efficiency improvements and emissions reduction in all sectors.

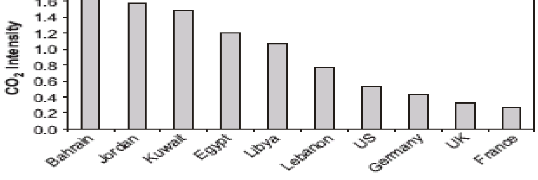


Figure. I: CO2 intensity in several countries

1.1. Jordan total energy input configuration

Since it is well established that Jordan is a non-fuel producing country; fuel imports is indicated and the data in table I shows the fuel consumption in the Jordanian's utility sector in years 2002 to 2006 (Central Electricity Generation Company (CEGCO), 2007).

Table I: Fuel consumption in the Jordanian utility sector in years 2002 to 2006

Fuel Type	2002	2003	2004	2005	2006
Heavy Fuel (Ton)	1629336	1380327	809252	675387	511993
Diesel (m^3)	45799	92025	160748	243165	89388
Natural Gas (Billion Btu)	-	8699	38843	47822	56511

1.2. Jordan's total demand of electricity

Through years, the maximum capacity in the power plants increased gradually reaching a value of 1901 MW in year 2006 with a weighted growth average of 8.7%. As for electricity production, it also reached a maximum value in 2006 of 11119 GWH, 80.62% of which produced by CEGCO and the rest by Asamrah power plants. Electricity generation, according to generation method used, is as displayed in Table II. As for consumption, it reached a value of 9593 GWH in 2006, that is, 2079 KWH per capita electricity consumption.

1.3. Clean Development Mechanism (CDM)

The Clean Development Mechanism (CDM) is an arrangement under the Kyoto Protocol allowing industrialized countries with a greenhouse gas reduction commitment (called Annex 1 countries) to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. The most important factor of a carbon project is that it establishes that it would not have occurred without the additional incentive provided by emission reductions credits.

The purpose of the CDM was defined that apart from helping Annex 1 countries comply with their emission reduction commitments, it must assist developing countries in achieving sustainable development, while also contributing to stabilization of greenhouse gas concentrations in the atmosphere.

With costs of emission reduction typically much lower in developing than in developed countries, developed countries can comply with their emission reduction targets at much lower cost by receiving credits for emissions reduced in developing countries as long as administration costs are low.

Table II: Electricity generation data in Jordan's utility sector (GWh)

Method of generation	2002	2003	2004	2005	2006
1) Electricity Sector	**7514.7**	**7227.4**	**8006.5**	**9138.1**	**10645.4**
Steam Turbines	6770.5	6430.2	7168.1	7524.2	5730.9
Combined Cycle	-	-	-	558.4	3840.7
Gas	679.9	746	775.7	988.4	1010.2
Diesel	2.6	0.95	1.43	1.86	3.05
Hydro	53.2	41.2	52.6	56.8	51.5
Wind	3.05	3.06	2.78	3.21	2.84
Bio Gas	5.4	6	5.8	5.1	6.2
2) Industrial Sector	**502**	**505**	**497**	**516**	**474**
Steam Turbines	434	428	423	445	446
Diesel	68	77	72	71	28
Total	**8016.7**	**7732.4**	**8503.5**	**9653.9**	**11119.7**

2. Methodology

The following procedural steps were used in this paper:

A) Develop a simple linear regression analysis model, based on historical data, for electricity consumption and generation, respectively.

B) Use time series forecasting techniques to predict electricity consumption and generation data for the years 2008 to 2028, using the parameters generated in the first step.

2.1. Simple linear regression model

Regression analysis is widely used to analyze single and multifactor data by building an equation that relates the response to a predictor or independent variables. The starting point of this analysis is to define the response variable and the important factors that might be relevant to explain the response's behavior. The model uses electricity generation and consumption as the response, respectively, however, without jumping to a totally different study, it was agreed upon to choose the year number, starting from year 1989 until year 2006, as the predictive variable, based the on generation and consumption data of the mentioned period. The following equation represents a suggested regression model:

$$E_c = \mu_0 + \mu_1 (YN) + \varepsilon \quad (1)$$

$$E_g = \mu_0 + \mu_1 (YN) + \varepsilon \quad (2)$$

Where Ec and Eg are the electricity consumption and generation, respectively, μ_0 the regression model intercept, μ_1 the regression model coefficient of the year's number YN, and ε the difference between the actual and the predicted electricity data.

