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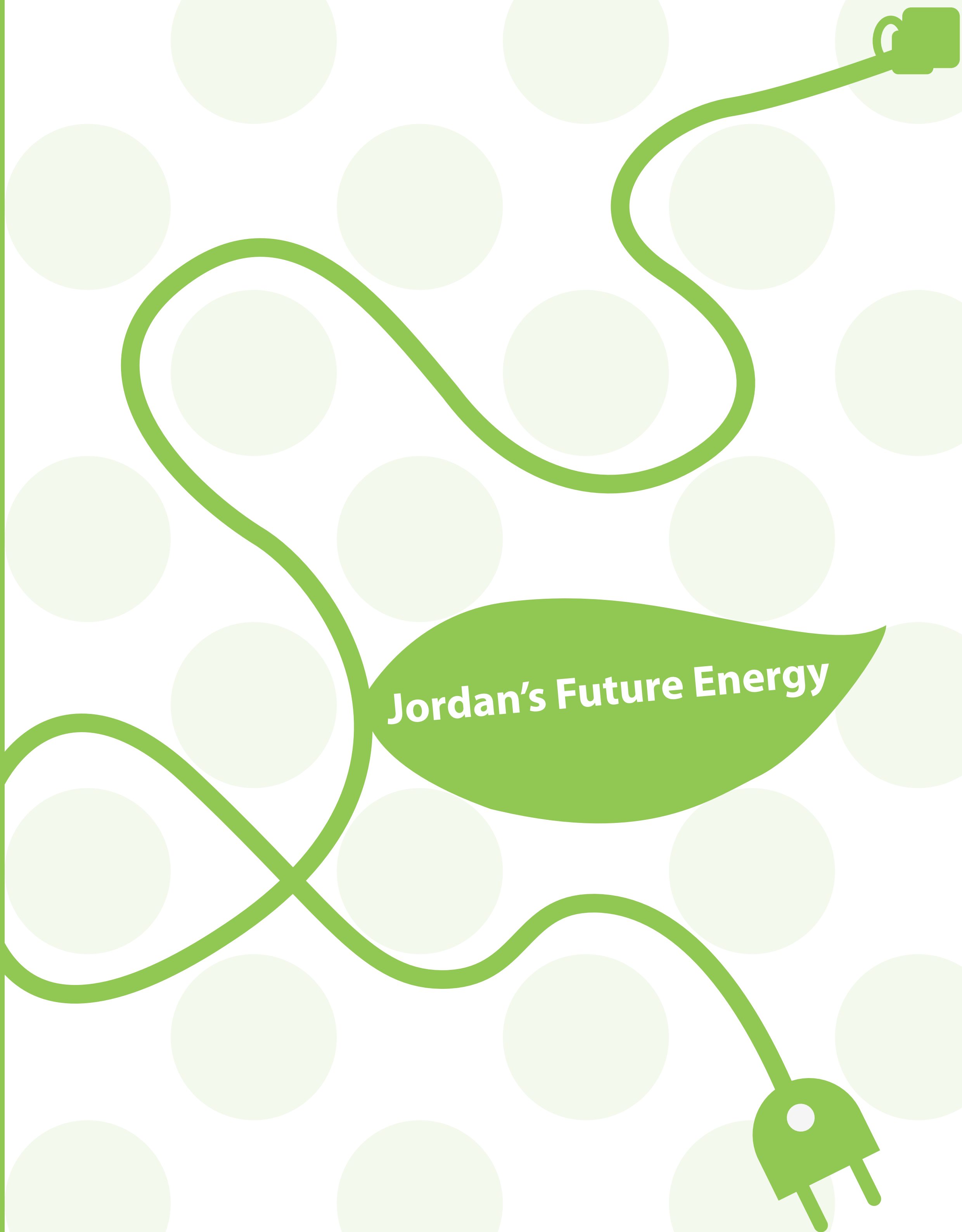
Jordan's Future Energy



Mediterranean

Executive Summary

Jordan is facing surmountable challenges in the energy sector with the rising cost of fuel and electricity. With every challenge comes an opportunity, and that is to become self-sufficient, and reliant on your own natural resources. Jordan is in fact very rich in renewable resources but, due to a lack of investment and foresight, these resources have not been exploited.

Renewable energy resources - particularly solar - can technically provide sixty times more than Jordan's electricity consumption in 2050.
More important, is that the economics of solar and wind is feasible today, and with the declining cost structure of these technologies, they will be at and below cost parity with other indigenous fossil fuel based power generation. Economic modelling results show that a target of 100% renewable energy by 2050 can be attained and can lead to total accumulated savings of approximately $80 billion (or $12 billion in present value terms), while providing 30,000 new jobs.

Most urgent, is that Jordan commits to a non-reversible path and vision for renewable targets, and does so by adopting the following key principles:

- A commitment to a phased approach involving an investment programme that exploits the cost and technical potential of each RE technology option.
- Removal of obstacles and facilitation of on-going projects as a matter of urgency and concomitant strengthening of public institutions.
- Developing a national RE master plan with stakeholder buy-in engaging with the rural communities as a key cornerstone of the renewable energy programme.
- Picking the lowest hanging fruit with the immediate launch of projects that eat away at the peak demand, including distributed energy projects that can yield immediate employment opportunities.
- Encouraging technological innovation.

Introduction

Jordan has abundant renewable energy resources to support 100% of its electricity needs well into the future. Jordan's natural wind and solar resources can provide over 60 times more electricity than the country's projected demand in 2050 (DLR, 2005).

We will demonstrate a plausible vision for energy independence that relies solely on the progressive deployment of renewables and the phasing out of carbon energy generation.

Our aim is to refute the argument that only nuclear power can provide base-load capacity at "low cost", and to demonstrate that nuclear is not an essential part of the future energy mix for electricity generation. By 2030, the Jordan Atomic Energy Commission aims to have some 4GW of nuclear generation providing more than 50% of Jordan's power requirements. As discussed above, the first of these plants was initially scheduled to come online by 2020 to provide up to 27% of the country's electricity requirements.

The gradual diversification of Jordan's energy mix, with a gradual phase out of fossil fuels (particularly natural gas), in the short to medium term is a more plausible and practical scenario for Jordan. In elaborating this scenario, we aim to examine Jordan's current energy situation from a cost structure perspective, and compare the cost structure of conventional and nuclear energy to the fast declining costs of renewable energies, where it can be deduced that a vision for 100% RE is both possible and realistic.

Jordan's Energy Policies and Challenges

Since the launch of the first Energy Sector Strategy in 2007, Jordan's vision has been to integrate renewables into its energy mix, with targets of 7% and 10% by 2015 and 2020 respectively. Due to the country's dependence on subsidised and low cost natural gas imported from Egypt, Jordan's government had failed, as of 2011, to initiate any meaningful progress in renewable energy and energy efficiency despite the obvious strategic importance of the same in providing energy security and establishing the basis for economic development.

Jordan has not been in a strong financial position to support RE projects as a result of cheap natural gas supplies, while the nuclear industry - despite a lack of support from parliament - has received significant investment on the false promise of cheap and abundant energy. Exacerbated by the increasing cost of power generation as reported by the government, (up to 184 fils per kilowatt-hour that is equivalent to USD 0.26/kWh) (Luck, 2012) due to the disruption of cheap Egyptian gas supplies, the urgency of developing RE has escalated dramatically.

Today, Jordan finds itself in a very precarious economic situation given that discounted Egyptian gas supply will not resume at the required quantities and that any resumption is uncertain at best. As of early 2012, and after a year of disruption, Jordan is receiving an average of 30 Million Standard Cubic Foot (MMSCF) – equivalent to 0.8 Million Metric Standard Cubic Metres (MMSCM) of the 250 MMSCF (equivalent to 7 MMSCM) it needs to power its generation capacity. This has resulted in a shift to imported oil derivatives that has come at a much greater cost to the government.

The cost of power generation for the National Electricity Production Company has steadily increased from a low of approximately 5-7 USD cents/kWh (for base load gas generation) and a blended cost of generation of 10 USD cents/kWh in 2010, to today's high of 25 USD cents/kWh. Very little of this increase has been passed on to the consumer due to socio-economic pressures. This has greatly affected Jordan's balance of payments, and has forced the kingdom to initiate plans for importing LNG, to fast-track energy efficiency programmes, and to focus on RE on a more urgent basis.

The Renewable Energy and Efficiency Law (REEL) passed by parliament in 2011 and subsequent by-laws issued by the Electricity Regulatory Commission in early 2012, aimed to facilitate the development of RE at a pace much slower than the private sector would have liked. The new by-laws, that empower the law, provide for several important instructions pertaining to:

- Connecting distributed RE projects to the grid, thereby allowing for net-metering.
- Connecting utility scale RE projects to the grid.
- Benchmark pricing for accepting unsolicited proposals for utility scale RE projects.

While the by-laws are important, they have not been tested, and there is considerable room for their improvement. For example, net-metering is not economical for some segments of the economy, such as industry, that have very low electricity tariffs, and hence some additional form of support will be required in the form of Feed in Tariffs. The reallocation of subsidies from conventional to renewable energy has not yet taken place and will be a gradual process given that Jordan's future cost of conventional energy generation could decline with imported or domestic gas finds.

The Ministry of Energy and Mineral Resources (MEMR) is progressing projects through an Expression of Interest (unsolicited proposals) framework that has attracted over 30 developers (proposing 1 GW of projects), and also through the planned tender of several projects supported by international lending organisations, including a 100MW CSP project and planned 200-300MW wind pooling project. The government had previously tendered several wind projects (such as Kamshah and 100 MW Fujeij) that failed to progress or were delayed due to inherent weaknesses in project planning.

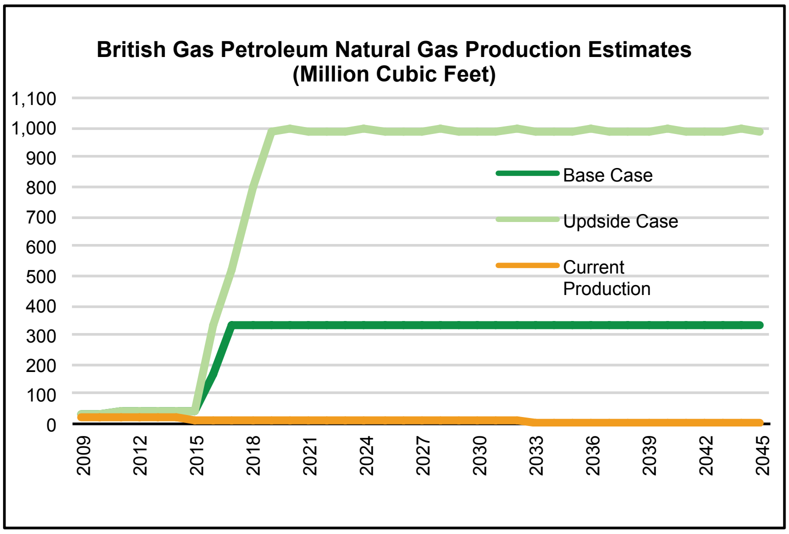
- Several financing programmes have also been launched to support renewables and energy efficiency including:
- The allocation of approximately $300 million from the Gulf Cooperation Council soft loan package to Jordan for supporting renewable energy projects.
- Launch of a public-sector energy efficiency fund together with German finance institution KfW to the tune of 30 million Euro to support efficiency measures on 700 public buildings.
- Mobilisation of the European Bank for Reconstruction and Development (EBRD) in Jordan with a partial focus on supporting renewables.
- The launch of micro-loans through the Development and Employment Funds for small scale systems.
- The placement of emphasis on renewables for projects supported by the Governorate Development Fund.
- The creation of the Renewable Energy and Efficiency Fund and its seeding with some$7 million in grant funding.

