Solar and Nuclear Power Generation in the Arab Region from a Water-Land use-Labour-Energy Nexus Perspective

Henri Boyé
– Senior engineer-
Coordinator of the Energy and Climate College

Expert Group meeting on the Water, Energy, Food Security Nexus in the Arab Region
Amman, 24-25 March 2015

Water-Food-Energy Nexus in the Arab countries

Growing demand of population in Water – Food – Energy Nexus

Energy
Water
Food Security
Growing Population Needs

Water is needed for irrigation
Energy is needed to make water accessible
Water produces Energy

Benchmark: Solar & Nuclear
Case studies WFE Nexus
Conclusions & recommendations
Water-Food-Energy Nexus in the Arab countries

In the MENA regions, the Water Food Energy Nexus is particularly discussed: few region rain falls, annual average water per person expected to fall to less than 550 m³, growing population, growing needs, climate change led to more drought, and reduction of renewable fresh water resources.

Water conservation is becoming one of the most important issues.

In parallel of water conservation, more and more Arab states are also investigating opportunities of diversifying their electricity mix away from hydrocarbon.

Among these opportunities, carbon-free technologies such as nuclear and solar power generation have a certain relevance in regard of the endowments of the region, and the objectives of the country.

Benchmarking Solar and Nuclear Power Generation

I / WATER USE FOR ELECTRICITY GENERATION

I.A) Nuclear power plants need water for cooling

→ 3 main cooling technologies

Once-through systems
- Nearby sources
- Simple / low cost
- Withdrawal and discharges in open loop

Wet - recirculating
- Re-use water in second cycle
- Cooling towers
- Evaporation & closed loop

Dry cooling systems
- Air cooling towers
  - Cost: – 170% of wet system cost
  - Land Footprint: – 300% higher
  - Water consumption decreased by 90%

Table 2, p.17: Table of Cooling System Tradeoffs

<table>
<thead>
<tr>
<th>Cooling Type</th>
<th>Water Withdrawal</th>
<th>Water Consumption</th>
<th>Capital Cost</th>
<th>Plant Efficiency</th>
<th>Ecological Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once-Through</td>
<td>intense</td>
<td>moderate</td>
<td>low</td>
<td>most efficient</td>
<td>intense</td>
</tr>
<tr>
<td>Wet Cooling</td>
<td>moderate</td>
<td>intense</td>
<td>moderate</td>
<td>efficient</td>
<td>moderate</td>
</tr>
<tr>
<td>Dry Cooling</td>
<td>none</td>
<td>none</td>
<td>high</td>
<td>less efficient</td>
<td>low</td>
</tr>
</tbody>
</table>
**I / WATER USE FOR ELECTRICITY GENERATION**

**I.B) Solar Power Comparison Table**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Cooling</th>
<th>Example of Ivanpah (US)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>Recirculating</td>
<td>Dry cooled project</td>
</tr>
<tr>
<td></td>
<td>Dry cooling</td>
<td>Water uses to clean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>heliostat mirrors and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>produce steam only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 Mgal./year</td>
</tr>
<tr>
<td>Power Tower</td>
<td>Recirculating</td>
<td>Dry cooled project</td>
</tr>
<tr>
<td></td>
<td>Combination Hybrid Parallel</td>
<td>100 – 450</td>
</tr>
<tr>
<td>Parabolic Trough</td>
<td>Recirculating</td>
<td>Dry cooling 78</td>
</tr>
<tr>
<td></td>
<td>Combination Hybrid Parallel</td>
<td>100 – 450</td>
</tr>
<tr>
<td>Dish / Engine</td>
<td>Mirror</td>
<td>Dry cooling 90</td>
</tr>
<tr>
<td>Fresnel</td>
<td>Washing</td>
<td>Dry cooling 78</td>
</tr>
</tbody>
</table>

Extracted from (US-DOE Report to Congress, 2009). p 17

Example of Ivanpah (US)
- Dry cooled project
- Water uses to clean heliostat mirrors and produce steam only
- 25 Mgal./year