2.2. Time series forecasting

The projected values of electricity consumption and generation data were developed using a forecasting tool based on time series techniques with double exponential smoothing as follows:

$$F_{t+m} = a_t + b_t m \tag{3}$$

where F_{t+m} is the forecasted variable for m periods ahead, a_t the intercept of the forecasting function, and b_t the slope of the forecasting function. The intercept and the slope are estimated as follows:

$$a_t = 2S_t^{'} - S_t^{''} \tag{4}$$

$$b_t = \frac{\alpha}{1-\alpha}(S_t^{'} - S_t^{''}) \tag{5}$$

$$0 \le \alpha < 1 \tag{6}$$

where α is the smoothing constant used to give weights to current and past observations, and $S_t^{'}$ and $S_t^{''}$ are the single and double exponential smoothing values for time *t*, respectively, and are calculated as thus:

$$S_t^{'} = \alpha X_t + (1-\alpha)S_{t-1}^{'} \tag{7}$$

$$S_t^{''} = \alpha S_t^{'} + (1-\alpha)S_{t-1}^{''} \tag{8}$$

where X_t is the observation at *t*. the higher the value of α, the more reactive the model is to trend changes. The selected α gives the smallest mean square error for the forecasts, and the values of $S_{t-1}^{'}$ and $S_{t-1}^{''}$ for *t* = 1 are assumed to be equal to the initial historical point, which is valid only for the electricity consumption data since it contains more than 20 points, or years, as for the electricity generation data, for which there are less than 20 points, they are estimated in accordance with:

$$S_o^{'} = a_{est} - (\frac{1-\alpha}{\alpha})b_{est} \tag{9}$$

$$S_o^{''} = a_{est} - (\frac{2(1-\alpha)}{\alpha})b_{est} \tag{10}$$

where $S_o^{'}$ and $S_o^{''}$ are the single and double exponential smoothing values for time $t = 1$ respectively, a_{est} and b_{est} are the regression model's intercept and slope, respectively.

2.3. Proposed scenarios, corresponding GHG emissions reductions, and expected financial benefits

Eleven different scenarios are suggested to estimate the impact of adopting clean technologies over the existing fossil-fuel based electricity generation technologies:

- Scenario A: The situation will remain unchanged during the study period.
- Scenario B: Clean technologies will take a yearly constant fully share of the new electricity generation from 2008 until 2028.
- Scenario C: Clean technologies will take a yearly constant share of 80% of the new electricity generation from 2008 until 2028.
- Scenario D: Clean technologies will take a yearly constant share of 60% of the new electricity generation from 2008 until 2028.

- Scenario E: Clean technologies will take a yearly constant share of 40% of the new electricity generation from 2008 until 2028.
- Scenario F: Clean technologies will take a yearly constant share of 20% of the new electricity generation from 2008 until 2028.

In all preceding scenarios, the existing power plants at current generation capacities are assumed unchanged. In addition to the above scenarios, another five scenarios (G, H, I, J, and K) will be established assuming that practices prior to the period of study will gradually convert to the proposed new generation practices. This conversion is assumed to be uniform along the duration of the study (one twentieth of the electricity will be converted each year). As for the possible GHG emissions reductions the same scenarios will be adopted based on electricity consumption data, since they are a function of electricity consumption data, through a weighted conversion factor as thus:

$$1\ KWh = 0.46kg\ \ CO_2\ \ equivalent$$

3. Results and discussion

3.1. simple-linear regression model

Table III displays the electricity generation data upon which the model was built. Figure. II shows the simple-linear regression analysis of the Jordanian electricity generation data, and the coefficient was found significant at a level of 0.05.

Table III: electricity generation in Jordan's utility sector

year	Electricity generated (GWH)	year	Electricity generated (GWH)
1989	3028.7	1998	6283.5
1990	3247.2	1999	6635.9
1991	3334.9	2000	6933.9
1992	4002.6	2001	7132.3
1993	4362.3	2002	7614.7
1994	4659.3	2003	7468.0
1995	5175.5	2004	8448.4
1996	5614.2	2005	9086.1
1997	5886.1	2006	10625.2

The regression equation is

$E_g = 2480 + 375(YN)$

Predictor	Coef	SE Coef	T	P
Constant	2479.84	69.46	35.70	0.000
YN	375.131	7.034	53.33	0.000