Due to the lack of Egyptian gas and the reliance on market-priced fossil fuels, the drive to kick-off renewable energy projects has not been stronger; however, it has been mired with bureaucracy and limited government capacity where quicker and more decisive action is needed. Today and for the coming two to three years, electricity costs can clearly be substituted by RE at no cost to the government. However, with the prospects of gas-based power generation whether from imported LNG (by 2013/2014) or from domestic supply of natural gas (by 2018) in the Risheh field, the burden of committing to a fixed-price 25 year RE power purchase agreement (PPA) seems daunting, yet necessary.

In 2012 Energy Minister Ala' Batayneh highlighted his ministry's intent to refresh the energy sector strategy through reconsideration of the energy mix and the targets, particularly in light of the gas prospects in Risheh, the Egyptian gas disruption, plans for importing LNG and new developments in oil shale and renewable energy. However, the lack of certainty of alternative fuel supply quantities and delivery times, and the lack of transparency regarding future energy costs present a challenge, particularly beyond 2020, from whence a comprehensive strategy for renewables does not yet exist.

Present and Future Cost Projections for Solar and Wind

As mentioned above, renewables are already at parity with power generated by most forms of unsubsidised fossil fuels, except where renewables compete with low cost natural gas. As the world and the Middle East region gain experience with the various RE technologies, costs are expected to continue coming down dramatically and to gain parity with natural gas. The following section clearly demonstrates the cost structure of conventional and renewable energy solutions (PV, CSP and wind). The rationale to support and prioritise the quick and aggressive implementation of renewable energy projects is very clear from an economic and security of supply perspective.



Conventional Energy Costs

In 2012, due to the interruptions of Egyptian natural gas supply, the government announced that the real cost of electricity had jumped from an estimated JD 0.07/kWh ($0.10/kWh) to JD 0.184/kWh (or $0.26/kWh) (Luck, 2012). This scenario is not expected to last long. with he government aiming to import LNG. Natural gas from the Risheh gas field in the eastern part of the country will be priced at market rates.

Shown below are the prospects for gas production at the Risheh field, where expected production from 2018 could provide up to 1,000 MMSCF per day. That would support 100% of Jordan's energy requirements up until 2025, whereas a production of 300 MMSCF will serve 50% of Jordan's needs starting in 2018.

In the interim, gas imports through an LNG terminal to be constructed by 2013/2014 may cost up to $16/MMBtu based on current international prices, which would translate to a power cost of generation of $0.13/kWh on a fuel cost basis, and $0.08/kWh if the gas price would be $10/MMBtu. The latter assumes that the entire power generation capacity is converted to combined cycle natural gas.

To summarise, the current cost of electricity is $0.25/kWh up until 2013/2014. The projected cost of electricity, depending on the final price of LNG, could be in the order of $0.13/kWh (at an LNG price of $16/MMBtu, fuel basis only), from 2013 until 2018. The cost of electricity generated based on Risheh field gas (by 2018) is uncertain although it may be in the range of $16/MMBtu - $10/MMBtu or $0.13 - $0.08/kWh equivalent electricity.

PV Cost and Economics

The cost of photovoltaic has come down dramatically in the last few years, spurred by heavy investment in research and development as well as increased supplies of polysilicon raw material and module manufacturing capacity. The PV sector is projected to continue to grow, in part due to feed in tariff support but, more importantly, due to grid parity economics in many countries.

According to the European Photovoltaic Industry Association, PV installations in 2011 reached 27.7GW; a 70% increase from the previous year. Accumulated installations reached 67.4GW at the end of 2011, up from 39.7GW at the end of 2010 (EPIA, 2011). The total power output of the world's PV capacity over a calendar year is equal to some 80 billion kWh of electricity. This is sufficient to cover the annual power supply needs of over 20 million households in the world. The manufacturing capacity of PV modules is also staggering at some 50 GW per year (IMS Research, 2011).

An analysis by Bloomberg in January 2011 (Bloomberg, 2011) demonstrated a clear investment case for PV in Saudi Arabia, where PV is a viable substitute for oil fired power plants, even at $2.73/Wp installed. By 2030, the Levelised Cost of Electricity (LCOE) is expected to be US$0.07/kWh in Saudi Arabia according to KACARE Senior Investment Consultant Mujahid Al Gain.

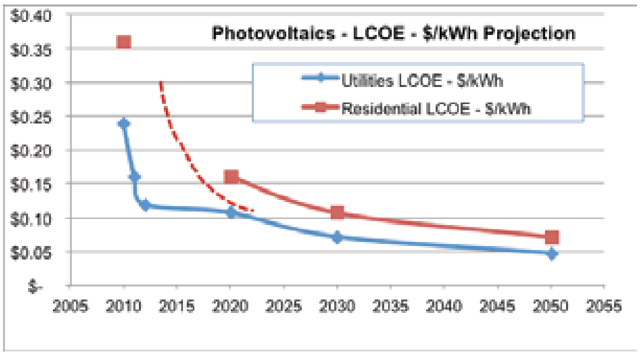
PV Facts

- 67.4 GW installed worldwide up until 2012.
- 50 GW/year module capacity.
- LCOE current at or below $0.12/kWh for Utility Scale projects in Jordan.
- LCOE expected to reach $0.07/kWh by 2030.

In Jordan, PV has already attained grid parity today, i.e., it is well below today's cost of electricity of production of $0.25/kWh, and below what some consumers pay (above $0.15/kWh). While the government has created legislation to allow net-metering for PV installations, net-metering is only viable for a small segment of consumers, who pay high tariffs, and not for industry and lower bracket consumers who pay well under $0.10/kWh.

The following charts and figures abstract estimated capital and LCOE for PV. The figures are from the International Energy Agency PV Road Map (IEA, 2010) with the exception of figures for 2011 and 2012 that are based on data from Bloomberg (Bloomberg, 2011) and market data respectively.

Figure 2 Historical and projected cost of PV systems (residential and utility scale) Source: (IEA, 2010), (Bloomberg, 2011) and market data.



Utilities

Year	2010	2011	2012	2020	2030	2050
Capital Cost - $/kWp	$ 4,000	$ 2,700	$ 2,000	$ 1,800	$ 1,200	$ 800
LCOE - $/kWh	$ 0.24	$ 0.16	$ 0.12	$ 0.11	$ 0.07	$ 0.05
Life of system (yrs)	25	25	25	30	35	40

Residential

Year	2010	2011	2012	2020	2030	2050
Capital Cost - $/kWp	$ 6,000	n.a.	Est. $2,700	$ 2,700	$ 1,800	$ 1,200
LCOE - $/kWh	$ 0.36	n.a.	Est. $0.16	$ 0.16	$ 0.11	$ 0.07

Assumptions: 9 % discount rate, 2 % inflation, 0.75% degradation, $10/MWh opex, 1800 kWh/kWp output, 25 year terms, and excluding land and development costs, and utility connection.

Accordingly, it can be concluded that:

- Not only is PV at parity with the grid today (i.e. lower than what consumers pay and lower than the current cost of product), and at 0.08 JD/kWh ($0.12/kWh), but it is also close to what was the blended cost of electricity in 2010.
- Government regulations for net metering, while helpful, do not take into consideration nor incentivise consumers who have low (subsidised) tariffs.
- By 2020, utility scale PV is expected to be at parity with the pre-2010 cost of generation of $0.12/kWh. PV is not suitable to satisfy base load capacity, yet can be an energy efficiency solution until such time as storage solutions become cost effective.
- Utility scale PV is already at parity with internationally priced LNG, and within close range of $0.08 /kWh power produced based on Risheh's natural gas (estimated price at $10/MMBtu) by 2018.
- Up until 2030, PV LCOE may be lower than natural gas depending on the final price of LNG or Al Risheh natural gas.

Concentrated Solar Power Economics and Costs

Concentrated solar power's (CSP) utilisation as a technology remains modest at 3GW installed capacity in comparison to PV installed capacity of 67GW of installed capacity globally as of 2011.

While the cost of CSP is generally higher than PV, the advantage of CSP plants is two-fold: storage and stability. CSP plants can provide thermal storage capacity to allow for 24 hour operation, utilising fuel as back up if necessary. In addition, due to the thermal inertia in the plants, intermittency as a result of a sudden drop in Direct Normal Incidence (DNI) does not necessarily affect output and grid stability to the same extent as PV.

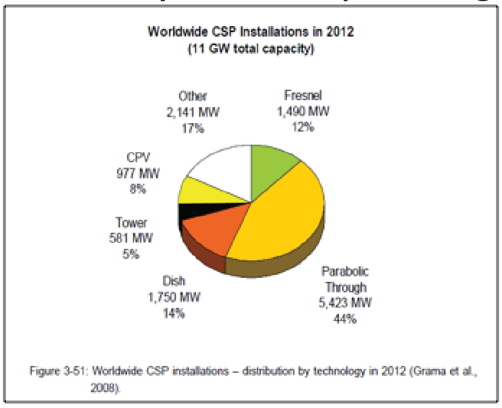
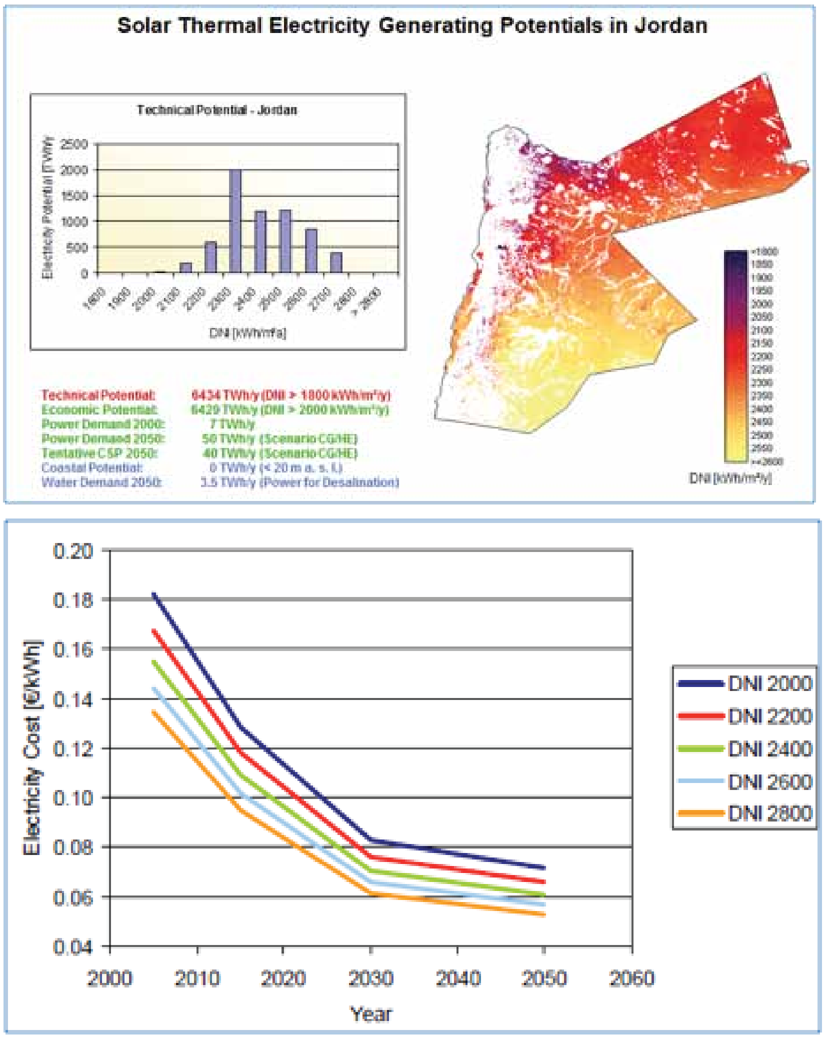


Figure 3 World Wide CSP Installations as of 2012, whereby only 3GW was actually realized.