**II / LAND USE FOOTPRINT AND REQUIREMENTS**

**II.A) Nuclear land use footprint**

**Land Availability**

For seawater cooled power plants
- One EPR (1500 MW): needs an area 40 ha, and 30 ha for the construction zone
- Two EPR: need 60ha, and 45 ha for the construction zone

If a cooling tower is used:
- Add 10ha by plant, and more area in case of dry cooling

**Civaux**
- 2 units of 1450MW
- 2 cooling towers (178m high)
- 150 ha

**Flamanville**
- 2 units of 1300MW + 1 EPR 1500 MW
- Once through refrigeration
- 60 ha

Credit photos: [http://www.connaissancedesenergies.org/sites/default/files/gallerie/flamanville_2.jpg](http://www.connaissancedesenergies.org/sites/default/files/gallerie/flamanville_2.jpg)
[http://fr.wikipedia.org/wiki/Centrale_nucl%C3%A9aire_de_Civaux#mediaviewer/File:Entr%C3%A9e_de_la_centrale_de_Civaux.JPG](http://fr.wikipedia.org/wiki/Centrale_nucl%C3%A9aire_de_Civaux#mediaviewer/File:Entr%C3%A9e_de_la_centrale_de_Civaux.JPG)

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II / LAND USE FOOTPRINT AND REQUIREMENTS

II.B) Solar land use footprint

- Quick order of magnitude:
  - Around 150 hectares for a 100 MW, generating ~ 200,000 MWh
  - Depends on solar irradiation, technology, storage, etc.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Direct Area Generation-weighted average land use (acres/GWh/year)</th>
<th>Total Area Generation-weighted average land use (acres/GWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed PV</td>
<td>3.1</td>
<td>4.1</td>
</tr>
<tr>
<td>2 axis flat panel</td>
<td>4.1</td>
<td>5.5</td>
</tr>
<tr>
<td>Parabolic trough</td>
<td>2.5</td>
<td>3.9</td>
</tr>
<tr>
<td>Tower</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Dish Stirling</td>
<td>1.5</td>
<td>5.3</td>
</tr>
<tr>
<td>Linear Fresnel</td>
<td>1.7</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Extracted from NREL 2013 «Land use requirements for solar power plants in the USA»

Nuclear energy is more concentrated, as Solar energy is more extensive
(by a ratio between 50 and 100 on the criteria of energy generated)

III / ENVIRONMENTAL AND SOCIO ECONOMICS IMPACTS

III.A) Environmental Impacts of Solar and Nuclear

All the environment issues must be taken into account with a life-cycle assessment of the impacts on local ecosystems.

Nuclear Environmental Issues

- Safety of NPP ensured at highest level standards
- Cooling water discharge structure designed to dilute heat without warming local ecosystems
- Waste management

Solar Environmental Issues

- Low carbon footprint controlled by life cycle assessment at each step of the project
- Monitoring control of storage and cooling system

⇒ Environmental impact study should be conducted to ensure the absence of any harmful consequences of new facilities
Benchmarking Solar and Nuclear Power Generation

III / ENVIRONMENTAL AND SOCIO ECONOMICS IMPACTS

III.B) Socio Economic Effects and Human Resources

Labour Jobs creation

Socio Economic Effects

- Large part (60% [1]) of the CSP value chain can be manufactured locally
- Job creation, Know How development and industrial opportunities are some of the effects
- Considering PV, the same objective is harder to target (key component manufactured in Asia at very competitive costs), but there is still a large part of the project that can be developed locally

Human Resources and Training

- Technical Human Resources are needed, especially to develop nuclear program
- Institutional framework must be established in advance
- Formation and international partnership are recommended to develop good behaving, in term of quality standards, transparency and control acceptance

CSP and PV solar technology have a high potential of local manufacturing, whereas staff competence and cooperation are required for nuclear projects development

[1]: According to the Fraunhofer and Ernst&Young report, January 2011

Benchmarking Solar and Nuclear Power Generation

IV / COSTS COMPETITIVENESS

IV.A) Levelized Cost Of Electricity (LCOE)

LCOE could be defined as the price at which one should sell the electricity throughout the lifetime of the installation to cover all costs

→ For Nuclear power plant, the Cour des Comptes report (2014) evaluates the LCOE of NPP around 75€/MWh in France in 2013.