S = 135.264   R-Sq = 99.5%   R-Sq(adj) = 99.5%

PRESS = 369498   R-Sq(pred) = 99.29%

Analysis of Variance

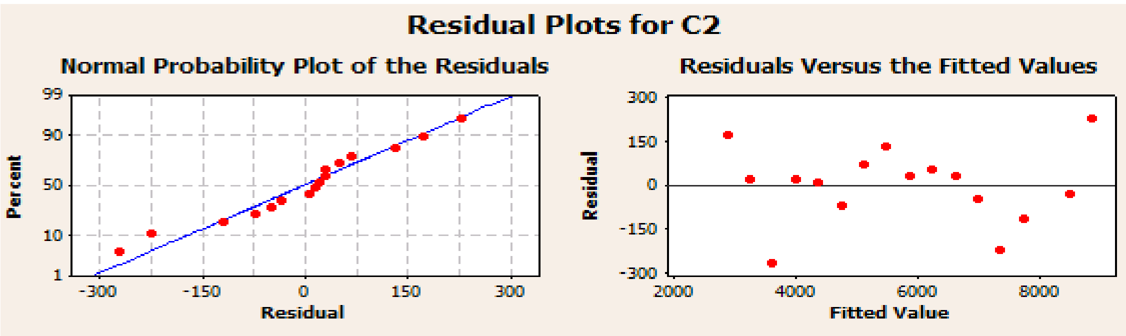
Source	DF	SS	MS	F	P
Regression	1	52032438	52032438	2843.89	0.000
Residual Error	14	256147	18296		
Total	15	52288585			

Figure. II: regression model of the electricity generation data

In order to verify the regression model, the following standard tests were conducted:

- *Assumptions validation:* regression analysis uses the Analysis of Variance (ANOVA) to verify the validity and significance of the model. Some of the assumptions on which ANOVA is based include the residuals being normally distributed and having constant variance. The graphical analysis of the residuals that was carried out for the regression model did not show any evidence that these assumptions were violated.

Figure III shows the residuals for the electricity generation model plotted against the fitted values and a cumulative normal probability plot. Since the cumulative normal distribution is approximately a straight line, when plotted in a log-normal graph, there was no reason to suspect that the normality assumption was violated. Additionally, since the residuals were evenly contained within a horizontal bend of ± around 0.00, there was, again, no reason to suspect that the constant variance assumption was violated.



(a) (b)

Figure. III: (a) Normal probability plot and (b) residual *versus* fitted values for the Jordanian electricity generation sector

- *Presence of outlier, leverage, and influence points (unusual points):* the presence of anomalies, in any model, is always expected, and, indeed, only two unusual points were detected in the constructed model in years 2003 and 2006, which were deleted from the analysis.

- *Goodness of fit*: the coefficients of multiple determination (R^2), the adjusted R^2, and the predicted R^2 statistics are the most popular measures of goodness of fit of the model to the data. The model, as indicated in figure. II has acceptable statistics.

- *Analysis of the model coefficients*: all coefficients in the model have the expected signs, and with reasonable magnitudes.

3.2. Time series forecasting

The values obtained via regression analysis were used in the time series forecasting method using a value of α, giving the least mean square error (MSE) and also exhibited the expected future growth. Figure. IV shows the historical and predicted electricity generation data, while figure V is dedicated for displaying the historical and predicted electricity consumption data in J ordan until year 2028.

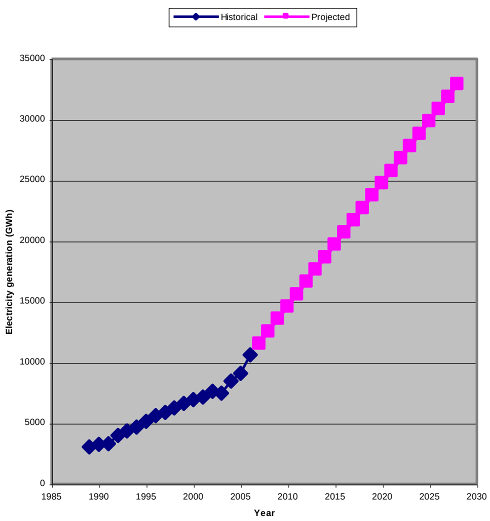


Figure. IV: historical and predicted electricity consumption until year 2028

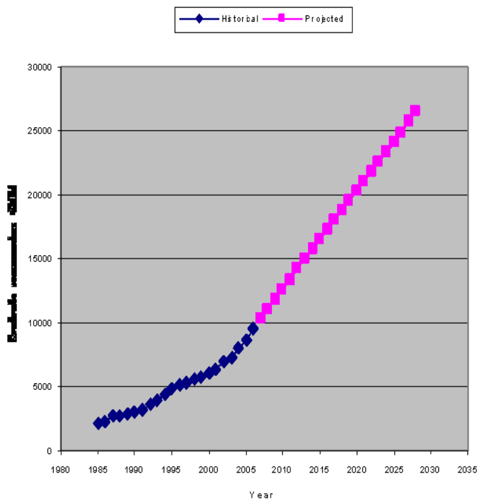


Figure. V: historical and predicted electricity generation until year 2028

3.3. Proposed scenarios, corresponding GHG emissions reductions, and expected financial benefits

Table IV displays the projected electricity consumption values for the years 2028 to 2028, and their corresponding GHG emissions, while table V shows the expected benefits, in million dollars, which are due if any of these scenarios is chosen for application in the Kingdom.