In a recent study by the International Renewable Energy Agency (IRENA) on CSP (IRENA, 2012-1), LCOE for CSP, depending on technology type and plant configuration, was projected to be from as low as $0.14/kWh for parabolic trough technology, and as low as 0.17 $/kWh for tower technology (on a 2011 cost basis). The road map for various technologies also projects a 30-40% reduction in CSP power plant costs. By 2020, the IEA expects parabolic technology LCOE to be within the range of $0.1 and $0.14/kWh.

In Jordan, where particular sites such as Guweira and Ma'an enjoy high levels of DNI (approximately 2,300 – 2,550 kWh/sqm/year), DLR provides long term LCOE projections that are well below 10 Eurocents/kWh ($0.13/kWh) by 2020. In fact the LCOE is expected to be below 8 euro cents ($0.10/kWh) by 2030 and decline further into 2050. Figure 4 is an extract from DRL's study on Concentrated Solar Power for the Mediterranean Region



Wind Economics and Cost

While Jordan has high quality wind resources, they are modest in relation to solar resources and potential. DLR projects the economic potential of wind in Jordan to be some 109 TWh/year, whereas solar is more than fifty times as high. Due to the localisation of good wind resources in specific areas, there is a limitation on land availability particularly on private lands and in proximity to urban centres. The utilisation of such lands may necessitate government ownership that is not enabled in the current Renewable Energy and Efficiency Law.

In comparison to solar, wind is a more cost effective option and a lower hanging fruit provided that grid connection is feasible. Installed costs for small scale wind farms are expected to decline from 30% from USD 1,350/kWp to USD 1,043/kWp by 2040 (IRENA, 2012-2). In Jordan, a capacity factor of 25-35% is not uncommon resulting in a maximum LCOE of under USD 0.14 /kWh, as per the above chart.

According to DLR studies, the technical potential for CSP in Jordan is approximately 6,400 TWh/year, which would be 60 times more than the total energy consumption per year in 2050, estimated at 90 TWh/year. A gradual investment program for CSP is proposed below based on the set targets for 100% RE by 2050. This would require large tracts of land (some 300 to 400 square km) and grid connection to be included in long term master plans for the country.

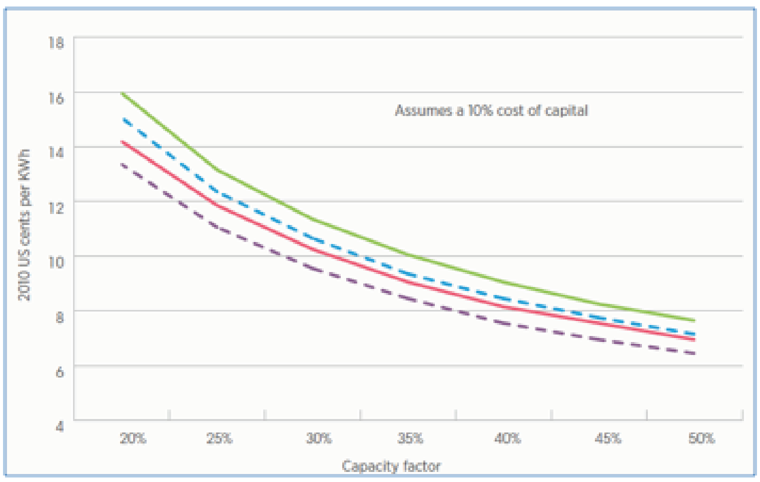


Figure 6 LCOE for wind and typical European onshore wind farms, 2011 to 2015. Source: (IRENA, 2012-2).

Conclusions: A Transition to the Green Economy is Feasible

Based on the projected LCOE for PV, CSP and wind above, it can be concluded that renewables are already at grid parity and that declining costs will put them at parity with gas-based generation by 2020-2025, well below the realistic price of nuclear energy stipulated to come on line after 2020. Furthermore, it is demonstrable that there is no additional burden on the Jordanian economy from this transition.
It is therefore imperative that Jordan proceeds in enabling renewable energy projects sooner rather than later, and takes on the challenge of reaching 100% renewables generation by 2050 through a gradual phasing-in of renewables, and a gradual phasing-out of carbon fuels.

In the lead in to the 100% RE target, natural gas would act as transitional fuel via the Risheh field. Leading to 2050, where Jordan's electricity requirement could top 91 ThWh/year we consider a scenario in which Jordan attains its renewable energy targets of 7% and 10% by 2015 and 2020 feasible and 100% by 2050 feasible. In doing so, renewables will gradually displace conventional energy including natural gas.

Accordingly, and based on NEPCO figures, we have projected Jordan's energy demand to 2050 and the share of conventional fossil fuels, primarily from indigenous sources or gas or LNG as follows:

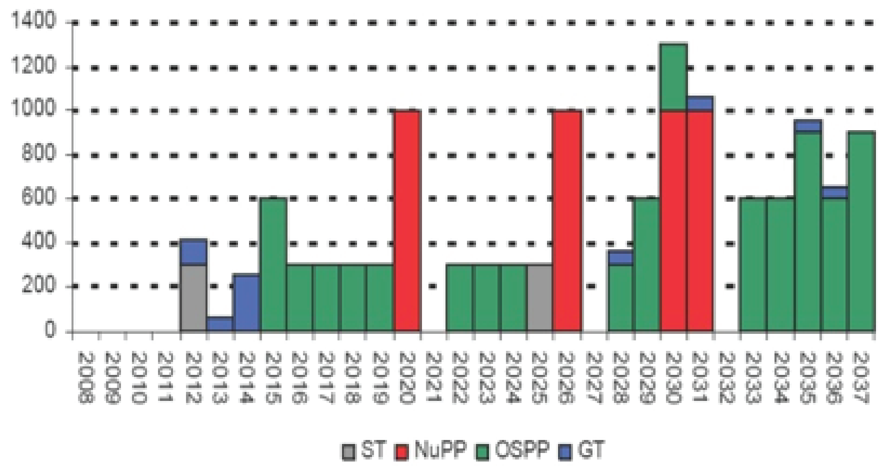
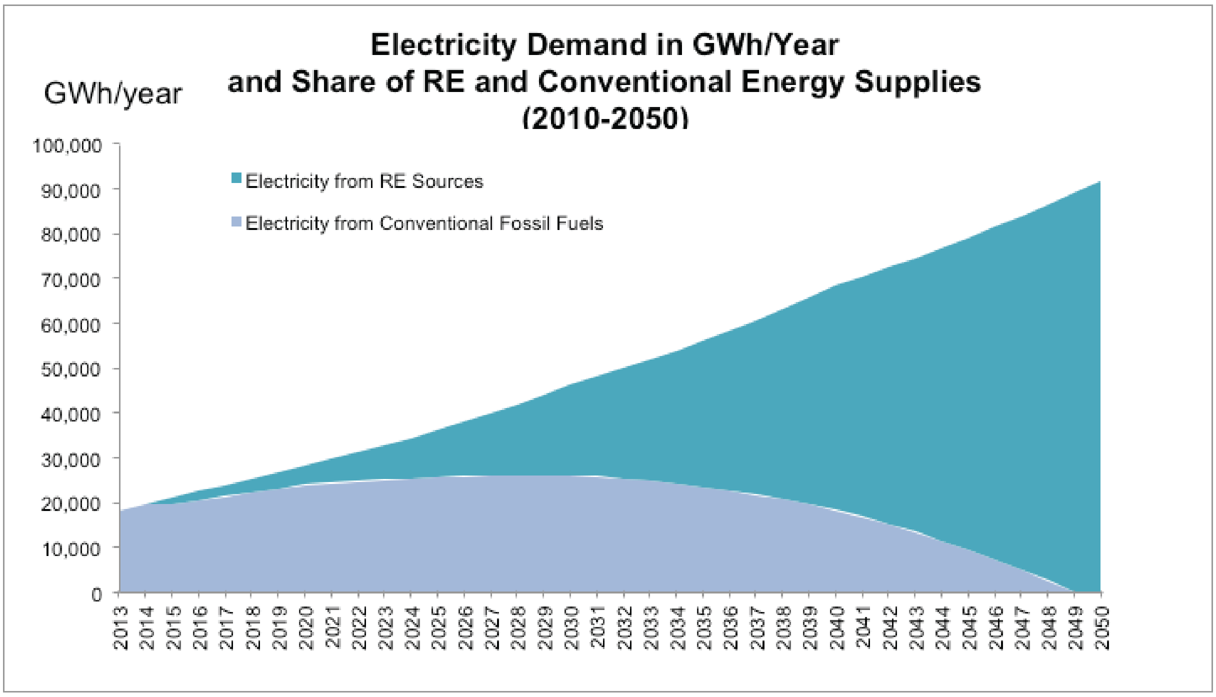


Figure 7: Generation Expansion Plan, GT – Gas Turbines (diesel oil), ST – Steam Turbines (HFO), OSPP - Oil shale power plants, NPP – Nuclear Power plants. Source: (NEPCO, 2009)

Figure 8 Projection of RE share up until 100% in 2050



The scenario shown above, and described below, demonstrates that RE can gradually take the lion's share of energy production by 2050, whereby the share of fossil fuels will remain practically steady (increasing slightly and peaking in 2030).Most new capacity additions will be from renewable energy sources. It must also be considered that both conventional and renewable energy power plants must also be renewed at their end of life.

The mix and phasing of renewable energy in this scenario will depend on a number of factors that include economics, readiness and adaptability of the grid, and matching of the load requirements of the Jordanian network. The strategy and phasing of the RE component is the subject of the next section.

How to go about it?

The development of a comprehensive renewable energy strategy must give consideration to the following:

1. Commitment to a phased approach grounded in good economics and technology innovation.

A pragmatic phased approach is needed wherein Jordan pick's the lowest hanging fruit and starts gradually to implement renewable energy projects that are feasible and economic, with a vision for long-term sustainability and innovation. To demonstrate the point, an economic model was developed based on the RE targets set out above and the economics of the various RE technologies, based on the development of a generation mix of PV, CSP and wind power plants. The base case scenario for electricity demand and RE capacity additions and investments is summarised in the table below.

The proposed phasing of the various renewable energy capacities shown in figure 9 below, stipulates the growth in electricity demand, as well as the potential of PV, CSP and wind projects up to 2050. The general mix of RE technologies and the conceptual economic model considers the following issues:

- The ease of deploying PV on a fast track basis.
- The planned capacity additions of wind and the limited wind resource in Jordan that can be economically harvested.
- The relatively long development time scale for CSP projects, which may take three to five years to develop, depending on the procurement process.
- The limitation of PV to no more than 30% of the total energy mix, which may result in grid stability (in the absence of any immediate storage technology options). This under the premise that CSP can provide a base load capacity.

Furthermore, the economic model assumes:

- A LCOE for fossil fuel to be \$0.25/kWh until 2015, declining to \$0.13 /kWh indefinitely thereafter.
- The LCOE for renewable and fossil fuel follows in Figure 11 below.

Figure 9 A Proposed RE Investment Program Needed to meet the 100% RE Target by 2050 (used in the economic model).