→ According to the Fraunhofer ISE, 2013 report, in high solar irradiation countries:
  - PV power plants achieve a LCOE less than 0.1 €/kWh
  - LCOE of CSP plants with storage is below 0.19€/kWh
  - By 2030, LCOE for CSP can sink to values between 0.096 and 0.13 €/kWh
Benchmarking Solar and Nuclear Power Generation

IV / COSTS COMPETITIVENESS

IV.B) Technological limitations, balancing costs

→ For Solar Power in particular:
  - Intermittency of supply
  - Storage capacities
  - Power regulation devices
  - Regional cooperation with grid interconnection
  - High voltage line (like Spain/Morocco)
  - Balancing costs

→ For Nuclear Power:
  - Safety & security standards to take into account
  - Regional or international cooperation
  - Technical complexity
  - No intermittency
  - ”carbon-free”technology for desalination purpose

SUMMARY: Solar & Nuclear Comparative Table

<table>
<thead>
<tr>
<th></th>
<th>Cost Competitiveness</th>
<th>Water Needs</th>
<th>Land Footprint</th>
<th>Environmental Impact</th>
<th>Socio Economics Co-effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LCOE</td>
<td>Balancing</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Costs (1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear Energy</td>
<td>++</td>
<td>+</td>
<td></td>
<td>++</td>
<td>[2]</td>
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<tr>
<td></td>
<td></td>
<td>One through cooling</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>Wet cooling tower</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dry cooling tower</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Energy</td>
<td>+</td>
<td>[3]</td>
<td>-</td>
<td>+</td>
<td>-</td>
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<td></td>
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</tr>
</tbody>
</table>

(1) Balancing costs contains the grid optimisation costs to make up intermittencies, or storage technologies installation, see Part
(2) e.g. Nuclear waste Management is an important issues for the long term sustainability and environmental impact
(3) See (Fraunhofer ISE, 2013) & Part 3.7  , CSP LCOE around 150 $/MWh with storage technology and PV LCOE is around 80 $/MWh in countries with high solar radiation in 2013
(4) Most part of the PV value chain are cheaper abroad, and as a consequence, the value in term of human resources and training is very poor for the country.
Case Studies on Water-Food-Energy Nexus

I / MAGHREB Region : Morocco Country Case Study

General Information Global Endowments and Comments (1)

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.6 %</td>
<td>67.1 %</td>
<td>18.1 %</td>
<td>2 %</td>
<td>47 %</td>
</tr>
</tbody>
</table>

→ Large part of water use is dedicated to agriculture

<table>
<thead>
<tr>
<th>Energy use (kg of oil eqv per capita) 2011</th>
<th>Electric power consumption (kWh per capita) 2011</th>
<th>Energy imports, net (% of energy use)</th>
</tr>
</thead>
<tbody>
<tr>
<td>539</td>
<td>826</td>
<td>96 %</td>
</tr>
</tbody>
</table>

→ High percentage of agriculture land corresponds to permanent meadows and pastures. Only 2% corresponds to permanent crops.

Current electricity mix contains yet a part of "carbon-free" energies

Moroccan solar plan in development

High solar irradiation, low water pressure of solar PV technologies compared to nuclear, economic feasibility and social impact in term of local manufacturing makes solar projects very relevant

ACWA Power, awarded for the 160 MW Ouarzazate solar farm in CSP, aims 42% of local content

Five sites have been already identified for Solar Energy

Moroccan solar plan aims to establish 2GW in solar energy by 2020

ESCWA - Henri Boyé

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Case Studies on Water-Food-Energy Nexus

I / MAGHREB Region : Morocco Country Case Study

General Information Global Endowments and Comments (2)

<table>
<thead>
<tr>
<th>Energy</th>
<th>2011</th>
<th>Total (MW)</th>
<th>Thermoelectric (% of total installed capacity)</th>
<th>Hydro (% of total installed capacity)</th>
<th>Wind (% of total installed capacity)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>6,677</td>
<td>69.7 %</td>
<td>26.5 %</td>
<td>3.8 %</td>
</tr>
</tbody>
</table>

→ Current electricity mix contains yet a part of "carbon-free" energies

Moroccan solar plan in development

Water pressure of the agriculture sector + Need of energy for water desalination in particular makes low water consuming technologies especially relevant in arid southern areas of Morocco.