Table VI displays the scenarios through which clean power plants it may contribute to the projected electricity generation in Jordan for the predicted years 2008 to 2028.

4. Conclusions

This Study, along side the two previous studies, represents a comprehensive analysis of historical, current, and future situation of the Jordanian utility sector. In this one, an empirical model, based on simple linear regression technique, was developed for electricity generation data in Jordan. The developed model has been proved to be adequate with high values of R^2 and R^2 adjusted. Also GHG emissions, based on projected electricity consumption data, were analyzed along side their possible financial benefits, through the terms of the CDM arrangement under the Kyoto protocol and minimum value of which reached 27.019 million dollars, and a maximum value of 232.755 million dollar.

The implementation of one of the mentioned scenario's, within the present circumstances the kingdom is going through, is very crucial to minimise the countries energy bill and such a study, if seriously taken, may guard this countries of any financial crisis that may occur at any moment due to the world-wide economical disturbance.

5. References

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Table IV: Projected electricity consumption values for the years 2008 to 2028, and their corresponding GHG emissions, in million kg

		Electricity consumed (GWh)	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario F	Scenario G	Scenario H	Scenario I	Scenario J	Scenario K
Base Year	2008	11101	5106	5106	5106	5106	5106	5106	5106	5106	5106	5106	5106
Target Years	2009	11869	5460	5106	5177	5248	5318	5389	4851	4922	4992	5063	5134
	2010	12636	5813	5106	5248	5389	5530	5672	4596	4737	4878	5020	5161
	2011	13404	6166	5106	5318	5530	5742	5954	4340	4552	4764	4976	5188
	2012	14172	6519	5106	5389	5672	5954	6237	4085	4368	4650	4933	5215
	2013	14940	6872	5106	5460	5813	6166	6519	3830	4183	4536	4889	5243
	2014	15708	7226	5106	5530	5954	6378	6802	3574	3998	4422	4846	5270
	2015	16476	7579	5106	5601	6095	6590	7084	3319	3814	4308	4803	5297
	2016	17243	7932	5106	5672	6237	6802	7367	3064	3629	4194	4759	5324
	2017	18011	8285	5106	5742	6378	7014	7649	2809	3444	4080	4716	5351
	2018	18779	8638	5106	5813	6519	7226	7932	2553	3260	3966	4672	5379
	2019	19547	8991	5106	5883	6660	7437	8214	2298	3075	3852	4629	5406
	2020	20315	9345	5106	5954	6802	7649	8497	2043	2890	3738	4586	5433
	2021	21082	9698	5106	6025	6943	7861	8780	1787	2706	3624	4542	5460
	2022	21850	10051	5106	6095	7084	8073	9062	1532	2521	3510	4499	5488
	2023	22618	10404	5106	6166	7226	8285	9345	1277	2336	3396	4455	5515
	2024	23386	10757	5106	6237	7367	8497	9627	1021	2151	3282	4412	5542
	2025	24154	11111	5106	6307	7508	8709	9910	766	1967	3168	4368	5569
	2026	24921	11464	5106	6378	7649	8921	10192	511	1782	3054	4325	5597
	2027	25689	11817	5106	6449	7791	9133	10475	255	1597	2940	4282	5624
	2028	26457	12170	5106	6519	7932	9345	10757	0	1413	2826	4238	5651

Table V: Expected financial benefits, in million dollars, due to the application if any of these scenario's is chosen