Capacity Additions (MW, assuming 25% overall capacity factor)						
	Demand Growth Rate	PV	CSP	Wind	Total	Estimated Investment ($billion)
2011-2015	7%	300	-	200	500	$0.84
2016-2020	6%	650	250	800	1,700	$3
2021-2030	5%	1,841	4,000	1,500	7,341	$18
2031-2040	4%	2,714	8,994	1,500	13,208	$31
2041-2050	3%	5,339	12,245	1,500	19,084	42
Total		10,844	25,489	5,500	41,833	$96

Figure 10 Scenarios for Adoption of RE Technologies

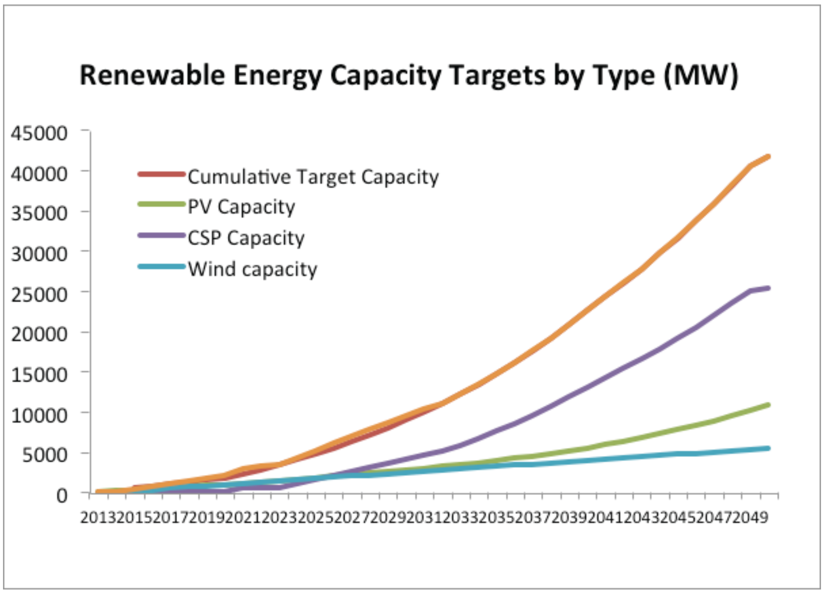
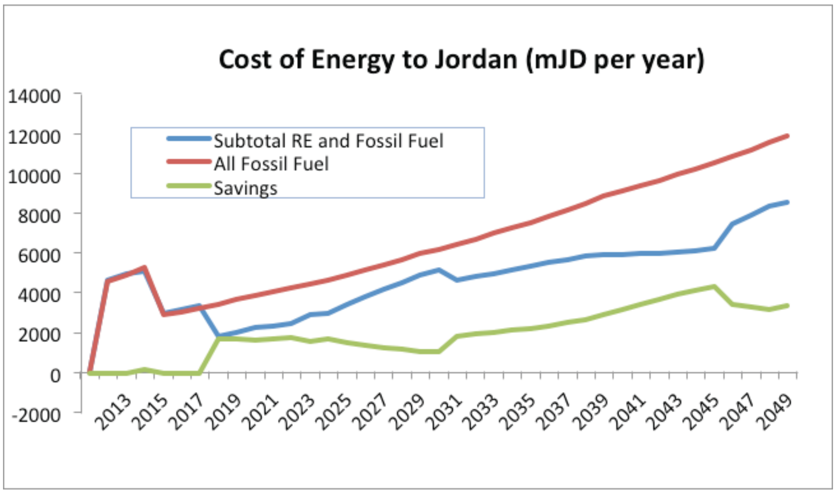


Figure 11 Projections for the LCOE used in the economic model ($/kWh)

	PV	CSP	Wind	Fossil fuel
2011-2015	0.17	0.20	0.14	0.25
2016-2020	0.15	0.17	0.12	0.13
2021-2030	0.11	0.13	0.11	0.13
2031-2040	0.07	0.10	0.10	0.13
2041-2050	0.07	0.10	0.10	0.13

The results clearly indicate that Jordan can see immediate savings from renewable energy projects that will continue into the future. A more aggressive implementation schedule is feasible (as shown in figure 12 below), wherein the cost of energy from conventional energy is projected to be higher in comparison to the stipulated scenario that would attain a 100% RE target by 2050. Up until 2017, there will be no noticeable savings. Beyond that, and up till 2050, the total accumulated savings from such a programme may amount to $80 billion
(or $12 billion in present value terms).

Figure 12 Cost of Electricity under the 100% RE by 2050 scenario (Expressed in present value at a discount rate of 8%)



The proposed energy mix and capacity additional plan would prioritise the development of PV projects, particularly distributed and community based projects, and see the initiation of pilot CSP projects on the near term horizon.

Establishing Jordan as a leader and an innovator in technology, not only to satisfy its own needs, but also as a base for export-oriented business will be a key by-product of the strategy. It is clear from examples in Germany, the US and China that RE stimulates job creation and economic development and that Jordan's labour force - particularly the expatriates and export-oriented small and medium enterprises (SMEs) working in the GCC countries - will benefit from the Jordanian experience. In addition, a reduced reliance on imported fuels will alleviate the burden on foreign currency reserves, while improving energy security and contributing to improving the GDP of the country.

It is important to note that the economic model above does not take carbon credits into account due to the difficulty in assigning a value to the same.

2.Removal of obstacles and facilitation of on-going projects as a matter of urgency

With previous failed attempts and changes in governments, Jordan's RE reputation is on the line. Correcting immediately the faults in the current legislation is critical, and taking a strategic look at the regulations and the RE sector structure for long term sustainability is imperative. Accordingly, we would recommend that the responsible authorities:

- Address the faults in the net metering system which does not incentivise all consumer segments and distribution companies, either by setting a feed in tariff or finding another mechanism to cover the difference between cost of generation and the current tariff structure.
- Prioritise RE solutions in public buildings with quick action for procurement of systems from local suppliers.
- Encourage self-generation for large consumers, where distribution companies can provide wheeling service.
- Address challenges pertaining to customs, sales tax, and income tax, and other incentives that would support RE sector development.
- Require more aggressive RE targets where the onus and the penalty is on the distribution companies and NEPCO to purchase renewable energy within a specified time frame. At present, the regulations limit the grid connected portion of RE to 1.5% of the distribution company's peak load.
- Develop a coherent transaction policy for the coming five years with a clear and transparent procurement process that is defensible and does not jeopardise the RE programme.
- Strengthening the Ministry of Energy and Mineral Resources' capacity to facilitate quicker and more effective procurement of utility scale projects through creating a programme management office.
- Support the private sector to ensure that sufficient training and monitoring of quality of goods and services is exercised;
as well as development of vocational and engineering training programmes in related fields.
- Adopt and maintain a commitment to renewable energy targets as a national priority to mitigate risks in future disruptions of fossil fuel supplies. This would help the kingdom cope with the disruption of fuel supplies from Egypt and weather other future geo-political circumstances that would prevent the import of fuel via the Red Sea, Iraq or GCC countries.

3. Engaging rural communities

Among Jordan's main economic and policy objectives is development of opportunities outside the main city centres and in governorates.
The renewable energy strategy must therefore address this objective as a priority.

Fortunately, the benefits of renewable energy can be greatly multiplied if rural communities are prioritised as key stakeholders in the green economy. This is true for a number of technical and socio-economic reasons. Firstly, as most rural and low income communities receive heavily subsidised power, the rationale for extending the same subsidy for renewable energy, is a win-win case for the government and the community. On one hand, the government can invest in a one-time subsidy that will alleviate the concerns of the community with regards to the rising cost of electricity and, on the other, the government will reduce its burden in the long run and provide an income generation opportunity for the community.

For example, community solar farms or small scale rural projects in which the local community can participate together with government in providing a token investment, would have a number of benefits. Since the communities are typically far from load centres where distribution losses are highest, rural projects can improve the performance and stability of the distribution company's grid. Land is more abundant and lower in cost that in the cities. This may motivate development of some of the capacity that would have been installed on the utility scale in rural communities. Most important is the opportunity to provide jobs and income for these communities.

The economics demonstrate that the government can afford to support renewable communities through significant subsidies on renewable energy projects. Rural communities pay the lowest tariff of electricity which is 50fils, where the government is losing some 130fils - since the government's current cost of production is 180 fils/kwh. For example, if the government provides the community with a PV system, from which the community do not pay for the output and get free power, the government will receive a five to six year payback on its investment in the PV system. Therefore, the replacement of subsidies is a win-win scenario. The subsidy to rural community power bills would better be served by subsidising capital investments in PV.

4.A national RE master plan

The rationale for selection of the RE mix is premised on the availability of RE resources in Jordan, and the respective cost of generation and transmission. According to a DLR study (Trieb, 2009), Jordan has an economic supply side potential that is more than 60 times the required power requirement by 2050. The table in Figure 13 below lists the DLR study's conclusions, noting that Jordan's solar generation potential far outweighs its wind resources, and that there may be a strong bias in the report for CSP where PV could substitute. Cultivating wind resources is a stated priority given lower costs; however, solar would ultimately prove to be a key contributor to the medium to long-term energy mix in Jordan.

The wind map of Jordan shows four or five areas with good wind potential, while solar resources (global or DNI) are rich by regional standards due to a number of factors: low humidity, moderate temperatures, the high elevation of most locations, and availability of flat terrain. It would appear that solar resources are most densely concentrated in the south (as pertains to utility scale projects).Nonetheless, solar can be cultivated in all parts of the kingdom. Jordan's wind resource is localised, often on private property or in urban settings. This imposes limitations on Jordan's wind generation.

Figure 13 Source: (DLR, 2005)

Supply Side Potential (ThW/y)		
	Technical	Economic
Biogas	NA	1.6
Wind	109	2
PV	NA	4.5
CSP	6434	6429
Subtotal Solar		6,433
Total		6,437

The above leads us to conclude that developing the solar resource is of key long-term priority and that wind resources should be cultivated early due to their competitive cost in relation to PV and CSP as described in the scheduling of capacities in figure 9 above.

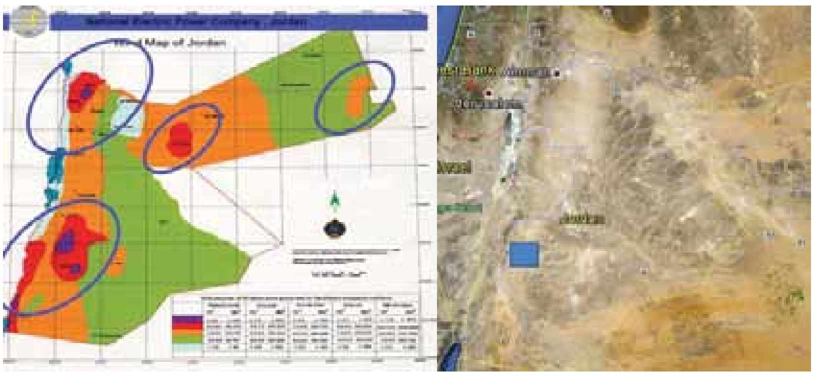


Figure 14 Maps showing the localised wind energy resources and the proposed location and area required for utility-scale solar projects to cover 100% of Jordan's power requirements by 2050 representing 0.6% of its area. Source: (Ma'abreh, 2011)

5.Picking the Lowest Hanging Fruits

Once a master plan is in place, picking the lowest hanging fruit is a function of cost of power, grid connectivity, and grid stability.

A balanced approach for developing both utility scale and distributed scale projects must be followed. The difference in economic benefit is difficult to measure, and each has its own advantages and disadvantages. Distributed energy projects are more expensive than utility scale projects. However, they benefit from reduced transmission losses, lower grid connection costs, and bring more employment generation. Based on employment factors, it can be deduced that by 2020, some 3,000 employment opportunities can be created (mostly in construction). Dependant on the level of in-country manufacturing, over 30,000 direct jobs can be created in this sector by 2050 - excluding job creation as a result of export opportunities (Greenpeace, 2012).