High solar irradiation, low water pressure of solar PV technologies compared to nuclear, economic feasibility and social impact in term of local manufacturing makes solar projects very relevant

ACWA Power, awarded for the 160 MW Ouarzazate solar farm in CSP, aims 42% of local content

Five sites have been already identified for Solar Energy

Moroccan solar plan aims to establish 2GW in solar energy by 2020
Case Studies on Water-Food-Energy Nexus

II / MASHREK Region: Egypt Country Case Study

General Information Global Endowments and Comments (1)

<table>
<thead>
<tr>
<th>Water</th>
<th>Total Renewable Water Resources (m³ per Capita) Average (2010)</th>
<th>Water Withdrawal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Use (million m³)</td>
<td>Agriculture (% of total)</td>
</tr>
</tbody>
</table>

- Egyptian agriculture (cotton and wheat historically) involve large water withdrawal

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.5 %</td>
<td>3.5 %</td>
<td>3.0 %</td>
<td>0.5 %</td>
<td>0 %</td>
</tr>
</tbody>
</table>

- No data about meadows and pastures, arable land and permanent crops mainly located around the Nile River

Urban trends

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>43.025 %</td>
<td>0.228 %</td>
<td>59.2 %</td>
<td>5.865 %</td>
</tr>
</tbody>
</table>

- Population is less urban than in Morocco
- Rural areas have important needs in water and energy

ESCWA - Henri Boyd

Energy sector 2011

<table>
<thead>
<tr>
<th>Energy sector</th>
<th>Total (MW)</th>
<th>Thermoelectric (% of total installed capacity)</th>
<th>Hydro (% of total installed capacity)</th>
<th>Wind (% of total installed capacity)</th>
<th>Solar (% of total installed capacity)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>29,312</td>
<td>88.1 %</td>
<td>0.5 %</td>
<td>1.87 %</td>
<td>0.48 %</td>
</tr>
</tbody>
</table>

- Current electricity mix mainly based on thermoelectric power generation
- It also contains a part of renewable energy (with the Aswan dam mainly)
- Nuclear deployment was slowed down by the recent political events

As rural areas are mainly located around the Nile River, the water pressure is less hard than in Morocco, but remains an important issue to overcome.
As a result low water consuming technologies are the most relevant.

Nuclear deployment seems also complex due to the current political context, but it still represents an interesting solution in term of constant power production and land availability, especially with a well-think water management.

However, in the widespread rural areas, distant from any connection to the electrical grid, solar energy makes particularly sense. Solar energies are also job generating, due to the possibility of local industry

ESCWA - Henri Boyd
III / GCC Region: Saudi Arabia Country Case Study

General Information Global Endowments and Comments (1)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.2 %</td>
<td>80.8 %</td>
<td>1.6 %</td>
<td>0.1 %</td>
<td>79.1 %</td>
</tr>
</tbody>
</table>

- Less renewable water resources than Egypt
- Large part of water withdrawal dedicated to agriculture
- Little value added from agriculture in regard of the Saudi Arabia GDP
- Very large part of the land area dedicated to agricultural land (mainly composed of meadows and pastures)
- Strong political will for developing agriculture for three decades, with important irrigation by pumping underground water.