	Scenario	**Scenario A**	**Scenario B**	**Scenario C**	**Scenario D**	**Scenario E**	**Scenario F**	**Scenario G**	**Scenario H**	**Scenario I**	**Scenario J**	**Scenario K**
Base Year	2008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Target Years	2009	0.000	6.755	5.404	4.053	2.702	1.351	11.638	10.287	8.936	7.585	6.234
	2010	0.000	13.510	10.808	8.106	5.404	2.702	23.276	20.574	17.872	15.170	12.468
	2011	0.000	20.264	16.211	12.159	8.106	4.053	34.913	30.860	26.808	22.755	18.702
	2012	0.000	27.019	21.615	16.211	10.808	5.404	46.551	41.147	35.743	30.340	24.936
	2013	0.000	33.774	27.019	20.264	13.510	6.755	58.189	51.434	44.679	37.925	31.170
	2014	0.000	40.529	32.423	24.317	16.211	8.106	69.827	61.721	53.615	45.509	37.404
	2015	0.000	47.283	37.827	28.370	18.913	9.457	81.464	72.008	62.551	53.094	43.638
	2016	0.000	54.038	43.230	32.423	21.615	10.808	93.102	82.294	71.487	60.679	49.872
	2017	0.000	60.793	48.634	36.476	24.317	12.159	104.740	92.581	80.423	68.264	56.106
	2018	0.000	67.548	54.038	40.529	27.019	13.510	116.378	102.868	89.359	75.849	62.340
	2019	0.000	74.302	59.442	44.581	29.721	14.860	128.015	113.155	98.294	83.434	68.573
	2020	0.000	81.057	64.846	48.634	32.423	16.211	139.653	123.442	107.230	91.019	74.807
	2021	0.000	87.812	70.249	52.687	35.125	17.562	151.291	133.729	116.166	98.604	81.041
	2022	0.000	94.567	75.653	56.740	37.827	18.913	162.929	144.015	125.102	106.189	87.275
	2023	0.000	101.321	81.057	60.793	40.529	20.264	174.566	154.302	134.038	113.774	93.509
	2024	0.000	108.076	86.461	64.846	43.230	21.615	186.204	164.589	142.974	121.358	99.743
	2025	0.000	114.831	91.865	68.899	45.932	22.966	197.842	174.876	151.910	128.943	105.977
	2026	0.000	121.586	97.269	72.951	48.634	24.317	209.480	185.163	160.845	136.528	112.211
	2027	0.000	128.340	102.672	77.004	51.336	25.668	221.117	195.449	169.781	144.113	118.445
	2028	0.000	135.095	108.076	81.057	54.038	27.019	232.755	205.736	178.717	151.698	124.679

Table VI: The scenarios through which clean power plants it may contribute, in GWh, to the projected electricity generation in Jordan for the years 2008 to 2028

	Scenario	Electricity Generation (GWh)	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario F	Scenario G	Scenario H	Scenario I	Scenario J	Scenario K
Base Year	2008	12545	0	0	0	0	0	0	0	0	0	0	0
Target Years	2009	13561	0	1016	813	610	406	203	1643	1440	1237	1034	830
	2010	14577	0	2032	1626	1219	813	406	3287	2880	2474	2067	1661
	2011	15594	0	3049	2439	1829	1219	610	4930	4321	3711	3101	2491
	2012	16610	0	4065	3252	2439	1626	813	6574	5761	4948	4135	3322
	2013	17626	0	5081	4065	3049	2032	1016	8217	7201	6185	5169	4152
	2014	18642	0	6097	4878	3658	2439	1219	9861	8641	7422	6202	4983
	2015	19659	0	7114	5691	4268	2845	1423	11504	10082	8659	7236	5813
	2016	20675	0	8130	6504	4878	3252	1626	13148	11522	9896	8270	6644
	2017	21691	0	9146	7317	5488	3658	1829	14791	12962	11133	9304	7474
	2018	22707	0	10162	8130	6097	4065	2032	16435	14402	12370	10337	8305
	2019	23724	0	11179	8943	6707	4471	2236	18078	15843	13607	11371	9135
	2020	24740	0	12195	9756	7317	4878	2439	19722	17283	14844	12405	9966
	2021	25756	0	13211	10569	7927	5284	2642	21365	18723	16081	13439	10796
	2022	26772	0	14227	11382	8536	5691	2845	23009	20163	17318	14472	11627
	2023	27789	0	15244	12195	9146	6097	3049	24652	21604	18555	15506	12457
	2024	28805	0	16260	13008	9756	6504	3252	26296	23044	19792	16540	13288
	2025	29821	0	17276	13821	10366	6910	3455	27939	24484	21029	17574	14118
	2026	30837	0	18292	14634	10975	7317	3658	29583	25924	22266	18607	14949
	2027	31854	0	19309	15447	11585	7723	3862	31226	27365	23503	19641	15779
	2028	32870	0	20325	16260	12195	8130	4065	32870	28805	24740	20675	16610