In the simplest terms, micro-industries and community based projects can have a remarkable effect on the people of Jordan in terms of developing economic independence, education, and employment. Among the successful examples in Jordan was an initiative by the Ministry of Environment, private sector sponsors and the Barefoot College in India to train Bedouin women on developing off grid systems to support their daily lives, and to pass this experience to their daughters.

Community based initiatives can also create a sense of ownership, loyalty and responsibility with regards to energy and its use in Jordan.

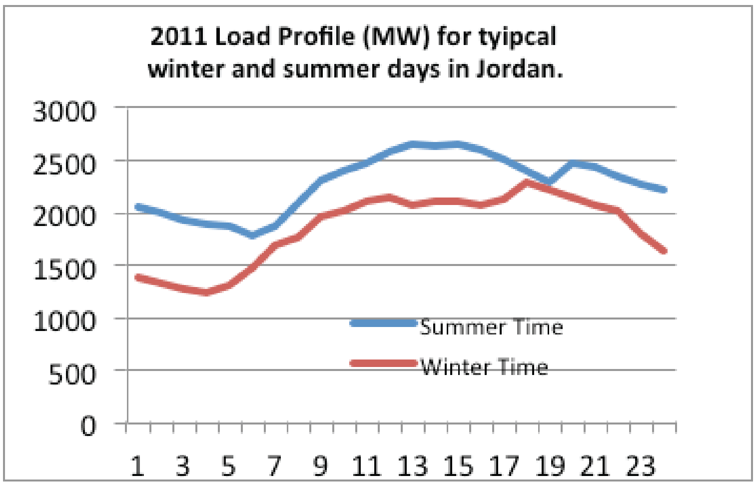


Figure 15 Jordan's load profile in a typical day. Source: NEPCO

PV is an excellent energy efficiency source, particularly in distributed generation, where transmission and distribution losses are reduced. If there is significant PV capacity on roof tops and close to urban centres or demand loads, PV output be a maximum during mid-day, coinciding with the peak load. The following chart demonstrates how Germany is adopting renewables and how peak shaving is exercised on a practical level.

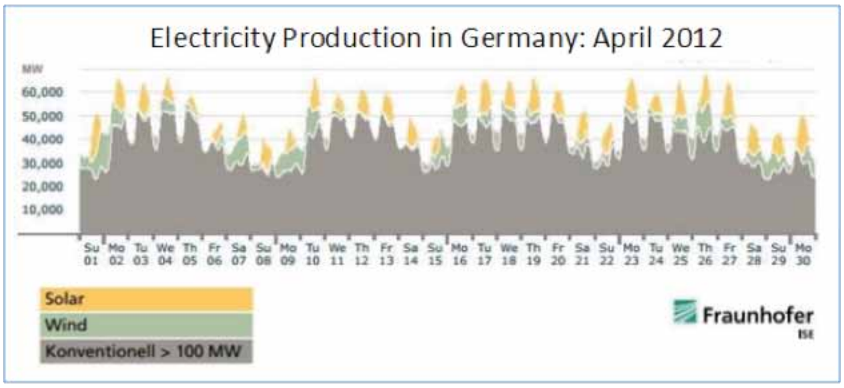


Figure 16 Germany's load profile and RE contribution. Sources: Fraunhofer and Burger, 2012

Recognising the long-term challenge of meeting base load demand, CSP is the obvious choice. While CSP comes at a higher cost, moving projects forward and gaining experience in CSP is critical to Jordan.
The challenges facing CSP are rather different than PV, in that the technology is under progressive development, and new technology options and designs are ready for market uptake on a large scale. Therefore, a learning curve is expected that also involves the adaptation of various CSP technologies to suit the needs of Jordan, in terms of cost, technology transfer and job creation.

Alternatively, water pumping (which consumes 20-30% of electricity in Jordan), can be considered as another energy storage technique. In the future, and with the advent of advanced and cost effective batteries or electric vehicles, PV will have a larger share of the energy mix.
Most importantly, PV can play an important role in ensuring that energy is economically produced as close as possible to the demand centres, helping to reduce losses in the network that may constitute anywhere from 10-20% of the electricity generated.

Encouraging technological innovation

Wind, solar and bio-fuels are in various stages of development globally and Jordan. In all three, Jordan's experience is very limited. However, by leveraging global experience and best in class technology, Jordan can also contribute to the technology development experience curve. In doing so, Jordan can emerge as one of the region's leaders and centres of excellence in renewables, which will contribute to job creation and economic development.

The EU's emphasis on the Royal Society for Scientific Research and the National Energy Research Center as centres of excellence for the deployment and piloting of new technologies is commendable. EU grants are helping support pilot wind and CSP projects in the south of Jordan. The World Bank's CTF financing mechanism and emphasis on developing CSP projects is also an important. It is this type of donor and international support that is needed to stimulate technological innovation in Jordan, and to elevate the profile of Jordan as a location where cutting edge RE deployment is encouraged.

A proactive attitude of wanting to experience and pursue a mix of technologies that works for Jordan, and developing a stake and competitive advantage in the technology road map or value chain, by way of manufacturing and intellectual knowledge development, will be important.

Engaging the national and international communities

Increasing national awareness and developing consensus on a comprehensive new strategy and plan will help Jordan's credibility when addressing the international community, which can support by way of long-term loans and project financing. Local finance sources for renewable energy must be developed, since dependence on Arab and International sources of finance and technology is not sustainable in the long run. Developing a sound and coordinated framework for investment in RE is critical, wherein RE is and energy Efficiency are prioritised. It is clear, with an estimated Present Value of $19billion, that this sector can afford a kick-start and support so that it can be elevated in importance and seen as a critical engine of economic development and sustainability.

Conclusions

Jordan has significant short-term energy challenges. From adversity, a golden opportunity arises wherein RE can take its rightful place in the energy mix at no added cost to Jordan. Beyond 2020, a vision for a nuclear free Jordan is possible, and a bold vision for 100% renewable is attainable by 2050. Not only is it attainable, but it will contribute significantly to the local economy with the creation of more than one hundred thousand direct and indirect jobs, and a saving of over $19 billion (on a present value basis) by 2050.

The key elements to realise such a vision see the following strategies put into motion:

- A commitment to a phased approach grounded in good economics and technology innovation – involving an investment programme that exploits the cost and technical potential of each RE technology option.
- Removal of obstacles and facilitation of on-going projects as a matter of urgency.
- Developing a national RE master plan that is both logical and measurable, with buy-in of the various stakeholders in the sector.
- Picking the lowest hanging fruit with the immediate launch of projects that eat away at peak demand, including distributed energy projects that can yield immediate employment opportunities.
- Engaging and benefiting rural communities as a key cornerstone of the renewable energy programme.
- Encouraging technology innovation by way of pilot projects, competition, research and development and community based projects.
- Engaging the national and international community to build a support network of policy makers and financiers that are genuinely interested in the future of RE in Jordan.

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Jordan's Nuclear Power Plans

Contents

Executive summary

Jordan's nuclear power programme is seriously misconceived on a number of grounds: technology; economics; commercial arrangements; and appropriateness for the Jordanian electricity system.

The two front-running technologies, the Sino-French Atmea1 and the Russian AES92, are unproven in operation. The work on the Atmea1 detailed design has not been started yet, a thorough review of the safety of the design has not been undertaken yet and, apart from Jordan, it has no firm prospects for orders. The AES92 design has been built in India and at the end of 2012 was reported to be ready to start operation, albeit after a prolonged and problematic construction phase.

The economics of nuclear power are acknowledged to be poor even for highly experienced nuclear countries. For example, the UK is negotiating to build a nuclear plant expected to generate power at a cost of the order £100-160/MWh ($160-250/MWh). Jordan's lack of nuclear expertise, the difficult siting issues (e.g., lack of cooling water, grid weakness and seismic concerns) mean the cost of power in Jordan would be highly likely to be higher.

From a commercial point of view, Jordan's lack of experience with nuclear power and its weak sovereign credit rating mean that it needs a foreign partner to take a majority equity stake to provide the necessary expertise in operations and maintenance and to obtain finance at an affordable cost. There seems little interest from appropriately qualified foreign utilities to take on this role.

Jordan's geographical and political situation and the size of its electricity grid lead to serious additional problems.

- Extra costs would be incurred to ensure the plant was able to withstand any earthquakes it might experience; the lack of cooling water means that an expensive and seldom used option of using waste water for cooling will have to be used;
- The Jordanian grid in its current state is far too weak and small to accommodate a reactor of the size proposed and would require major investment, including international interconnectors and additional running costs such a 'spinning reserve' so the system does not collapse when the reactor breaks down as it inevitably will occasionally;
- The chronic political instability in the region mean special attention will have to be paid to ensure the structure can stand up to any credible military/terrorist action;

These major problems are likely to prove insurmountable and Jordan's attempts to build nuclear power plants will fail. Already around five years, in which other more viable and cost-effective options could have been pursued, have been wasted on the assumption that nuclear power would solve Jordan's electricity needs problems. The sooner Jordan abandons its ill-conceived nuclear plans and concentrates on options that will give it a secure, sustainable and affordable electricity supply, the better.

1.Introduction

This paper examines the commercial aspects of Jordan's policy to order new nuclear power plants. It includes discussion of the choice of technology and supplier, the issues raised by the need to obtain finance for this project, the economics of the power that a reactor would produce and the practicalities of operating a nuclear power plant in a small electricity system like that of Jordan.

2.History of the current programme

Jordan has been pursuing the option of nuclear power for several years. An agreement with France was announced in 2008 to supply a reactor to Jordan between the French reactor vendor, Areva, and the Jordan Atomic Energy Commission (JAEC), signed by President Nicholas Sarkozy.
The reactor was expected on-line in 2015.

By March 2009, four vendors had expressed an interest in supplying reactors to Jordan: Areva, offering the Atmea1 design (1000-1150MW) developed by a Mitsubishi/Areva joint venture, Atmea; the Korean Electric Power Corporation (KEPCO) offering either the 1400MW APR1400 PWR or the 1000MW OPR PWR; a Russian design not then specified; and a Canadian design also not then specified. It was expected that the vendor and technology would be selected by early 2011. By then, the target of completing the first reactor by 2015 had slipped to 2018. In 2009, Jordan had also signed a Memorandum of Understanding with Rio Tinto to develop its uranium reserves.

In May 2010, Jordan rejected the Korean options amongst others, shortlisting the Atmea1 design, a Candu design, Atomic Energy of Canada Limited's (AECL) 700-MW-class Enhanced Candu 6 Pressurised Heavy Water Reactor (PHWR) and the Russian Atomstroyexport (ASE) 1050MW AES92. A larger more modern design from Russia, AES2006, was rejected because the site proposed, near Aqaba and the Red Sea did not have a strong enough grid to accommodate larger units.

By 2011, the target completion date had slipped to 2020 and the site near Aqaba had been abandoned, on grounds of its high seismicity, in favour of Al Majdal, about 25 miles north of the capital Amman. JAEC said that vendors had to include innovations in reactor design to take account of the special needs of Jordan. These included enhanced ability to withstand earthquakes and the need to take account of Jordan's limited water resources, which had implications for the cooling method. JAEC also said the design would need to include the ability to withstand a large commercial aircraft crash and minimize the size of the exclusion zone around the plant.

In September 2011, Jordan's then minister of Energy and Mineral Resources, Khaled Toukan, said the three shortlisted bids would be evaluated by March 2012. In the wake of the Fukushima disaster, he announced key new requirements for Jordan including: 'capability to shut down the reactor and maintain safe shutdown; continued operation of emergency core cooling and residual heat removal systems; structural integrity of containment, spent fuel pool and buildings housing important safety functions; exclusion of any fire or explosion hazard inside the containment, fuel pool or other safety-important buildings; and "respect of safe radiological limits" in case of any release of radioactive material to the environment.' He also implied there would be a need for a 'core-catcher'. He estimated the cost of a reactor would be $4900/kW excluding finance costs.