Urban Trends

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>82.719 %</td>
<td>2.871 %</td>
</tr>
</tbody>
</table>

- Large part of total population is urban population
- Demographics pressure (Net migration 2012: 300,000; Annual population growth = 1.89 %)

Energy Sector 2011

<table>
<thead>
<tr>
<th>Energy (MW) 2011</th>
<th>Total (MW)</th>
<th>Thermolectric (% of total installed capacity)</th>
<th>Nuclear (% of total installed capacity)</th>
<th>Solar (% of total installed capacity)</th>
<th>Solar (% of total installed capacity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>53,588</td>
<td>82.8 %</td>
<td>0 %</td>
<td>9 %</td>
<td>17.2 %</td>
<td>17.2 %</td>
</tr>
</tbody>
</table>

- Current electricity mix mainly based on thermolectric power generation
- Saudi Arabia is able to fulfil its energy demand, but with environmental and economic impacts
- Capabilities of developing large nuclear projects in term of economic and human resources.

To maintain the same level of water food and security, it is relevant to develop nuclear in term of land requirements, constant power generation

- Strong water pressure of agriculture
- Very arid and isolated areas
- Capabilities to launch large solar plants putting in value the high solar irradiation

As a result, Solar Energy are also relevant in term of low water impact (in PV more than in CSP), and socio economic benefits
Case Studies on Water-Food-Energy Nexus

**IV / LDC Region : Sudan Country Case Study**

### General Information Global Endowments and Comments (1)

<table>
<thead>
<tr>
<th>Water</th>
<th>Water Withdrawal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use (million m³)</td>
<td>Agriculture (% of total)</td>
</tr>
<tr>
<td>1,481</td>
<td>37,100</td>
</tr>
</tbody>
</table>

- Very large part of water withdrawal dedicated to agriculture

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>27.7 %</td>
<td>57.5 %</td>
<td>8.1 %</td>
<td>0.1 %</td>
<td>49.3 %</td>
<td></td>
</tr>
</tbody>
</table>

- High percentage of agriculture value added in regard of the Sudan GDP
- Large part of the agricultural land dedicated to meadows and pastures
- Only 8.2 % of land are are classified as arable land and permanent crops
- Still a very agricultural economy

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>33.46 %</td>
<td>0.965 %</td>
<td></td>
</tr>
</tbody>
</table>

- Large part of total population is rural population

### Energy sector

<table>
<thead>
<tr>
<th>Total (MW)</th>
<th>Thermolectric (% of total installed capacity)</th>
<th>Hydro (% of total installed capacity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,850</td>
<td>44.1 %</td>
<td>55.9 %</td>
</tr>
</tbody>
</table>

- Energy sector mainly driven by hydro electricity power generation
- Hydropower is a renewable, carbon-free, and non-intermittent source of energy, economically competitive in Sudan

Solar deployment will be most relevant for rural electrification in remote and scarcely populated areas, distant from any connection to the electrical grid. In these less developed areas, PV solar energy represents an interesting option for diversifying the electricity mix with a low water pressure.
**Conclusion and Recommendations**

**Technological Conclusions**

- Nuclear is a more concentrated, more constant, cheaper source of energy than solar energy, it involves high skilled worker, a waste management, security standards. It has an important environmental impact, especially in water use.

- Among the different solar technologies, intrinsically intermittent, PV is low cost, with almost no water requirements, but with a more little land use than CSP. PV presents also the advantage of a little locally manufactured part of the value chain.

- CSP is more water consuming than PV, with more land requirements, but it presents an important socio economic effects with almost all its value chain which can be locally manufactured.

**Countries Recommendations**

- For GCC countries, such as KSA, both technologies are relevant, a combination of them could bring many benefit by combining the advantages and making up the respective shortcomings.

- In LDC, Sudan is a very particular case, because its hydroelectric power generation does not really a shift to nuclear or solar. But in very isolated areas, CSP technology (for the local manufacturing) or PV (for the little water use) may be relevant in the same way as in Mashrek or Maghred isolated areas.

- In Egypt (Mashrek), current geopolitical context slow down any nuclear project, but solar plan is very relevant and should be investigated further.

- In Morocco, the Moroccan solar plan is yet very developed and make sense in regard of the endowments of the country and the objective of the government.