In May 2012, the JAEC announced that it had eliminated the Candu option and that the Areva/Mitsubishi Atmea1 and ASE AES-92 were the best qualified options. Nucleonics Week reported that: its [the Jordanian nuclear project] financial viability depended on Jordan's attracting a strong strategic partner or partners, but that this process was proving difficult.'

In June 2012, the Jordanian Parliament voted to suspend the country's nuclear power and uranium mining program pending completion of economic feasibility and environmental surveys. In October 2012, the Jordanian government announced the termination of an agreement with Areva to develop Jordanian uranium resources. In November 2012, Khaled Toukan, by then Chair of the JAEC, stated that the choice of reactor designs would be made by March 2013.

3.The technologies

3.1 Atmea1 technology

The joint venture, Atmea, between Mitsubishi Heavy Industries and Areva was announced in 2007, when they stated that a 1000MW design, to be called Atmea1, would be developed using technology from both companies. It was stated the reactor would have three coolant loops. Nucleonics Week reported that:

'Its safety is based mainly on active systems, but the design has some of the same safety features as Areva's EPR - a core catcher, protection of key structures against crashes of military and civilian aircraft, and hydrogen control capability.'

In 2008, Atmea stated the design would be ready in 2009. It said that half of the staff for Atmea would come from MHI and the other half from Areva. Its target markets were in Asia, for example, Vietnam, Indonesia, Thailand. Other potential customers subsequently mentioned include Brazil, Hungary, Turkey, the Czech Republic and Argentina, although none of these markets is anywhere near as advanced as Jordan.

In 2009, the French regulatory agency, Autorité de Sûreté Nucléaire (ASN) announced that it was setting up a design review process for reactors supplied by a French vendor that would not be built in France. ASN said it would charge fees for reviewing reactor designs that were not connected to a specific nuclear power plant project in France. A spokesperson for ASN described Atmea1 as 'derived from the design of the EPR [European Pressurised water Reactor, 1700MW sold to Finland, France and China].'
It was not clear how in-depth the design review would be and whether it would be comparable to the generic design reviews now underway in the USA and UK, which are taking at least five years to complete.

In 2010, GDF Suez, one of the two large French utilities (with minority French government ownership) announced it would take part in the design of Atmea1. GDF Suez has formally requested government permission to build an Atmea1 in France, but there has been no response. In 2011, following the publication of the Roussely report (Roussely, 2010) - commissioned by the French government following on from the failure of the Areva EPR to win a contest in the UAE - EDF joined the design team for Atmea1. Roussely found:

'ATMEA 1 could be one of those products [better suited to countries not wanting a large reactor]. It is a third generation PWR between 1000 and 1150 MW, currently being jointly designed by AREVA and Mitsubishi Heavy Industries. However, once it is certified, ATMEA1 will have real commercial opportunities only if the design studies take into account the contribution of experienced operators in particular EDF and if a prototype reactor based on this design is constructed in a country with experience in nuclear matters.'

In February 2012, ASN announced that, after 18 months work by its technical support organisation Institute of Radiological Protection and Nuclear Safety (IRSN) and the standing advisory group on reactors, it had approved the main safety features of the Atmea1. It was not specified who had paid for this evaluation.

The ASN review covered the basic design of Atmea1 and ASN said in a press release that during the detailed design phase, particular attention would have to be paid to issues such as 'measures necessary to the "practical elimination" of accidents leading to early large radioactive releases'. Such issues would certainly be part of the US and UK generic design reviews and it is clear ASN's approval is no more than an assertion that the design can be safe if the detailed design is good enough. The approval seems to be of the same nature as the approval given by the Finnish regulator, STUK and by ASN before start of construction of Olkiluoto 3 and Flamanville 3 respectively. As has been documented elsewhere, a significant number of design issues have arisen during construction at these sites, leading to delays and, in some cases, one-off sub-optimal solutions having to be implemented where construction had progressed too far or there was no time to wait to allow the final solution to be implemented (Thomas, 2011) .

The Atmea web-site vendor bills it as a midsize Generation III+ design based on the two companies' larger PWRs, EPR and APWR, with an equivalent safety level. It claims the following safety features:

- The ATMEA1 reactor has three divisions of reliable safety systems with 100% capacity for each division: a fourth train is provided to allow partial online maintenance during power operation;
- Long-term containment integrity through hydrogen-control and core catcher
- Designed to resist the crash of large commercial airplanes
- Measures against station blackout.

In July 2012, MHI and Areva were still discussing the schedule for proceeding to detailed design. The problem for the Atmea joint venture is that, without a specific customer and knowledge of who will carry out the safety review, it is difficult for them to know what standards to design to. For example, US and European safety authorities have different safety philosophies and a design that would be acceptable in Europe might not be acceptable in the US (and vice versa).

In June 2012, Mitsubishi senior executive Kano Saito, told Nucleonics Week: "If Atmea finds a customer, the detailed design work will be tailored to the requirements presented by the company. If not, we may do standard detailed design instead." Carrying out the detailed design work is a major task and might take two to three years. When the detailed design work was complete, it could be submitted to a safety regulatory body for a comprehensive review of the safety of the plant. The Jordanian safety regulatory body lacks the experience to carry out such a review and it would have be carried out by one of the regulatory bodies in Europe or the US. The process of 'generic' design assessment, so that all major design issues are resolved before construction starts, is underway in the UK and the US and seems likely to take up to six years for a new design. Until the detailed design work is complete and has been approved by a safety regulatory it would be premature to order such a reactor because until the design is finalised, costing could not be accurately done.

3.2 Other MHI and Areva technologies

It is useful to identify where the Atmea1 design fits within the strategies of the two members of the joint venture.

3.2.1 APWR

MHI was, until 2006, when Westinghouse was taken over by Mitsubishi's major competitor, Toshiba, licensed to Westinghouse. After this, it opted to try to sell the APWR design it had developed, first announced more than 30 years ago but never built in Japan, in the US. In its US form, this is a 1700MW PWR. It has been undergoing a full generic design assessment by the US Nuclear Regulatory Commission (NRC) since 2007 but this is not expected to be complete before 2015 and the two utilities that have declared an interest in building APWRs are not actively pursuing their interest. An order for Japan has long been mooted (Tsuruga) but in 2012, construction had not started. It is therefore far from clear that the APWR will be built anywhere.

3.2.2 EPR

The EPR, supplied by Areva NP was first announced in 1992 (See Thomas 2010a for more details of the technology). Areva was a joint venture set up to merge the nuclear divisions of Framatome and Siemens with Areva holding 66 per cent of the company and Siemens the rest. In 2009, Siemens announced its intention to exit the joint venture and Areva NP is now wholly owned by Areva, itself 92 per cent controlled by the French government. The EPR is a 1600MW PWR that is under construction in France, Finland and China. It is said to combine aspects of its predecessor designs, the Framatome N4 and the Siemens Konvoi. Areva had hoped for sales in the UK, Italy, South Africa, India and the USA but these are now, at best, no more than possibilities.

3.2.3 ACPR1000

The most potentially interesting competitor to the Atmea1 is also being developed by France. It would be based on the Chinese CPR1000, itself developed from the 900MW design exported to China and which forms the basis of 34 of France's 58 PWRs. The reactor is based on the M310 technology transferred to China by Areva's predecessor Framatome in the 1990s. In January 2012, EDF, Areva and China Guangdong Nuclear Power Holding Co (CGNPC) agreed on terms of a partnership to jointly develop and build 1000MW PWRs.

The CPR1000 is usually seen as a Generation II design, although China claims the modifications undertaken for reactors in service and under construction in China mean it should be seen as Gen II+. The ACPR would be Gen III. It was claimed in Jan 2012, that the design would be ready in 2013. It seems strange that Areva should be developing two products of the same size and with apparently the same markets.

3.3 Russian technology

3.3.1 AES-92 technology

After the Chernobyl disaster and break-up of the Soviet Union, Russian reactor vendors won few new orders for the next 20 years until 2009, when Russia began to order about two reactors a year for its home market. The main exceptions to this were orders for two reactors by India, using AES-92 technology, and China, using AES-91 technology (see below).

The orders for the Kudankulam site in India were placed in 1998 and used the AES92. These orders had been agreed a decade earlier. Construction started in 2002 and, although construction work was completed in 2012, permission to load fuel was only given in August 2012. By the end of 2012, criticality had still not been achieved. India and Russia have signed ambitious agreements for up to 16 further reactors but whether and when these will go ahead and what technology will be used is not clear.

The AES-91 (V428) and AES-92 (V466) are said to be closely related. The AES-91 was developed for the Finnish market and was bid in the aborted 1991 contest for a fifth reactor for Finland. The AES-92 was expected to be built at the Belene project in Bulgaria, now abandoned, and was reported to form the basis for the most recent Russian design, ASE claims
the AES-2006(1200MW), which has been ordered for several units in Russia, can be seen as Gen III+ technology. The AES-2006 was not chosen for Jordan because it was considered to be too large but has been ordered for Turkey (Akkuyu) and Vietnam, although construction has not started yet at either of these sites.

Both the AES-91 and AES-92 have a core-catcher and the AES-92 has a double containment to help protect against external impacts. The AES-92 has greater passive safety features - 12 heat exchangers for passive decay heat removal, while the AES-91 has extra seismic protection. It is not clear what if any modifications would be made to the AES-92 design for Jordan as compared to the version built at Kudankulam.

As is the case for Atmea1, it is likely a comprehensive safety review would be required before a plant of the AES-92 design could be built. The AES-92 has not been built in Russia and has not been sold elsewhere. It is not clear what safety review was carried out for the plants in India and by whom.

3.3.2 AES-91 technology

The Tianwan orders for China sold to the Jiangsu Nuclear Power Corp (JNPC) using the AES-91 design (1060MW) were placed in 1997.
Construction began in 1999 and they entered service in 2006 about three years late. The Chinese customer was unhappy with the delays and
the quality of components. For example, the steam generators were
damaged reportedly caused by the failure of the Russian supplier to protect the tubes from corrosion during a sea transport halfway around the world.
The problem was rectified by plugging about 700 tubes in China after the steam generators were delivered. There was an agreement to build a second pair of reactors between the Russian and Chinese governments but this has not been taken up. An official with JNPC, Li Tizhong told journalists at a nuclear conference in Moscow in 2009 that the high price being asked for the reactors is preventing signature of a contract. The reliability of the plants since then has been reasonable with their cumulative load factor in their four to five years of commercial operation about 85 per cent.

3.3.3 AES-2006 technology

This technology (for which there are two variants, V-491 and V-392M) has been used at five of the reactors on which construction has started from 2008 onwards, but was not considered for Jordan because it is too large to be accommodated on the grid. The first reactor of this design is forecast to go critical in 2013. The design is expected to be used in Turkey and Vietnam if these orders proceed.

3.4 Issues for Jordan

Arguably, the only post-Chernobyl design from any vendor with any operating experience is the Russian AES-91, while the AES-92 design is said to be ready for operation in India. The only other post-Chernobyl designs on which construction has started are the EPR and the AP1000, neither of which is under consideration for Jordan. Two EPRs are under construction in Europe and are subject to massive cost over-runs and delay and two more are under construction in China; these are said to be on time after three years of construction. The four AP1000s under construction are also all in China and after about three years of construction are also said to be on-time.

Jordan therefore does not have the option of choosing a proven post-Chernobyl design at this stage.

Most of Russia's exports of nuclear power plants are accounted for by sales to the former Soviet bloc and Eastern Europe prior to the Chernobyl disaster. It also exported two reactors to Finland in the 1970s. Since 1990, Russia has exported two reactors to both India and China. The exports to China have been problematic. The reliability of the units seems adequate, but the three year delay and the high cost of these plants are worrying. The Kudankulam AES-92 reactors are said to be complete, albeit after more than 10 years of construction but their operation is being delayed by opposition and legal challenges.

The other option, Atmea1 is much less proven. It has no orders and its only realistic prospect of orders in the next few years is from Jordan. It has not undergone a thorough design assessment and until this has been done, it will not be clear what the final design will be and how much it will cost unless the customer and the local regulatory body is prepared to accept whatever design is offered to it. The commitment of the vendor to it is also questionable. MHI has a very weak position in the world reactor market and seems unlikely to be able to win any orders for its own designs in the short to medium-term. Areva seems to have put most of its resources into the larger EPR, while its recent agreement with Chinese interests to develop a different reactor design of the same size as Atmea1 does raise questions regarding its commitment to Atmea1.

4. Commercial issues

In this section we look at the linked issues of the economics and obtaining finance and also at who would build, own and operate the plant

4.1 Economics

A comprehensive review of the economics of a nuclear plant is beyond the scope of this paper and would include detailed discussion of construction costs, operating costs, decommissioning costs, waste disposal costs and tacit public subsidies such as the limitation on liability of both the utility owning the plant and the company supplying it (Thomas, 2010b). However under conventional accounting procedures, the cost of a kWh of nuclear electricity will be dominated by the costs associated with its construction. These may account for at least two thirds of the cost of a kWh of nuclear electricity and will have to be paid regardless of how much or little the plant is operated.

There are three main elements that determine the size of the fixed costs in a kWh of nuclear electricity:

- The cost of construction. This should be the so-called overnight costs and exclude the cost of finance but include the cost of the first fuel charge. To help comparison between the cost of plants of different sizes and built in different locations, costs are usually quoted in dollars per kilowatt of installed capacity.
- The cost of capital. This will be typically made up of debt, that is, borrowing from financial institutions, and equity, that is, self-finance or sale of shares in the company. Equity has a higher cost than debt and combining the two elements gives the 'weighted average cost of capital' or WACC.
- The reliability of the plant as measured by the load factor. The load factor is the number of kWh of electricity produced as a proportion of the output it would have produced had it operated uninterrupted at full power. The more kWh produced, the more thinly the fixed costs can be spread.

The cost of capital is discussed in detail in the following section.

4.1.1 Construction cost

The cost of construction is discussed in detail in Thomas (2010b). Throughout the more than 50 years of commercial history of nuclear technology, the nuclear industry has promised that real construction costs would start to fall as learning, technical change and scale economies – the factors that with normal technologies lead to falling real costs – took effect. This promise has never been fulfilled and real construction costs have consistently risen.

About a decade ago, the nuclear industry began to talk about a ‘nuclear renaissance.’ Under this a new generation of nuclear plants, so-called Generation III+, would be safer, simpler and therefore cheaper and easier to build than its predecessors. It was claimed overnight construction costs would be no more than $1000/kW (so a 1000MW reactor like Atmea1 would cost about $1bn) and at this level, they would produce cheaper power even than gas-fired power plants. It is now clear that this was hopelessly over-optimistic. Most credible forecasts of construction costs of Gen III+ designs are in excess of $5000/kW. For example, it has been widely reported that the cost of an EPR planned to be built in the UK would be about £7bn, which at an exchange rate of £1=$1.6, equates to about $6600/kW. Press reports suggest that the contract price for power from such a plant would have to be about £140/MWh ($22.4/MWh) for the plants to be viable.

Care should be taken not to read too much into relatively small differences between different estimates of construction cost. There may be variations due to:

- General inflation if the estimates are made in different years;
- Exchange rate fluctuations, for example, if a plant is purchased in Euro, the cost in $/kW will depend on the exchange rate used and this can vary by up to 20% over quite a short period;
- Variations in local costs (see below).

Local costs include the specific costs incurred due to the plant’s location. For Jordan, this might include additional costs: to ensure seismic protection measures are adequate; because of the high cost of obtaining water for cooling; and because of the need to build transmission links and strengthen the grid to ensure the power can be effectively used.

Costs might also be higher if there is a shortage of local labour with the relevant skills in construction and specific nuclear skills and due to a lack of experience in nuclear construction.

For Jordan, with no experience of civil nuclear power, there would be additional set-up costs to include the establishment, staffing and training of an independent and highly competent safety regulatory body, the setting up of waste storage and disposal facilities.

On this basis, it seems highly likely that a plant built in Jordan would be more expensive than a plant of the same design built in a less challenging environment by a more experienced customer. For some non-nuclear technologies, vendors may be prepared to take the construction cost risk by offering a fixed price contract. This would give some reassurance to utilities (and financiers) that cost escalation was not an issue.

These fixed price contracts have seldom been offered in the nuclear industry because the high risk of cost escalation means they are generally too risky for vendors to contemplate. Recent experience with the Olkiluoto plant, where Areva is refusing to honour the turnkey contract, suggests that even if a turnkey contract was offered it would not be credible to financiers.

Even experienced utilities can run into serious problems of delays and cost escalation and Electricité de France's, the most experienced nuclear utility in the world, has severe problems with its Flamanville plant. This should have been complete in 2012 and cost €3.3 billion but is now not expected to be complete before 2016 and is expected to cost €8.5billion.

4.1.2 Reliability

There has been a common assumption by the nuclear industry over the entire history of nuclear power that nuclear power plants would be very reliable and achieve load factors in excess of 85 per cent or even 90 per cent. In practice, this level of reliability has never been achieved over the life of any plant.

This has a significant impact on the cost of a kWh of nuclear electricity. For example, let us assume that it is forecast that the load factor will be 90 per cent and fixed costs account for two thirds of the cost of a kWh at this level of reliability. If the load factor was actually 60 per cent, even if no other costs were incurred reflecting this poor reliability, the cost of a kWh would go up by a third.

By about 1980, the average load factor of reactors worldwide was less than 60 per cent. Some countries did much better than this average and in the late 1980s, with the founding of national and international peer review processes amongst utilities, reliability did improve and in recent years, the average has been around 80 per cent. So the risk of poor reliability seems to be less but is by no means negligible. For example, the four most recent plants completed in France used a new, unproven design (N4) and there were serious technical problems in the first four years of operation, such that the average load factor for these four units in this period was less than 50 per cent. So even the most experienced nuclear utility in the world, Electricité de France, can suffer from unreliability. New untested designs are a particular risk.

4.1.3 Implications for economics for Jordan

Even in a country, like the UK, with unproblematic sites with good transmission links, vast nuclear experience, a skilled workforce and all the infrastructure in terms or regulatory bodies, waste disposal facilities etc., needed to support a nuclear programme, the expected cost of power is three to four times the level of the current wholesale electricity price. It seems highly unlikely that the cost of power from a Jordanian power plant would be any cheaper. The two front-runner technologies have no experience of construction or full regulatory approval in Europe and North America and Atmea1 technology clearly requires significant further design work before it can be offered for sale so both options remain untested. A credible turnkey (fixed price) contract would reduce the risk to the customer but there seems little prospect one will be offered.

Poor reliability is also a risk and if, after 30 years of experience building nuclear power plants, even EDF cannot guarantee to be able to operate its plants reliably as was the case with its most recent plants, the N4s, poor reliability is clearly a risk for Jordan especially given that the technologies chosen are unproven.

4.2 Finance

The cost structure of nuclear power and the dominance of construction costs plus the poor record of reliability and cost control for nuclear projects mean nuclear power is by far the riskiest power generation option. This should have meant that the cost of borrowing would be high reflecting the risk the project would fail. However, in the past, and for developed countries, finance for nuclear projects was cheap and easy to obtain. This was because the credit rating of utilities was high - the original 'blue chip' companies were US utilities - because under a monopoly, utilities could generally pass on whatever costs were incurred to their consumers and this gave banks confidence that their loans would be repaid.

For developing countries, where, for example, the country credit rating was low, currencies were unstable and the price of electricity was subject to political influence, lending for any power plant was much more risky. Many developing countries with plans to build nuclear plants found these were not viable because of the cost and difficulty of obtaining finance.

For developed countries, the assumption of cost pass-through no longer applies. When US economic regulators became unwilling to pass nuclear cost over-runs on to consumers, banks immediately placed pressure on utilities to give up their nuclear plans. Ordering in the USA stopped abruptly in 1979 and more than 100 nuclear orders including all placed after 1974 were cancelled including some that were almost complete.

In Europe, the opening of electricity markets to competition from 1990 onwards had a similar impact on nuclear ordering. If electricity is sold via a market, if nuclear is not competitive, its owner will go bankrupt and any bank loans will not be repaid. As a result, it was often claimed that nuclear projects and competitive electricity markets were incompatible.

The US and the UK governments have tried to disprove this claim. In the UK, the government launched a policy to restart nuclear ordering in 2006, but by 2012, it was clear massive subsidies would be required in the form of a long-term contract backed by the government to buy the power produced on fixed price terms, reported to be about £140/MWh. Even with this guarantee, the project may prove difficult to finance unless the contract allows for additional costs, for example, if the construction cost escalates, to be passed on to consumers.

In the US, the government assumed that Gen III+ plants would be economically viable (see Thomas, 2010b for a full account of the US nuclear programme). It just needed a small number of subsidised plants to demonstrate the merits of the new designs before nuclear plants would be ordered without subsidy. It soon became clear that the key subsidy was federal loan guarantees. This meant that if the utility failed, US taxpayers would repay the loan. For banks, this meant the loans guaranteed in this way were extremely low risk. Utilities tried to increase the proportion of coverage of the loan guarantees to 100 per cent of the construction costs from the initial proposal of 50 per cent but the government was unwilling to go beyond 80 per cent. Borrowing under loan guarantees would cost little more than the banks' base rates.

More than 30 new reactors have been proposed on this basis but it has become clear that loan guarantees do not offer the solution to difficulties of obtaining finance that they first seemed to:

- First, the escalation in construction costs meant that the scale of guarantees was massive. Fifteen plants were expected to be eligible to receive loan guarantees and if we assume each plant would cost $8 billion, this would mean the government would have to give guarantees worth about $100 billion.
- Second, while loan guarantees would protect the banks, they would not protect the utilities themselves, which would go bankrupt if the project went badly enough wrong. Consumers would face large extra costs if their local utility went out of business.
- Third, if costs escalated, the utility would have to go to the market to borrow additional funds. Borrowing to finance a failing project would be extremely expensive.
- Fourth, under OECD guidelines, loan guarantees should attract a fee that reflects the riskiness of the project. In the USA, one of the projects likely to go ahead (Vogtle) is in a state where electricity is still a regulated monopoly and where the regulator has given strong indications that all costs will be recoverable and the fee was reported to be about two per cent of the amount borrowed. For a reactor proposed for a state that is part of a competitive market (the Calvert Cliffs plant in Baltimore), the fee was reported to be nearly 12 per cent and the project was effectively abandoned.

The Olkiluoto plant in Finland, ordered in 2004, was also seen as being very low risk. Finland had a very high reputation for the efficient operation of its four existing reactors which were amongst the most reliable in the world. The vendor gave a fixed price contract (turnkey) for €3 billion so that whatever the plant cost to build, the buyer would only pay the contract price. As this was the first order for EPR, it was assumed Areva, the vendor, would put in whatever resources were necessary to make it a success. The French and Swedish governments gave loan guarantees worth €750 million. At that time, the level of loan guarantees was seen as high, but given experience at Olkiluoto and demands by US utilities, only 25 per cent coverage seems inadequate.

As a result of the loan guarantees and the turnkey contract, the banks believed this project to be very low risk and offered finance worth about €2 billion (the rest was from equity) at an interest rate of only 2.6 per cent. The project, which was expected to take four years to build from mid-2005, has gone seriously wrong. By mid-2012, the project was still about three years from completion and costs had doubled. Areva is refusing to honour the turnkey contract and liability for the cost over-run is being decided in the Stockholm Court of Arbitration. This experience has been chastening for the banks and for the governments offering loan guarantees. If the customer does go bankrupt, French and Swedish taxpayers will lose up to €750 million and the banks will lose some of the €1.25 billion not protected by loan guarantees. Finnish electricity consumers are already facing increased costs to replace the power expected to come from Olkiluoto.

4.2.1 Implications for finance for Jordan

The country risk for Jordan is high. Jordan's credit rating was downgraded twice and in July 2012 Standard and Poors confirmed Jordan's long-term foreign and local currency sovereign credit ratings as BB, while Moody's rates Jordan ba2. Both ratings are below 'investment grade' rated as speculative, sometimes known as junk. The outlook in both case is negative, i.e., likely to get worse.

For Jordan, because of its inexperience in nuclear technology, the 'technology' risk – the risk that the plant will cost much more than forecast – is at least as high as in other countries and probably higher.
The commercial risk is different. There is no realistic chance of Jordan introducing competitive electricity markets but there may be concerns that it would not be feasible to pass on very high costs to consumers. If there was implicit cost pass-through to consumers, it would be essential that consumers understood clearly the costs they were bearing.

If offered, loan guarantees would tend to reduce the cost of borrowing but there has been no clear indication from the governments or the vendors involved that these would be offered. If they were, it is not clear how rigorously the OECD's guidelines, that an economic fee should be charged, would be followed. As noted above, loan guarantees by no means solve all the financial issues. If costs were to over-run the problems of finance would be severe and if the plant owner was bankrupted, serious costs would fall on Jordanian citizens.

4.3 Who would build, own and operate the plant?

Throughout, the JAEC, the main Jordanian partner, has stressed the need for a foreign partner to take on a lead role in the construction and operation of the plant. In parallel with the process of selecting the reactor vendor, there has been a much less publicised attempt to identify a foreign partner that would take the role of an investor/operator. In March 2011, then minister of Energy and Mineral Resources, Khaled Toukan, said that invitations for expressions of interest (EOI) had been sent out to 27 international companies including Datang International Power Generation (China), GDF Suez (France/Belgium), Kansai Electric Power Co (Japan) and Rosatom (Russia). In September 2011, Toukan was reported to have said: 'Jordan needs a "strong partner" to help it build and operate the plant, especially after Fukushima and a "downgrade to Jordan's financial risk" that he said could "result in higher cost of financing."'

Whether any of these companies would be willing to take the risk of taking on a nuclear project in Jordan is unclear. None has announced their intention to place an EOI and if a foreign partner cannot be found, it is hard to see how the programme would proceed. What is even harder to determine is whether any of the companies has the capability to manage such a major, challenging project in a foreign country. Of the companies named, none has significant recent experience of managing a nuclear project outside their home territory. Taking such a project on would offer major additional challenges because of factors such as, language and cultural differences.

There is some suggestion that a plant would be built on a Build Own Operate (BOO) basis as is planned for Turkey. This is an arrangement that has not been used anywhere in the world for nuclear power plants and the plant in Turkey is not expected to start construction till late 2014 so the model remains entirely unproven.

4.4 Cooling water

One of the particular issues for Jordan, particularly for the Al Majdal site, is the lack of availability of cooling water. Nuclear power plants require large quantities of cooling water, usually from a large river, the sea, or a large lake. For the Al Majdal site, it is proposed that 'grey water' is used following the Palo Verde model. Palo Verde is a nuclear power station in New Mexico comprising three reactors each of about 1300MW. Palo Verde is the only large nuclear plant cooled using waste water, using the 91st Avenue Waste Water Treatment plant. One of its owners states : 'it uses treated effluent from several area municipalities to meet its cooling water needs, recycling approximately 20 billion gallons [75 billion litres] of wastewater each year.' For Al Majdal, it is proposed that the Khirbet Al Samra Wastewater Plant be used to provide the cooling water. A full evaluation of the issues raised by use of waste water as a coolant is beyond the scope of this paper but it would require use of: 'adding secondary filtration that may be required, the need to select materials capable of coping with gray water's higher corrosion potential, and special chemical treatment requirements'. How far use of water from the Khirbet Al Samra for cooling would compromise the use of the water for irrigation is not clear.

4.5 Security issues

Inevitably a particular concern for a plant sited in Jordan will be security and the potential for the reactor to be a target for sabotage. Issues that will need careful consideration include:

- the ability of the reactor shell to stand up to impact from a missile or an aircraft;
- the vulnerability to interruptions in the cooling water supply;
- interruptions to the external power supply;
- non-availability of the reactor's on-site back-up power sources.

In addition to these man-made hazards, the siting of the plant in an area of relatively high seismic activity will require additional measures to ensure the integrity of the plant in the event of an earthquake of the largest plausible magnitude.

It is beyond the scope of this report to evaluate what other requirements would be needed in addition to those needed for a reactor in a more typical position. However, it is clear there will be significant additional costs over and above those required for a reactor sited in a less sensitive position.

4.6 Grid strength

A nuclear power plant of 1000-1100MW would be by almost an order of magnitude be the largest unit on the Jordanian power grid, where, in 2010, the largest unit was 130MW. The National Electric Power Company reported that in 2012, total generating capacity was 3186MW and demand was about 15.1TWh. It is assumed by the government that by 2020, capacity would have grown to about 5000MW and if demand were to grow at the same rate, demand would be about 24TWh. This would mean a nuclear unit of 1100MW would comprise about 22 per cent of capacity and, assuming a load factor of 85 per cent, would account for 34 per cent of demand. This degree of reliance on only one generator is far higher than would be considered prudent elsewhere.

The IAEA's advice on grid stability states : 'A practical limit to the sudden loss, and hence of the maximum capacity of a single generating unit, is around 10% of the minimum system demand.'

The IAEA also states: If an NPP is too large for a given grid the operators of the NPP and the grid may face several problems :

- Off-peak electricity demand might be too low for a large NPP to be operated in baseload mode, i.e. at constant full power.
- There must be enough reserve generating capacity in the grid to ensure grid stability during the NPP's planned outages for refuelling and maintenance.
- Any unexpected sudden disconnect of the NPP from an otherwise stable electric grid could trigger a severe imbalance between power generation and consumption causing a sudden reduction in grid frequency and voltage. This could even cascade into the collapse of the grid if additional power sources are not connected to the grid in time.

Jordan has limited international interconnections, to Syria and Egypt (significantly less than the output of the proposed nuclear plant) and it is not clear how much these interconnections could contribute to reducing the scale of the problems.

At best, introducing such a large single generation unit (whether or not it was nuclear) would impose significant additional costs, for example the need to have 1100MW of generating capacity hot and burning fuel in readiness to generate at seconds' notice (so-called spinning reserve). At worst, the Jordanian grid could be destabilised leading to chronic insecurity of supply.

This problem was most recently illustrated in South Africa, where its two nuclear reactors are situated in the Cape Town region. The South African system comprises a single integrated system of about 40,000MW of generating plant but the Cape Town district is only relatively weakly connected with the rest of the country. As a result, in the period from 2006 onwards, electricity supplies in the Cape region have become unreliable with frequent black-outs and the need for planning power cuts.

4.7 Uranium reserves

From the start of the attempt to launch a nuclear power programme in Jordan, there has been talk of exploitation of Jordan's uranium resources. Indeed, the alleged existence of uranium reserves has been put forward as a justification for a nuclear power programme. This makes no sense. If uranium was available in commercial quantities and quality, it would be perfectly possible to exploit these reserves and sell them profitably on the world market. If nuclear power is not a cheap source of electricity, this would make far more sense than building a nuclear power plant to use them.

How far the nuclear power programme was driven by the perceived advantages of exploiting uranium reserves is not clear, nor is it clear how far Areva's interest in Jordan was sparked by a wish to exploit these reserves.

Rio Tinto Zinc (RTZ) and Areva began to investigate Jordan's uranium reserves in 2009 and by 2010, the JAEC was claiming reserves would be sufficient to last 100 years. However, in 2011, RTZ withdrew from it uranium interest in Jordan. In September 2012, the Jordanian government claimed it had terminated its agreement with Areva , while Areva said that the agreement had simply expired. There was some controversy about whether the extent of the reserves had been exaggerated. The JAEC claimed that exploration and resource estimation work would be continued through its commercial arm, Jordan Energy Resources, Inc.,
with the intention of producing a bankable feasibility study. How realistic this is given Areva and RTZ's lack of interest in proceeding is not clear. How far relations between Jordan and Areva have been damaged by this episode is also hard to tell.

5. Conclusions

By many criteria the Jordanian nuclear programme seems misconceived.

5.1Design

Neither of the two designs shortlisted has undergone a comprehensive safety review carried out by a credible, experienced international safety regulatory body. Areva's Atmea1 plant has not been designed in detail yet and, if as present, it has no other serious customers, Areva may decide not to incur the expense. The AES-92 has only been offered for sale in India and after a construction programme of 10 years, the plant is still not on-line. It is not clear what regulatory reviews this design has undergone, nor what design changes would be needed to bring it up to current international standards.

5.2 Economics

In Europe and North America, it is now widely accepted that even for a very experience user, nuclear power does not represent a cheap source of electricity. None of the current generation of nuclear power plant designs is in service yet and so it is too early to determine how expensive they will be. Jordan's lack of experience and the special requirements of the Jordanian situation, for example, political insecurity, specific siting requirements such as cooling water, inadequate grid size etc., mean that a Jordanian reactor will inevitably be significantly more expensive than a similar reactor in Europe and North America.

5.3 Commercial Issues

Jordan does not have the capability or experience to operate a nuclear power plant so it is expected that a foreign partner, an electric utility with substantial experience of operating nuclear power plants, would be involved, at least for the first decade, in a 'Build Own Operate' (BOO) or 'Build Operate Transfer' mode and take an equity stake in the plant. There is no evidence that any such partners will be emerge for what would appear to be a financially risky venture with the scope to cause serious reputational damage.

Obtaining the finance needed to build the plant appears a major problem with Jordan unlikely to be able to obtain finance by itself because of its poor credit rating. There is speculation the French or Russian governments may be persuaded to offer loan guarantees that would mean financiers would have much greater certainty of having their loans repaid. However, in the current financial climate, government Treasuries will be very reluctant to increase their national debts and will be reluctant to allow them.

5.4 Design issues

The geographical and geopolitical position of the plant mean it will require additional features to protect it from the potential man-made and natural hazards it could come up against. At best, these will incur major extra costs in construction and operation, and at worst will result in a plant that is vulnerable to such hazards.

5.5 Overall evaluation

It seems likely that the issues raised above will mean that the Jordanian nuclear power programme will prove not to be feasible. However, it remains to be seen how long it will take for the government to bow to the inevitable. It has already spent four years pursuing an option, nuclear power, that is likely to prove infeasible and this is time and resources that was not available to other resources more likely to meet Jordan's priorities of ensuring reliable, affordable and environmentally sound electricity supply. There is also the issue of the diversion of valuable human resources, talented young Jordanian engineers and scientists, away from productive sectors to the nuclear project. These 'opportunity' costs may well be more significant than the actual financial costs.

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The energy from PWRs is taken away in coolant loops. In PWRs derived originally from the Westinghouse design, like those offered by MHI and Areva (both formerly licensed to Westinghouse) each coolant loop has a power of about 350-400MW so a two-loop plant would have an output of 700-800MW, a three loop plant 1050-1200MW and a four-loop plant, like the Areva EPR and the MHI APWR an output of 1400-1600MW.

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